Dylan Reference Manual

Draft, September 29, 1995

Contents

About This Book

This book is a draft of the Dylan Reference Manual.

It contains the complete language description, incorporating all language design decisions made to date (September, 1995).

The book is a draft because it has not undergone final review or proofreading. It is, however, believed to be complete.

The book is designed as specification and reference for the Dylan language. It is not designed as a tutorial. Programmers who wish to learn Dylan may want to begin with a book written for that purpose before moving on to this volume.

The book is divided into three parts: the first part contains a number of concept chapters describing the overall structure and semantics of the language; the second part contains reference chapters describing every class, function, and syntactic construct in the language; the third part contains the BNF for Dylan's syntax and a glossary of terms.

CHAPTER 1

Introduction

Contents

Background and Goals

Dylan is a general-purpose high-level programming language, designed for use both in application and systems programming. Dylan includes garbage collection, type-safety, error recovery, a module system, and programmer control over runtime extensibility of programs.

Dylan is designed to allow efficient, static compilation of features normally associated with dynamic languages.

Dylan was created out of the belief that programs have become too complex for traditional static programming languages. A new generation of software—software that can be built quickly and enhanced over time—requires higher-level programming tools. The core of these tools is a simple and expressive language, one which protects the programmer from low-level implementation details, but still produces efficient executables.

Dylan was designed from the ground up with a thoroughly integrated object model, syntax, and control structures. It is not source code compatible with any existing languages, and can therefore be more internally self-consistent. At the same time, Dylan's syntax and object-model allow a high-level of integration with libraries written in other languages such as C and C++.

Dylan avoids providing multiple ways of doing the same thing. Quite the opposite, the language often uses a single construct to achieve several ends. For example, Dylan's type declarations improve the efficiency and readability of programs, they ensure type safety, and they provide the basis of polymorphic dispatch, the basic mechanism of object-oriented flow of control.

And while simplicity of language is very important, it should not and need not come at the price of expressiveness. Multi-method dispatch is an example of a Dylan feature that makes the language more powerful and simultaneously makes Dylan programs easier to understand.

Dylan demonstrates that a programming language can be highly expressive, can encourage the use of appropriate abstraction, can make programming more productive, and can make the programming process enjoyable, all without sacrificing the ability to compile into code that is very close to the machine, and therefore very efficient.

Language Overview

Dylan is written in a very regular syntax. In addition to making the language easier to read and write, the layered composition of the syntax supports a macro system that is language-aware. The macro system does not simply perform text substitution, but rather performs syntax fragment substitution. This allows the extension of the language within bounds that are safe, semantically well-defined, and in accord with the 'syntactic flavor' of the language.

Bindings (Dylan's analog to variables) are lexically scoped and fully resolved at compile time. Binding names are not retained in running programs. The module system allows bindings to be private or shared. Names can be changed upon import to a module, so the possibility of irreconcilable name conflicts among separately developed modules is eliminated. Modules can provide multiple interfaces to the same code base, decreasing the chance of exposing a client to inappropriate interfaces.

Flow of control is supported through polymorphic function calls, a variety of conditional and iteration constructs, and a non-local transfer mechanism (with protected regions).

All objects are first class, including numbers, classes and functions. This means that all objects can be used as arguments to functions, returned as values, stored in data structures, and are subject to introspection. All objects are typed, and type-safety is guaranteed, either through compile-time or runtime type checking. There are no facilities for deallocating objects. Objects are deallocated automatically when they can no longer be reached by a program.

Types are used to categorize and specify the behavior of objects. An object may be an instance of any number of types. Classes are a particular kind of type used to define the structure and inheritance of instances. Every Dylan object is a direct instance of exactly one class, and a general instance of that class and each of its superclasses. The root of the class hierarchy (and of the type hierarchy) is a class called `<object>`.

Values associated with an instance are stored in slots of the instance.

Classes do not define scopes for names. Names are scoped by modules and local binding declarations.

Functions are the active portions of Dylan programs. Functions accept zero or more arguments and return zero or more values. Functions are specialized to accept arguments of particular types, and will signal an error if they are called with arguments that are not instances of those types. The return values of functions are similarly type-checked.

A method is a basic unit of callable code. When a method is called, it creates local bindings for its arguments and executes a body in the resulting environment. A method can be called directly by a program or indirectly through a generic function that contains it.

A generic function contains a number of methods. When a generic function is called, it finds the methods which are applicable to the arguments, and passes control to the most specific of those methods.

Slots are accessed through functions. This ensures that instances present an abstract interface to their clients, which assists both in polymorphism and in program redesign.

Sealing declarations allow the programmer to declare portions of the class hierarchy and set of functions to be invariant. This supports the enforcement of protocols, compile-time resolution of polymorphic behavior, and efficient inline slot access. Portions of a program which are not sealed can be extended at run time or by additional libraries.

Dylan includes a number of predefined libraries, including an exception system, collections, arithmetic, higher-order functions, and introspection.

The exception system is object-based. It uses calling semantics (thereby allowing recovery) but also provides exiting handlers.

The collection system includes a number of predefined collection classes and operations built on a simple iteration protocol. Additional classes defined in terms of this protocol have access to the full suite of collection operations.

Arithmetic is fully object-based and extensible.

A library of higher-order operations on functions supports function composition.

A library of introspective functions supports the run time examination of objects, including classes and functions.

Manual Notation

This manual uses a small number of typographic conventions:

- `Monospaced font` (courier 12) is used to indicate text which should appear verbatim in programs.
- *Italic font* is used to name parameters, placeholders for actual program text.
- References to entries in the BNF are given the same name as in the BNF, and are followed by a subscripted italic $_{bnf}$.
- **Bold** is used for the first use of terms.
- **Bold** is also used for meta-syntactic punctuation, as follows:
  - **[ ]** Contents are optional
  - **{ }** Contents appear once
  - **{ }*** Contents appear zero or more times
  - **{ }+** Contents appear one or more times
  - **|** A choice between the item on the left of the vertical bar and the item on the right of the vertical bar, but not both.

If a comma appears between a right curly brace and the following asterisk or plus-sign, it indicates that multiple occurances of the contents are separated by a comma. There is no comma after the last occurance.

If a semicolon appears between a right curly brace and the following asterisk or plus-sign, it indicates that multiple occurances of the contents are separated by a semicolon. A semicolon following the last occurance is optional.

Sample Dylan code is shown in `small monospaced font`. When the return value of an expression is shown, it is preceded by an ⇒.

Chapter 10, “Macros,” and Appendix A, “BNF,” each use a distinctive notation, described at the start of the chapter and appendix.

C H A P T E R 2

Syntax

Contents

Overview

This chapter describes the syntax and structure of a Dylan program, from the outside in. This is one of the two defining characteristics of Dylan. The other is the set of objects on which a Dylan program operates; objects and their types are discussed in the following chapters. This section is only an overview; language constructs briefly mentioned here are explained in detail in later sections. A formal specification of Dylan syntax appears in Appendix A, "BNF."

Libraries and Modules

A complete Dylan **program** consists of one or more **libraries**. Some of these libraries are written by the programmer, others are supplied by other programmers or by the Dylan implementation. A library is Dylan's unit of separate compilation and optimization. The libraries that compose a program can be linked together as early as during compilation or as late as while the program is running. Program structure inside of a library is static and does not change after compilation. However, many Dylan implementations provide an incremental compilation feature which allows a library under development to be modified, while the program is running, by modifying and recompiling portions of the library.

A library contains one or more **modules**. A module is Dylan's unit of global name scoping, and thus of modularity and information hiding. A module can be exported from its library; otherwise it is internal to that library. A library can import modules from other libraries. Only an exported module can be imported.

A module contains zero or more source records and a set of bindings.

A **source record** is an implementation-defined unit of source program text. For example, in a file-based development environment each source file would be one source record. As another example, in an interactive Dylan interpreter each executable unit of programmer input would be a source record. The source program text in a source record is a body, a grammatical element used in several places in Dylan.

Bindings

A **binding** is an association of a name with a value. The bindings in a module persist for the life of the program execution. The scope of such a binding is its module. That is, the binding is visible to all source-records in the module. A module can export bindings and can import bindings from other modules. Only an exported binding can be imported. A binding is visible to all source-records in a module that imports it.

A binding may be **specialized**. This restricts the types of values that may be held in the binding. An error will be signaled on any attempt to initialize or assign the binding to a value that is not of the correct type.

A binding is either **constant** or **variable**. A constant (or read-only) binding always has the same value. In contrast, a variable (or writable) binding can have its value changed, using the assignment operator `:=`. Most bindings in a typical Dylan module are constant.

Macros

A **macro** is an extension to the core language that can be defined by the programmer, by the implementation, or as part of the Dylan language specification. Much of the grammatical structure of Dylan is built with macros. A macro defines the meaning of one construct in terms of another construct. The original construct is the call to the macro. The replacement construct is the expansion of the macro. The compiler processes the expansion in place of the call.

Portions of the call to a macro are substituted into part of the macro definition to create the expansion. This substitution preserves the meanings of names. In other words, each name inserted into the expansion from the macro call refers to the same binding that it referred to in the call, and each name inserted into the expansion from the macro definition refers to the same binding that it referred to in the definition.

A macro is named by a binding and thus is available for use wherever that binding is visible. There are three kinds of macros: defining macros, which extend the available set of definitions; statement macros, which extend the available set of statements; and function macros, which look syntactically like function calls but have more flexible semantics.

Bodies

A **body** is a sequence of zero or more constituents. When multiple constituents are present, they are separated by semicolons. When at least one constituent is present, the last constituent can optionally be followed by a semicolon; this allows programmers to regard the semicolon as either a terminator or a separator, according to their preferred programming style.

A **constituent** is either a definition, a local declaration, or an expression. Definitions and local declarations form the structure of a program and do not return values. In contrast, expressions are executed for the values they return and/or the side-effects that they perform.

Definitions

A **definition** is either a call to a user-defined defining macro, a call to a built-in defining macro, or a special definition. Typically, a definition defines a binding in the module containing the definition. Some definitions define more than one binding, and some do not define any bindings.

A **user-defined defining macro** is a macro that defines a definition in terms of other constructs. A call to a user-defined defining macro always begins with the word `define` and includes the name of the defining macro. This name when suffixed by "`-definer`" is the name of a visible binding whose value is the defining macro. The rest of the syntax of a call to a user-defined defining macro is determined by the particular macro. Some definitions include a body. Advanced programmers often define new defining macros as part of structuring a program in a readable and modular way.

A **built-in defining macro** is like a user-defined defining macro but is specified as part of the Dylan language. There are eight built-in defining macros:

`define class`, `define constant`, `define generic`, `define inert`, `define library`, `define method`, `define module`, and `define variable`.

A **special definition** is a definition construct that is built into the grammar of Dylan. There is only one special definition: `define macro`.

An implementation can add new kinds of definitions as language extensions. Such definitions may be implemented as special definitions. However, they will more commonly take the form of user-defined definition macros that are the values of bindings exported by implementation-defined modules.

Local Declarations

A **local declaration** is a construct that establishes local bindings or condition handlers whose scope is the remainder of the body following the local declaration.

Unlike module bindings, local bindings are established during program execution, each time the local declaration is executed. They persist for as long as code in their scope is active. Local bindings persist after the body containing them returns if they are referenced by a method created inside the body and a reference to the method escapes from the body, so that it could be called after the body returns. Unlike module bindings, local bindings are always variable. However, since a local binding has a limited scope, if there is no assignment within that scope, the local binding is effectively constant.

A local binding shadows any module binding with the same name and any surrounding local binding with the same name. The innermost binding is the one referenced.

The name of a local binding cannot be the name of a macro.

There are three kinds of local declaration: local value bindings (`let`), local method bindings (`local`), and condition handler establishment (`let handler`).

The **local value bindings** construct, `let`, executes an expression and locally binds names to the values returned by that expression.

The **local method bindings** construct, `local`, locally binds names to bare methods. These bindings are visible in the remainder of the body and also inside the methods, permitting recursion.

The **condition handler establishing** construct, `let handler`, establishes a function to be called if a condition of a given type is signaled during the execution of the remainder of the body or anything the body calls. The handler is disestablished as soon as the body returns. Unlike the other two kinds of local declaration, `let handler` does not establish any bindings.

Expressions

An **expression** is a construct that is executed for the values it returns and/or the side-effects that it performs. The “active” portions of a Dylan program are expressions. An expression is either a literal constant, a named value reference, a function call, a unary operator call, a binary operator call, an element reference, a slot reference, a parenthesized expression, or a statement.

An **operand** is a restricted expression: it cannot be a unary or binary operator call nor a symbol literal. The other seven forms of expression are allowed. Operands appear in situations in the grammar where an expression is desirable but the full generality of expressions would make the grammar ambiguous.

A **literal constant** directly represents an object. Literal constants are available for numbers, characters, strings, symbols, boolean values, pairs, lists, and vectors. For example:

number	`123, 1.5, -4.0, #x1f4e`
character	`'a', '\n'`
string	`"foo", "line 1\nline 2"`
symbol	`test:, #"red"`
boolean value	`#t, #f`
pair	`#(1 . "one")`
list	`#(1, 2, 3)`
vector	`#[1, 2, 3]`

Literal constants are immutable. Attempting to modify an immutable object has undefined consequences. Immutable objects may share structure. Literal constants that are equal may or may not be identical.

A symbol can be indicated in two ways: as a keyword (for example, `test:`) or as a unique string (for example, `#"red"`). The difference is purely syntactic; the choice is provided to promote program readability.

A string literal can be broken across lines by writing two string literals in a row, separated only by whitespace; they are automatically concatenated (without a newline character).

A **named value reference** returns the value of a visible binding given its name. For example, `foo`. The referenced binding can be a module binding (either constant or variable) or a local binding established by a local declaration or by a parameter list. The value of the binding must not be a macro.

A **reserved word** is a syntactic token that has the form of a name but is reserved by the Dylan language and so cannot be given a binding and cannot be used as a named value reference. There are seven reserved words in Dylan: `define`, `end`, `handler`, `let`, `local`, `macro`, and `otherwise`.

A **function call** applies a function to arguments, and returns whatever values the function returns. The function is indicated by an operand and can be a generic function, a method, or a function macro. The arguments are indicated by expressions separated by commas and enclosed in parentheses. For example, `f(x, y)`. For readability, the comma can be omitted between the two arguments in a keyword/value pair, for example `element(c, k, default: d)` is a function call with four arguments.

A **unary operator call** consists of an operand preceded by one of the two unary operators `-` (arithmetic negation) or `~` (logical negation). For example, `- x`. This is actually an abbreviated notation for a function call.

A **binary operator call** consists of two expressions separated by one of the binary operators `+` (addition), `-` (subtraction), `*` (multiplication), `/` (division), `^` (exponentiation), `=` (equality), `==` (identity), `<` (less than), `>` (greater than), `<=` (less than or equal), `>=` (greater than or equal), `~=` (not equal), `~==` (not identical), `&` (logical and), `|` (logical or), or `:=` (assignment). When binary operator calls are chained together, they are grouped by rules of precedence and associativity and by parentheses. For example, `(a - b) * x + c * x ^ 2`. Except for the last three operators, a binary operator call is actually an abbreviated notation for a function call. The last three operators (`&`, `|`, and `:=`) are treated specially be the compiler.

An **element reference** consists of an operand that indicates a collection and an expression in square brackets that indicates a key. Instead of a key, there can be multiple expressions separated by commas that indicate array indices. For example, `c[k]` or `a[i, j]`. This is actually an abbreviated notation for a function call.

A **slot reference** is another abbreviated notation for a function call. It consists of an operand that indicates an object, a period, and a named value reference that indicates a one-argument function to apply to the object. Typically the function is a slot getter but this is not required. For example, `airplane.wingspan`.

A **parenthesized expression** is any expression inside parentheses. The parentheses have no significance except to group the arguments of an operator or to turn a general expression into an operand. For example, `(a + b) * c`.

Statements

A **statement** is a call to a statement macro. It begins with the name of a visible binding whose value is a statement macro. The statement ends with the word `end` optionally followed by the same name that began the statement. In between is a program fragment whose syntax is determined by the macro definition. Typically this fragment includes an optional body. For example, `if (ship.ready?) embark(passenger, ship) end if`.

A **statement macro** can be built-in or user-defined.

A **user-defined statement macro** is a macro that defines how to implement a statement in terms of other constructs. Advanced programmers often define new statement macros as part of structuring a program in a readable and modular way.

A **built-in statement macro** is like a user-defined statement macro but is specified as part of the Dylan language. There are nine built-in statement macros: `begin`, `block`, `case`, `for`, `if`, `select`, `unless`, `until`, and `while`.

An implementation can add new kinds of statements as language extensions. Such a statement takes the form of a user-defined statement macro that is the value of a binding exported by an implementation-defined module.

Parameter Lists

Several Dylan constructs contain a **parameter list**, which describes the arguments expected by a function and the values returned by that function. The description includes names, types, keyword arguments, fixed or variable number of arguments, and fixed or variable number of values. The argument names specified are locally bound to the values of the arguments when the function is called. The value names specified are only for documentation.

The syntactic details of parameter lists are described in “Methods” on page 412.

Lexical Syntax

Dylan source code is a sequence of tokens. Whitespace is required between tokens if the tokens would otherwise blend together. Whitespace is optional between self-delimiting tokens. Alphabetic case is not significant except within character and string literals.

Whitespace can be a space character, a tab character, a newline character, or a comment. Implementations can define additional whitespace characters.

A **comment** can be single-line or delimited. Although comments count as whitespace, the beginning of a comment can blend with a preceding token, so in general comments should be surrounded by genuine whitespace.

A **single-line comment** consists of two slash characters in a row, followed by any number of characters up to and including the first newline character or the end of the source record. For example, `// This line is a kludge!`.

A **delimited comment** consists of a slash character immediately followed by a star character, any number of characters including balanced slash-star / star-slash pairs, and finally a star character immediately followed by a slash character. For example, `/* set x to 3 */`.

A single-line comment may appear within a delimited comment; occurances of slash-star or star-slash within the single line comment are ignored.

A **token** is a name, a #-word, an operator, a number, a character literal, a string literal, a symbol literal, or punctuation.

A **name** is one of the following four possibilities:

- An alphabetic character followed by zero or more name characters.
- A numeric character followed by two or more name characters including at least two alphabetic characters in a row.
- A graphic character followed by one or more name characters including at least one alphabetic character.
- A "\" (backslash) followed by a function operator.

An **alphabetic character** is any of the 26 letters of the Roman alphabet in upper and lower case.

A **numeric character** is any of the 10 digits.

A **graphic character** is one of the following:

```
! & * < = > | ^ $ % @ _
```

A **name character** is an alphabetic character, a numeric character, a graphic character, or one of the following:

```
- + ~ ? /
```

The rich set of name characters means that name and operator tokens can blend. Thus Dylan programs usually set off operators with whitespace.

Implementations can add additional characters but programs using them will not be portable.

A **#-word** is one of `#t`, `#f`, `#next`, `#rest`, `#key`, or `#all-keys`. The first two are literal constants, the others are used in parameter lists. Implementations can add additional implementation-defined #-words, but programmers cannot add their own #-words.

An **operator** is one of the following:

`+`	addition
`-`	subtraction and negation
`*`	multiplication
`/`	division
`^`	exponentiation
`=`	equality
`==`	identity
`<`	less than
`>`	greater than
`<=`	less than or equal
`>=`	greater than or equal
`~=`	not equal
`~==`	not identical
`&`	logical and
`|`	logical or
`:=`	assignment
`~`	logical negation

Programmers cannot add their own operators.

A **number** is a decimal integer with an optional leading sign, a binary integer, an octal integer, a hexadecimal integer, a ratio of two decimal integers with an optional leading sign, or a floating-point number. The complete syntax of numbers is given in "Numbers" on page 406.

A **character literal** is a printing character (including space, but not ' nor \) or a backslash escape sequence enclosed in a pair of single-quote characters '.

A **string literal** is a sequence of printing characters (including space, but not " nor \) and backslash escape sequences enclosed in a pair of double-quote characters ".

The backslash escape sequences used in character and string literals allow "quoting" of the special characters ', ", and \, provide names for "control" characters such as newline, and allow Unicode characters to be specified by their hexadecimal codes.

A **symbol literal** is a keyword or a unique string. A **keyword** is a name followed immediately by a colon character ":". A **unique string** is a sharp sign "#" followed immediately by a string literal.

Punctuation is one of the following:

`( )`	parentheses
`[ ]`	square brackets
`{,}`	curly brackets
`,`	comma
`.`	period
`;`	semicolon
`=`	defaulting/initialization
`::`	type specialization
`==`	singleton specialization
`=>`	arrow
`#(`	list/pair literal
`#[`	vector literal
`?,??`	macro pattern variables
`...`	macro ellipsis

Note that some tokens are both punctuation and operators. This ambiguity is resolved by grammatical context.

Note that some punctuation tokens (for example period and equal sign) are capable of blending into some other tokens. Where this can occur, whitespace must be inserted to delimit the token boundary.

Special Treatment of Names

Escaping Names

The escape character (\ ) followed by any name or operator-name has the same meaning as that name or operator-name, except that it is stripped of special syntactic properties. If it would otherwise be a reserved word or operator, it is not recognized as such.

For example, `\if` and `if` are names for the same binding, but `\if` is treated syntactically as a named value reference, while `if` is the beginning of a statement. Similarly, `\+` and `+` refer to the same binding, but the former is treated syntactically as a named value reference, and the latter as an operator.

For reserved words, this allows the names of statement macros to be exported and imported from modules. It does not allow them to be used as the names of local bindings, nor does it allow them to be executed. (That is, they cannot be used as bindings to runtime values.)

For operators, it allows the operator to be used where a named value reference is required, for example as the name in a method definition, as an argument to a function, or in a `define module` export clause. This feature can only be used for operators which provide a shorthand for a function call. It cannot be used for special operators.

Function Call Shorthand

Dylan provides convenient syntax for calling a number of functions. These include the operators which are not special operators, the array reference syntax, and the singleton syntax.

In all cases, the syntax is equivalent to using the name of the function in the current environment. The syntax does not automatically refer to a binding in the Dylan module.

Top-Level Definitions

Dylan's built-in defining macros can only be used at top level. When the expansion of a user-defined macro includes a call to a built-in defining macro, the user-defined macro also can only be used at top level.

A constituent is **at top level** if and only if it is a direct constituent of a body, no preceding constituent of that body is a local declaration, and the body is either the body of a source record or the body of a `begin` statement that is itself a constituent at top level. When a constituent appears inside a call to a macro, whether that constituent is at top level must be determined after macro expansion.

The effect of the above rule is that a constituent at top level is not in the scope of any local declarations, is not subject to any condition handlers other than default handlers, and is not affected by any flow of control constructs such as conditionals and iterations. This restriction enhances the static nature of definitions.

Dylan Interchange Format

The **Dylan interchange format** is a standard file format for publishing Dylan source code. Such a file has two parts, the **file header** and the **code body**. The file header comes before the code body.

The code body consists of a source record.

The file header consists of one or more keyword-value pairs, as follows:

- A keyword is a letter, followed by zero or more letters, digits, and hyphens, followed by a colon, contains only characters from the ISO 646 7-bit character set, and is case-independent.
- A keyword begins on a new line, and cannot be preceded by whitespace.
- All text (excluding whitespace) between the keyword and the next newline is considered to be the value. Additional lines can be added by having the additional lines start with whitespace. Leading whitespace is ignored on all lines.
- The meaning of the value is determined by the keyword.
- Implementations must recognize and handle standardized keywords properly, unless the specification for a keyword explicitly states that it can be ignored.
- When importing a file, implementations are free to ignore any non-standard keyword-value pairs that they do not recognize.
- When exporting a file, implementations must use standard keywords properly. Implementations are free to use non-standard keywords.
- The definition of a keyword may specify that the keyword may occur more than once in a single file header. If it does not, then it is an error for the keyword to occur more than once. If it does, it should specify the meaning of multiple occurances.

The file header cannot contain comments, or other Dylan source code.

Blank lines may not appear in the file header. A blank line defines the end of the file header and the beginning of the code body. The blank line is not part of the code body. (A "blank line" is a line consisting of zero or more space or tab characters, ending in a newline character.)

The following standard keywords are defined:

`language:` ***language-name*** **[Header keyword]**

The source record in the file is written in the named language. The only portable value for this keyword is `infix-dylan`.

`module:` ***module-name*** **[Header keyword]**

The source record in the file is associated with the named module. This keyword is required.

`author:` ***text*** **[Header keyword]**
`copyright:` ***text*** **[Header keyword]**
`version:` ***text*** **[Header keyword]**

These are provided for standardization. They are optional, and can be ignored by the implementation.

A typical Dylan source file might look like this:

```
module: quickdraw
author: J. Random Rect
        Linear Wheels, Inc., "Where quality is a slogan!"
        rect@linear.com
copyright: (c) 1995 Linear Wheels, Inc., All rights reserved
version: 1.3 alpha (not fully tested)

define constant $black-color = ...
```

Naming Conventions

Several conventions for naming module bindings help programmers identify the purposes of bindings. In general, the names of bindings do not affect the semantics of a program, but are simply used to improve readability. (The exceptions to this rule are the "`-definer`" suffix used by definition macros, and the "`-setter`" suffix, described below.)

- Module bindings used to hold types begin and end with angle brackets.

```
<window>
<object>
<character>
<number>
<stream>
<list>
```

- Variable module bindings begin and end with asterisks.

```
*parse-level*
*incremental-search-string*
*machine-state*
*window-count*
```

- Program constants begin with a dollar sign.

```
$pi
$end-of-file
```

- The names of most predicate functions end with a question mark. Predicates are functions which return a true or false value.

```
subclass?
even?
instance?
```

- Operations that return a value similar to one of their arguments and which also destructively modify the argument end in a `!`. (It will often also be the case that destructive and non-destructive variations of the function exist.) `!` isn't a universal warning that an operation is destructive. Destructive functions that return other values (like `-setter` functions and `pop`) don't need to use the `!` convention.

```
reverse!
sort!
```

- Operations that retrieve a value from a location are called **getters**. Operations that store into a location are called **setters**. In general, getters and setters come in pairs. Setter binding names are derived by appending "`-setter`" to the corresponding getter binding name. This convention is used to generate setter names automatically, and it is used by `:=`, the assignment operator, to find the setter that corresponds to a given getter.

```
element     element-setter
size        size-setter
color       color-setter
```

CHAPTER 3

Program Structure

Contents

Modules

Modules are used for creating large-scale namespaces of bindings. The bindings accessible in a module are visible to all the code within the module (except where shadowed by a local binding). Only the bindings explicitly exported are visible from outside the module.

Some languages have module systems with distinct support for exporting variables, functions, types, and classes. Dylan modules operate only on bindings. Because functions and classes are commonly named by bindings, access to them is controlled by controlling access to the bindings that name them. By exporting the binding naming a class or function, a program has effectively exported the class or function. If the binding is not exported, then the class or function is effectively private.[*]

A module definition defines the imports and exports of a module, and may specify bindings owned by the module. A complete description of module definitions is given on page 369.

Defining Module Bindings

A module consists of a set of bindings. A binding may be **owned** by a module, or a module may **import** the binding from another module by **using** the other module. Modules **export** bindings to make them accessible to other modules. Only exported bindings can be imported by other modules.

Within a given module, a name refers to at most one module binding. It is an error to create or import two or more different bindings with the same name in a single module. If a name does refer to a binding, the binding is said to be **accessible** from the module. Each binding is owned by exactly one module, but it can be accessible from many modules.

Module bindings are created by definitions. **Explicit definitions** are created by `define constant`, `define variable`, `define generic`, `define macro` and the class name in `define class`. **Implicit definitions** are created by `define method` and the slot specifications of `define class`.

[*] This privacy can sometimes be circumvented through certain introspective operations.

Within a library, a module binding may have no explicit definition or it may have one explicit definition. It may not have more than one explicit definition. If a module binding has no explicit definition, it must have one or more implicit definitions. If it does have an explicit definition, it can have zero or more implicit definitions.

A binding may be declared by the `create` clause of a module definition. This does not define the binding, but instead declares that it is owned by the module. Other modules may import the binding from that module. The binding must be defined by one of the modules which imports it.

If a binding is not declared by the `create` clause of a module definition, it is owned by the module in which its explicit definition appears. If it does not have an explicit definition, it is owned by one of the modules in which at least one of its implicit definitions appears; the exact owning module cannot be determined.

It is an error to reference a name for the purpose of getting or setting its value if the name does not designate either a local or module binding in the environment where the reference occurs.

Libraries

A library consists of the following parts:

- A library definition. This specifies a name for the library, a set of modules which are exported from the library for use by other libraries, and a set of modules that are imported from other libraries for use by the library being defined. A complete description of library definitions is given on page 374.
- The association of source code with the library. The mechanism by which this association is made is controlled by the programming environment and is implementation-defined.
- The association of executable code with the library. The mechanism by which this association is made is implementation-defined. The mechanism by which the compiler is invoked to produce the executable code is implementation-defined.
- The export information of the library. The format of this information and the mechanism by which it is associated with the library is

implementation-defined. The export information comprises the information required to process the source code of another library that imports the library.

The library export information is the only part of a Dylan library that is needed to allow some other library to import it. A library that exports some modules does not have any additional declarations providing information to the compiler when it is processing the code that imports those modules. Rather, any such information that is needed is obtained in some implementation-defined way while processing the source code of the exporting library and is retained in the library export information of the exporting library.

Exporting a module from a library makes all of the bindings exported by the module available for import by modules in other libraries.

Importing a module into a library allows the module to be used by modules defined within the library. This gives the library's modules access to the bindings of the module being imported.

Importing a module into a library does not allow source records in the importing library to be contained in the imported module.

Each implementation must provide a library named `dylan` which exports a module named `dylan`. That module must export exactly those bindings documented as being part of the Dylan language, and the values of those bindings must be as specified by the Dylan language. The `dylan` library is permitted to export additional implementation-defined modules.

Each library contains an implicitly defined module whose name is `dylan-user`. Within this module, all the bindings specified by the Dylan language are accessible using their specified names. Additional implementation-dependent bindings may also be accessible from this module.

C H A P T E R 4

Program Control

Contents

Overview

Dylan provides a number of program control constructs, implementing function calls, operators, assignment, conditional execution, iteration, and non-local flow of control.

This chapter also describes the multiple-value facility and the rules for order of execution of Dylan programs.

Function Calls

General Syntax

The general syntax for function calls is

function`(`*arg1*`,` *arg2*`,` … *argn*`)`

function has the syntax of an operand and is the function to be called. The *args* have the syntax of expressions, and are the arguments to the function. The *function* will often be a named value reference, but it can be any other kind of operand as well.

In the following example, the function being called is the value of the binding `average`.

```
average(x, y)
```

In the following two examples, the function being called is the value of a `method` statement. The examples differ only in that the second example puts parentheses around the `method` statement, to make the code somewhat more readable.

```
method(x) x + 1 end (99)
```

```
(method(x) x + 1 end) (99)
```

In the following examples, the function being called is the result of another function call. `key-test` takes a collection as an argument, and returns a predicate function. The predicate function is then applied to the two keys. The following three program fragments will have the same effect.

```
key-test(collection)(key1, key2)

(key-test(collection))(key1, key2)

begin
 let fun = key-test(collection);
 fun(key1, key2);
end
```

Slot Reference

Dylan provides a shorthand syntax for functions which accept one argument. The syntax *argument*`.`*function* applies *function* to *argument*. This syntax is commonly used for slot reference, to access the *function* slot of *argument*.

Order of execution aside, the following pairs of function calls are equivalent:

```
america.capital
capital(america)

window.position
position(window)
```

Slot reference syntax can be cascaded and is left associative. Order of execution aside, the following pair of expressions are equivalent. Each returns the origin of the root-view of a window.

```
window.root-view.origin
origin(root-view(window))
```

Element Reference

Dylan provides a shorthand syntax for element reference. The syntax *sequence*`[`*i*`]` is equivalent to the function call `element(`*sequence*`,` *i*`)`. The syntax *array*`[`i_1`,` i_2`,` … i_n`]` is equivalent to the function call `aref(`*array*`,` i_1`,` i_2`,` … i_n`)`.

Order of execution aside, the following pairs of expressions are equivalent:

```
*all-windows*[0]
element(*all-windows*, 0)

*tic-tac-toe*[1, 2]
aref(*tic-tac-toe*, 1, 2)
```

The names `element` and `aref` are looked up in the environment of the element reference expression.

Operators

Dylan provides a small number of unary and binary operators. Three of these are special operators with explicitly defined syntax and execution rules. The remainder are syntactic shorthand for function calls.

Operators and their operands must be separated by whitespace or parentheses. All binary operators are left-associative, except for the assignment operator, `:=`, which is right-associative.

Each operator that is syntactic shorthand for function call corresponds to a binding name, given in the table below. When an operator is called, the corresponding name is looked up in the environment of the call. (It is not looked up in the Dylan module, and will only refer to a binding in the Dylan module if that binding has been imported in the current module and has not been shadowed by a lexical binding.)

If the name given in the table has the same spelling as the operator, it must be escaped with \ to be used as a named value reference. For example, to add a method to + with `define method`, you use \+. To use < as an argument to `sort`, you write \<.

Special operators do not correspond to any binding name, and cannot be used with any alternate syntax.

With the exception of calls to the three special operators (&, |, and :=), the operands of a binary operator call are executed in left to right order. Special operators have their own flow of control rules, described in “Special Operators” on page 397.

The operators are listed below in descending order of precedence. Operators within a group share the same precedence. When a function call using slot reference syntax reference appears as an operands, it has greater precedence than any of the binary operators.

Table 4-1 Operators

Operator	Unary/Binary	Description	Name
`-`	unary	arithmetic negation	`negative`
`~`	unary	logical negation	`~`
`^`	binary	exponentiation	`^`
`*`	binary	multiplication	`*`
`/`	binary	division	`/`

Table 4-1 Operators

Operator	Unary/Binary	Description	Name
+	binary	addition	+
-	binary	subtraction	-
=	binary	equality	=
==	binary	identity	==
~=	binary	non-equality	~=
~==	binary	non-identity	~==
<	binary	less than	<
>	binary	greater than	>
<=	binary	less than or equals	<=
>=	binary	greater than or equals	>=
&	binary	logical and	{none}
|	binary	logical or	{none}
:=	binary	assignment	{none}

Assignment

The special operator `:=` is used to set variables to new values and as an alternate syntax for calling setter functions and macros.

The assignment operator is described in detail on page 397.

The following examples show the use of `:=` to change the value of a module binding.

```
define variable *foo* = 10;
*foo*
 ⇒  10
*foo* := *foo* + 100;
 ⇒  110
*foo*
 ⇒  110
```

The following examples show the use of `:=` as shorthand for calling a setter function. In general, using this syntax to call a function *fun* is equivalent to calling the function *fun*`-setter`.

```
define variable *foo* = vector (10, 6, 8, 5);
element(*foo*, 2)
 ⇒  8
element(*foo*, 2) := "bar"
 ⇒  "bar"
*foo*
 ⇒  #[10, 6, "bar", 5]
```

The following examples show the use of `:=` as shorthand for calling a setter function using slot access notation.

```
window.position := point(100, 100)
vector.size := 50
```

The following examples show the use of `:=` as shorthand for calling `element-setter` or `aref-setter`.

```
my-vector[2] := #”two”
my-array[1,1] := #”top-left”
```

Conditional Execution

There are a number of statements and special operators that can be used to conditionally execute code. These are described in detail in Chapter 14, “The Built-In Macros and Special Operators.”

Table 4-2 Conditional Execution

Macro	Description	Page
`if`	Executes an implicit body if the value of a test is true or an alternate if the test is false.	383
`unless`	Executes an implicit body unless the value of a test is true.	385
`case`	Executes a number of tests until one is true, and then executes an implicit body associated with the true test.	385
`select`	Compares a target object to a series of potential matches, and executes an implicit body associated with the first match found.	386
`|`	Returns the value of the first of two operands which is true.Returns the value of the first of two operands which is true. This is a logical or operation.	399
`&`	Executes a second operand and returns its values if the value of the first operand is true. This is a logical and operation.	400

True and False

For the purposes of conditional execution, there is a single object that counts as false, and all other objects count as true.

The false object is the constant `#f`. There is a canonical true object, `#t`, which can be used for clarity of code. `#t` and `#f` are instances of the class `<boolean>`.

Because all values besides `#f` count as true, the term "true or false" is not equivalent to "`#t` or `#f`".

The special operator ~ is used for logical negation. If its operand is true, it returns `#f`. If its operand is `#f`, it returns `#t`.

Iteration

Iteration is supported through a number of statements, as well as through recursive functions.

Iteration Statements

The statemens supporting iteration are described in detail in Chapter 14, "The Built-In Macros and Special Operators."

Table 4-3 Iteration Statements

Macro	Description	Page
`while`	Repeatedly executes a body until a test expression is false.	388
`until`	Repeatedly executes a body until a test expression is true.	388
`for`	Performs general iteration over a body, updating bindings and performing end tests on each iteration.	389

Tail Recursion

Implementations are encouraged to optimize tail recursive function calls whenever possible. Tail recursion occurs when a function F_1 returns the values of a call to another function F_2. In many cases, this can be used to create loops using self-recursive or mutually-recursive functions. (Among the cases which cannot be optimized are those in which the return value types of F_1 and F_2 differ, requiring the F_1 to check the types of the values before returning them.)

The following example uses tail recursion to compute the name of the root volume on which a given file system object is stored.

```
define method root-volume-name (f :: <file-or-directory>)
  if ( root-volume?(f) )
    f.name
  else
    root-volume-name(f.container)
  end if;
end method;
```

The example above can execute with constant stack size, regardless of how deeply nested the file system hierarchy may be.

Non-Local Exits and Cleanup Clauses

Non-local exits allow the direct transfer of control to a previous point in program execution. The normal chain of function returns is aborted.

Cleanup clauses are bodies which are guaranteed to execute, even if the program segment of which they are a part is aborted by a non-local exit.

Non-local exits and cleanup clauses are implemented by the `block` statement. A complete description of the `block` statement is given on page 392.

Multiple Values

The execution of an expression can yield one value, more than one value, or no values at all. This capability is called **multiple values**.

Multiple values are generated by the function `values`. They are received by the bindings of `let` declarations and `define constant` and `define variable` definitions.

Many statements will return multiple values if the last expression they execute returns multiple values. Similarly, a function will return all the values of the last subexpression it executes.

```
define method return-three-values (a, b, c)
  values(a, b, c)
end method return-three-values;

begin
  let (foo, bar, baz) = return-three-values (1, 2, 3);
  list (foo, bar, baz)
end
  => #(1, 2, 3)
```

Each expression in the argument list of a function call supplies only one argument to the function call. That argument is the first value returned by the expression. Additional values returned by the expressions are ignored.

```
list (return-three-values(1, 2, 3),
      return-three-values(1, 2, 3),
      return-three-values(1, 2, 3))
 ⇒ #(1, 1, 1)
```

Multiple values can be used to perform parallel binding:

```
begin
  let x = 10;
  let y = 20;
  let (x, y) = values (y, x);
  list (x, y);
end
 ⇒  #(20, 10)
```

The following rules apply when matching up an expression which returns multiple values with a binding declaration or definition that receives multiple values.

- If there are the same number of bindings and values, the bindings are initialized to the corresponding values.

- If there are more bindings than there are values, the extra bindings are initialized to `#f`. (If a binding is typed, `#f` must be an instance of its type or an error is signaled.)
- If there are more values returned than there are bindings, the excess values are placed in a sequence which is used as the initial value for rest-binding or discarded there is no rest-binding.

```
begin
  let (one #rest nums) = return-three-values(1, 2, 3);
  nums;
end
 ⇒  #(2, 3)
```

- If there is a rest-binding but there are no excess values, rest-binding is initialized to an empty sequence.

Order of Execution

Order of execution is defined for the constituents within a body. With some exceptions noted below, this execution order is left-to-right.

Definitions form the overall structure of a program and are not said to execute. In particular, module bindings are not created in any order, but all exist when program execution commences. To the extent that these bindings must be initialized by the values of some expressions which cannot be analyzed at compile time, references to the bindings are constrained by the execution order of the expressions within the surrounding body.

Dylan implementations are encouraged to allow forward references to module bindings whenever possible.

The order of execution of the components of a call to a user-defined macro is determined by the macro.

Execution Order Within Expressions

In general, execution within an expression proceeds left-to-right. The chief exception to this rule is the assignment operator, which is executed right-to-left.

- In a standard function call, the function operand is executed first, followed by the argument expressions. (Remember, the function need not be a named value reference, but can be a more complex operand). After the function operand has been executed and each of the argument expressions has been executed, the function is applied to the arguments.

```
one(two, three, four)
```

- In slot references, the object operand is executed first, followed by the function named value reference. Then the function is applied to the object.

```
one.two
```

- In element references, the collection operand is executed first, followed by the key expressions in order. Then the element access is performed. The execution time of the binding `element` or `aref` is unspecified.

```
  one[two, three]
```

- In an operator call, the operands are executed left-to-right. The execution time of the binding specified by the operand (e.g. `+` or `*`)is unspecified.

```
one + two - three
```

- In an assignment to a place which represents a function call, the order of execution is largely the same as it would be in a call to the corresponding setter function. The new-value expression is executed first, followed by the argument expressions. The execution time of the binding named by the setter function is undefined.

```
function-setter(one, two, three)
function(two, three) := one

slot-setter(one, two)
two.slot := one

element-setter(one, two, three)
two[three] := one

aref-setter(one, two, three, four)
two[three, four] := one
```

CHAPTER 5

Types and Classes

Contents

Overview

The Dylan type system is used to categorize all objects. In concert with generic functions, types determine the behavior of objects. When an object is passed as an argument to a generic function, the generic function looks at the type of the object to determine which method should be run.

Dylan supports several kinds of types, including classes, singletons, union types, and limited types.

- Classes are used to define the structure, inheritance, and initialization of all objects. An object can be an instance of any number of types, but will always be a direct instance of exactly one class.
- Singletons are used to indicate individual objects.
- Union types are used to indicate objects which are instances of one of a set of specified types.
- Limited types are used to indicate objects which are instances of another type and have additional constraints. There are several kinds of limited types.

All types are first-class objects, and are general instances of `<type>`. Implementations may add additional kinds of types. The language does not define any way for programmers to define new subclasses of `<type>`.

The Type Protocol

The type protocol comprises the following:

- All types may be used as specializers for method parameters, bindings, and slots.
- `instance?(`*object*`, ` *type*`)` tests type membership.
- `subtype?(`*type1*`, ` *type2*`)` tests type inclusion.
- `make(`*type* …`)` makes an instance. This operation is only supported if the type is instantiable.

- Type objects are immutable.
- If two type objects are equivalent and are not classes, it is unspecified whether they are ==.

The following is an informal description of type relationships: The function `subtype?` defines a partial ordering of all types. Type t_1 is a subtype of type t_2 (i.e. `subtype?(`t_1`, `t_2`)` is true) if it is impossible to encounter an object that is an instance of t_1 but not an instance of t_2. It follows that every type is a subtype of itself. Two types t_1 and t_2 are said to be **equivalent types** if `subtype?(`t_1`, `t_2`)` and `subtype?(`t_2`, `t_1`)` are both true. t_1 is said to be a **proper subtype** of t_2 if t_1 is a subtype of t_2 and t_2 is not a subtype of t_1.

`subtype?` on classes is defined by inheritance. A class is a subtype of itself and of its general superclasses.

`subtype?` on singletons is defined by object type and identity. If *x* is an object and *t* is a type, `subtype?(singleton(`*x*`), `*t*`)` will be true only if `instance?(`*x*`, `*t*`)` is true.

`subtype?` rules for union types are given in "Union Types" on page 71. `subtype?` rules for limited integer types are given in "Limited Integer Types" on page 72. `subtype?` rules for limited collection types are given in "Limited Collection Types" on page 124.

`<object>` is the root of the type hierarchy. All objects are instances of `<object>`, and all types are subtypes of `<object>`.

A number of operations on types are described in "Reflective Operations on Types" on page 331.

Base Types and Pseudosubtypes

Every type has a **base type**. The base type for a class is the class itself. The base type of a singleton is the singleton itself. The base type of a union is the union of the base types of its component types. The base type of a limited type `limited(`*C*`, …)` is *C*.

The type t_1 is a **pseudosubtype** of the type t_2 if t_1 is a subtype of the base type of t_2 and t_1 and t_2 are not disjoint.

Note that t_1 being a subtype of t_2 implies that t_1 is a pseudosubtype of t_2, but t_1 being a pseudosubtype of t_2 does not imply that t_1 is a subtype of t_2. Note also that if t_2 is not a limited type or some other non-standard type, then pseudosubtype is the same as subtype.

Base types and pseudosubtypes are used in the rules for sealing, described in Chapter 9, "Sealing."

Type Disjointness

Informally, two types are disjoint if there can be no object that is an instance of both types. Formally, the disjointness of types is specified by the following set of rules. (Some of these rules reference definitions given in "Limited Integer Types" on page 72, "Element Types" on page 122 and "Limited Collection Types" on page 124.)

- Two classes are disjoint if they have no common subclasses.
- A union type is disjoint from another type if both of the union type's component types are disjoint from that other type.
- A singleton type is disjoint from another type if the singleton's object is not an instance of that other type.
- A limited collection type is disjoint from a class if their base types are disjoint, or the class is a subclass of `<collection>` and its element type is definite and not equivalent to the limited collection type's element type, or the class is a subclass of `<collection>` and its element type is indefinite and not a supertype of the limited collection type's element type.
- A limited collection type is disjoint from a limited integer type. (Because the classes `<collection>` and `<integer>` are disjoint.)
- Two limited collection types are disjoint if their base types are disjoint, or their element types are not equivalent, or their sizes are not compatible. Two sizes are compatible if either is `#f`, or they are `=` to each other, or one is a sequence of integers and the other is the product of those integers.
- Two limited integer types are disjoint if the minimum value of one is greater than the maximum value for the other.
- A limited integer type is disjoint from a class if their base types are disjoint or the class is a subclass of `<integer>` whose range is disjoint from the limited integer type's range.

Classes

Classes are used to define the inheritance, structure, and initialization of objects.

Every object is a **direct instance** of exactly one class, and a general instance of the **general superclasses** of that class.

A class determines which **slots** its instances have. Slots are the local storage available within instances. They are used to store the state of objects.

Classes determine how their instances are initialized by using the **initialization protocol**.

Features of Classes

There are four features of classes, each of which is independent of the others.

- A class can be **abstract** or **concrete**. If the class is concrete, it can have direct instances. If it is abstract, it cannot have direct instances, but only indirect instances.
- A class can be **instantiable** or **uninstantiable**. If the class is instantiable, it can be used as the first argument to `make`. If it is uninstantiable, it cannot be used as the first argument to `make`.
- A class can be **primary** or **free**. This controls how a class can be used for multiple inheritance. For a full description of this feature, see “Declaring Characteristics of Classes” on page 132.
- A class can be **sealed** or **open**. This controls whether a class can be subclassed outside the library where it is defined. For a full description of this feature, see “Declaring Characteristics of Classes” on page 132.

Creating Classes

New classes may be created by calling `make` on `<class>`, or with the definition `define class`. In most programs the latter is more commonly used.

When a class is created with `make`, it is instantiated and returned just like any other object. The options available when creating a class with `make` are described on page 186.

When a class is created with `define class` it is used to initialize a new module binding. `define class` allows the specification of superclasses, slots, initialization behavior, and options related to sealing. The complete syntax of `define class` is given on page 366.

The following simple class definition creates a class named by the module binding `<new>`. The class inherits from `<object>`, and does not specify any slots.

```
define class <new> (<object>)
end class <new>;
```

The following class definition illustrates the creation of a class with multiple superclasses. Again, there are no slots.

```
define class <color-window> (<palette>, <window>)
end class <color-window>;
```

Class Inheritance

When a class is created, its **direct superclasses** are specified. The new class directly inherits from these classes; it is a **direct subclass** of each of these classes. There can be no duplicates in the direct superclasses of a class.

The subclass relationship is transitive. If a class C is a direct subclass of C_1, C_1 is a direct subclass of C_2, and C_2 is a direct subclass of C_3, then C is an **indirect subclass** of C_2 and C_3. A **general subclass** is a direct or indirect subclass.

Inheritance cannot be circular. A class cannot be its own general subclass.

A class is a subtype of each of its general superclasses.

Every class is a general subclass of `<object>`.

Computing the Class Precedence List

The definition of a class specifies a total ordering on that class and its direct superclasses. This ordering is called the **local precedence order**. In the local precedence order, the class precedes its direct superclasses, and each direct superclass precedes all other direct superclasses following it in the sequence of direct superclasses given in the class definition.

The **class precedence list** for a class *C* is a total ordering on *C* and its superclasses that is consistent with the local precedence orders of each of *C* and its superclasses as well as with the ordering in the class precedence list of each of its superclasses.

Sometimes there are several possible total orderings on *C* and its superclasses that are consistent with the local precedence orders for each of *C* and its superclasses. Dylan uses a deterministic algorithm to compute the class precedence list, which chooses one of the possible total orderings.

Sometimes there is no possible total ordering on *C* and its superclasses that is consistent with the local precedence orders for each of *C* and its superclasses. In this case, the class precedence list cannot be computed, and an error is signaled.

To compute the class precedence list for class *C*:

- Let *S* be the set of class *C* and all of its superclasses.
- Let $C_1 \ldots C_n$ be the members of *S*.
- Let $D_1 \ldots D_m$ be the direct superclasses of *C*.
- Let *L* be the class precedence list of *C*.
- Let $CPL_1 \ldots CPL_m$ be, respectively, the class precedence lists of $D_1 \ldots D_m$.
- A class C_1 is said to **precede** class C_2 if C_1 must appear before C_2 in *L*.
  - **Local precedence order constraint**
    Class *C* precedes every D in $D_1 \ldots D_m$. Every D_i in $D_1 \ldots D_m$ precedes every D_j, such that $i < j$.
  - **Monotonicity constraint**
    For every class precedence list *K* in $CPL_1 \ldots CPL_m$, every class in *K* precedes all the classes which occur later in *K*.

- To compute L, pick a class N in S such that there are no classes in S that precede N. If there is no such class, the class C is inconsistent and its creation is not permitted.
- If there are several classes from S with no predecessors, select the one that has a direct subclass rightmost in the partial class precedence list computed so far. (In more precise terms, let $\{N_1,\ldots N_m\}$, $m>=2$, be the classes from S with no predecessors. Let $(C_1,\ldots,C_n)$, $n>=1$, be the partial class precedence list computed so far. C_1 is the most specific class, and C_n is the least specific. Let $1<=j<=n$ be the largest number such that there exists an i where $1<=i<=m$ and N_i is a direct superclass of C_j. Select N_i as N.)
- Remove N from S. Add N to the end of L. Continue adding classes from S to L, as above, until S is empty.

This algorithm can be implemented with the following Dylan program:

```
define method compute-all-superclasses (c :: <class>)
  let local-precedence-order-constraints
    = add!(compute-constraints(c.direct-superclasses),
           list(c, first(c.direct-superclasses)));
  let monotonicity-constraints
    = reduce1(concatenate,
              map(compose(compute-constraints, all-superclasses),
                  c.direct-superclasses));
  let constraints
    =
remove-duplicates(concatenate(local-precedence-order-constraints,
                                    monotonicity-constraints),
                        test: \=);
  let all-supers
    = reduce(union, list(c),
             map(all-superclasses, c.direct-superclasses));
  topological-sort(all-supers, constraints, tie-breaker-rule)
end method compute-all-superclasses;

// Given an ordered list, pair up adjacent elements to give the
// constraint set for the ordering.
```

```
define method compute-constraints (l :: <list>)
  if (empty?(l) | empty?(l.tail))
    #()
  else
    pair(list(l.first, l.second), compute-constraints(l.tail))
  end
end method compute-constraints;
```

```
define method topological-sort
    (elements :: <list>,
     constraints :: <list>,
     tie-breaker :: <function>)
  local method sort (remaining-constraints,
                     remaining-elements,
                       result)
          local method next-minimal-elements
                            (remaining-elements :: <list>)
                  choose(method (class)
                           ~member?(class,
                                    remaining-constraints,
                                       test: method (a, b)
                                                  a == b.second
                                                 end method)
                              end method,
                           remaining-elements)
                end method next-minimal-elements;
          let minimal-elements =

next-minimal-elements(remaining-elements);
          if (empty?(minimal-elements))
            if (empty?(remaining-elements))
              result
            else
              error("Inconsistent precedence graph ~S.",
                      remaining-elements)
            end if
          else
            let choice =
                if (empty?(minimal-elements.tail))
                  minimal-elements.head
                else
                  tie-breaker(minimal-elements, result)
                end if;
            sort(remove(remaining-constraints,
                        choice,
                          test: method (a, b) member?(b, a) end),
                 remove(remaining-elements, choice),
                 concatenate(result, list(choice)))
          end if
        end method sort;
  sort(constraints, elements, #())
end method topological-sort;

define method tie-breaker-rule (minimal-elements, cpl-so-far)
  block (return)
    for (cpl-constituent in cpl-so-far.reverse)
      let supers = cpl-constituent.direct-superclasses;
      let common = intersection(minimal-elements, supers);
      unless (empty?(common))
        return(common.head)
      end unless;
    end for
  end block
end method tie-breaker-rule;
```

Slots

Slots are the interface to information about instances. They correspond to the fields or instance variables of other object-oriented programming languages. By default, each instance of the class has private storage for each slot, so one instance can have one value in the slot and another instance can have another value. Some slots are shared among instances, as described in “Slot Allocation” on page 59.

All slot access is performed by function calls.* The method that returns the value of a slot is called the **getter method**, and the method that sets the value of a slot is called the **setter method**. The getter and setter methods are added to generic functions. When defining a class, you specify slots by specifying the generic functions to which the getter and setter methods should be added.

For example, the class definition for `<point>` might be

```
define class <point> (<object>)
  slot horizontal;
  slot vertical;
end class;
```

This definition indicates that instances of `<point>` should have two slots, `horizontal` and `vertical`. The getter method for the first slot is added to the generic function `horizontal`, and the getter method for the second slot is added to the generic function `vertical`. The setter method for the first slot is added to the generic function `horizontal-setter`, while the setter method for the second slot is added to the generic function `vertical-setter.`

The following two code fragments are equivalent. Each returns the horizontal coordinate of a point:

```
horizontal(a-point)
a-point.horizontal;
```

The following three code fragments each set the horizontal coordinate of a point to 10:

```
horizontal-setter(10, my-point)
horizontal(my-point) := 10;
my-point.horizontal := 10;
```

A slot setter method returns its new value argument.

* This is in contrast to some other languages where slots are accessed through named value references.

Slot Inheritance

Slots are inherited from superclasses.

The collection of all the getter and setter generic functions for slots specified in a class or inherited from its superclasses must not contain any duplicates.

If a superclass is inherited through multiple paths, its slots are inherited once. For example, if class *A* has direct superclasses *B* and *C*, and both *B* and *C* have *D* as a direct superclass, *A* inherits from *D* both through *B* and through *C*, but the slots defined by *D* are only counted once. Because of this, multiple inheritance does not by itself create any duplicates among the getters and setters.

Note that two classes which specify a slot with the same getter or setter generic function are **disjoint** —they can never have a common subclass and no object can be an instance of both classes.

Slot Specifications

A slot specification describes a slot.

A slot specification must include the name of the getter of the slot (i.e. the name of the generic function to which the getter method will be added). This is how slots are identified. The specification may optionally include the name of the setter method. If it does not, a default name is generated by appending "`-setter`" to the name of the getter.

A number of other options are available in slot specifications:

- An initial value for the slot may be specified with an **init specification**.
- An init-keyword may be specified. This allows a value for the slot to be supplied when an instance is created.
- Slot allocation may be specified. This controls whether storage for the slot is allocated in each instance, or some other way.
- A slot may be specifed as constant. There will be no setter for the slot.
- A type may be specified. The value of the slot will be constrained to be an instance of that type.

- A sealing directive may be specified. See “Define Inert Domain” on page 133 for a complete description of the sealing constraints imposed by this directive.

For the complete syntax of slot specifications, see the reference entry of `define class` on page 366.

The following example defines a class with three slots, using a variety of slot options.

```
define class <window> (<view>)
  slot title :: <string> = “untitled”;
  slot position :: <point>, init-keyword: window-position:;
  slot color, init-keyword: color:, init-value: $blue-color;
end class <window>;
```

Init Specifications

An init specification provides a default initial value for a slot. It can do this directly (if it is an init specification of a slot) or it can do it indirectly by providing a default value for an init-keyword (if it is an init specification of an init-keyword).

There are three kinds of init specifications:

- An **init value** specifies a value that is used to initialize the slot. Each time the slot needs to be initialized, the identical value is used.
- An **init function** specifies a function to be called to generate a value that is used to initialize the slot. Each time the slot needs to be initialized, the function is called and its value is used. This allows slots to be initialized to fresh values, or to values computed from the current program state.
- An **init expression** specifies an expression to be executed to generate a value that is used to initialize the slot. Each time the slot needs to be initialized, the expression is executed and its value is used. This allows slots to be initialized to fresh values, or to values computed from the current program state.

Only one init specification may be supplied in a given slot specification, inherited slot specification, or initialization argument specification.

In general, an *init-function* will only be called and an *init-expression* will only be executed if its value will actually be used.

Init Keywords

An init-keyword allows the value of a slot to be specified by a keyword argument in the call to `make` when an instance is created. An init-keyword may be optional or required.

When the value of a slot is provided by a keyword in a call to `make`, it is called an **initialization argument**.

If an init-keyword is specified, the slot is said to be **keyword initializable**.

Slot Allocation

Options for slot allocation include `instance`, `class`, `each-subclass`, and `virtual`.

`instance` allocation specifies that each instance gets its own storage for the slot. This is the default.

`class` allocation specifies there is only one storage location used by all the general instances of the class. All the instances share a single value for the slot. If the value is changed in one instance, all the instances see the new value.

`each-subclass` allocation specifies that the class gets one storage location for the slot, to be used by all the direct instances of the class. In addition, every subclass of the class gets a storage location for the slot, for use by its direct instances.

`virtual` allocation specifies that no storage will be allocated for the slot. If allocation is `virtual`, then it is up to the programmer to define methods on the getter and setter generic functions to retrieve and store the value of the slot. Dylan will ensure the existence of generic functions for any specified getter and setter but will not add any methods to them. A virtual slot cannot specify an init specification or init-keyword. Any required initialization for the slot must be performed in a method on `initialize`.

Constant Slots

Specifying a slot as constant is equivalent to specifying `setter: #f`. If the constant adjective is supplied, it is an error to supply an explicit value for the `setter:` keyword in the slot specification. Such slots can only be given values at instance creation time (with an init specification or init-keyword).

```
define class <person> (<being>)
  constant slot birthplace, required-init-keyword: birthplace:;
end class <person>;

define class <astronaut> (<person>)
  constant class slot employer = #"NASA";
end class <astronaut>;

define class <hair-trigger> (<object>)
  constant slot error-if-touched;
end class <hair-trigger>;
```

Specializing Slots

Slots may be specialized by declaring the type of the slot when a class is created. Specializing a slot has the following effects on the getter and setter methods of the slot:

- The automatically defined slot getter method has its single parameter specialized on the class that specified the slot and has a value type declaration that indicates that it returns a single value of the type specified for the slot.
- The automatically defined slot setter method has its instance argument specialized on the class that specified the slot, has its new-value argument specialized on the type specified for the slot, and has a value type declaration that indicates that it returns a single value of the type specified for the slot.

The following example demonstrates how an explicitly defined setter method can be used to coerce a slot value of the wrong type (`<sequence>`) to the right type (`<simple-object-vector>`).

```
define class <person> (<object>)
  slot friends :: <simple-object-vector>, init-value: #[];
end class;
```

```
   define method friends-setter (f :: <sequence>, p :: <person>)
     p.friends := as(<simple-object-vector>, f);
     f;            // return new-value argument
   end method

   tom.friends := list(dick, harry);
```

The assignment expression invokes the method with the new-value parameter specialized on `<sequence>`, which reinvokes the function with a new-value argument that is a `<simple-object-vector>`, which invokes the slot setter method.

Overriding Slots in Subclasses

Some slot options related to instance initialization can be overridden in subclasses. The mechanisms for doing this are described in “Inherited Slot Specifications” on page 66 and in “Initialization Argument Specifications” on page 67.

Using Slots

Because slots are accessed through methods in generic functions, they appear to clients just like any other methods in generic functions. It is possible for a value to be stored in a slot in instances of one class, but computed from auxiliary values by instances another class. It is possible to filter the value of a slot when it is retrieved or stored. In all of these cases, the interface to the value is a function call, thus hiding the implementation details from clients.

In the following example, the class `<view>` stores `position` directly, while `<displaced-view>` performs a transformation on the value of the slot when storing or retrieving it.

```
define class <view> (<object>)
  instance slot position;
end class;

define class <displaced-view> (<view>)
end class;
```

```
define method position (v :: <displaced-view>)
  // call the  inherited method (the raw slot getter)
  // and transform the result
  displace-transform (next-method (v));
end method;

define method position-setter (new-position,
                               v :: <displaced-view>)
  // call the inherited method (the raw slot setter)
  // on the result of untransforming the position
  next-method (displace-untransform (new-position, v);
  new-position;  // return the new position
end method;
```

In other situations, a programmer will want storage in an instance for a slot value, but will want to perform some auxiliary action whenever the slot is accessed. In this case, the programmer should define two slots: an instance slot to provide the storage and a virtual slot to provide the interface. In general, only the virtual slot will be documented. The instance slot will be an internal implementation used by the virtual slot for storage. An example of such use would be a slot that caches a value.

```
define class <shape> (<view>)
  virtual slot image;
  instance slot cached-image, init-value: #f;
  ...
end class;

define method image (shape :: <shape>)
  cached-image (shape)
    | (cached-image (shape) := compute-image (shape));
end method;

define method image-setter (new-image, shape :: <shape>)
  cached-image (shape) := new-image;
end method;
```

Instance Creation and Initialization

The creation and initialization of instances is controlled by the generic functions `initialize` and `make`, using initialization information supplied by the class definition and by keyword arguments in the call to `make`. Much of this behavior is supplied by the default `make` method defined on `<class>`.

Overview

Instance creation and initialization proceeds through the following steps:

- The program calls `make` specifying a class and a set of keyword arguments.
- Optionally, the default `make` method may be shadowed by a user-supplied method specialized with a singleton specializer. This enables the user method to get at all the arguments to `make`, and to provide actual instantiation and initializations based on them. For example, a singleton method on an abstract class can reinvoke `make` on a concrete subclass of the abstract class, passing along the same or augmented initialization arguments.
- The default `make` method examines its keyword arguments, which are known as the **supplied initialization arguments**. It then produces a set of **defaulted initialization arguments** by augmenting the supplied initialization arguments with any additional initialization arguments for which default values are defined by the class or any of its superclasses. If the supplied initialization arguments contains duplicate keywords, `make` will use the leftmost occurance. This is consistent with keyword argument conventions used in function calls.
- The default `make` method signals an error if any required init-keyword is absent from the defaulted initialization arguments, or if any of the defaulted initialization arguments are not valid for initialization of that class. An initialization argument is valid if it is specified as an init-keyword in a slot specification or initialization argument specification, or if it is permitted by one or more of the `initialize` methods applicable to an instance of the class.
- The default `make` method allocates an instance and initializes all the slots for which it can provide values, as follows

- □ If the slot is keyword initializable and its keyword is present in the defaulted initialization arguments, then the slot is initialized from the defaulted initialization arguments.
- □ If the slot is not initialized by a keyword but has an init specification, it is initialized from the init specification.
- □ In either case, an error of type `<type-error>` is signaled if the value is not of the type declared for the slot.

- ■ The default `make` method then calls `initialize` on the initialized instance and the defaulted initialization arguments. Methods on initialize can access these arguments by accepting them as keyword parameters or in a rest parameter. If they are accepted in a rest parameter and the defaulted initialization arguments contained duplicate keywords, it is undefined whether any entries other than the leftmost for that keyword will be present.
- ■ Each `initialize` method typically calls `next-method`, and then performs its own initializations. (Note that it won’t have to initialize slots that were initialized by the default method on `make`.)
- ■ The default `make` method ignores the value of the call to `initialize` and returns the instance.

The values of virtual slots are not automatically initialized when a new instance is created. The programmer must perform any necessary initialization. This would usually be done inside a method on `initialize`. Because the values of virtual slots are often computed from other values at run-time, many virtual slots will not require any explicit initialization.

Additional Behavior of Make and Initialize

The object returned by `make` is guaranteed to be a general instance of the first argument to `make`, but not necessarily a direct instance. This liberality allows `make` to be called on an abstract class; it can instantiate and return a direct instance of one of the concrete subclasses of the abstract class.

```
define abstract class <dog> (<object>)
end class

define class <yorkshire-terrier> (<dog>)
end class
```

```
define method make (the-class == <dog>, #rest init-args, #key)
  apply(make, <yorkshire-terrier>, init-args)
end

make(<dog>)
⇒  {instance of <yorkshire-terrier>}
```

`make` is not required to return a newly allocated instance. It may return a previously created instance if that is appropriate. If a new instance is allocated, `make` will call `initialize` on the instance before returning it.

The `make` method on `<class>` returns a newly allocated direct instance of its first argument.

Programmers may customize `make` for particular classes by defining methods specialized on singletons of classes. These methods may reinvoke `make` on a subtype of the class, or they may obtain the default `make` behavior by calling next-method.

The default `make` method signals an error if its first argument is an abstract class. An instantiable abstract class must override this method with its own method for `make`.

Initialization of Class Allocated Slots

The initalization of slots with allocation class or each-subclass is performed in the following way:

- If the slot is not keyword initializable and the class definition does not include an init specification for the slot, the slot remains uninitialized until it is explicitly assigned by the program.
- If the slot is not keyword initializable and the class definition does include an init specification for the slot, the slot is initialized from the init specification before or during the creation of the first instance of the class.
- If the slot is keyword-initializable and the class definition also includes an init specification for the slot, the slot may be initialized or assigned by the default method of `make` whenever an instance is created, as follows:
  - If the corresponding initialization argument is absent from the defaulted initialization arguments of the call to `make` and the slot has not yet been initialized, then the slot is initialized from the init specification. If the slot has already been initialized, no action is taken.

- □ If the corresponding initialization argument is present in the defaulted initialization arguments of the call to `make`, then the slot is set to the value of that initialization argument, regardless of whether the slot was previously initialized.

Testing the Initialization of a Slot

A program can test to see whether a slot has been initialized, using the `slot-initialized?` function, described on page 248. There is no portable mechanism for resetting a slot to the uninitialized state once it has been initialized.

To support the `slot-initialized?` protocol in a virtual slot, programmers must define a method for `slot-initialized?` that specializes on the getter of the slot and the class.

Inherited Slot Specifications

An inherited slot specification is used to provide an init specification for a slot inherited from a superclass. It can add an init specification if one was not already present, or it can override an existing an init specification.

Inherited slot specifications identify the slot to be modified by the getter name. The inherited slot specification is only allowed if the class does indeed inherit a slot with that getter.

(An inherited slot specification is not required to include an init specification. If it does not, its only purpose is to ensure that the slot is present in a superclass. Because init specifications are not allowed for virtual slots, this is the only valid form of inherited slot specification for virtual slots.)

If an inherited slot specification supplies an init specification, it overrides any init specification inherited from a superclass. This allows the init specification of an inherited slot to be replaced in a subclass, thereby changing the default initial value of the slot.

```
define class <animal> (<object>)
  slot n-legs, init-value: 4;
end class;
```

```
define class <spider> (<animal>)
  inherited slot n-legs, init-value: 8;
end class;
```

Initialization Argument Specifications

Initialization argument specifications provide options for the handling of initialization arguments. They appear in `define class` forms, and have a syntax similar to that of slot specifications.

Initialization argument specifications allow the type of an initialization argument to be restricted, they allow an initialization argument to be declared to be required, and they allow the specification of a default value for an initialization argument.

Note that an initialization argument will only be used if it is specified to be the init-keyword of a slot, or if it is used as a keyword argument in an applicable method on `initialize`. An initialization argument specification can supply a default value for an initialization argument, and it can restrict the type of the argument or make it required, but it does not by itself cause the argument to be used when initializing an instance.

There are two kinds of initialization argument specifications: required initialization argument specifications, and optional initialization argument specifications.

A required initialization argument specification asserts that the initialization argument must be present in the defaulted initialization arguments. The default `make` method will signal an error if no such initialization argument is present.

An optional initialization argument specification can be used to specify a default value for the initialization argument, using an init specification. When a call to `make` does not specify the initialization argument, the default `make` method will add it to the defaulted initialization arguments with the value of the init specification.

The type argument has the same meaning in both kinds of initialization argument specification: it restricts the type of that initialization argument. Note that this is not the same thing as restricting the type of the slot.

The following example shows how initialization argument specifications can be used to override the behavior of a superclass:

```
define class <person> (<object>)
  slot favorite-beverage, init-value: #"milk",
                    init-keyword: favorite-beverage:;
  slot name required-init-keyword: name:;
end class <person>;

define class <astronaut> (<person>)
  keyword favorite-beverage: init-value: #"tang";
  keyword name: init-value: "Bud";
end class <astronaut>;
```

In this example, thet `<astronaut>` class provides default values for the `favorite-beverage:` and `name:` init-keywords. In addition to indirectly supplying default values for these slots, this also has the effect of making the `name:` argument optional in calls to `make` on `<astronaut>`. If the call to `make` does not specify a `name:`, the `name:` will be added to the defaulted initialization arguments by the default `make` method before the defaulted initialization arguments are checked for completeness.

More than one keyword initializable slot may be initialized from the same initialization argument (that is, more than one keyword initializable slot may specify the same init-keyword). However, an error is signaled if a single `define-class` form has more than one initialization argument specification for the same keyword. An error will also be signaled if a single `define-class` form has a keyword initializable slot which includes an init specification and also includes an initialization argument specification for the same keyword that is either required or provides a default value. These error situations are all indications of code that can never be reached.

Initialization Argument Inheritance

The inheritance of initialization argument specifications is defined as follows.

- A slot specification which supplies an init-keyword *K* by using `required-init-keyword:` is treated as if the initialization argument specification `required keyword` *K* had been specified in the class definition.

- A slot specification which supplies both an init-keyword and also an init specification is not equivalent to an initialization argument specification which includes both the init-keyword and an init specification. In the former case the init specification is used to default the value of the slot directly, but does not affect the defaulted initialization arguments; in the latter case the init specification is used to default the value of the slot indirectly, by affecting the defaulted initialization arguments.
- If the initialization argument is being specified for the first time (it is not inherited from any superclass) there are three factors to consider:
  - The `type:` argument, which defaults to `<object>`, specifies the required type of the initialization argument. (This does not specify the type of the slot.)
  - If the initialization argument is specified with `required keyword` then it is required, otherwise it is optional.
  - If the initialization argument is specified with `keyword`, then it can provide an init specification which is used by the default `make` method to provide a default value for the initialization argument in the defaulted initialization arguments.
- If an initialization argument specification is being specified for an initialization argument which is inherited from a single superclass, the following factors hold:
  - The type must be a subtype of the type of the inherited initialization argument. This implies that the type must be specified unless the type of the inherited initialization argument is `<object>`.
  - The initialization argument is required if the overriding initialization argument specification uses `required keyword`, or if the inherited initialization argument specification is required and the overriding initialization argument specification does not provide an init specification. When the the overriding initialization argument specification uses `required keyword`, any init specification in the inherited initialization argument specification is discarded. This means that a subclass can make an initialization argument used by a superclass become required; it can also make a required initialization argument become optional by specifying a default value for it.
  - Otherwise, the initialization argument is optional. If the overriding specification provides an init specification, then that is used to compute the defaulted initialization argument when the class is instantiated. Otherwise, the inherited initial value specification is used.

- When an initialization argument specification is being inherited from multiple superclasses, if the superclasses have exactly the same definition for the initialization argument, then that definition can simply be inherited. If the definitions differ, then the class which combines these other classes must provide an initialization argument specification which is compatible with all of the inherited ones, as described above.

Singletons

Singleton types are used to indicate individual objects. When determining whether a singleton specializer matches a given object, the object must be `==` to the object used to create the singleton.

A singleton for an object is created by passing the object to the function `singleton`, or by calling the function `make` on the class `<singleton>`.

Singleton methods are considered more specific than methods defined on an object’s class. Singletons are the most specific specializer.

```
define method double (thing :: singleton(#”cup”))
  #"pint"
end method
double (#"cup")
 ⇒  #"pint"
```

Dylan provides a concise syntax for singletons used as method specializers. The folowing definition is equivalent to the one above; it generates a call to the binding of `singleton` in the current lexical environment.

```
define method double (thing == #"cup")
  #"pint"
end method
double (#"cup")
 ⇒  #"pint"
```

Union Types

Union types represent the union of the instances of two other types. Union types are created with the function `type-union`. They are not classes.

Union types are useful as slot specializers, and describe the return types of many common functions. For example, the return type of the collection method on `size` could be expressed as `type-union(<integer>, singleton(#f))`.

```
define constant <green-thing> = type-union(<frog>, <broccoli>);

define constant kermit = make(<frog>);

define method red? (x :: <green-thing>)
  #f
end method;

red?(kermit)
  ⇒  #f
```

The following rules govern `subtype?` and `instance?` for union types.

Given

- *x* is an object.
- $s_1 \ldots s_m$ and $t_1 \ldots t_n$ are non-union types.
- The notation `type-union*(`$t_1 \ldots t_n$`)` stands for any arrangement of nested calls to `type-union`, where none of the arguments is a subtype of any other, and none of the arguments forms an exhaustive partition of any other type.

Then

`type-union(`t_1`, `t_1`)` is type equivalent to t_1

`type-union(`t_1`, `t_2`)` is type equivalent to `type-union(`t_2`, `t_1`)`

`type-union(`t_1`, type-union(`t_2`, `t_3`))` is type equivalent to `type-union(type-union(`t_1`, `t_2`), `t_3`)`

`type-union(`t_1`, `t_2`)` is type equivalent to t_2 when `subtype?(`t_1`, `t_2`)`

`instance?(x, type-union*(`$t_1 \ldots t_n$`))` will be true if and only if `instance?(`x`, `t`)` is true for some t in $t_1 \ldots t_n$.

`subtype?(type-union*(`$t_1 \ldots t_n$`), `s_1`)` will be true if and only if `subtype?(`t`, `s_1`)` is true for every t in $t_1 \ldots t_n$.

`subtype?(`s_1`, type-union*(`$t_1 \ldots t_n$`))` will be true if and only if `subtype?(`s_1`, `t`)` is true for some t in $t_1 \ldots t_n$.

`subtype?(type-union*(`$s_1 \ldots s_m$`) type-union*(`$t_1 \ldots t_n$`))` will be true if and only if every s in $s_1 \ldots s_m$ is a subtype of some t in $t_1 \ldots t_n$.

Limited Types

Limited types are subtypes of classes constrained by additional criteria. Limited types are created with the generic gunction `limited`. `limited(<integer> ,min: 0 max: 255)` and `limited(<array>, of: <single-float>)` are examples of limited types which are useful both for error checking and for optimization of compiled code.

Limited types are not classes.

Limited Type Constructor

Limited types are created with the generic function `limited`. The first argument to limited is a class. Depending on the class, additional keyword arguments are allowed to specify the constraints of the limited type.

Not all classes support `limited`; the methods for `limited` are documented individually on page 251.

Limited Integer Types

Limited integer types are subtypes of `<integer>` containing integers which fall within a specifed range. The range is specified by `min:` and `max:` keyword arguments to `limited`.

For example:

```
// accepts integers between -1000 and 1000 inclusive.
define method f (x :: limited(<integer>, min: -1000,
                                         max: 1000))
  …
  end method f;

//accepts all strictly positive integers.
define method f (x :: limited(<integer>, min: 1))
  …
  end method f;
```

Limited Integer Type Protocol

If *w*, *x*, *y*, and *z* are integers, the following equivalences hold:

- `instance?(`*x* `limited(<integer>, min:` *y* `max:` *z*`))` will be true if and only if `instance?(`*x*`, <integer>)`, `(`*y* `<=` *x*`)`, and `(`*x* `<=` *z*`)` are all true.
- `instance?(`*x*`, limited(<integer>, min:` *y*`))` will be true if and only if `instance?(`*x*`, <integer>)` and `(`*y* `<=` *x*`)` are both true.
- `instance?(`*x*`, limited(<integer>, max:` *z*`))` will be true if and only if `instance?(`*x*`, <integer>)` and `(`*x* `<=` *z*`)` are both true.
- `subtype?(limited(<integer>, min:` *w*`, max:` *x*`),`
  `limited(<integer>, min:` *y*`, max:` *z*`))` will be true if and only if `(`*w* `>=` *y*`)` and `(`*x* `<=` *z*`)` are both true.
- `subtype?(limited(<integer>, min:` *w* …`),`
  `limited(<integer>, min:` *y* …`))` will be true if and only if `(`*w* `>=` *y*`)` is true.
- `subtype?(limited(<integer>,`… `max:` *x*`),`
  `limited(<integer>,`… `max:` *z*`))` will be true if and only if `(`*x* `<=` *z*`)` is true.

Limited Collection Types

Limited collection types are subtypes of `<collection>` (and of subclasses of `<collection>`) which may be constrained to be a specified size and to contain elements of a specified type.

A complete description of limited collection types is given in "Limited Collection Types" on page 124 in Chapter 8, "Collections."

C H A P T E R 6

Functions

Contents

Overview

All operations in Dylan are functions.

Functions accept zero or more arguments, and return zero or more values. The **parameter list** of the function describes the number and types of the arguments which the function accepts, and the number and types of the values it returns.

There are two kinds of function, methods and generic functions. Both are invoked in the same way. The caller does not need to know whether the function it is calling is a method or a generic function.

A method is the basic unit of executable code. A method accepts a number of arguments, creates local bindings for them, executes an implicit body in the scope of these bindings, and then returns a number of values.

A generic function contains a number of methods. When a generic function is called, it compares the arguments it received with the parameter lists of the methods it contains. It selects the most appropriate method, and invokes it on the arguments. This technique of **method dispatch** is the basic mechanism of polymorphism in Dylan.

All Dylan functions are objects, instances of `<function>`. Generic functions are instances of `<generic-function>` and methods are instances of `<method>`.

Generic Functions

Generic functions can be created with `define generic` or by calling `make` on the class `<generic-function>`. They are most often created with `define generic`.

Generic functions may also be created implicitly by `define method` or by slot specifications in class definitions.

A generic function definition includes a parameter list, which constrains the methods that can be added to the generic function; some aspects of the parameter must be matched by any method added. In addition, a generic function parameter list may specify that all keyword arguments are permitted in a call to the generic function.

Parameter list congruency is described on page 91. The complete syntax of `define generic` is given on page 364.

The following definition defines a generic function which accepts a single required argument. All methods added to this generic function must also accept a single required argument.

```
define generic double (thing)
```

The following definition defines a generic function which accepts two arguments of type `<number>`. All methods added to the generic function must accept two required arguments of type `<number>` or subtype of `<number>`.

```
define generic average (n1 :: <number>, n2 :: <number>)
```

Generic functions created with `define generic` may be sealed or open. For details of this option, see "Declaring Characteristics of Generic Functions" on page 133.

Methods

Methods can be created with `define method`, `local`, and `method` program constituents. `define method` is used to define a method and add it to a generic function in a module binding. `local` is used to create local bindings that contain self-recursive and mutually-recursive methods. `method` is used to create and return methods for immediate application, for use as function arguments, or for storage in a variable or other data structure. Methods are also created for slot getters and setters when a class is created.

Methods cannot be created with `make`.

The parameters and return values of a method are described in its parameter list. The specializers in the parameter list declare the types of the arguments acceptable to the method. The method can be called only with arguments that match the specializers of the parameters. A complete description of parameter lists is given in "Parameter Lists" on page 82.

When the method is invoked, it executes its implicit body. Statements in the implicit body are executed in order, in an environment which contains the parameters bound to the arguments.

Methods may be invoked directly (used as functions), or indirectly through the invocation of a generic function.

Methods in Generic Functions

`define method` creates a method and adds it to a generic function in a module variable. If the module variable indicated is not already defined, it is defined as with `define generic`. Thus, `define method` will create a new generic function or extend an old one, as needed. Methods added to a generic function must have parameter lists that are congruent with the generic function's parameter list.

The following method accepts a single argument of type `<number>`, and returns the number doubled. The method will be added to the generic function in the module binding `double`.

```
define method double (thing :: <number>)
  => nother-thing :: <number>;
  thing + thing;
end method;
```

`define method` allows the programmer to control aspects of the sealing of the generic function to which the method is added. For more details, see "Abbreviations for Define Inert Domain" on page 136.

A generic function with no required parameters can contain a single method. Adding a new method has the effect of replacing the existing method.

The complete syntax of `define method` is given on page 365.

Local Methods

`local` is used for creating methods in local bindings. A single `local` declaration may create one or more such methods. These methods may be self-recursive and they may be mutually-recursive with other methods created by the same `local` declaration.

`local` is similar to `let` in that it creates local bindings in the current body. The parameters and the bodies of the methods are within the scope of the bindings. In this way, the methods can refer to themselves and to other methods created by the same `local` declaration.

The complete syntax of `local` is given on page 379.

```
define method newtons-sqrt (x :: <number>)
   local method sqrt1 (guess)
           // note call to other local method
           if (close-enough? (guess))
              guess
           else
              sqrt1 (improve (guess))  // note self-recursive
call
           end if
         end sqrt1,
         method close-enough? (guess)
           abs (guess * guess - x) < .0001
         end close-enough?,
         method improve (guess)
           (guess + (x / guess)) / 2
         end improve;
    sqrt1 (1)
end method newtons-sqrt;
```

Bare Methods

Methods can also be created and used directly with the `method` statement.

Methods created directly can be stored in module variables, passed as arguments to generic functions, stored in data structures, or immediately invoked.

The following example creates a method and stores it in the module variable square. It is appropriate to define a method in this way (rather than with define method) when the protocol of the function being defined does not require multiple methods.

```
define constant square = method (n :: <number>)
                           n * n;
                           end method;
```

It is sometimes useful to create a method inline and pass it directly to another function which accepts a method as an argument, as in the following example.

```
// sort accepts a test argument, which defaults to \<
sort(person-list,
     test: method(person1, person2)
             person1.age < person2.age
            end method)
```

Methods created directly with the `method` statement may be called directly or they may be added to generic functions. Usually, however, when you want to add a method to a generic function, you create and add the method in a single declarative step, with `define method`.

Closures

Methods created with `method` or `local` can be passed to functions and returned from functions. In both cases, the methods retain access to the lexical context in which they were created. Such methods are called **closures**.

The following example defines a function which returns score-card methods. The method which is returned is **closed over** the `score` parameter. Each time this method is called, it updates the `score` parameter and returns its new value.

```
define method make-score (points :: <number>)
  method (increase :: <number>)
    points := points + increase;
  end method;
end method make-score;

define constant score-david = make-score(100)

define constant score-diane = make-score(400)

score-david(0)
 ⇒  100
score-david(10)
 ⇒  110
score-david(10)
 ⇒  120
score-diane(10)
```

```
 ⇒  410
score-david(0)
 ⇒  120
```

Each invocation of `make-score` creates a new binding for `score`, so each closure returned by `make-score` refers to a different binding. In this way, assignments to the variable made by one closure do not affect the value of the variable visible to other closures.

The following example defines a method for `double` that works on functions. When you double a function, you get back a method that accepts arguments and calls the function twice, passing the same arguments both times. The method that is returned is closed over the function which was passed in as an argument.

```
define method double (internal-method :: <function>)
  method (#rest args)
    apply (internal-method, args);
    apply (internal-method, args);
    #f
  end method
end method;

define constant double-dave = double(score-david);

score-david(0)
 ⇒  120
double-david(10)
 ⇒  140
score-david(0)
 ⇒  140
```

Parameter Lists

The parameter list of a function describes the number and types of the arguments which the function accepts, and the number and types of the values it returns.

The parameter list of a generic function is used to define the overall protocol of the generic function. It constrains the methods that may be added to the generic function, through the parameter list congruency rules described on page 91. It may also specify that calls to the generic function may contain any keyword arguments.

The parameter list of a method specifies the types of arguments to which the method is applicable, and declares local bindings to which those arguments will be bound during the execution of the body of the method. It may also declare the return value types of the method.

Kinds of Parameters

Dylan parameter lists support **required parameters**, **rest parameters**, **keyword parameters**, and sometimes a **next-method parameter**. They also may include **return type declarations**.

The complete syntax of parameter lists is given in "Methods" on page 412.

Required parameters correspond to arguments which must be supplied when a function is called. The arguments are supplied in a fixed order and must appear before any other arguments.

Each required parameter may be a name or a name **specialized** by a type. Specifying a type declares that supplied argument must be a general instance of that type.

A rest parameter allows a function to accept an unlimited number of arguments.* After the required arguments of a function have been supplied, any additional arguments are collected in a sequence, which is passed as the value of the rest parameter. This sequence may be immutable, and it may or may not be freshly allocated. The types of rest parameters cannot be declared.

Keyword parameters correspond to arguments that are optional and may be given in any order. Symbols are used among the arguments to guide matching of arguments to parameters. These symbols are usually written in keyword syntax and so they are known as keywords. Keyword arguments can only be supplied after all required arguments are supplied. Keyword parameters may be specialized, restricting which values may be supplied for them. Keyword

* In practice, an implementation may place a reasonable limit on the number of arguments that may be passed to any function.

parameters may also be given default values to be used when the caller does not supply a value.

Required parameters come first in the parameter list, followed by the rest parameter, if any, and then the keyword parameters, if any. A rest parameter is indicated by the token `#rest` followed by the name of the parameter. Keyword parameters are indicated by the token `#key` followed by the keyword parameter specifiers, optionally followed by the token `#all-keys`.

If `#rest` and `#key` are used in the same parameter list, `#rest` must come first. The rest parameter will be bound to a sequence containing all the keyword arguments and their corresponding values.

A next-method parameter is indicated by the token `#next`, followed by the name of the parameter. It is not normally necessary to specify a next-method parameter explicitly. If a next-method parameter is not specified by the programmer, `define method` inserts one with the name `next-method`. If an explicit next-method parameter is given, it must come after the required parameters and before the rest and keyword parameters. Details of using next-method are given in "Calling Less Specific Methods" on page 96.

Kinds of Parameter Lists

Each function (generic function or method) has an argument passing protocol specified by its parameter list. The argument passing protocol for a method must be compatible with the argument passing protocol of any generic function to which it is added, as described in "Parameter List Congruency" on page 91.

The argument passing protocol of a function can be described in one of the following ways:

- A function is said to **require a fixed number of arguments** if its parameter list does not specify either `#rest` or `#key`.
- A function is said to **accept keyword arguments** if its parameter list specifies `#key`. The parameter list could also specify `#rest` if it is a method, but not if it is a generic function.
- A function is said to **accept all keyword arguments** if its parameter list specifies `#all-keys` in addition to `#key`.

- A function is said to **accept a variable number of arguments** if its parameter list specifies `#rest` but does not specify `#key`. (Note: if the parameter list specifies `#key` in addition to `#rest` it is not said to accept a variable number of arguments.)

A method that accepts keyword arguments is said to **recognize** the keywords mentioned in its parameter list. (A method may, of course, mention them in the parameter list and then ignore their values. It is still said to recognize them.) It is possible for a method to accept keyword arguments in general but not recognize any particular keywords; it does this by specifying `#key` without any subsequent keyword parameters.

If a generic function that accepts keyword arguments mentions any specific keyword arguments in its parameter list, these are the **mandatory keywords** of the generic function. Every method added to the generic function must recognize these keywords.

A function may accept all keyword arguments by specifying `#all-keys` in its parameter list.

When a function that accepts keyword arguments is called, it is said to **permit** a keyword argument in the call if one of the following is true

- The function is a method that recognizes the keyword.
- The function is a generic function and the keyword is recognized by any of the applicable methods of the call.
- The function accepts all keyword arguments.
- The function is a generic function and any of the applicable methods of the call accepts all keyword arguments.

If a function that accepts keyword arguments is called, it will signal an error if called with a keyword argument that it does not permit, or if the arguments following the required arguments are not keyword/value pairs. This is true even if the function specifies `#rest`.

If a method is called via a generic function or via next-method (rather than directly), the method itself does not check whether it received any keyword arguments it does not permit, nor does it check that the arguments following the required arguments are keyword/value pairs. This check is performed by the generic function or next-method, and is made relative to the call as a whole, not relative to an individual method or the methods remaining to be called.

A call to a function may supply the same keyword argument more than once. When this is done, the leftmost keyword/value pair is used.

Specializing Required Parameters

When you define a generic function or method, you may specify the types of the arguments appropriate for the generic function or method. This is called **specializing** the generic function or method, or specializing the parameters of the generic function or method.

The following example defines a method specialized on `<number>`. The method will be applicable when `double` is called on a general instance of `<number>`.

```
define method double (thing :: <number>)
  thing + thing;
end method;
```

Specialization constrains the values that may be passed as the value of a parameter. The function can be called only with arguments that are instances of the specializers of the corresponding parameters.

Specialization is useful in three way:

- It makes the intent of the program clear. It indicates to the compiler and to anyone reading the code that an error is signaled if an argument is not of the specializer type.
- It allows the compiler to perform additional optimizations.
- It is used to control method dispatch. By defining methods on the same generic function with different specializers, you can define behavior applicable to different sets of types. A generic function chooses among its methods on the basis of the methods' specializers. The generic function chooses the method whose specializers most closely match the types of the arguments.

Syntactically, specializers are operands. These operands are executed once when the function is created. They are not re-executed each time the function is called. The value of the operand must be a type.

It is most common for specializers to be constant module bindings or calls to a built-in type constructor such as `singleton`, `limited`, or `union`.

There is a convenient syntax for **singleton specializers**, which is equivalent to explicitly calling `singleton` in the current lexical scope.

Keyword Parameters

The syntax of a keyword parameter is:

[*keyword*] *name* [`::` *operand*] [= *expression*]

If *keyword* is not supplied, then *name* is used to indicate both the keyword and the name of the parameter. If the *keyword* and *name* are given independently, the *keyword* is used when calling the method, and the *name* is used as the name of the parameter inside the body of the method.

The *expression* supplies a default value for the parameter. It is used when the method is called and the keyword is not supplied. It is executed each time the method is called and the corresponding keyword argument is not supplied. If no *expression* is specified, the parameter corresponding to an unsupplied keyword argument is initialized to `#f`. The *expression* is executed in a scope that includes all the preceding parameters, including required parameters, the rest parameter (if any), the preceding keyword parameters, and the next-method parameter (if any).

In the following example, all three keyword parameters have default values, and all three use the same name for the keyword and the parameter.

```
define method percolate (#key brand = #"maxwell-house",
                              cups = 4,
                              strength = #"strong")
  make-coffee (brand, cups, strength);
end method;
```

The caller can choose which keyword arguments to supply and what order to supply them in:

```
percolate (brand: #"java", cups: 10);
percolate (strength: #"strong",
           brand: #"starbucks",
            cups: 1);
```

The following method has two keyword parameters. In each, the name of the keyword and the name of the parameter is specified separately. The first keyword parameter has a default value, the second does not.

```
define method layout (widget, #key position: the-pos = 0,
                                   size: the-size)
  let the-sibling = sibling (widget);
  unless (the-pos = position (the-sibling))
    align-objects (widget, the-sibling, the-pos, the-size);
end method;

layout(my-widget, position: 100, size: 500);
layout(my-widget, size: query-user-for-size() );
```

The keyword parameter syntax in which the keyword name and parameter name are given separately is needed to allow keyword names such as `position:` without forcing the method to use `position` as a local binding. If a method uses `position` as a local binding, it cannot access the module binding `position` (which contains a function). The local binding would shadow the module binding.

All required arguments must be supplied before any keyword arguments can be supplied. The following call to `layout` will signal an error:

```
layout(position: 100, size: 500);
```

Types for Keyword Parameters

When a type is indicated for a keyword parameter in a method, it is the same as establishing a type for a local binding. Specifically, the types of any keyword parameters are not used for method dispatch. Keyword parameter types are not allowed in generic function definitions, and do not figure into parameter list congruency.

The following two method definitions are equivalent:

```
method (#key X :: <integer>)
  ... X ...
end method;
```

```
method (#key X)
  let X :: <integer> = X;
  ... X ...
end method;
```

If a keyword parameter is given a type, if #f is not an instance of that type, and if they keyword parameter is not given a default value, then the keyword parameter is essentially required. An error of type <type-error> will be signaled if a call to the method does not include the keyword.

The following examples include keyword parameters that include both a type and a default value.

```
define method find-happiness (#key hint :: <symbol> =  #"here")
  ...
end method find-happiness;

define method find-food (#key hint :: <restaurant>
                              =  lookup-default-restaurant())
  ...
end method find-food;
```

Result Values

Parameter lists may include value declarations. Value declarations come at the end of the parameter list and are separated from the parameters by =>. For each return value, a value declaration can specify a name and an operand or just a name if the type is <object>. The complete syntax of value declarations is given in “Methods” on page 412.

The result of executing the operand at the time the function is defined is a type, called a **value type**. The name never comes into scope. It is included for documentation and for syntactic consistency with parameters. It is valid for the same name to be used in both one parameter and one value declaration in the same parameter list; this is useful as documentation that a function returns one of its arguments.

The last value declaration can be preceded by #rest to indicate a variable number of return values. A value declaration preceded by #rest is called a **rest value declaration**. A value declaration not preceded by #rest is called a **required value declaration**. The value type in a rest value declaration is the type of each one of the remaining individual values, not the type of a conceptual sequence of multiple values.

If a parameter-list does not contain a value declaration, it defaults to `=> #rest x :: <object>`. That is, the function can return any number of values of any type.

A function will always return the number and types of values declared in its parameter-list. More precisely:

- Each value returned by a function must be an instance of the corresponding value type, or else an error of type `<type-error>` will be signaled.
- If fewer values are returned by the function's body (or by the applicable method if the function is a generic function) than the number of required value declarations in the function's parameter-list, the missing values are defaulted to `#f` and returned. If `#f` is not an instance of the corresponding value type, an error of type `<type-error>` is signaled.
- If a function does not have a rest value declaration, and more values are returned by the function's body (or by the applicable method if the function is a generic function) than the number of required value declarations in the function's parameter-list, the extra values are discarded and not returned.

Because of the parameter list congruency rules for result value declarations, the values returned by a generic function do not have to be checked by the generic function. The check inside a method will always be enough to verify that the return values are valid for the generic function.

```
define method average (x :: <number>, y :: <number>)
 => mean :: <number>;
 (x + y) / 2
end method;

// Returning multiple values
define method limits (center :: <number>, radius :: <number>)
 => (min :: <number>, max :: <number>);
 values(center - radius, center + radius);
end method;
```

```
// The same name used both as a parameter and as a value type
define method rotate (image :: <picture>)
 => (image :: <picture>, rotation-angle :: <number>);
 …
end method;

// This method can return one, two, or three values
define method family (kid :: <person>)
  => (kid :: <person>, #rest parents);
  let mom = kid.mother;
  let dad = kid.father;
  case
    mom & dad => values(kid, mom, dad);
    mom => values(kid, mom);
    dad => values(kid, dad);
    otherwise => kid;
  end case
end method family;
```

Note that the following example does not declare a return value of type `<number>`. It declares a return value of type `<object>`. To specify a type, both the name and the type must be specified. If only one is given, it is taken as the name.

```
define method average (x :: <number>, y :: <number>)
 => <number>;
 (x + y) / 2
end method;
```

Parameter List Congruency

For any given generic function, the generic function and all methods for that function must have **congruent parameter lists**. Two parameter lists are congruent if they satisfy the following conditions:

- They have the same number of required arguments.
- Each of the method's parameter specializers is a subtype of the corresponding parameter specializer of the generic function.

- One of the following is true:
  - both accept keyword arguments
  - both accept a variable number of arguments
  - both require a fixed number of arguments
- If the generic function accepts keyword arguments, each method must recognize the mandatory keywords of the generic function.

In addition, the value declarations must be congruent, defined as follows:

- If the generic function's parameter list does not contain a rest value declaration, then
  - The method's parameter list must not contain a rest value declaration.
  - The two parameter lists must contain the same number of required value declarations.
  - Each value type in the method's parameter list must be a subtype of the corresponding value type in the generic function's parameter list.
- If the generic function's parameter list contains a rest value declaration, then:
  - The method's parameter list is permitted, but not required, to contain a rest value declaration.
  - The method's parameter list must contain at least as many required value declarations as the generic function's parameter list.
  - Each value type in the method's parameter list must be a subtype of the corresponding value type in the generic function's parameter list. If the method has a rest value type, it corresponds to the generic function's rest value type. If the method has more required value types than the generic function, the extra ones must be subtypes of the generic function's rest value type.

Parameter Lists of Implicitly Defined Generic Functions

As a general principle, the parameter list of an implicitly defined generic function will impose as few constraints as possible on the methods that may be added. If a more constrained generic function definition is desired, an explicit definition should be used.

The parameter list of an implicitly defined generic function is determined by its method definitions. These method definitions include both methods defined using `define method` and slot getter and setter methods defined using `define class`.

- The implicitly defined generic function has the same basic argument pattern as the methods. Either they must all require a fixed number of arguments, they must all accept a variable number of arguments, or they must all accept keyword arguments. A set of methods that includes members with more than one of these patterns violates the parameter list congruency requirement, and is an error.
- The implicitly defined generic function has the same number of required arguments as the methods. A set of methods that includes members with different numbers of required arguments violates the parameter list congruency requirement, and is an error.
- Each required argument of the implicitly defined generic function is specialized on `<object>`.
- If the implicitly defined generic function accepts keyword arguments, it does not have any mandatory keywords, nor does it accept all keyword arguments.
- The implicitly defined generic function has a rest value declaration of `<object>`.

Method Dispatch

When a generic function is called, the generic function uses the types of the arguments to determine which methods to call. This process is called **method dispatch**.

Method dispatch occurs in three phases. First, all the applicable methods are selected. Next, the applicable methods are sorted by specificity. Finally, the most specific method is called.

Method Specificity

For any two methods *A* and *B* that are applicable to a given generic function call, one method may be **more specific than** the other, or the methods may be **ambiguous methods**.

To order two methods *A* and *B* with respect to a particular set of arguments, compare each of *A*'s specializers with *B*'s specializer in the corresponding position using the argument that was supplied for that position. The comparison works in the following way.

- If the specializers are type equivalent, then *A* and *B* are unordered at the current argument position. That is, this argument position provides no information about the order of the two methods.
- Otherwise, if the specializer of *A* is a subtype of the specializer of *B*, then *A* precedes *B* at the current argument position.
- Otherwise, if both specializers are classes, then their order in the class precedence list of the argument's class is used to determine which is more specific. If *A*'s specializer precedes *B*'s specializer in the class precedence list of the argument's class, then *A* precedes *B* at the current argument position.
- Otherwise, the methods are unordered in the current argument position.

The method *A* is more specific than the method *B* if and only if *A* precedes *B* in at least one argument position, and *B* does not precede *A* in any argument position. Similarly, *B* is more specific than *A* if and only if *B* precedes *A* in at least one argument position, and *A* does not precede *B* in any argument position. If neither of these cases apply then *A* and *B* are ambiguous methods.

When the applicable methods are sorted by specificity, the sorted list is divided into two parts, each possibly empty. The first part contains methods that are more specific than every method that follows them. The second part (which cannot itself be sorted) begins at the first point of ambiguity; there are at least two methods that could equally well go first in the second part. When a generic function is called, if the first part of the sorted applicable methods is empty then an error is signaled. Similarly, if the last method in the first part attempts to call next-method, an error is signaled.

Consider the following class definitions:

```
define class <sentient> (<life-form>) end class;

define class <bipedal> (<life-form>) end class;

define class <intelligent> (<sentient>) end class;

define class <humanoid> (<bipedal>) end class;

define class <vulcan> (<intelligent>, <humanoid>) end class;
```

Computing the class precedence list for `<vulcan>` yields

```
#(<vulcan>,<intelligent>,<sentient>,<humanoid>,<bipedal>,<life-fo
rm>)
```

The class precedence lists computed for two different classes may have different precedence orders for some intermediate superclasses. This is not a problem as long as there is no class which inherits from both classes. For example, we could define a class `<human>` as follows:

```
define class <human> (<humanoid>, <intelligent>) end class;
```

For the class `<human>` defined as above, the class precedence list would be

```
(<human>,<humanoid>,<bipedal>,<intelligent>,<sentient>,<life-form
>)
```

It is not a problem that the two class precedence lists give different orders to some of the intermediate superclasses such as `<bipedal>` and `<sentient>` as long as no class is added which inherits from both `<vulcan>` and `<human>`.

When sorting the applicable methods, each specializer needs to be viewed with respect to the class precedence list for the class of the argument passed to the generic function in that argument position. For example, given the following definitions

```
define method psychoanalyze (being :: <intelligent>)
  …
   end method;
```

```
define method psychoanalyze (being :: <humanoid>)
  …
   end method;
```

calling the generic function `psychoanalyze` on a being of type `<human>` would cause the method for `<humanoid>` to be called first, while calling the generic function on a being of type `<vulcan>` would cause the method for `<intelligent>` to be called first.

The order of arguments is not significant when computing method specificity. Given the above class definitions, the following methods are unambiguous when their generic function is called on two beings of type `<vulcan>` or two beings of type `<human>`, but the methods are ambiguous when the call includes one being of type `<vulcan>` and one of type `<human>`.

```
define method superior-being (a :: <intelligent>,
                              b :: <intelligent>)
  most-intelligent-being (a, b)
  end method;

define method superior-being (a :: <humanoid>,
                              b :: <humanoid>)
  best-looking-being (a, b)
  end method;
```

Calling Less Specific Methods

In many situations, a subtype wants to modify the behavior of a method, rather than replace it completely; it wants to perform some work but also use the inherited behavior. This can be accomplished with **next-method**. Next-method is a function that, when called, invokes the next most specific method applicable in the generic function. The next-method is the value of the `#next` parameter. Normally this parameter is named `next-method`, though it can have other names at the programmer's discretion.

One can think of next-method as invoking the method which would have been called if the current method did not exist.

If there are no more methods available, the next-method parameter will be bound to the value `#f` instead of to a method.

Passing Different Arguments to Next-Method

In the usual case, next-method is called with no arguments. This indicates that the next-method should be passed the same arguments that were supplied to the current method.

It is valid to supply arguments, including different arguments, when calling next-method. However, if you pass different arguments, the new arguments must result in the same ordered sequence of applicable methods as the original arguments. Otherwise, the program behavior is undefined.

In some cases, the methods in a generic function accept different keyword arguments. In such cases, it's convenient for the methods also to accept a rest parameter. That way, all the keyword/value pairs passed to the generic function are captured in the rest parameter. By using `apply`, the next-method can be invoked with the complete set of arguments. (This technique is only necessary, of course, when the method calls next-method and passes arguments explicitly.)

As usual, if there are duplicates of a given keyword argument, the leftmost occurance is used. This allows keyword arguments to be easily overridden.

The Next-Method Parameter

The value of the next-method parameter is supplied by the generic function dispatch mechanism. When a method is called by its generic function, the generic function dispatch mechanism automatically passes the appropriate value for next-method. There is no way for a user program to specify the next-method argument when calling a method.

If you create a method directly (i.e., with `method` rather than with `define method`) and you want this method to accept a next-method parameter, then you should insert a `#next` into the parameter list explicitly. You would do this if you are creating a method that you plan to add to a generic function, and you want this method to be able to call next-method. You can also supply the next-method parameter when using `define method`, in cases where you want to give the parameter a different name.

Operations on Functions

The Dylan language defines a number of functions which operate on other functions.

There are two broad categories of these functions:

- Introspective functions take a function as an argument and return information about it. These are described in “Reflective Operations on Functions” on page 340.
- Higher order functions take one or more functions as arguments, and return a new function. These are described in “Functional Operations” on page 334.

C H A P T E R 7

Conditions

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C H A P T E R 7

Conditions

Background

A long-standing problem of software engineering is the need to develop an organized way to deal with exceptions, situations that must be handled gracefully but that are not conceptually part of the normal operation of the program.

Of course it is possible to program exception handling without using special linguistic features. For example, all functions could return an extra result that indicates whether they succeeded or failed, functions could take an extra argument that they consult if an exception occurs, or a designated exception-handling function could be called whenever a problem arises. All of these approaches have been used in one real-life system or another, but they are deficient in two ways. First, they are too informal and don't provide enough structure to allow an organized, systematic approach to exception handling. Second, and more importantly, the first two approaches do not provide textual separation between "normal code" and "code for dealing with exceptions"; exception-related code is sprinkled throughout the program. This leads to two problems: one is the well-known mistake of forgetting to test error codes and thus failing to detect an exception (perhaps because the programmer believed the error could never occur); the other is that program clarity is lost because it isn't easy to think about the main flow of the program while temporarily ignoring exceptions.

All exception systems involve the concept of "signal" (sometimes with a different name, such as "raise" or "throw") and the concept of "handle" (sometimes with a different name such as "on-unit" or "catch"). Most exception systems dynamically match signalers with handlers, first invoking the most recently established matching handler still active, and then, if that matching handler declines to handle the exception, invoking the next most recent matching handler, and so on.

In addition, it is necessary to have a way to clean up when execution of a function is terminated by a non-local exit initiated either by the function itself or by something it explicitly or implicitly called.

Exception systems may be name-based or object-based, they may be exiting or calling, and they may or may not provide formal recovery mechanisms.

In a name-based exception system a program signals a name, and a handler matches if it handles the same name or “any.” The name is a constant in the source text of the program, not the result of an expression.

In an object-based exception system a program signals an object, and a handler matches if it handles a type that object belongs to. Object-based exceptions are more powerful, because the object can communicate additional information from the signaler to the handler, because the object to be signaled can be chosen at run-time rather than signaling a fixed name, and because type inheritance in the handler matching adds abstraction and provides an organizing framework.

In an exiting exception system, all dynamic state between the handler and the signaler is unwound before the handler receives control, as if signaling were a non-local goto from the signaler to the handler.

In a calling exception system the signaler is still active when a handler receives control. Control can be returned to the signaler, as if signaling were a function call from the signaler to the handler.

Exiting exception systems are acceptable for errors. However, they do not work for an exception that is not an error and doesn’t require an exit, either because there is a default way to handle it and recover or because it can safely be ignored by applications that don’t care about it. Non-error exceptions are quite common in networked environments, in computers with gradually expiring resources (such as batteries), in complex user interfaces, and as one approach for reflecting hardware exceptions such as page protection violations or floating-point overflow to the application.

Most languages have not formalized how to recover from exceptions, leaving programmers to invent ad hoc mechanisms. However, a formal recovery mechanism is useful for several reasons: it ensures that recovery is implemented correctly; it allows options for recovery to be categorized just as exceptions are categorized; and it allows introspection on the options for recovery, for example by a debugger.

The Dylan exception facility is object-based. It uses calling semantics but also provides exiting handlers. It provides formal recovery.

Conditions

Overview

The Dylan exception system is built on top of an underlying signal system. Together, the signal system and the exception system comprise the Dylan condition system.

At the signal layer, the condition system provides a way of establishing a run-time connection between a **signaler** and a **handler** through a **condition**. This is essentially a run-time analog to the more usual fixed connection between a caller and a callee established through function-name matching. This layer of the condition system is little more than a way to locate and call a function. The function call does not necessarily involve any exceptional situation or non-local flow of control.

At the exception layer, the condition system specifies a set of protocols for categorizing and handling exceptional situations through **recovery** or **exit**. This higher layer provides overall structure, eliminates the possibility of failing to notice an exceptional situation, and provides a clean separation between "normal code" and "code for dealing with exceptions."

The non-local exit and clean-up features of the `block` statement are often used in conjunction with the facilities described in this chapter. `block` is described on page 392.

Signalers, Conditions, and Handlers

A condition is an object used to locate and provide information to a handler. A condition represents a situation that needs to be handled. Examples are errors, warnings, and attempts to recover from errors. All conditions are instances of `<condition>`. Several subclasses of `<condition>` are provided for additional behavior. These are described in "Conditions" on page 234.

A handler is a function for handling conditions of a particular type. Handlers may be installed dynamically with the local declaration `let handler`, and with the `exception` clause of the `block` statement. Dynamically installed handlers are active for the duration of the execution of a body. More recently installed handlers take precedence over less recently installed handlers. If no dynamically installed handler handles a condition, the generic function `default-handler` is called. `default-handler` has predefined methods and may also have program-defined methods.

Signaling is the mechanism for locating the most recently installed handler for a condition. The basic mechanism for signaling is the function `signal`. Several functions built on `signal` are provided for additional behavior. These are described in "Signaling Conditions" on page 346.

When a condition is signaled, the condition facility locates the most recently installed applicable handler and calls it. An applicable handler is one that matches the signaled condition by type and by an optional test function associated with the handler. The condition system is simply a way for a signaler and a handler to be introduced to each other. Once they have met, they communicate through an ordinary function call. The condition object is the argument to that call.

Like any function, the called handler either returns some values or takes a non-local exit. Either way, the handler has handled the condition, and the act of signaling is completed.

A handler also has the option of declining to handle the condition by passing control to the next applicable handler. It does this by tail recursively calling a next-handler function which it received as an argument. The next-handler function calls the next most recently installed applicable handler with appropriate arguments. This is analogous to the next-method function used in methods of generic functions.

(The call to next-handler is described as tail-recursive to ensure that all values returned by the call are returned by the handler. Not returning all the values could interfere with the condition's recovery protocol. A handler that really knows what it is doing could use a non-tail-recursive call, but anything that knows what it's doing in this situation is probably unmodular. Note that a handler might not know the full recovery protocol, because the condition might be a subtype of the handler's expected type.)

Every signaled condition is handled, because the system ensures that there is always an applicable default handler which does not decline.

If a handler handles a condition by returning (rather than by taking a non-local exit) the values it returns are returned by `signal`.

Exception Handling

A set of classes, functions, and associated conventions extend the underlying condition handling capabilities to provide a complete exception handling facility.

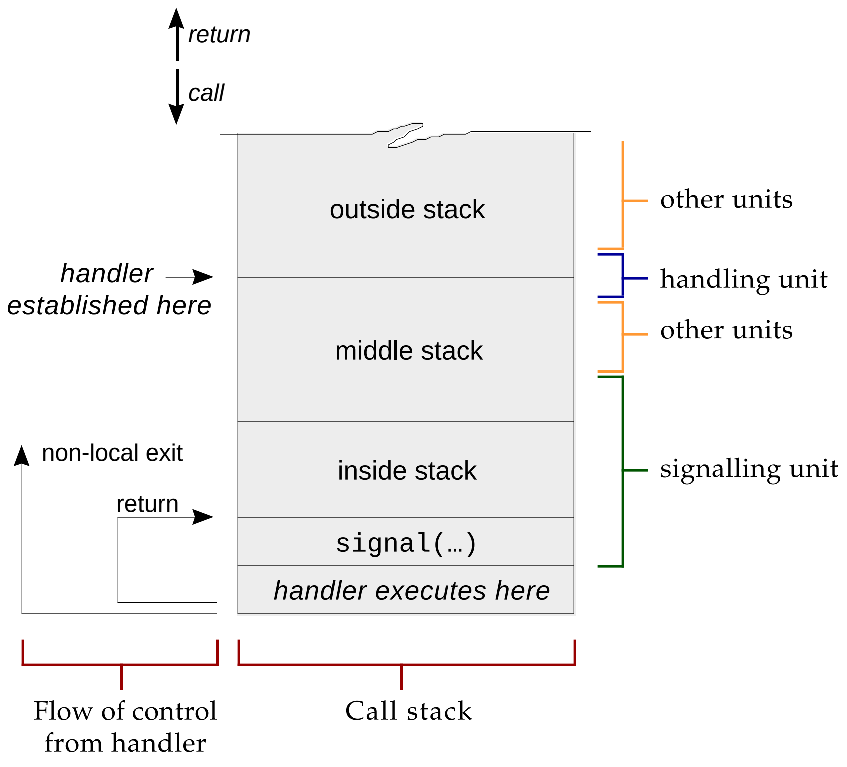
The classes are described in "Conditions" on page 234, and the functions are described in "Signaling Conditions" on page 346.

Stack Model

Condition handlers are installed dynamically, with more recent handlers shadowing previously installed handlers. In addition, exception handling often involves the use of non-local exits. For these reasons it is useful to describe the behavior of the exception system using the following terms from the stack model of function calling.

- **outside stack**
  The state existing just before the handler was established
- **signaling unit**
  The conceptual program component that includes the expression that signaled the condition and does not include the expression that established the handler. This informal concept provides a notion of where the interface boundary between the signaler and the handler lies.
- **middle stack**
  The state existing just before the signaling unit was called, minus the outside stack. In other words, the state between the handler and the signaling unit.
- **inside stack**
  The state existing just before signaling occurred, minus the middle stack and outside stack. In other words, the portion of the signaling unit prior to the call to `signal`.

Figure 7-1



The handler in Figure 7-1 may either return normally, in which case execution resumes as the call to `signal` returns normally, or the handler may make a non-local exit, such as calling the exit function from a dynamically active `block` statement.

Recovery and Exits

There are two ways to handle an exception: by **recovery**, or by **exit**. Recovery involves making some repair to the program state and leaving control in the signaling unit. Exit involves transfering control outside of the signaling unit through the use of a non-local exit.

The simplest way to handle an exception is to exit the signaling unit by taking a non-local exit to a target established in the outside stack. The `exception` clause of the `block` statement provides a convenient mechanism for accomplishing this.

A less common handling style is to exit the signaling unit by taking a non-local exit to a target established in the middle stack, thus leaving the handler in force.

Instead of exiting, a handler can recover by returning control to the signaling unit. This can be done either by returning values that the signaling unit will understand or by taking a non-local exit to a target established in the inside stack.

The following examples show three ways of handling a copy-protection violation while copying a series of files. Note that the signaling code does not need to know how the condition will be handled. The only changes are in the code which handles the condition.

```
// Assume there is a class for file-system errors.
// We are interested in a special kind of file-system error
// that occurs when attempting to copy a copy-protected file,
// so we define a new class to indicate such errors.
define class <copy-protection-violation> (<file-system-error>)
  slot file, init-keyword: file:;    // Store the file name
end class;

// Define a function to copy a single file. This
// function signals a <copy-protection-violation> if
// the file is copy-protected.
define method copy-file (source, destination)
  if ( copy-protected?(source) )
    signal(make(<copy-protection-violation>, file: source));
  else
    // copy normally
    notify-user("Copying %s to %s.", source, destination);
  end if;
end method;
```

```
// The following function copies a sequence of files.
// If one of the files is copy-protected, the user is
// notified, and the remaining files are copied.
define method backup-all-possible (volume, archive)
  let handler <copy-protection-violation>
       = method (condition, next)
           // The handler just notifies the user and continues
           notify-user("The file %s could not be copied.",
                       condition.file);
         end method;
  // start copying files, with the handler in effect
  for (each-file in volume)
    copy-file(each-file, archive)
  end for;
end method;

// The following function stops copying as soon as it
// hits a copy-protected file
define method backup-exit (volume, archive)
  // set up a block so we can do a non-local exit
  block (exit)
   let handler <copy-protection-violation>
       = method (condition, next)
           // Notify the user and abort the backup
           notify-user(
    "Backup interrupted: the file %s could not be copied.",
                       condition.file);
           exit(#f);
         end method;
  // start copying files, with the handler in effect
    for (each-file in volume)
      copy-file(each-file, archive)
    end for;
  end block;
end method;
```

```
// The following function uses the convenient exception clause of
// the block statement to achieve essentially the same effect as
// as backup-exit.
define method backup-block (volume, archive)
  // get ready to do backups
  block ()
    // start copying files
    for (each-file in volume)
      copy-file(each-file, archive)
    end for;
  exception (condition :: <copy-protection-violation>)
    notify-user(
   "Backup interrupted: the file %s could not be copied.",
                condition.file);
  end block;
end method;
```

Restarts

Recovering or exiting can be accomplished directly, or a more formal mechanism called **restarting** can be used. Using restarts provides more assurance that the handler and the signaling unit agree on the meaning of what they are doing and provides some isolation of the handler from names and data representations internal to the signaling unit.

A handler restarts by signaling a restart. All restarts are instances of `<restart>`. Any values needed for recovery are passed in the restart (that is, in initialization arguments that the restart remembers, typically in slots). The restart is handled by a restart handler which either returns or takes a non-local exit. If the restart handler returns some values, `signal` returns those values and the handler that called `signal` also returns them. The call to `signal` from the signaling unit that signaled the original condition returns the same values, and the signaling unit recovers as directed by those values.

Recovery Protocols

For every condition class there should be a **recovery protocol** that defines the meaning of handling by returning, the meaning of the values returned, and which restart handlers are supposed to be established by the signaling unit. The recovery protocol tells the handler what to expect from the signaler. For many condition classes, this is the empty protocol: handling by returning isn't allowed, and no particular restart handlers are provided. In this case only handling by exiting is possible. (Exiting might be accomplished by signaling a restart whose handler was established in the outside or middle stack and does a non-local exit back to where it was established, or by an ordinary non-local exit.) The recovery protocol for a subclass should be compatible with the recovery protocol of a superclass. That is, a handler that applies a class's recovery protocol should operate correctly when the condition is an instance of some subclass of that class.

An example recovery protocol for a hypothetical `<unbound-slot>` condition could include the following:

- Returning is allowed. Returning a value uses that value as if it had been the contents of the slot.
- A restart handler for `<new-value>` is available. `<new-value>` has initialization arguments `value:`, the value to use, and `permanent:`, which indicates whether to store the value into the slot or leave the slot unbound.

At present, no formal mechanism is provided for describing recovery protocols; they are left to the documentation of a condition class. Introspective functions are provided for discovering which recovery facilities are actually available, but this is different from (and sometimes is a superset of) the recovery facilities guaranteed by a recovery protocol always to be available.

The debugger is the condition handler of last resort which receives control if no program-provided handler handles a serious condition. (This is true even if the debugger provided cannot analyze or intervene in the execution of programs but can only abort or restart them. The debugger might be merely a "core dumper," a "bomb box," or something similar.) An interactive debugger ought to offer the user the ability to signal any restart for which a restart handler is applicable and to return if the condition's recovery protocol allows it. This could, for example, be done with a menu titled "Recovery."

Condition Messages

Some condition classes provide a message to communicate the meaning of the condition to the program user.

Condition messages are constructed using **format strings**. A format string is a string template into which values can be inserted to construct a message. The two-character **format directives** `%d`, `%b`, `%o`, `%x`, `%c`, `%s`, and `%=` are replaced by the corresponding element of the associated sequence of **format arguments**. Upper and lower case letters are equivalent in these format directives. The inserted value is formatted according to the following table:*

Table 7-1 Format Directives

Directive	Argument Type	Textual Format
`%d`	`<integer>`	decimal number
`%b`	`<integer>`	binary number
`%o`	`<integer>`	octal number
`%x`	`<integer>`	hexadecimal number
`%c`	`<character>`	character (with no quotes)
`%s`	`<string>`	string (with no quotes)
`%s`	`<condition>`	condition message (with no quotes)
`%=`	`<object>`	unspecified, but works with any object
`%%`	none	literal %

The text printed by the `%=` format directive for any given object is implementation-defined. The behavior when a format argument is not of the type specified in the table above is implementation-defined. The behavior

* These format directives are designed for compatibility with C's `printf`, with some ommisions and with the addition of `%=`.

when too many or too few format arguments are supplied is implementation-defined.

The two-character sequence `%%` does not consume a format argument, but inserts a `%` character.

All other uses of the `%` character in a format string are implementation-defined.

There is no standard way to get the message from a condition (although it can be inserted into another message). Debuggers get the message using implementation-dependent mechanisms. A streams library or other implementation-dependent feature might include a function to get the message from a condition. However, in some implementations, the message might only exist in the debugger, not in the program runtime.

There is no standard way for a user-defined condition class to supply a message. Individual implementations and libraries can specify such a mechanism that is appropriate to their needs.

Introspective Operations

The function `do-handlers` allows introspection of all the dynamically active handlers. For each handler, it provides the type, test, function, and init-arguments that were declared when the handler was installed. `do-handlers` is typically used by the debugger or other error-recovery system to discover what restart handlers are available before signaling a restart.

Additional operations support introspection on conditions. See "Introspection on Conditions" on page 351 for a complete description of these introspective functions.

CHAPTER 8

Collections

Contents

Overview

Collections are aggregate data structures which map from **keys** to **elements**. All collections are instances of the class `<collection>`.

`<collection>` has two covering subclasses: <sequence> and `<explicit-key-collection>`. Every concrete subclass of `<collection>` must also be a subclass of `<sequence>` or `<explicit-key-collection>`. **Sequences** use successive non-negative integers as keys; **explicit key collections** may use any object as a key. Both of these classes have predefined subclasses and may be additionally subclassed by programmers. See "Collections" on page 199 for a complete description of these classes.

A large number of functions are available on collections, including functions for iteration, mapping, random access of elements, sorting, filtering, etc. See "Collection Operations" on page 281 for a complete description of these functions.

The Iteration Protocol

All collections implement an **iteration protocol** that allows iteration to be specified abstractly. Many higher level operations on collections can be defined in terms of only the iteration protocol. For many programs these higher level operations are sufficient; they will not need to use the iteration protocol directly. The iteration protocol is used by programs defining new collection types, and for certain types of iteration that cannot be handled by the built-in higher level operations.

The iteration protocol centers on the notion of a "state" object for an iteration. Each collection class chooses its own most appropriate representation for an iteration state, and only the functions of the iteration protocol are affected by this choice.

Use of the iteration protocol is based on the assumption that the collection over which iteration occurs remains static for the duration of the iteration. That is, arbitrary changes to a mutable collection while an iteration is in progress may cause the iteration to produce unpredictable results.

With notable exceptions, two or more iterations over the same collection are not guaranteed to produce the same values in the same order, even if the collection is unaltered. For details, see "Iteration Stability and Natural Order" on page 116.

The built-in collection functions are implemented in terms of the iteration protocol. When defining a new collection class, a programmer need only define the iteration protocol for the class. Once this is done, instances of the class can be used with all the built-in collection functions. Of course, in some cases it will be more efficient to define methods on these functions optimized for the new class, rather than relying on the default implementation based on the iteration protocol.

Collection Keys

All collections in Dylan are keyed. That is, all collections can be viewed abstractly as partial functions that map keys to elements. (This choice precludes pure sets from being considered collections, although it is straightforward simply to ignore the keys for a collection and consider it simply as a set of elements.) The `element` function implements this partial mapping of keys to elements.

Every collection has a **key test**, which is the test used for determining whether a given key matches a key in the collection. The key test of a collection can be accessed using the `key-test` function.

Iteration Stability and Natural Order

A collection is **stable under iteration** if any two iterations over the collection are guaranteed to produce the same values in the same order in the absence of modifications to the table. If this guarantee does not hold, the collection is **unstable under iteration**.

Sequences are required to be stable under iteration. Explicit key collections may or may not be stable under iteration.

The order in which elements and keys are enumerated by the iteration protocol for a particular iteration is known as the **natural order** for that iteration over the collection. If a collection is stable under iteration, then every iteration over that collection will have the same natural order, and we may speak of the natural order of the collection itself. Most of the operations on collections are required to operate in natural order, usually for the purpose of understanding interactions among side effects.

Mutability

Some collections can be modified after they have been created while others cannot. The `<mutable-collection>` and `<stretchy-collection>` mixin classes are provided to allow methods to distinguish between mutable and immutable collections. Instances of `<mutable-collection>` can have their elements changed after they are created. Instances of `<stretchy-collection>` can have keys added and removed after they are created.

An element of a mutable collection is set to a new value with `element-setter`. If the collection is not stretchy, than the key specified must already be present in the collection; its value will be changed. If the collection is stretchy, then the key will be added if it is not already present. If the collection is a stretchy sequence and the key is not already present, then the size of the sequence will first be set to the new key minus 1, and then the value of the new key will be set.

A key and its corresponding value can be removed from an explicit key collection with the function `remove-key!`.

Collection Alteration and Allocation

The contents of a collection are the key/value pairs stored in the collection. The contents are said to be **altered** when:

- Keys are added or removed (according to the collection's key test).
- The value of a key (according to the key test) changes (as tested by ==).

- The ordering of the key/value pairs changes. This type of alteration is only possible for explicit key collections which are stable under iteration.

A function **destructively modifies** its argument collection if calling the function could alter the contents of the argument collection. Unless explicitly documented to do so, functions do not destructively modify their arguments.

The `!` convention, described on page 23, is used to indicate some destructive operations.

Unless explicity noted, destructive operations are not required to leave their arguments in a well-defined state. More particularly, a destructive operation does not in general turn the argument into the result. It may reuse components of the argument or alter the argument in some unpredictable way in order to produce the result. As a general rule, the return value of the function should be used.

A collection *C* is **fresh** if modification of any pre-existing collection's contents can never modify the contents of *C* and if modifications to *C* can never modify the contents of any pre-existing collection. Immutable collections cannot be modified, so a fresh immutable collection can share structure with other immutable collections.

For example, given that `<pair>` is mutable and the result of a call to `list` is a fresh instance of `<pair>`, we can guarantee that the following expression is always false:

```
list(1) == list(1)
```

Collection Alignment

Some operations on collections are defined to allow the use of more than a single collection. For example, some looping functions accept any number of collections and operate on these collections in parallel. Each pass through the loop uses one element from each collection. The presence of collections which are unstable under iteration can create problems for multi-collection operations unless special care is taken. If iteration is effectively performed in random order, then naively performing parallel iterations over two different collections would randomly combine values from the two collections. This would presumably have no meaning.

To prevent such random combinations, operations on more than one collection must in general align the collections. **Collection alignment** consists of effectively computing the intersection of the collections' key sequences and then using the random-access operations (`element` and `element-setter`) to operate on the collections themselves.

If implemented naively, this definition of alignment has the potential for extreme inefficiency because of its dependence on `element` and the potential loops implied by the calls to `key-sequence`. However, an important special case of this problem is that of iterating over multiple sequences. In this case, the intersection of key sequences will always be the non-negative integers up to the length of the shortest sequence. Further, unlike collections in general, sequences are required to exhibit stability so the explicit computation of key sequences is not actually required. It is correct simply to iterate until one or more of the sequences is exhausted.

Iteration operations that store results in a target collection must generally include the the target collection during alignment. This alignment requirement is relaxed if the target collection is a `<stretchy-collection>`. In this case, the target collection is not considered during alignment. Rather, only the source collections are aligned. New keys may be added to the target collection during the course of the iteration, and keys may be given new values. Other keys are left undisturbed.

It is only possible to align collections which have identical key tests.

Defining a New Collection Class

Every collection class must provide an implementation of the iteration protocol. A method on `forward-iteration-protocol` is required. A method on `backward-iteration-protocol` is optional.

Every collection must provide or inherit methods for `element` and `key-test`. If the collection is also a `<mutable-collection>`, it must provide or inherit a method for `element-setter`. A collection that is not a `<mutable-collection>` must provide an implementation of `type-for-copy`.

Individual collection classes may impose further requirements on their subclasses. For example, concrete subclasses of `<table>` must provide or inherit a method for `table-protocol`.

For efficiency, it may be desirable to provide specialized implementations for certain generic functions. Collections that can implement functions such as `size` or `member?` more efficiently should do so. Sequences that can reuse storage to implement functions such as `reverse!` and `sort!` should do so.

Tables

Tables map arbitrary keys to elements. Table keys may be any object, including complex objects such as strings. All tables are instances of `<table>`. `<table>` is the only instantiable subclass of `<explicit-key-collection>` defined by Dylan. Tables are unstable under iteration.

The iteration protocol for tables is implemented in terms of the function `table-protocol`. Every concrete subclass of `<table>` must provide or inherit a method for `table-protocol`. This function accepts a table as an argument, and returns an equivalence predicate and hash-function, as described below.

The **equivalence predicate** of a table is used to compare keys. (It is the table's key-test.) The table maps keys that are equivalent under the predicate to the same table element. An equivalence predicate is a boolean function of two arguments that returns true if and only if the arguments are considered to be the same according to some specified criteria. For a function to be used as an equivalence predicate, it must be reflexive, commutative, and transitive. That is, for a function *F* and any arguments *X*, *Y*, and *Z* in the domain of *F*, the following must be true:

- $F(X,X)$ must be true.
- $F(X,Y)$ must be true if and only if $F(Y,X)$ is true.
- If both $F(X,Y)$ and $F(Y,Z)$ are true then $F(X,Z)$ must be true.

An **equivalence class** (for an equivalence predicate) is a set of objects, or potential objects, that are all the same under the specified equivalence predicate and different from all objects not in the class. (This use of the term "class" does not refer to Dylan classes.)

An object is said to be **visibly modified** with respect to an equivalence predicate if the modification changes the equivalence class of the object. The modifications that are visible to an equivalence predicate are determined by the definition of the predicate. (For example, changing a character in a string would be a visible modification with respect to an equivalence predicate that compared strings character by character, but it would not be a visible modification with respect to an equivalence predicate that compared objects by identity, without regard for their contents.)

If an object *X* is a key in a table *T* and is visibly modified with regard to the test function of *T*, then the consequences are unspecified if any of the following objects are used as a key in any subsequent operations on *T*:

- The original object, *X*.
- Some object *Y* that is in the same equivalence class (as determined by the test function) as *X* prior to the modification of *X*.
- Some object *Z* that is in the same equivalence class (as determined by the test function) as *X* after the modification of *X*.

Each table also has an associated **hash function**, which is a function that relates table keys and table elements by computing **hash codes**. A hash code is a conceptual object consisting of a **hash id** and its associated **hash state**. (It is not an actual Dylan object.) A hash id is an integer encoding of an object. A hash state is an object of implementation-dependent type which is associated with a particular hash id and can be used by the implementation to determine whether the hash id has been invalidated. A hash function accepts one argument, a key, and returns two values, a hash id and a hash state, which together represent the hash code.

Each hash function is associated with a specific equivalence predicate, and must obey the following constraints:

- The domain of the hash function must include the domain of valid arguments to the corresponding equivalence predicate. A hash function need not be defined for all Dylan objects, only those which are acceptable as arguments to the equivalence predicate.
- All objects in a given equivalence class have the same (=) valid hash id, where validity is determined from the associated hash state.

In addition, a hash function should have the property that the hash ids computed by it are well distributed over the range of possible values. That is, it should be unlikely that two randomly chosen equivalence classes have the same valid hash id.

Element Types

Each instance X of `<collection>` has a conceptual **element type** which is an instance of `<type>`. If the element type of X is T, X stores elements of type T. The `element` method will always return an instance of T and the `element-setter` method (if X is mutable) will accept any instance of T. The analogous functions returned by the iteration protocol also return/accept any instance of T.

Each subclass C of `<collection>` has a conceptual element type which is either T_1 or indefinite $\Leftarrow T_1$, where T_1 is a type. (The symbol "$\Leftarrow$ " in the "indefinite $\Leftarrow T_1$" notation is an abbreviation for "subtype.")

If the element type of C is T_1, each general instance of C must have an element type T_2 that is type equivalent to T_1. Each subclass of C must have an element type T_3 that is type equivalent to T_1.

If the element type of C is indefinite $\Leftarrow T_1$, each general instance of C must have an element type T_2 that is a subtype of T_1. Therefore `element` on that instance will return an instance of T_1 (and will not return all possible instances of T_1 if T_2 is a proper subtype of T_1). It is not determined by C what the applicable `element-setter` method will accept (thus C's element type is said to be "indefinite"). Each subclass of C must have element type T_3 or indefinite $\Leftarrow T_3$, where T_3 is a subtype of T_1.

User-defined collection classes must also follow these rules.

Note: the above statements about the value returned by `element` only apply when no `default:` keyword argument is specified.

Table 8-1 Element Types of Built-in Collections

Collection	Element Type
`<collection>`	`indefinite` $\Leftarrow$ `<object>`
`<explicit-key-collection>`	`indefinite` $\Leftarrow$ `<object>`
`<mutable-collection>`	`indefinite` $\Leftarrow$ `<object>`
`<stretchy-collection>`	`indefinite` $\Leftarrow$ `<object>`
`<sequence>`	`indefinite` $\Leftarrow$ `<object>`
`<mutable-explicit-key-collection>`	`indefinite` $\Leftarrow$ `<object>`
`<mutable-sequence>`	`indefinite` $\Leftarrow$ `<object>`
`<table>`	`indefinite` $\Leftarrow$ `<object>`
`<object-table>`	`indefinite` $\Leftarrow$ `<object>`
`<array>`	`indefinite` $\Leftarrow$ `<object>`
`<vector>`	`indefinite` $\Leftarrow$ `<object>`
`<simple-vector>`	`indefinite` $\Leftarrow$ `<object>`
`<stretchy-vector>`	`indefinite` $\Leftarrow$ `<object>`
`<deque>`	`indefinite` $\Leftarrow$ `<object>`
`<string>`	`indefinite` $\Leftarrow$ `<character>`
`<range>`	`indefinite` $\Leftarrow$ `<real>`
`<simple-object-vector>`	`<object>`
`<unicode-string>`	K_1 (see note below)
`<byte-string>`	K_2 (see note below)
`<list>`	`<object>`
`<pair>`	`<object>`
`<empty-list>`	`<object>`

Note: K_1 and K_2 are subtypes of `<character>` that have not been given standardized names.

By convention, if *C* is an instantiable subtype of `<collection>` and *C*'s element-type is indefinite $\Leftarrow$ `<object>`, then instantiating *C* produces a collection whose element type is `<object>`.

Instantiating `<range>` produces a collection whose element-type is unspecified except that it is a subtype of `<real>` and every element of the range is an instance of the element type.

The preceding section describes the element type of every object that is created by `make` of an instantiable built-in collection class. The element type of an instance of a user-defined collection class is unspecified, but should follow the rules given here in order to preserve the property that any operation that works on an instance of a supertype must work on an instance of a subtype.

Limited Collection Types

Limited collections are subtypes of `<collection>` which are constrained to have a particular size or dimensions and which are constrained to hold elements of a particular type.

If *C* is a subclass of `<collection>` whose element type is indefinite $\Leftarrow T_1$, then it is possible to create any number of limited collection types which can be described as `limited(`*C*`, of: `T_2`, size: `*S*`)`.

Like a collection class, a limited collection type has a conceptual element type. The element type of `limited(`*C*`, of: `T_2`, size: `*S*`)` is T_2. T_2 must be an instance of `<type>` and a subtype of T_1. *C* is the base class of the new limited collection type.

S limits the size of instances of a limited collection type. *S* can be `#f`, which means no limitation, or a non-negative integer, which means that every instance of the limited collection type has exactly that many elements.

S must be `#f` if *C* is stretchy (e.g. `<table>`, `<stretchy-vector>`, or `<deque>`).

If *C* is `<array>` then it is also possible to create any number of limited collection types which can be described as `limited(<array>, of: `*T*`, dimensions: `*D*`)`. *D* must be a sequence of non-negative integers; the rank of each instance is `size(`D`)` and the dimensions of each instance are the elements of D. You cannot specify both `size:` and `dimensions:` in the same type.

Some limited collection types are instantiable. `make(limited(`C`, …), …)` returns a direct instance of some subclass of C. Typically this class is not standardized and its name is not exported, but it is valid for this class to be C itself. There is nothing special about this class; it is simply a class known to the applicable `limited` method and its creation is subject to all the usual sealing restrictions.

An object X is an instance of a limited collection type `limited(`C`, of:` T_2, `size:` S`)` if and only if all of the following are true:

- `object-class(`X`)` is a subclass of C.
- X's size matches S, as described above.
- If X is an instance of `<stretchy-collection>` then S must be `#f`.
- The element type of X is equivalent to T_2.

An object X is an instance of a type `limited(`C`, of:` T_2`, dimensions:` D`)` if and only if all of the following are true:

- `object-class(`X`)` is a subclass of C.
- `dimensions(`X`)` = D.
- X is not an instance of `<stretchy-collection>`.
- The element type of X is equivalent to T_2.

Each element of an instance of a limited collection type must be an instance of the element type. Fetching an element of the collection is guaranteed to return an instance of the element type. Setting or initializing an element will check that the new element is an instance of the element type and signal an error of type `<type-error>` if it is not.

If L_1 is a subtype of L_2 and L_2 is a limited collection type, then L_1 is either a singleton of an instance of L_2 or a limited collection type that satisfies one of the following sets of rules:

1. If neither L_1 nor L_2 specifies a `dimensions:` attribute, let L_1 be `limited(`C_1`, of:` T_1`, size:` S_1`)`, and L_2 be `limited(`C_2`, of:` T_2`, size:` S_2`)`. All of the following must be true:
   - □ C_1 is a subclass of C_2.
   - □ If S_2 is not `#f`, $S_1 = S_2$.

- T_1 and T_2 are equivalent types.

2. If either L_1 or L_2, specifies a `dimensions:` attribute, then all of the following must be true. Let L_1 be `limited(`C_1`, of: `T_1`, dimensions: `D_1`)`, and L_2 be either `limited(`C_2`, of: `T_2`, dimensions: `D_2`)` or `limited(`C_2`, of: `T_2`, size: `S_2`)`.
   - C_1 is a subclass of C_2.
   - D_1 is present (i.e. L_1 must specify a dimensions attribute)
   - If D_2 is present, $D_1 = D_2$.
   - If S_2 is not `#f`, `reduce1(\*, `D_1`) = `S_2.
   - T_1 and T_2 are equivalent types

The limited collection type `limited(`C`, of: `T`, size: `S`)` is a subtype of C. The limited collection type `limited(`C`, of: `T`, dimensions: `D`)` is a subtype of C.

Element Type Subclassing

The element-type subclassing rules are generalized to limited collection types as follows (this is implied by the preceding and is included here for explanatory purposes only):

If the element type of a limited collection type L_1 is T_1, each instance of L_1 stores elements of type T_1. The `element` method will always return an instance of T_1 and the `element-setter` method will accept any instance of T_1. Each limited collection type that is a subtype of L_1 must have an element type T_2 that is equivalent to T_1.

If the element type of a class C_1 is indefinite $\Leftarrow T_1$, each limited collection type that is a subtype of C_1 has an element type T_2 and T_2 must be a subtype of T_1. Thus `element` on any instance of C_1 will return an instance of T_1 (and will not return all possible instances of T_1 if T_2 is a proper subtype of T_1), and it is not determined by C_1 what the applicable `element-setter` method will accept (hence the term "indefinite").

The above statements about the value returned by `element` only apply when no `default:` keyword argument is specified.

Creating Limited Collection Types

You obtain a type object for a limited collection type by calling the `limited` generic function on a collection class. There are several built-in methods for `limited` specialized for specific subclasses of `<collection>`. Each of these methods accepts a required keyword argument `of:` and also accepts an optional keyword argument `size:` if the class is not stretchy. If the class is `<array>` the optional keyword argument `dimensions:` is also accepted. Each method returns a type. The returned type is never a class. If the `size:` keyword argument is accepted but not supplied, it defaults to `#f`.

Users cannot write portable methods for `limited`. There are no built-in methods for `limited` applicable to user-defined classes.

Uninstantiable Limited Collection Types

Methods on `limited` support the creation of uninstantiable limited types for the following classes:

- `<collection>`
- `<explicit-key-collection>`
- `<mutable-collection>`
- `<stretchy-collection>`
- `<mutable-explicit-key-collection>`
- `<sequence>`
- `<mutable-sequence>`

While limited types created from these classes cannot be instantiated, they are still useful as specializers.

Instantiable Limited Collection Types

Methods on `limited` support the creation of instantiable limited types for the following classes:

- `<table>`
- `<object-table>`

- `<array>`
- `<vector>`
- `<simple-vector>`
- `<stretchy-vector>`
- `<string>`
- `<range>`

These methods are are described in Chapter 12, “The Built-In Functions,” on page 251.

C H A P T E R 9

Sealing

Contents

Sealing

Overview

This chapter describes techniques for **sealing** portions of a Dylan program by declaring that classes or functions will never be used in particular ways, or will never be extended in particular ways. These **sealing directives** enable a range of compiler optimizations, and also clarify the programmer's intent.

The sealing directives include:

- Declaring a class to be `sealed` or `open`. This controls whether a class can be directly subclassed outside the library in which it is defined.
- Declaring a class to be `abstract` or `concrete`. This controls whether a class can have direct instances.
- Declaring a class to be `primary` or `free`. This controls how a class can be used for multiple inheritance.
- Declaring a generic function to be `sealed` or `open`. This controls whether methods can be added to the generic function from outside the library in which the generic function is defined.
- Using `define inert domain`, or using the abbreviations `define inert method` and `inert slot`. These disallow the addition of some methods from outside the library in which the generic function is defined.

With the exception of `define inert domain`, these directives are expressed as adjectives on the generic function definition, class definition, method definition, or slot specification.

Explicitly Known Objects

A class, generic function, or method may or may not be **explicitly known** to a given library. A sealing restriction may limit the set of classes, generic functions, and methods to those which are explicitly known; others cannot be added.

- A class *C* is explicitly known in a library *L* if it is defined by `define class` in *L* or in a library used by *L*.

- A generic function *G* is explicitly known in a library *L* if *G* is defined by `define generic` in the library or in one of the libraries *L* uses, or if *G* is implicitly defined by the definition of a method explicitly known in *L* or if *G* is implicitly defined by a slot specification for a class explicitly known in *L*.
- A method *M* is explicitly known in a library *L* if *M* is defined by `define method` in *L* or in one of the libraries *L* uses, or if *M* is defined by a slot specification for a class explicitly known in *L*.

Declaring Characteristics of Classes

A class definition may include the adjectives `sealed`, `open`, `primary`, `free`, `abstract`, or `concrete`. These adjectives declare characteristics of the class.

Additional restrictions on the ability to subclass classes may be imposed by `define inert domain`.

- An explicitly defined class can be declared to be either sealed or open. If a class is sealed then no additional direct subclasses other than those explicitly known in the same library may be created. Thus, it is an error to define a direct subclass of a sealed class in some library other than the one which defined the sealed class, or to use `make` of `<class>` with a sealed class included in the direct superclasses specified by the `superclasses:` initialization argument. An open class does not prohibit such operations. When explicitly defining a class, the default is for the class to be sealed. This may be overriden by explicitly specifying that it is open. A class created using `make` of `<class>` is open. There is no specified way to create a sealed class using `make`.
- An explicitly defined class may be declared to be either primary or free. The default is free. It is illegal for a class to have more than one primary superclass unless each is a subclass of another. Slots defined in a primary class may be accessed more efficiently than slots defined in a free class.
- An explicitly defined class may be defined to be either abstract or concrete. The default is concrete. The superclasses of an abstract class must be abstract. The default method on `<make>` will signal an error if passed an abstract class. For an abstract class to be instantiable, it must define a method on `make` which delegates to a concrete subclass.

Declaring Characteristics of Generic Functions

A generic function definition may include either the adjective `sealed` or the adjective `open`. These adjectives declare whether the generic function is sealed.

If a generic function is sealed then no additional methods other than those explicitly known in the same library may be added to the generic function. Thus, it is an error to define a method for a sealed generic function in some library other than the one which defined the sealed generic function, or to apply `add-method` or `remove-method` to a sealed generic function. An open generic function does not prohibit these operations.

When explicitly defining a generic function, the default is for the generic function to be sealed. It can be declared to be open by using the `open` adjective in the generic function definition. A generic function that has no explicit definition but has an implicit definition provided by explicit definitions of generic function methods or slot accessors is also sealed. A generic function created using `make` of `<generic-function>` is open. There is no specified way to create a sealed generic function using `make.`

Additional restrictions on the ability to add methods to a generic function may be imposed by `define inert domain`.

Define Inert Domain

`define inert domain` is used to make specific portions of a generic function and of the class hierarchy invariant without disallowing all future changes. The arguments to `define inert domain` are an explicitly known generic function and a series of types, one for each required argument of the generic function.

The complete syntax of `define inert domain` is given on page 376.

A `define inert domain` definition in a library *L* for a generic function *G* with types $T_1 \ldots T_n$ imposes the following constraints on programs:

1. A method *M* which is congruent to *G* and which is not an explicitly known method in *L* may be added to *G* only if at least one of the specializers for *M* is disjoint from the corresponding *T*.
2. A method *M* may be removed from *G* only if at least one of the specializers for *M* is disjoint from the corresponding *T*.
3. A class *C* (with direct superclasses $D_1 \ldots D_m$) which is not explicitly known in *L* may be created only if no method in *G* actually blocks *C*.
   - A method *M* (with specializers $S_1 \ldots S_n$) in *G* potentially blocks *C* at argument position *i* if there exist *j* and *k* such that D_j is a pseudosubtype of S_i, D_k is a pseudosubtype of T_i, and D_k is not a pseudosubtype of S_i.
   - A method *M* actually blocks *C* if *M* potentially blocks *C* at some argument position, and for every argument position *i* where S_i and T_i are disjoint, *M* potentially blocks *C* at *i*.

The third constraint is illustrated by the following example:

```
define generic m (x);
define class <t> (<object>) end class <t>;
define class <s> (<object>) end class <s>;
define method m (s :: <s>) end method m;
define inert domain m (<t>);

define class <c> (<s>, <t>) end class <c>;
```

The definition of class `<c>` would be valid if it appeared in the same library as the preceding definitions or in a library used by them, but invalid if it appeared in a different library. The reason is that without the definition of `<c>`, the method defined on `m` is not within the domain declared by the `define inert domain`, but with the definition of `<c>` the method is within that domain.

Rationale

`define inert domain` permits the compiler to assume certain properties of the program which can be computed based on explicitly known classes and methods, with a guarantee that an attempt to violate any of those assumptions will be detected.

The goal of rule 3 is that the creation of the class C must not make any method M applicable to a part of the inert domain to which it was not previously applicable.

The "potentially blocks" concept describes the mechanism for testing whether the set of objects that are instances of both S_i and T_i (i.e. to which the method is applicable at the *i*th argument position and that are within the inert domain at that argument position) would change as a result of creating C. By specifying what valid programs are allowed to do, rule 3 implicitly specifies the assumptions a compiler can make. A `define inert domain` definition accomplishes this by permitting the compiler to eliminate some of the known methods on a generic function from the set of methods that might be applicable to a particular call at runtime. For example, if this leaves exactly one applicable method, the compiler can eliminate a run-time method dispatch and consider additional optimizations such as inlining.

Specifically, suppose the compiler is compiling a call to G and has determined that the argument at position i is an instance of some type U (where U is not necessarily a standard Dylan type, but could instead be a compiler-internal extension to the type system, such as a difference of two types). For the compiler to be able to rely on the `define inert domain` definition, U must be a subtype of T_i. For the compiler to determine that M is not applicable, U must be disjoint with S_i. Creating C can't change whether U is a subtype of T_i, but it can change whether U is disjoint with S_i. If there could be an object that is simultaneously an instance of U, C, and S_i, it would violate the compiler's assumption that M is not applicable in the call to G, and therefore creating C would be a sealing violation. If there can't be such an object, then creating C is allowed.

This maps onto rule 3 as follows (ignoring for the moment the added complication of limited types that lead to the use of the pseudosubtype relationship rather than subtype):

U is a subtype of D_k and therefore is a subtype of T_i, because subtype is transitive.

D_k is not a subtype of S_i, because if it were then U could not be disjoint from S_i.

D_j is a subtype of S_i.

If U and C would have a non-empty intersection, then the creation of C must be prevented, else U would no longer be disjoint from S_i. One possible U is the set of all general instances of D_k that are not also general instances of any of the explicitly known direct subclasses of D_k. That U would indeed have a non-empty intersection with *C*. The existence of this *U* makes the proposed rule 3 necessary.

Rule 3 does not need to address the possibility of multiple inheritance being used to combine classes involved in the element types of limited collection classes. Changes to the disjointness relationships between element types does not affect the relationships between collection types with those element types.

Pseudosubtype Examples

Suppose *A* and *B* are disjoint subclasses of `<collection>`, S_i is `limited(`*A*`, of: `*T*`)`, and T_i is `limited(`*B*`, of: `*T*`)`. Thus, S_i and T_i are disjoint and *M* is outside the inert domain. If *C* inherits from *A* and *B* it should be potentially blocked by *M*, because an instance of `limited(`*C*`, of: `*T*`)` would be an instance of both S_i and T_i. Since *B* is not a subtype of T_i, there would be no blockage if the constraints in rule 3 were defined in terms of `subtype`. However, *B* is a pseudosubtype of T_i, so specifying rule 3 using the pseudosubtype relationship correctly causes *M* to potentially block *C*.

Suppose S_i is `limited(<stretchy-vector>, of: <integer>)` and T_i is `limited(<sequence>, of: <integer>)`. Attempt to create `<stretchy-string>`, a direct subclass of `<stretchy-vector>` and `<string>`. The element-type of `<stretchy-string>` must be a subtype of `<character>`, therefore, assuming `<integer>` and `<character>` are disjoint, `<stretchy-string>` is disjoint from both S_i and T_i, and so is not blocked. This example shows the need for the non-disjointness requirement in the definition of pseudosubtype.

Abbreviations for Define Inert Domain

`define inert method` defines a method on a generic function and also seals the generic function for the types that are the specializers of the method.

The following two program fragments are equivalent:

```
define inert method insert (source :: <list>, i :: <object>)
  => (result :: <list>)
  …
end method insert;
```

and

```
define method insert (source :: <list>, i :: <object>)
  => (result :: <list>)
  …
end method insert;
define inert domain insert (<list>, <object>);
```

The `inert slot` option to `define class` defines a slot and also makes the getter generic function inert over the class, and the setter generic function, if there is one, inert over the type of the slot and the class.

The following two program fragments are equivalent:

```
define class <polygon> (<shape>)
  inert slot sides :: <integer>, required-init-keyword: sides:;
end class <polygon>;
```

and

```
define class <polygon> (<shape>)
  slot sides :: <integer>, required-init-keyword: sides:;
end class <polygon>;
define inert domain sides (<polygon>);
define inert domain sides-setter (<polygon>, <integer>);
```

Implied Restrictions on Method Definitions

To avoid potential sealing violations among separately developed libraries, one of the following conditions should be true for every method *M* defined in a library *L*:

- Either the generic function to which *M* is added should be defined in the library *L*, or
- One of the specializers of *M* should be a subtype of a type defined in library *L*.

The following example illustrates why this condition is necessary.

Library L_1 defines and exports the following:

```
define generic g (x)
define class <c1> (<object>) end class <c1>;
```

Library L_2 uses L_1 and defines the following

```
define class <c2> (<c1>) end class <c2>;
define method g (x :: <c2>) end method;
define inert domain g (<c2>)
```

Library L_3 uses L_1 and defines the following

```
define method g (x :: <c>) end method;
```

Libraries L_2 and L_3 are developed independently, and have no knowledge of each other. An application that attempts to use both L_2 and L_3 contains a sealing violation. L_2 is clearly valid. Therefore, L_3 is at fault for the sealing violation. Because the compiler cannot prove that use of L_3 will lead to an error (and indeed, it will only lead to an error in the presence of L_2), it is appropriate to issue a warning but not disallow the compilation of L_3.

C H A P T E R 1 0

Macros

Contents

Overview

A **macro** is an extension to the core language that can be defined by the user, by the implementation, or as part of the Dylan language specification. Much of the grammatical structure of Dylan is built with macros. A macro defines the meaning of one construct in terms of another construct. The compiler substitutes the new construct for the original. The purpose of macros is to allow programmers to extend the Dylan language, for example by creating new control structures or new definitions. Unlike C, Dylan does not intend macros to be used to optimize code by inlining. Other parts of the language, such as sealing and `define constant`, address that need.

Throughout this chapter, *italic font* and SMALL CAPS are used to indicate references to the formal grammar given in Appendix A, "BNF."

Compilation and Macro Processing

Compilation consists of six conceptual phases:

1. Parsing a stream of characters into tokens, according to the lexical grammar in Appendix A, "BNF."
2. Parsing a stream of tokens into a program, according to the phrase grammar in Appendix A, "BNF."
3. Macro expansion, which translates the program to a core language.
4. Definition processing, which recognizes special and built-in definitions and builds a compile-time model of the static structure of the program.
5. Optimization, which rewrites the program for improved performance.
6. Code generation, which translates the program to executable form.

Portions of a program can be macro calls. Macro expansion replaces a macro call with another construct, which can itself be a macro call or contain macro calls. This expansion process repeats until there are no macro calls remaining in the program, thus macros have no space or speed cost at run time. Of course, expanding macros affects the speed and space cost of compilation.

A macro definition describes both the syntax of a macro call and the process for creating a new construct to replace the macro call. Typically the new construct contains portions of the old one, which can be regarded as arguments to the macro. A macro definition consists of a sequence of rewrite rules. The left-hand side of each rule is a pattern that matches a macro call. The right-hand side is a template for the expansion of a matching call. Pattern variables appearing in the left-hand side act as names for macro arguments. Pattern variables appearing in the right-hand side substitute arguments into the expansion. Macro arguments can be constrained to match specified elements of the Dylan grammar. Auxiliary rule sets enhance the rewrite rule notation with named subrules.

Some implementations and a future version of the Dylan language specification might allow macro expansions to be produced by compile-time computation using the full Dylan language and an object-oriented representation for programs. Such a "procedural macro" facility is not part of Dylan at this time.

The input to, and output from, macro expansion is a fragment, which is a sequence of elementary fragments. An elementary fragment is one of the following:

- A token: the output of the lexical grammar. The bracket tokens `(`, `)`, `[`, `]`, `{`, `}`, `#(`, and `#[` are not allowed. Core reserved words (except `otherwise`), BEGIN-WORDS, and FUNCTION-WORDS are not allowed unless quoted with backslash.
- A bracketed fragment: balanced brackets (`()`, `[]`, or `{}`) enclosing a fragment.
- A macro call fragment: a macro call.
- A parsed fragment: a single unit that is not decomposable into its component tokens. It has been fully parsed by the phrase grammar. A parsed fragment is either an expression, a definition, or a local declaration.

The second and third phases of compilation (parsing and macro expansion) are interleaved, not sequential. The parsing phase of the compiler parses a macro call just enough to find its end. See *definition-macro-call, statement, function-macro-call, body-fragment, list-fragment,* and *basic-fragment* in Appendix A, "BNF." This process of parsing a macro call also parses any macro calls nested inside it. The result is a macro call fragment.

This loose grammar for macro calls gives users a lot of flexibility to choose the grammar that their macros will accept. For example, the grammar of macro calls doesn't care whether a bracketed fragment will be interpreted as an argument list, a parameter list, a set of `for` clauses, or a module import list.

The compiler can compute the expansion of a macro call fragment immediately, or delay computing it until it is needed. When the compiler computes the expansion of a macro call fragment, it obeys the macro's definition. Constraints on pattern variables can cause reparsing of portions of the macro call.

A *constituent*, *operand*, or *leaf* that is a macro call expands the macro some time before the definition processing and optimization phases. The compiler brackets the expansion in `begin` … `end`, using the standard binding of `begin` in the Dylan module, and then reparses it as a *statement*. This reparsing may discover more macro calls. A parse error while reparsing a macro expansion could indicate an invalid macro definition or an incorrect call to the macro that was not detected during pattern matching. Once the cycle of macro expansion and reparsing has been completed, no tokens, bracketed fragments, or macro call fragments remain and the entire source record has become one parsed fragment.

This `begin` … `end` bracketing ensures that the expansion of a macro call will not be broken apart by operator precedence rules when the macro call is a subexpression. Similarly it ensures that the scopes of local declarations introduced by a macro will not extend outside that macro expansion when the macro call is a statement in a body.

The fragment produced by parsing a macro call, which is the input to macro expansion, looks like this:

- Local declarations and special definitions are parsed fragments.
- Calls to macros are macro call fragments.
- List constants and vector constants are parsed expression fragments.
- Anything in brackets is a bracketed fragment.
- If the macro call was not the result of macro expansion, everything else is represented as sequences of tokens. There are a few restrictions on the tokens, for example semicolons must appear in certain places and bare brackets cannot appear; for details see the definition of *body-fragment* and *list-fragment* in Appendix A, “BNF.”

- In a macro call that is the result of macro expansion, additional items can be parsed fragments, due to pattern-variable substitution.
- Many built-in macros expand into implementation-specific parsed fragments.

The parser recognizes parsed fragments as well as raw tokens. The nonterminals *expression*, *definition*, and *local-declaration* in the phrase grammar accept parsed fragments of the same kind. The nonterminal *constant* accepts parsed expression fragments that are constants. The nonterminals ORDINARY-NAME and NAME accept parsed expression fragments that are named value references. The nonterminal *operand* accepts all parsed expression fragments. The nonterminals *macro*, *definition-macro-call*, *statement*, and *function-macro-call* accept macro call fragments.

Extensible Grammar

There are three kinds of macros: definition macros, which extend the available set of definitions; statement macros, which extend the available set of statements; and function macros, which syntactically resemble function calls but are more flexible. Named value references and local declarations cannot be macro calls. Only statements, function calls, and definitions are extensible.

Definition Macros

A definition macro extends the *definition-macro-call* production of the Dylan phrase grammar to recognize additional constructs as valid definitions, by creating a new DEFINE-BODY-WORD that is recognized by the following grammar line:

definition-macro-call:
  `define` *modifiers*$_{opt}$ DEFINE-BODY-WORD *body-fragment*$_{opt}$ *definition-tail*

or by creating a new DEFINE-LIST-WORD that is recognized by the following grammar line:

definition-macro-call:
  `define` *modifiers*$_{opt}$ DEFINE-LIST-WORD *list-fragment*$_{opt}$

This allows programmers to extend Dylan by defining new kinds of definitions. The syntax of the definition must be parseable by one of these two predefined grammar rules. The first handles body-style definitions like `define class`, `define method`, and `define module`, while the second handles list-style definitions like `define constant`. See Appendix A, "BNF," for the details.

The new DEFINE-BODY-WORD or DEFINE-LIST-WORD becomes a partially reserved word in each module where the macro definition is visible. In particular a DEFINE-BODY-WORD or DEFINE-LIST-WORD cannot be used as a modifier in a definition. It can still be used as a variable-name.

Statement Macros

A statement macro extends the *statement* production of the Dylan phrase grammar to recognize additional constructs as valid statements, by creating a new BEGIN-WORD that is recognized by the following grammar line:

statement:
  BEGIN-WORD *body-fragment*$_{opt}$ *end-clause*

The new BEGIN-WORD becomes a reserved word in each module where the macro definition is visible. It can only be used at the beginning and end of this new statement.

Function Macros

A function macro extends the *function-macro-call* production of the Dylan phrase grammar to recognize additional constructs, by creating a new FUNCTION-WORD that is recognized by the following two grammar lines:

function-macro-call:
  FUNCTION-WORD **(** *body-fragment*$_{opt}$ **)**
  FUNCTION-WORD **(** *body-fragment*$_{opt}$ **)** **:=** *expression*

The new FUNCTION-WORD becomes a reserved word in each module where the macro definition is visible. It can only be used at the beginning of a macro call.

A *function-macro-call* containing an assignment operator,

FUNCTION-WORD (*body-fragment*$_{opt}$) := *expression* becomes

```
begin let temp = expression ;
      FUNCTION-WORD-setter ( temp,  body-fragment_opt  );
      temp
end
```

where FUNCTION-WORD`-setter` is FUNCTION-WORD with a "`-setter`" suffix and `temp` is a unique name. If the *body-fragment* is missing then the comma preceding it is omitted. Assignment does not expand a macro call on the left-hand side.

To simplify its presentation, the grammar in Appendix A, "BNF," is ambiguous. A *function-macro-call* containing an assignment operator could also be parsed as an expression consisting of the first form of *function-macro-call*, followed by `:=` and further *binary-operands* and BINARY-OPERATORS. This alternative parse is disallowed.

Macro Names

A macro is named by a constant module binding. The macro is available to be called in any scope where this binding is accessible. Macro names can be exported and can be renamed during module importing just like any other module binding. Macro bindings are constant and cannot be changed by the assignment operator `:=`.

The name bound to a definition macro is the macro's DEFINE-BODY-WORD or DEFINE-LIST-WORD suffixed by "`-definer`". This suffixing convention is analogous to the naming convention for setters and allows the DEFINE-BODY-WORD or DEFINE-LIST-WORD to be used for another purpose. The name bound to a statement macro is the macro's BEGIN-WORD. The name bound to a function macro is the macro's FUNCTION-WORD.

A named value reference is not allowed when the value of the binding is a macro, because macros are not run-time objects.

A macro cannot be named by a local binding. Macro definitions are always scoped to modules.

Attempting to create a local binding that shadows a binding to a macro is an error.

Reserved words created by a macro definition are reserved in any module where the binding that names the macro is accessible. In other modules, the same words are ordinary names. Each module has an associated syntax table which is used when parsing code associated with that module. The syntax table controls the lexical analyzer's assignment of names to the DEFINE-BODY-WORD, DEFINE-LIST-WORD, BEGIN-WORD, and FUNCTION-WORD categories. Importing a macro into a module makes the same modifications to that module's syntax table that would be made by defining that macro in the module. If a definition macro is renamed when it is imported, the DEFINE-BODY-WORD or DEFINE-LIST-WORD derives from the new name. If the new name does end in "`-definer`", the imported macro cannot be called.

A NAME or UNRESERVED-NAME in the lexical grammar can be a backslash ('\') character followed by a word. This prevents the word from being recognized as a reserved word during parsing, but does not change which binding the word names. Quoting the name of a statement or function macro with a backslash allows the name to be mentioned without calling the macro, for example to export it from a module.

When a binding that names a macro is exported from a module that is exported from a library, clients of that library can call the macro. Information derived from the macro definition goes into the library export information part of the library description.

Rewrite Rules

The grammar of a macro definition is **`define macro`** *macro-definition*. For details see Appendix A, "BNF."

If the optional NAME at the end of a *macro-definition* is present, it must be the same NAME that appears at the beginning of the *macro-definition*.

The kind of macro being defined, and thus the Dylan grammar production that this macro extends, is determined by which kind of rules appear in the macro's *main-rule-set*.

The NAME preceding the *main-rule-set* is the name of the binding whose value is this macro. It must be consistent with each left-hand side of the *main-rule-set*. It can be any name, even a reserved word or backslash followed by an operator. For statement and function macros this NAME must be the same as the NAME that appears as the first token in each *main-rule-set* pattern. For definition macros this NAME must be the same as the NAME in the *xxx-style-definition-rule* with the suffix "`-definer`" added.

A NAME can belong to more than one of the lexical categories BEGIN-WORD, FUNCTION-WORD, DEFINE-BODY-WORD, and DEFINE-LIST-WORD. A NAME cannot belong to both BEGIN-WORD and FUNCTION-WORD. A NAME cannot belong to both DEFINE-BODY-WORD and DEFINE-LIST-WORD.

For simplicity of documentation, the *xxx-style-definition-rule* productions are written ambiguously. The NAME in the left-hand side of the rule must be the NAME immediately following `define macro` with the "`-definer`" suffix removed, not an arbitrary NAME, which would be ambiguous with *modifier*.

The general idea is that the *main-rule-set* is an ordered sequence of rewrite rules. Macro expansion tests the macro call against each left-hand side in turn until one matches. The corresponding right-hand side supplies the new construct to replace the macro call. The left- and right-hand sides can contain pattern variables. The portion of the macro call that matches a particular pattern variable on the left replaces each occurrence of that pattern variable on the right. It is an error for the right-hand side of a rule to contain a pattern variable that does not appear on the left-hand side of the same rule.

If none of the left-hand sides match, the macro call is invalid. If more than one left-hand side matches, the first matching rule is used.

The punctuation marks `?`, `??`, and `?=` used in patterns and templates are customarily written without any whitespace following them.

Patterns

Approximately speaking, a pattern looks like the construct that it matches, but contains pattern variables that bind to portions of the construct. Hence a left-hand side in the *main-rule-set* looks like a macro call. However, the grammar of patterns is not the same as the grammar of programs, but contains just what is required to match the portions of the Dylan grammar that are extensible by macros. Patterns have a simple nested grammar, with semicolons, commas, and brackets used to indicate levels of nesting. See the definition of *pattern* in Appendix A, "BNF."

A pattern matches a fragment (a sequence of elementary fragments) by executing the following algorithm from left to right. It is easy to create patterns that are ambiguous when considered as grammars. This ambiguity is resolved by the left to right processing order and the specified try-shortest-first order for matching wildcards. Pattern matching succeeds only if all sub-patterns match. If pattern matching fails, the current rule fails and control passes to the next rule in the current rule set. If all patterns in a rule set fail to match, the macro call is invalid.

Multiple occurrences of the same pattern variable name in a single rule's left-hand side are not valid.

A *pattern* matches a fragment as follows:

- If the pattern consists of just one pattern-list, go to the next step. Otherwise divide the pattern into subpatterns and the fragment into subfragments at semicolons, and match subpatterns to subfragments individually in order. The subpatterns and subfragments do not include the semicolons that separate them. Suppose the pattern consists of N + 1 pattern-lists separated by N semicolons. Locate the first N semicolons in the fragment (without looking inside of elementary fragments) and divide up the fragment into subfragments accordingly. The match fails if the fragment contains fewer than N - 1 semicolons. As a special case, if the fragment contains N - 1 semicolons, the match still succeeds and the last subfragment is empty. If the fragment contains more than N semicolons, the extra semicolons will be in the last subfragment.

A *pattern-list* matches a fragment as follows:

- If the pattern-list consists of just a pattern-sequence, go to the next step. If the pattern-list consists of just a property-list-pattern, go to that step. Otherwise divide the pattern-list into subpatterns and the fragment into subfragments at commas, and match subpatterns to subfragments individually in order. The subpatterns and subfragments do not include the commas that separate them. Suppose the pattern consists of N + 1 subpatterns separated by N commas. Locate the first N commas in the fragment (without looking inside of elementary fragments) and divide up the fragment into subfragments accordingly. The match fails if the fragment contains fewer than N - 1 commas. As a special case, if the fragment contains N - 1 commas, the match still succeeds and the last subfragment is empty. If the fragment contains more than N commas, the extra commas will be in the last subfragment. Note that the subdivision algorithms for commas and semicolons are identical.

A *pattern-sequence* matches a fragment as follows:

- Consider each simple-pattern in the pattern-sequence in turn from left to right. Each simple-pattern matches an initial subsequence of the fragment and consumes that subsequence, or fails. The entire pattern match fails if any simple-pattern fails, if the fragment is empty and the simple-pattern requires one or more elementary fragments, or if the fragment is not entirely consumed after all simple-patterns have been matched. There is a special backup and retry rule for wildcards, described below.

A *simple-pattern* matches a fragment as follows:

- A NAME or `=>` consumes one elementary fragment, which must be identical to the *simple-pattern*. A NAME matches a name that is spelled the same, independent of modules, lexical scoping issues, alphabetic case, and backslash quoting. As a special case, after the word `otherwise`, an `=>` is optional in both the pattern and the fragment. Presence or absence of the arrow in either place makes no difference to matching.
- A *bracketed-pattern* matches and consumes a *bracketed-fragment*. If the enclosed *pattern* is omitted, the enclosed *body-fragment* must be empty, otherwise the enclosed *pattern* must match the enclosed *body-fragment* (which can be empty). The type of brackets (`()`, `[]`, or `{}`) in the *bracketed-fragment* must be the same as the type of brackets in the *bracketed-pattern*.

A *binding-pattern* matches a fragment as follows:

- *pattern-variable* `::` *pattern-variable* consumes as much of the fragment as can be parsed by the grammar for *variable.* It matches the first pattern-variable to the *variable-name* and the second to the *type*, a parsed expression fragment. If no specializer is present, it matches the second pattern-variable to a parsed expression fragment that is a named value reference to `<object>` in the Dylan module. This matching checks the constraints on the pattern variable, fails if the constraint is not satisfied, and binds the pattern variable to the fragment.
- *pattern-variable* `=` *pattern-variable* consumes as much of the fragment as can be parsed by the grammar for *variable* = *expression.* It matches the first

pattern-variable to the *variable*, a fragment, and the second to the *expression*, a parsed expression fragment.

- *pattern-variable* `::` *pattern-variable* = *pattern-variable* consumes as much of the fragment as can be parsed by the grammar for *variable* = *expression*. It matches the first two pattern-variables the same as the first kind of *binding-pattern* and it matches the third pattern-variable the same as the second kind of *binding-pattern.*

A *pattern-variable* matches a fragment as follows:

- When the constraint is a wildcard constraint (see "Pattern Variable Constraints" on page 154), the pattern variable consumes some initial subsequence of the fragment, using a backup and retry algorithm. First, the wildcard consumes no elementary fragments, and matching continues with the next *simple-pattern* in the *pattern-sequence*. If any *simple-pattern* in the current *pattern-sequence* fails to match, back up to the wildcard, consume one more elementary fragment than before, and retry matching the rest of the *pattern-sequence*, starting one elementary fragment to the right of the previous start point. Once the entire *pattern-sequence* has successfully matched, the pattern variable binds to a fragment consisting of the sequence of elementary fragments that it consumed.
- It is an error for more than one of the *simple-patterns* directly contained in a *pattern-sequence* to be a wildcard.
- When the constraint is other than a wildcard constraint, the pattern variable consumes as much of the fragment as can be parsed by the grammar specified for the constraint in "Pattern Variable Constraints" on page 154. If the parsing fails, the pattern match fails. The pattern variable binds to the fragment specified in "Pattern Variable Constraints." This can be a parsed fragment rather than the original sequence of elementary fragments.
- The ellipsis *pattern-variable*, `...`, can only be used in an auxiliary rule set. It represents a pattern variable with the same name as the current rule set and a wildcard constraint.

A *property-list-pattern* matches a fragment as follows:

- Parse the fragment using the grammar for *property-list*$_{opt}$. If the parsing fails or does not consume the entire fragment, the pattern match fails.
- If the *property-list-pattern* contains `#key` and does not contain `#all-keys`, the match fails if the SYMBOL part of any property is not the NAME in some *pattern-keyword* in the *property-list-pattern*. Comparison of a SYMBOL to a

NAME is case-insensitive, ignores backslash quoting, and is unaffected by the lexical context of the NAME.

- If the *property-list-pattern* contains `#rest`, bind the pattern variable immediately following `#rest` to the entire fragment. If the pattern variable has a non-wildcard constraint, parse the *value* part of each property according to this constraint, fail if the parsing fails or does not consume the entire *value* part, and substitute the fragment specified in "Pattern Variable Constraints" on page 154 for the *value* part.
- Each *pattern-keyword* in the *property-list-pattern* binds a pattern variable as follows:
  - A single question mark finds the first property whose SYMBOL is the NAME of the *pattern-keyword* . Comparison of a SYMBOL to a NAME is case-insensitive, ignores backslash quoting, and is unaffected by the lexical context of the NAME. If the *pattern-keyword* has a non-wildcard constraint, parse the property's *value* according to this constraint, fail if the parsing fails or does not consume the entire *value* , and bind the pattern variable to the fragment specified in "Pattern Variable Constraints" on page 154. If the *pattern-keyword* has a wildcard constraint, bind the pattern variable to the property's *value* .
  - A double question mark finds every property with a matching SYMBOL, processes each property's *value* as for a single question mark, and binds the pattern variable to a sequence of the values, preserving the order of properties in the input fragment. This sequence can only be used with double question mark in a template. Constraint-directed parsing applies to each property *value* individually.
- If a single question mark *pattern-keyword* does not find any matching property, then if a *default* is present, the pattern variable binds to the default expression, otherwise the property is required so the pattern match fails.
- If a double question mark *pattern-keyword* does not find any matching property, then if a *default* is present, the pattern variable binds to a sequence of one element, the default expression, otherwise the pattern variable binds to an empty sequence.
- Note: the default expression in a *pattern-keyword* is not evaluated during macro expansion; it is a parsed expression fragment that is used instead of a fragment from the macro call. The default is not subject to a pattern variable constraint.

Special Rules for Definitions

A list-style definition parses as the core reserved word `define`, an optional sequence of modifiers, a DEFINE-LIST-WORD, and a possibly-empty *list-fragment.* The left-hand side of a *list-style-definition-rule* matches this by treating the *definition-head* as a *pattern-sequence* and matching it to the sequence of modifiers, and then matching the *pattern* to the *list-fragment.* If no *definition-head* is present, the sequence of modifiers must be empty. If no *pattern* is present, the *list-fragment* must be empty. The word `define` and the DEFINE-LIST-WORD do not participate in the pattern match because they were already used to identify the macro being called and because the spelling of the DEFINE-LIST-WORD might have been changed by renaming the macro during module importing.

A body-style definition parses as the core reserved word `define`, an optional sequence of modifiers, a DEFINE-BODY-WORD, a possibly-empty *body-fragment,* the core reserved word `end`, and optional repetitions of the DEFINE-BODY-WORD and the NAME (if any) that is the first token of the *body-fragment.* The left-hand side of a *body-style-definition-rule* matches this by treating the *definition-head* as a *pattern-sequence* and matching it to the sequence of modifiers, and then matching the *pattern* to the *body-fragment.* If no *definition-head* is present, the sequence of modifiers must be empty. If no *pattern* is present, the *body-fragment* must be empty. If the *body-fragment* ends in a semicolon, this semicolon is removed before matching. The optional semicolon in the rule is just decoration and does not participate in the pattern match. The word `define` and the DEFINE-BODY-WORD do not participate in the pattern match because they were already used to identify the macro being called and because the spelling of the DEFINE-BODY-WORD might have been changed by renaming the macro during module importing. The word `end` and the two optional items following it in the macro call are checked during parsing, and so do not participate in the pattern match.

It is an error for a *definition-head* to contain more than one wildcard.

Special Rules for Statements

A statement parses as a BEGIN-WORD, a possibly-empty *body-fragment,* the core reserved word `end`, and an optional repetition of the BEGIN-WORD. The left-hand side of a *statement-rule* matches this by matching the *pattern* to the *body-fragment.* If the rule does not contain a *pattern,* the *body-fragment* must be empty. If the *body-fragment* ends in a semicolon, this semicolon is removed before matching. The optional semicolon in the rule is just decoration and does not participate in the pattern match. The BEGIN-WORD does not participate in the pattern match because it was already used to identify the macro being called and because its spelling might have been changed by renaming the macro during module importing. The word `end` and the optional item following it in the macro call are checked during parsing, and so do not participate in the pattern match.

Special Rules for Function Macros

A call to a function macro parses as a FUNCTION-WORD followed by a parenthesized, possibly-empty *body-fragment*. The left-hand side of a *function-rule* matches this by matching the *pattern* to the *body-fragment.* If the rule does not contain a *pattern,* the *body-fragment* must be empty. The FUNCTION-WORD does not participate in the pattern match because it was already used to identify the macro being called and because its spelling might have been changed by renaming the macro during module importing. The parentheses in the rule are just decoration and do not participate in the pattern match.

Pattern Variable Constraints

Each *pattern-variable* in the left-hand side of a rule in a macro definition has a constraint associated with it. This prevents the pattern from matching unless the fragment matched to the pattern-variable satisfies the constraint. In most cases it also controls how the matching fragment is parsed.

You specify a constraint in a *pattern-variable* by suffixing a colon and the constraint name to the pattern variable name. Intervening whitespace is not allowed. As an abbreviation, if a pattern variable has the same name as its constraint, the *pattern-variable* can be written `?:`*the-name* instead of `?`*the-name*`:`*the-name*.

The following constraints are available:

Table 10-1 Available constraints

Constraint name	Grammar accepted	Binds pattern variable to
`expression`	*expression*	parsed expression fragment
`variable`	*variable*	fragment(1)
`name`	NAME	one-token fragment
`token`	TOKEN	one-token fragment
`body`	$body_{opt}$ (2)	parsed expression fragment (3)
`case-body`	$case\text{-}body_{opt}$ (2)	fragment(1)
`macro`	*macro*	fragment(4)
`*`	(wildcard)	fragment

Notes:

1. Where *expression, operand, constituents* or *body* appears in the grammar that this constraint accepts, the bound fragment contains a parsed expression fragment, not the original elementary fragments.
2. Parsing stops at an intermediate word.
3. The body is wrapped in `begin` … `end` to make it an expression, using the standard binding of `begin` in the Dylan module. An empty body defaults to `#f`.
4. A pattern-variable with a `macro` constraint accepts exactly one elementary fragment, which must be a macro call fragment. It binds the pattern variable to the expansion of the macro.

Some implementations and a future version of the Dylan language specification might add more constraint choices to this table.

When a pattern variable has the same name as an auxiliary rule-set, its constraint defaults to wildcard and can be omitted. Otherwise a constraint must be specified in every *pattern-variable* and *pattern-keyword*.

A constraint applies only to the specific pattern variable occurrence to which it is attached. It does not constrain other pattern variable occurrences with the same name.

Intermediate Words

When a *pattern-variable* has a constraint of `body` or `case-body`, its parsing of the fragment stops before any token that is an intermediate word. This allows intermediate words to delimit clauses that have separate bodies, like `else` and `elseif` in an `if` statement. The intermediate words of a macro are identified as follows:

- Define a body-variable to be a pattern variable that either has a constraint of `body` or `case-body`, or names an auxiliary rule-set where some left-hand side in that rule-set ends in a body-variable. This is a least fixed point, so a recursive auxiliary rule-set does not automatically make its name into a body-variable! Note that an ellipsis that stands for a pattern variable is a body-variable when that pattern variable is one.
- Define an intermediate-variable to be a pattern variable that either immediately follows a body-variable in a left-hand side, or appears at the beginning of a left-hand side in an auxiliary rule-set named by an intermediate-variable.
- An intermediate word is a NAME that either immediately follows a body-variable in a left-hand side, or occurs at the beginning of a left-hand side in an auxiliary rule-set named by an intermediate-variable. Intermediate words are not reserved, they are just used as delimiters during the parsing for a *pattern-variable* with a `body` or `case-body` constraint.

Templates

Approximately speaking, a template has the same structure as what it constructs, but contains pattern variables that will be replaced by fragments extracted from the macro call. Thus a template in the *main-rule-set* looks like the macro expansion.

However, templates do not have a full grammar. A template is essentially any sequence of tokens and *substitutions* in which all of Dylan's brackets are balanced: `()`, `[]`, `{}`, `#()`, and `#[]`. Substitution for pattern variables produces a sequence of tokens and other elementary fragments.

Note that using unparsed token sequences as templates allows a macro expansion to contain macro calls without creating any inter-dependencies between macros. Since the template is not parsed at macro definition time, any macros called in the template do not have to be defined first, and macros can be compiled independently of each other. This simplifies the implementation at the minor cost of deferring some error checking from when a macro is defined until the time when the macro is called.

The grammar for templates is the definition of *template* in "Templates" on page 415.

All *template-elements* other than *substitution* are copied directly into the macro expansion. The various kinds of *substitution* insert something else into the macro expansion, as follows:

`?` NAME — The fragment bound to the pattern variable named NAME.

name-prefix$_{opt}$ `?` *name-string-or-symbol name-suffix*$_{opt}$

The fragment bound to the pattern variable named *name-string-or-symbol*, converted to a string or symbol and/or concatenated with a prefix and/or suffix. Note that this rule applies only when the first rule does not. The fragment must be a NAME. Concatenate the prefix, if any, the characters of the fragment, and the suffix, if any. The alphabetic case of the characters of the fragment is unspecified. Convert this to the same grammatical type (NAME, STRING, or SYMBOL) as *name-string-or-symbol*. When the result is a NAME, its hygiene context is the same as that of the fragment.

`??` NAME *separator*$_{opt}$ `...`

The sequence of fragments bound to the pattern variable named NAME, with *separator* inserted between each pair of fragments. The pattern variable must have been bound by a `??` *pattern-keyword. Separator* can be a binary operator, comma, or semicolon. If the size of the sequence is 1 or *separator* is omitted, no separator is inserted. If the sequence is empty, nothing is inserted.

`...` — The fragment bound to the pattern variable that names this rule set; this is only valid in an auxiliary rule set.

`?=` NAME	A reference to NAME, in the lexical context where the macro was called.

It is an error for a single question-mark *substitution* to use a pattern variable that was bound by a double question-mark *pattern-keyword.*

It is an error for a double question-mark *substitution* to use a pattern variable that was bound by a single question-mark *pattern-variable* or *pattern-keyword.*

It is an error for a *substitution* to use a pattern variable that does not appear on the left-hand side of the same rule.

When a template contains a *separator* immediately followed by a *substitution*, and the fragment inserted into the macro expansion by the *substitution* is empty, the separator is removed from the macro expansion.

Auxiliary Rule Sets

Auxiliary rule sets are like subroutines for rewrite rules. An auxiliary rule set rewrites the value of a pattern variable after it is bound by a pattern and before it is substituted into a template. Auxiliary rule sets only come into play after a pattern has matched; the failure of all patterns in an auxiliary rule set to match causes the entire macro call to be declared invalid, rather than back-tracking and trying the next pattern in the calling rule set.

See the definition of *auxiliary-rule-sets* in “Auxiliary Rule Sets” on page 416.

A SYMBOL flags the beginning of an auxiliary rule set. For readability it is generally written as `name:` rather than `#"name"`. The name of the symbol is the same as the name of the pattern variable that is rewritten by this auxiliary rule set. All occurrences of this pattern variable in all rule sets are rewritten. A pattern variable can occur in the very auxiliary rule set that rewrites that pattern variable; this is how you write recursive rewrite rules, which greatly expand the power of pattern-matching.

When an auxiliary rule set's pattern variable occurs in a double question-mark *pattern-keyword*, the auxiliary rule set rewrites each property value in the sequence individually.

The order of auxiliary rule sets in a macro definition is immaterial.

The ellipsis `...` in patterns and templates of an auxiliary rule set means exactly the same thing as the pattern variable that is rewritten by this auxiliary rule set. Using ellipsis instead of the pattern variable can make recursive rewrite rules more readable.

Hygiene

Dylan macros are always **hygienic**. The basic idea is that each named value reference in a macro expansion means the same thing as it meant at the place in the original source code from which it was copied into the macro expansion. This is true whether that place was in the macro definition or in the macro call. Because a macro expansion can include macro calls that need further expansion, named value references in one final expansion can come from several different macro definitions and can come from several different macro calls, either to different macros or—in the case of recursion—distinct calls to the same macro.

(Sometimes the property that variable references copied from a macro call mean the same thing in the expansion is called "hygiene" and the property that variable references copied from a macro definition mean the same thing in the expansion is called "referential transparency." We include both properties in the term "hygiene.")

Specifically, a macro can bind temporary variables in its expansion without the risk of accidentally capturing references in the macro call to another binding with the same name. Furthermore, a macro can reference module bindings in its expansion without the risk of those references accidentally being captured by bindings of other variables with the same name that surround the macro call. A macro can reference module bindings in its expansion without worrying that the intended bindings might have different names in a module where the macro is called.

One way to implement this is for each *template-element* that is a NAME to be replaced in the macro expansion by a special token which plays the same grammatical role as a NAME but remembers three pieces of information:

- The original NAME.
- The lexical context where the macro was defined, which is just a module since macro definitions are only allowed at top level, not inside of bindings.

- The specific macro call occurrence. This could be an integer that is incremented each time a macro expansion occurs.

In general one cannot know until all macros are expanded whether a NAME is a bound variable reference, a module binding reference, a variable that is being bound, or something that is not a binding name at all, such as a definition *modifier* or an intermediate word. Thus the information for each of those cases is retained in the special token. A named value reference and a binding connect if and only if the original NAMES and the specific macro call occurrences are both the same. (In that case, the lexical contexts will also be the same, but this need not be checked.) A named value reference and a binding never connect if one originated in a template and the other originated in a macro call.

For purposes of hygiene, a *pattern-keyword default* is treated like part of a template, even though it is actually part of a pattern.

The mapping from getters to setters done by the `:=` operator is hygienic. In all cases the setter name is looked up in the same lexical context and macro call occurrence as the getter name.

Intentional Hygiene Violation

Sometimes it is necessary for a macro to violate the hygienic property, for example to include in a macro expansion a named value reference to be executed in the lexical context where the macro was called, not the lexical context where the macro was defined. Another example is creating a local binding in a macro expansion that will be visible to the body of the macro. This feature should be used sparingly, as it can be confusing to users of the macro, but sometimes it is indispensable.

The construct `?=` NAME in a template inserts into the expansion a reference to NAME, in the lexical context where the macro was called. It is as if NAME came from the macro call rather than from the template.

Hygiene Versus Module Encapsulation

A named value reference in a macro expansion that was produced by a *template-element* that is a NAME and that does not refer to a local binding created by the macro expansion must have the same meaning as would a named value reference with the same name adjacent to the macro definition.

This is true even if the macro call is in a different module or a different library from the one in which the macro definition occurs, even if the binding is not exported.

This allows exported macros to make use of private bindings without requiring these bindings to be exported for general use. The module that calls the macro does not need to import the private bindings used by the expansion.

Implementations must use some automatic mechanism for marking the bindings potentially referenced by macro expansions and must make such bindings available to any library where the macro is accessible. In general one cannot tell when a macro is defined what bindings are going to be referenced by macro expansions, because the right-hand sides of rewrite rules are not fully parsed until after a macro is called and expanded. However, an upper bound on this set of bindings can be computed.

Rewrite Rule Examples

The following definitions of all of the built-in macros are provided as examples. This section is not intended to be a tutorial on how to write macros, just a collection of demonstrations of some of the tricks.

The built-in macros cannot really be implemented this way, for example, `if` and `case` cannot really both be implemented by expanding to the other. Certain built-in macros cannot be implemented with rewrite rules or necessarily rewrite into implementation-dependent code, so blank right-hand sides are shown for them.

Statement Macros

Begin

```
define macro begin
  { begin ?:body end } => { ?body }
end;
```

Block

```
define macro block
  { block (?:name) ?ebody end }
   => { with-exit(method(?name) ?ebody end) }
  { block () ?ebody end }
   => { ?ebody }

 // Left-recursive so leftmost clause is innermost
 ebody:
  { ... exception (?excp, #rest ?options:expression,
                          #key ?test:expression,
                               ?init-arguments:expression)
           ?:body }
   => { with-handler(method() ... end,
                     method() ?body end,
                     ?excp, ?options) }
  { ?abody cleanup ?cleanup:body}
   => { with-cleanup(method() ?abody end, method () ?cleanup
end) }
  { ?abody }
   => { ?abody }

 abody:
  { ?main:body afterwards ?after:body }
   => { with-afterwards(method() ?main end, method () ?after
end) }
  { ?main:body }
   => { ?main }

 excp:
  { ?type:expression }           => { ?type }
  { ?:name :: ?type:expression } => { ?type, condition: ?name }
end;
```

Case

```
define macro case
  { case ?:case-body end }           => { ?case-body }
 case-body:
  { ?test:expression => ?:body ... } => { if (?test) ?body
                                          else ... end if }
  { otherwise ?:body }               => { ?body }
  { }                                => { #f }
end;
```

For

```
// This macro has three auxiliary macros, whose definitions
follow
define macro for
  { for (?header) ?fbody end }       => { for-aux ?fbody ?header
end }

 // pass main body and finally body as two expressions
 fbody:
  { ?main:body }                     => { ?main, #f }
  { ?main:body finally ?val:body }   => { ?main, ?val }

 // convert iteration clauses to property list via for-clause
macro
 header:
  { ?v:variable in ?c:expression, ... }
   => { for-clause(?v in ?c) ... }
  { ?v:variable = ?e1:expression then ?e2:expression, ... }
   => { for-clause(?v = ?e1 then ?e2) ... }
  { ?v:variable from ?e1:expression ?to, ... }
```

```
   => { for-clause(?v from ?e1 ?to) ... }
  { #key ?while:expression }         => { for-clause(~?while
stop) }
  { #key ?until:expression }         => { for-clause(?until
stop) }
  { }                                => { }

 // parse the various forms of numeric iteration clause
 to:
  { to ?limit:expression by ?step:expression }
                                     => { hard ?limit ?step }
  { to ?limit:expression }           => { easy ?limit 1   > }
  { above ?limit:expression ?by }    => { easy ?limit ?by <= }
  { below ?limit:expression ?by }    => { easy ?limit ?by >= }
  { ?by }                            => { loop ?by }

 by:
  { by ?step:expression }            => { ?step }
  { }                                => { 1 }
end;

// Auxiliary macro to make the property list for an iteration
clause.
// Each iteration clause is a separate call to this macro so the
// hygiene rules will keep the temporary variables for each
clause
// distinct.
// The properties are:
//  init0: - constituents for start of body, outside the loop
//  var1:  - a variable to bind on each iteration
//  init1: - initial value for that variable
//  next1: - value for that variable on iterations after the
first
//  stop1: - test expression, stop if true, after binding var1's
//  var2:  - a variable to bind on each iteration, after stop1
tests
//  next2: - value for that variable on every iteration
//  stop2: - test expression, stop if true, after binding var2's
```

```
define macro for-clause

  // while:/until: clause
  { for-clause(?e:expression stop) }
   => { , stop2: ?e }

  // Explicit step clause
  { for-clause(?v:variable = ?e1:expression then ?e2:expression)
}
   => { , var1: ?v, init1: ?e1, next1: ?e2 }

  // Collection clause
  { for-clause(?v:variable in ?c:expression) }
   => { , init0: [ let collection = ?c;
                   let (initial-state, limit,
                        next-state, finished-state?,
                        current-key, current-element)
                       = forward-iteration-protocol(collection);
]
        , var1: state, init1: initial-state
        , next1: next-state(collection, state)
        , stop1: finished-state?(collection, state, limit)
        , var2: ?v, next2: current-element(collection, state) }

  // Numeric clause (three cases depending on ?to right-hand
side)
  { for-clause(?v:name :: ?t:expression from ?e1:expression
               loop ?by:expression) }
   => { , init0: [ let init = ?e1;
                   let by = ?by; ]
        , var1: ?v :: ?t, init1: init, next1: ?v + by }
  { for-clause(?v:name :: ?t:expression from ?e1:expression
               easy ?limit:expression ?by:expression
?test:token) }
   => { , init0: [ let init = ?e1;
                   let limit = ?limit;
                   let by = ?by; ]
        , var1: ?v :: ?t, init1: init, next1: ?v + by
        , stop1: ?v ?test limit }

  { for-clause(?v:name :: ?t:expression from ?e1:expression
               hard ?limit:expression ?by:expression) }
   => { , init0: [ let init = ?e1;
                   let limit = ?limit;
                   let by = ?by; ]
        , var1: ?v :: ?t, init1: init, next1: ?v + by
        , stop1: if (by >= 0) ?v > limit else ?v < limit end if }
end;

// Auxiliary macro to expand multiple for-clause macros and
// concatenate their expansions into a single property list.
define macro for-aux
  { for-aux ?main:expression, ?value:expression, ?clauses:* end }
   => { for-aux2 ?main, ?value ?clauses end }

 clauses:
  { ?clause:macro ... } => { ?clause ... }
  { } => { }
end;

// Auxiliary macro to assemble collected stuff into a loop.
// Tricky points:
// loop iterates by tail-calling itself.
// return puts the finally clause into the correct lexical scope.
// ??init0 needs an auxiliary rule set to strip off the shielding
// brackets that make it possible to stash local declarations in
// a property list.
// ??var2 and ??next2 need a default because let doesn't allow
// an empty variable list.
// ??stop1 and ??stop2 need a default because if () is invalid.
define macro for-aux2
  { for-aux2 ?main:expression, ?value:expression,
             #key ??init0:*, ??var1:variable,
                  ??init1:expression, ??next1:expression,
                  ??stop1:expression = #f,
                  ??var2:variable = x, ??next2:expression = 0,
                  ??stop2:expression = #f
    end }
   => { ??init0 ...
        local method loop(??var1, ...)
                let return = method() ?value end method;
                if (??stop1 | ...) return()
                else let (??var2, ...) = values(??next2, ...);
                     if(??stop2 | ...) return()
                     else ?main; loop(??next1, ...)
                     end if;
                end if;
              end method;
        loop(??init1, ...) }

 // strip off brackets used only for grouping
 init0:
  { [ ?stuff:* ] } => { ?stuff }
end;
```

If

```
define macro if
  { if (?test:expression) ?:body ?elses end }
                                     => { case ?test => ?body;
                                          otherwise ?elses end }
 elses:
  { elseif (?test:expression) ?:body ... }
                                     => { case ?test => ?body;
                                          otherwise ... end }
  { else ?:body }                    => { ?body }
  { }                                => { #f }
end;
```

Method

```
define macro method
  { method (?parameters:*) => (?results:*) ; ?:body end }     =>
  { method (?parameters:*) => (?results:*) ?:body end }       =>
  { method (?parameters:*) => ?result:variable ; ?:body end } =>
  { method (?parameters:*) ; ?:body end }                     =>
  { method (?parameters:*) ?:body end }                       =>
end;
```

Select

```
define macro select
  { select (?what) ?:case-body end } => { ?what; ?case-body }

 what:
  { ?object:expression by ?compare:expression }
                                    =>  { let object = ?object;
                                          let compare = ?compare
}
  { ?object:expression }            =>  { let object = ?object;
                                          let compare = \== }
 case-body:
  { otherwise ?:body }              => { ?body }
  { }                               => { error("select error") }
  { ?keys => ?:body ... }           => { if (?keys) ?body
                                             else ... end if }

 keys:
  { ?key:expression }               => { compare(?key, object) }
  { ?key:expression, ... }          => { compare(?key, object) |
... }
end;
```

Unless

```
define macro unless
  { unless (?test:expression) ?:body end }
   => { if (~ ?test) ?body end }
end;
```

Until

```
define macro until
  { until (?test:expression) ?:body end }
   => { local method loop ()
                if (~ ?test)
                  ?body;
                  loop()
                end if;
              end method;
        loop() }
end;
```

While

```
define macro while
  { while (?test:expression) ?:body end }
   => { local method loop ()
                if (?test)
                  ?body;
                  loop()
                end if;
              end method;
        loop() }
end;
```

Definition Macros

Define Class

```
define macro class-definer
  { define ?mods:* class ?:name (?supers) ?slots end }  =>

 supers:
  { ?super:expression, ... }                            =>
  { }                                                   =>

// the = feature in slot specs is missing from this.
 slots:
  { inherited slot ?:name, #rest ?options:*; ... }      =>
  { ?mods:* slot ?:name, #rest ?options:*; ... }        =>
  { ?mods:* slot ?:name :: ?type:expression, #rest ?options:*;
... }
                                                        =>
  { required keyword ?key:expression, #rest ?options:*; ... }  =>
  { keyword ?key:expression, #rest ?options:*; ... }    =>
  { }                                                   =>
end;
```

Define Constant

```
define macro constant-definer
  { define ?mods:* constant ?vars:* = ?init:expression } =>
end;
```

Define Domain

```
define macro domain-definer
  { define inert domain ?:name ( ?types ) }             =>

 types:
  { ?type:expression, ... } => { ?type, ... }
  { } => { }
end;
```

Define Generic

```
define macro generic-definer
  { define ?mods:* generic ?:name ?rest:* }             =>

 rest:
  { ( ?parameters:* ), #key }                           =>
  { ( ?parameters:* ) => ?:variable, #key }             =>
  { ( ?parameters:* ) => (?variables:*), #key }         =>
end;
```

Define Library

```
define macro library-definer
  { define library ?:name ?items end }                  =>

 items:
  { use ?:name, #rest ?options:*; ... }                 =>
  { export ?names; ... }                                =>
  { }                                                   =>
 names:
  { ?:name }                                             =>
  { ?:name, ... }                                        =>
end;
```

Define Method

```
define macro method-definer
  { define ?mods:* method ?:name ?rest end }             =>

 rest:
  { (?parameters:*) => (?results:*) ; ?:body }           =>
  { (?parameters:*) => (?results:*) ?:body }             =>
  { (?parameters:*) => ?result:variable ; ?:body }       =>
  { (?parameters:*) ; ?:body }                           =>
  { (?parameters:*) ?:body }                             =>
end;
```

Define Module

```
define macro module-definer
  { define module ?:name ?items end }                    =>

 items:
  { use ?:name, #rest ?options:*; ... }                  =>
  { export ?names; ... }                                 =>
  { create ?names; ... }                                 =>
  { }                                                    =>

 names:
  { ?:name }                                             =>
  { ?:name, ... }                                        =>
end;
```

Define Variable

```
define macro variable-definer
  { define ?mods:* variable ?vars:* = ?init:expression } =>
end;
```

Additional Examples

The following macros are not built-in, but are simply supplied as examples. Each is shown as a definition followed by a sample call.

Test and Test-setter

```
define macro test
  { test(?object:expression) } =>
                               { frame-slot-getter(?object,
#"test") }
end macro;

define macro test-setter
  { test-setter(?value:expression, ?object:expression) }
   => { frame-slot-setter(?value, ?object, #"test") }
end macro;

test(foo.bar) := foo.baz;
```

Transform!

```
define macro transform!
 // the main rule
 { transform!(?xform:expression, ?x:expression, ?y:expression,
              #rest ?more:expression) }
  => { let xform = ?xform;
       let (nx, ny) = transform(xform, ?x, ?y);
       ?x := nx; ?y := ny;
       transform!(xform, ?more) }
 // base case
 { transform!(?xform:expression) } => { ?xform }
end macro;

transform!(w.transformation, xvar, yvar, w.pos.x, w.pos.y);
```

Formatting-table

```
define macro formatting-table
  { formatting-table (?:expression,
                      #rest ?options:expression,
                      #key ?x-spacing:expression = 0,
                           ?y-spacing:expression = 0)
      ?:body end }
   => { do-formatting-table(?expression, method() ?body end,
                            ?options) }
end macro;

formatting-table (stream, x-spacing: 10, y-spacing: 12)
  foobar(stream)
end;
```

With-input-context

```
define macro with-input-context
  { with-input-context (?context-type:expression,
                        #key ?override:expression = #f)
     ?bbody end }
   => { do-with-input-context(?context-type, ?bbody,
                              override: ?override) }

 bbody:
  { ?:body ?clauses }  => { list(?clauses), method() ?body end }

 clauses:
  { }                  => { }
  { on (?:name :: ?spec:expression, ?type:variable) ?:body ... }
   => { pair(?spec, method (?name :: ?spec, ?type) ?body end),
        ... }
end macro;

with-input-context (context-type, override: #t)
      // the body that reads from the user
      read-command-or-form (stream);
    // the clauses that dispatch on the type
    on (object :: <command>, type) execute-command (object);
    on (object :: <form>, type) evaluate-form (object, type);
end;
```

Define Command

```
define macro command-definer
 { define command ?:name (?arguments:*) (#rest
?options:expression)
     ?:body end }
  => { define-command-1 ?name (?arguments) ?body end;
       define-command-2 ?name (?arguments) (?options) end }
end macro;
```

```
// define the method that implements a command
// throws away the "stuff" in each argument used by the command
parser
define macro define-command-1
 { define-command-1 ?:name (?arguments) ?:body end }
  => { define method ?name (?arguments) ?body end }

 // map over ?arguments, reducing each to a parameter-list entry
 // but when we get to the first argument that has a default, put
 // in #key and switch to the key-arguments loop

 arguments:
  { ?:variable = ?default:expression ?stuff:*, ?key-arguments }
   => { #key ?variable = ?default, ?key-arguments }
  { ?argument, ... } => { ?argument, ... }
  { } => { }

 // map over keyword arguments the same way, each must
 // have a default
 key-arguments:
  { ?key-argument, ... } => { ?key-argument, ... }
  { } => { }

 // reduce one required argument spec to a parameter-list entry
 argument:
  { ?:variable ?stuff:* } => { ?variable }

 // reduce one keyword argument spec to a parameter-list entry
 key-argument:
  { ?:variable = ?default:expression ?stuff:* }
   => { ?variable = ?default }
end macro;

// generate the datum that describes a command and install it
define macro define-command-2
 { define-command-2 ?:name (?arguments) (#rest ?options:*) end }
  => { install-command(?name, list(?arguments), ?options) }
 // map over ?arguments, reducing each to a data structure
 arguments:
  { ?argument, ... } => { ?argument, ... }
  { } => { }

 // reduce one argument specification to a data structure
 argument:
  { ?:name :: ?type:expression = ?default:expression ?details }
   => { make(<argument-info>, name: ?"name", type: ?type,
               default: ?default, ?details) }
  { ?:name :: ?type:expression ?details }
   => { make(<argument-info>, name: ?"name", type: ?type,
?details) }

 // translate argument specification to <argument-info> init
keywords
 details:
  { ?key:name ?value:expression ... } => { ?#"key" ?value, ... }
  { } => { }
end macro;

define command com-show-home-directory
       (directory :: <type> provide-default #t,
        before :: <time> = #() prompt "date",
        after  :: <time> = #() prompt "date")
       // Options
       (command-table: directories,
        name: "Show Home Directory")
    body()
end command com-show-home-directory;
```

Get-resource

```
// The idea is that in this application each library has its own
// variable named $library, which is accessible to modules in
that
// library.  Get-resource gets a resource associated with the
library
// containing the call to it. Get-resource-from-library is a
function.
// The get-resource macro is a device to make programs more
concise.

define macro get-resource
  { get-resource(?type:expression, ?id:expression) }
   => { get-resource-from-library(?=$library, ?type, ?id) }
end macro;

show-icon(get-resource(ResType("ICON"), 1044));
```

Completing-from-suggestions

```
// The completing-from-suggestions macro defines a lexically
visible
// helper function called "suggest", which is only meaningful
inside
// of calls to the completer. The "suggest" function is passed
as an
// argument to the method passed to complete-input;
alternatively it
// could have been defined in a local declaration wrapped around
the
// method.
define macro completing-from-suggestions
  { completing-from-suggestions (?stream:expression,
                                 #rest ?options:expression)
      ?:body end }
   =>{ complete-input(?stream,
                      method (?=suggest) ?body end,
                      ?options) }
end macro;

completing-from-suggestions (stream, partial-completers: #(' ',
'-'))
  for (command in commands)
    suggest (command, command-name (command))
  end for;
end completing-from-suggestions;
```

Define Jump-instruction

```
define macro jump-instruction-definer
  { define jump-instruction ?:name ?options:* end }
   => { register-instruction("j" ## ?#"name",
                             make(<instruction>,
                                  debug-name: "j" ## ?"name",
                                  ?options)) }
end macro;

define jump-instruction eq cr-bit: 2, commutative?: #t end;
```

CHAPTER 10

Macros

CHAPTER 11

The Built-In Classes

Contents

Overview

This chapter contains an entry for every class defined by Dylan.

The superclasses listed for a class *C* are those classes defined by the Dylan language from which *C* most directly inherits. They are not required to be the direct superclasses of *C*, because implementations are free to insert implementation-defined classes in the class hierarchy. However, any classes defined by Dylan which appear in the class precedence list of *C* must appear in the same order in which they would appear if the specified superclasses were the direct superclasses of *C*, in the order given.

All classes are specified as open or sealed. A class may be specifed as abstract; if it is not, then it is concrete. A class may be specified as primary; if it is not, than it is free. A class may be specified as instantiable. If it is not, then it is uninstantiable. Chapter 9, “Sealing,” contains a complete description of these characteristics.

An implementation may choose to impose fewer restrictions than specified. For example, a class specified as sealed may be left open, and a class specified as primary may be left free. However, any program which takes advantage of this liberality will not be portable.

Each class entry includes tables of operations defined on the class. These tables are cross references to Chapter 12, “The Built-In Functions,” and represent redundant information. A function, generic function, or method is listed under a class if one of its arguments is specialized on the class. In addition, constructors are listed. Not all generic functions which specialize on `<object>` are listed.

Objects

`<object>` [Open Abstract Class]

The class of all Dylan objects.

Superclasses: None. `<object>` is the root of the Dylan class hierarchy.

Init-keywords: None.

Description: The class `<object>` is the root of the type system. All objects are general instances of `<object>`, all types are subtypes of `<object>`, and all classes are subclasses of `<object>`.

Operations: The class `<object>` provides the following operations:

Table 11-1 Functions on <object>

Function	Description	Page
`identity`	Returns its argument.	274
`always`	Returns a function that always returns a particular object.	338
`instance?`	Tests whether an object is an instance of a type.	331
`object-class`	Returns the class of an object.	332
`==`	Compares two objects for identity.	255
`~==`	Compares two objects for nonidentity.	256
`object-hash`	The hash function for the equivalence predicate ==.	331

Table 11-2 Generic functions on <object>

Function	Description	Page
`initialize`	Performs instance initialization that cannot be specified declaratively by a class definition.	247
`as`	Coerces an object to a type.	275
`shallow-copy`	Returns a copy of its argument.	279

Table 11-2 Generic functions on <object> (continued)

Function	Description	Page
`type-for-copy`	Returns an appropriate type for creating mutable copies of its argument.	279
`size`	Returns the size of its argument.	281
`empty?`	Returns true if its argument is empty.	281

Table 11-3 Methods on <object>

Function	Description	Page
`initialize`	Performs instance initialization that cannot be specified declaratively by a class definition.	247
`type-for-copy`	Returns an appropriate type for creating mutable copies of its argument.	279
`=`	Compares two objects for equality.	256

Types

Types

<type> [Sealed Abstract Class]

The class of all types, including classes and other types.

Superclasses: `<object>`

Init-keywords: None.

Description: The class of all types. All types (including `<type>` and `<class>`) are instances of `<type>`.

Operations: The class `<type>` provides the following operations:

Table 11-4 Functions on <type>

Function	Description	Page
`instance?`	Tests whether an object is an instance of a type.	331
`subtype?`	Tests whether a type is a subtype of another type.	332
`union`	Returns the union of two types.	253

Classes

`<class>` [Sealed Instantiable Class]

The class of all Dylan classes.

Superclasses: `<type>`

Init-keywords: The class `<class>` supports the following init-keywords:

`superclasses:`
: An instance of `<class>` or `<sequence>` specifying the direct superclasses of the class. If it is a sequence, the elements of the sequence must be instances of `<class>`. The default value is `<object>`. The meaning of the order of the superclasses is the same as in `define class`.

`abstract?:` An instance of `<boolean>` specifying whether the class is abstract or concrete. The default value is `#f`.

`slots:` An instance of `<sequence>` containing slot specs, where each slot-spec is a sequence of keyword/value pairs.

The following keywords and corresponding values are accepted by all implementations. Implementations may also define additional keywords and values for use within slot specs.

`getter:` A generic function of one argument. Unless the allocation of the slot is virtual, the getter method for the slot will be added to this generic function. This option is required.

`setter:` A generic function of two arguments, or `#f` indicating "no setter." Unless the allocation of the slot is virtual, the setter method for the slot will be added to this generic function. The default value is `#f`.

`type:` A type. Values stored in the slot are restricted to be of this type. The default value is `<object>`.

`deferred-type:`
A function of no arguments, which returns a type, and is called once to compute the type of the slot, within the call to `make` which constructs the first instance of that class. For a given slot spec, either `type:` or `deferred-type:` may be specified, but not both.

`init-value:`
A default initial value for the slot. This option cannot be specified along with `init-function:` or `required-init-keyword:` and it cannot be specified for a virtual slot. There is no default.

`init-function:`
A function of no arguments. This function will be called to generate an initial value for the slot when a new instances is created. This option cannot be specified along with `init-value:` or `required-init-keyword:` and it cannot be specified for a virtual slot.. There is no default

`init-keyword:`
A keyword. This option permits an initial value for the slot to be passed to `make`, as a keyword argument using this keyword. This option cannot

be specified for a virtual slot. There is no default. This option cannot be specified along with `required-init-keyword:`.

`required-init-keyword:`
: A keyword. This option is like `init-keyword:`, except it indicates an init-keyword that must be provided when the class is instantiated. If `make` is called on the class and a required init-keyword is not provided in the defaulted initialization arguments, an error is signaled. There is no default. This option cannot be specified if `init-keyword:`, `init-value:`, or `init-function:` is specified, or for a virtual slot.

`allocation:`
: One of the keywords `instance:`, `class:`, `each-subclass:`, or `virtual:`, or an implementation defined keyword. The meaning of this option is the same as adding the corresponding adjective to a `define class` form.

Description: The class of all classes. All classes (including `<class>`) are general instances of `<class>`.

In most programs the majority of classes are created with `define class`. However, there is nothing to prevent programmers from creating classes by calling `make`, for example, if they want to create a class without storing it in a module binding, or if they want to create new classes at runtime.

If `make` is used to create a new class and creating the new class would violate any restrictions specified by sealing directives, then an error of type `<sealed-object-error>` is signaled.

Operations: The class `<class>` provides the following operations::

Table 11-5 Functions on <class>

Function	Description	Page
`all-superclasses`	Returns all the superclasses of a class.	332
`direct-superclasses`	Returns the direct superclasses of a class.	333
`direct-subclasses`	Returns the direct subclasses of a class.	333

Table 11-6 Generic functions on <class>

Function	Description	Page
`make`	Returns a general instance of its first argument.	246
`limited`	Returns a limited subtype of a class.	251

Table 11-7 Methods on <class>

Function	Description	Page
`make`	Returns a general instance of its first argument.	247

Singletons

`<singleton>` **[Sealed Instantiable Class]**

The class of types that indicate a single object.

Superclasses: `<type>`

Init-keywords: The class `<singleton>` supports the following init-keyword:

`object:` An instance of `<object>`. The object that the singleton indicates. There is no default for this argument. If it is not supplied, an error will be signaled.

Description: The class of singletons.

If a singleton for the specified object already exists, implementations may return it rather than allocating a new singleton.

Operations: None.

Simple Objects

Characters

<character> **[Sealed Class]**

The class of characters.

Superclasses: `<object>`

Init-keywords: None.

Description: The class of characters. All characters are instances of `<character>`.

Operations: The class `<character>` provides the following operations:

Table 11-8 Methods on <character>

Function	Description	Page
<	Returns true if its first operand is less than its second operand.	258

Table 11-8 Methods on <character> (continued)

Function	Description	Page
`as-uppercase`	Coerces an object to uppercase.	277
`as-lowercase`	Coerces an object to lowercase.	278
`as`	Coerces an object to a type.	275

Symbols

`<symbol>` [Sealed Class]

The class of symbols.

Superclasses: `<object>`

Init-keywords: None.

Description: The `<symbol>` class provides a built-in, non-case-sensitive dictionary that associates a string with a unique immutable object that can be compared with `==` (which should be faster than calling a string-comparison routine). This dictionary is accessed through the `as` function: `as(<symbol>,` *string*`)` and `as(<string>,` *symbol*`)`. Any string can be used.

Operations: The class `<symbol>` provides the following operations:

Table 11-9 Methods on <symbol>

Function	Description	Page
`as`	Coerces an object to a type.	275

Booleans

`<boolean>` [Sealed Class]

The class of boolean values.

Superclasses: `<object>`

Init-keywords: None.

Operations: None.

Description: The class of boolean values. The literal constants `#t` and `#f` are general instances of `<boolean>`. Note that for the purposes of conditional expressions, all objects besides `#f` count as true. (This does not imply any other objects are instances of `<boolean>`.)

Numbers

Numbers

`<number>` [Open Abstract Class]

The class of all numbers.

Superclasses: `<object>`

Init-keywords: None.

Operations: None.

Description: The class of all numbers.

The class `<number>` is open, to allow programmers to create additional numeric classes. The built-in numeric operations do not provide default implementations for `<number>`, but for `<complex>`, a sealed subclass of `<number>`.

Complex Numbers

`<complex>` **[Sealed Abstract Class]**

The class of complex numbers.

Superclasses: `<number>`

Init-keywords: None.

Description: The sealed superclass of all built-in numbers, including real numbers. There are no non-real subclasses of `<complex>` defined by the language, but implementations may define such subclasses. Because `<complex>` and all its defined subclasses are sealed, implementation-defined subclasses may be added efficiently.

Many built-in functions are defined to have methods on `<complex>`. This means that the function is defined on all built-in subclasses of `<complex>`. It does not imply that there is a single method specialized on the `<complex>` class.

Operations: The class <complex> provides implementations for the following functions:

Table 11-10 Methods on <complex>

Function	Description	Page
`=`	Compares two objects for equality.	256
`zero?`	Tests for the property of being equal to zero.	262
`+`	Returns the sum of its arguments.	264
`*`	Returns the product of its arguments.	265

Table 11-10 Methods on <complex> (continued)

Function	Description	Page
`-`	Returns the difference of its arguments.	265
`/`	Returns the quotient of its arguments.	265
`^`	Raises an object to a specified power.	270
`abs`	Returns the absolute value of its argument.	271

Reals

`<real>` [Sealed Abstract Class]

The class of real numbers.

Superclasses: `<complex>`

Init-keywords: None.

Description: The class of real numbers.

Operations: The class `<real>` provides implementations for the following functions:

Table 11-11 Functions on <real>

Function	Description	Page
`floor`	Truncates a real number towards negative infinity.	266
`ceiling`	Truncates a real number towards positive infinity.	267
`round`	Rounds a real number towards the nearest mathematical integer.	267
`truncate`	Truncates a real number towards zero.	268

Table 11-11 Functions on <real> (continued)

Function	Description	Page
`floor/`	Returns the floor of the quotient of two numbers.	268
`ceiling/`	Returns the ceiling of the quotient of two numbers.	268
`round/`	Rounds off the quotient of two numbers.	269
`truncate/`	Returns the truncated quotient of two numbers.	269
`modulo`	Returns the second value of floor/.	270
`remainder`	Returns the second value of truncate/.	270

Table 11-12 Methods on <real>

Function	Description	Page
`<`	Returns true if its first operand is less than its second operand.	258
`positive?`	Tests for the property of being positive.	263
`negative?`	Tests for the property of being negative.	263
`integral?`	Tests for the property of being integral.	263
`negative`	Returns the negation of an object.	266

Floats

The classes `<single-float>` and `<double-float>` are intended but not required to be the corresponding IEEE types. The class `<extended-float>` is intended but not required to have more range and/or precision than `<double-float>`.

If an implementation has fewer than three floating point classes, the names `<single-float>`, `<double-float>` and `<extended-float>` may all refer to the same object.

`<float>` [Sealed Abstract Class]

The class of floating-point numbers.

Superclasses: `<real>`

Init-keywords: None.

Description: The class of all floating-point numbers. This class is abstract. All floating point numbers will be instances of some concrete subclass of this class.

Operations: None.

`<single-float>` [Sealed Class]

The class of single-precision floating-point numbers.

Superclasses: `<float>`

Init-keywords: None.

Description: The class of single-precision floating-point numbers. This class is intended but not required to correspond to IEEE single-precision.

Operations: None.

`<double-float>` [Sealed Class]

The class of double-precision floating-point numbers.

Superclasses: `<float>`

Init-keywords: None.

Description: The class of double-precision floating-point numbers. This class is intended but not required to correspond to IEEE double-precision.

Operations: None.

`<extended-float>` **[Sealed Class]**

The class of extended-precision floating-point numbers.

Superclasses: `<float>`

Init-keywords: None.

Description: The class of extended-precision floating-point numbers. This class is intended but not required to provide more precision that `<double-float>`.

Operations: None.

Rationals

`<rational>` **[Sealed Abstract Class]**

The class of rational numbers.

Superclasses: `<real>`

Init-keywords: None.

Description: The class of rational numbers.

Operations: None.

Integers

`<integer>` **[Sealed Class]**

The class of integers.

Superclasses: `<rational>`

Init-keywords: None.

Description: The class of integers.

Implementations are required to support integers with at least 28 bits of precision. The overflow and underflow behavior is implementation-defined. (Some implementations may choose to have integers of unlimited size, but this is not required.)

The result of dividing two integers with `/` is implementation defined. Portable programs should use `floor/`, `ceiling/`, `round/`, or `truncate/` to divide two integers.

Operations: The class `<integer>` provides the following operations:

Table 11-13 Functions on <integer>

Function	Description	Page
`odd?`	Tests for the property of being an odd number.	262
`even?`	Tests for the property of being an even number.	262
`logior`	Returns the bitwise inclusive or of its integer arguments.	271
`logxor`	Returns the bitwise exclusive or of its integer arguments.	271
`logand`	Returns the bitwise and of its integer arguments.	272
`lognot`	Returns the bitwise not of its integer argument.	272
`logbit?`	Tests the value of a particular bit in its integer argument.	272
`ash`	Performs an arithmetic shift on its first argument.	273
`lcm`	Returns the least common multiple of two integers.	273
`gcd`	Returns the greatest common divisor of two integers.	274

Table 11-14 Methods on singleton(<integer>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

Collections

This section describes collections, Dylans aggregate data structures.

An overview of collections is given in Chapter 8, “Collections.”

Collections

<collection> [Open Abstract Class]

The class of collections, aggregate data structures.

Superclasses: `<object>`

Init-keywords: None.

Description: The class of collections.

`<collection>` is the root class of the collection class hierarchy. It provides a set of basic operations on all collections.

The element type of `<collection>` is `indefinite` ⇐ `<object>`.

Operations: The class `<collection>` provides the following operations:

Table 11-15 Functions on <collection>

Function	Description	Page
`do`	Iterates over one or more collections for side effect.	315
`map`	Iterates over one or more collections and collects the results in a freshly allocated collection.	316
`map-as`	Iterates over one or more collections and collects the results in a freshly allocated collection of a specified type.	316
`map-into`	Iterates over one or more collections and collects the results in an existing mutable collection.	317
`any?`	Returns the first true value obtained by iterating over one or more collections.	318
`every?`	Returns true if a predicate returns true when applied to all corresponding elements of a set of collections.	319

Table 11-16 Generic Functions on <collection>

Function	Description	Page
`element`	Returns the collection element associated with a particular key.	286
`key-sequence`	Returns a sequence containing the keys of its collection argument.	286
`reduce`	Combines the elements of a collection and a seed value into a single value by repeatedly applying a binary function.	320

Table 11-16 Generic Functions on <collection> (continued)

Function	Description	Page
`reduce1`	Combines the elements of a collection into a single value by repeatedly applying a binary function, using the first element of the collection as the seed value.	321
`member?`	Returns true if a collection contains a particular value.	322
`find-key`	Returns the key in a collection such that the corresponding collection element satisfies a predicate.	323
`key-test`	Returns the function used by its collection argument to compare keys.	285
`forward-iteration-protocol`	Returns a group of functions used to iterate over the elements of a collection.	326
`backward-iteration-protocol`	Returns a group of functions used to iterate over the elements of a collection in reverse order.	328

Table 11-17 Methods on <collection>

Function	Description	Page
`=`	Compares two objects for equality.	256
`empty?`	Returns true if its argument is empty.	281
`size`	Returns the size of its argument.	281
`shallow-copy`	Returns a copy of its argument.	279

Table 11-18 Methods on singleton(<collection>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

Explicit Key Collections

`<explicit-key-collection>` [Open Abstract Class]

The class of all collections that are not sequences.

Superclasses: `<collection>`

Init-keywords: None.

Description: The class of all collections that are not sequences.

This class is disjoint from `<sequence>` because `key-test` is inert over the domain `<sequence>`.

The element type of `<explicit-key-collection>` is `indefinite` ⇐ `<object>`.

Operations: The class `<explicit-key-collection>` provides the following operations:

Table 11-19 Methods on singleton(<explicit-key-collection>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

Sequences

`<sequence>` [Open Abstract Class]

The class of collections whose keys are consecutive integers starting from zero.

Superclasses: `<collection>`

Init-keywords: None.

Description: The class of collections whose keys are consecutive integers starting from zero.

Sequences must be stable under iteration, and the iteration order must match the order of keys. Thus, the key associated with a sequence's iteration state can be determined by keeping a counter in parallel with the iteration state.

The default methods for `add`, `add-new`, `remove`, `choose`, `choose-by`, `intersection`, `union`, `remove-duplicates`, `copy-sequence`, `concatenate`, `reverse`, and `sort` all return new sequences that are instances of the `type-for-copy` of their primary sequence argument. However, more specialized methods are permitted to choose a more appropriate result class; for example, `copy-sequence` of a range returns another range, even though the `type-for-copy` value of a range is the `<list>` class.

`<sequence>` is disjoint from `<explicit-key-collection>` because of the inert domain over the function `key-test` for `<sequence>`.

The element type of `<sequence>` is `indefinite` ⇐ `<object>`.

Operations: The class `<sequence>` provides the following operations:

Table 11-20 Functions on <sequence>

Function	Description	Page
`concatenate`	Returns the concatenation of one or more sequences in a sequence of a type determined by the type-for-copy of its first argument.	311
`concatenate-as`	Returns the concatenation of one or more sequences in a sequence of a specified type.	312
`first`	Returns the first element of a sequence.	290
`second`	Returns the second element of a sequence.	290
`third`	Returns the third element of a sequence.	291

Table 11-21 Generic Functions on <sequence>

Function		Page
`add`	Adds an element to a sequence.	296
`add!`	Adds an element to a sequence.	297
`add-new`	Adds a new element to a sequence.	298
`add-new!`	Adds a new element to a sequence.	299
`remove`	Removes an element from a sequence.	300
`remove!`	Removes an element from a sequence.	300
`choose`	Returns those elements of a sequence that satisfy a predicate.	321
`choose-by`	Returns those elements of a sequence that correspond to those in another sequence that satisfy a predicate.	322
`intersection`	Returns the intersection of two sequences.	307
`union`	Returns the union of two sequences.	308
`remove-duplicates`	Returns a sequence without duplicates.	309
`remove-duplicates!`	Returns a sequence without duplicates.	310
`copy-sequence`	Returns a freshly allocated copy of some subsequence of a sequence.	311
`replace-subsequence!`	Replaces a portion of a sequence with the elements of another sequence.	313
`reverse`	Returns a sequence with elements in the reverse order of its argument sequence.	303
`reverse!`	Returns a sequence with elements in the reverse order of its argument sequence.	304
`sort`	Returns a sequence containing the elements of its argument sequence, sorted.	305

Table 11-21 Generic Functions on <sequence> (continued)

Function		Page
`sort!`	Returns a sequence containing the elements of its argument sequence, sorted.	306
`last`	Returns the last element of a sequence.	293
`subsequence-position`	Returns the position where a pattern appears in a sequence.	314

Table 11-22 Methods on <sequence>

Function	Description	Page
`=`	Compares two objects for equality.	256
`key-test`	Returns the function used by its collection argument to compare keys.	285

Table 11-23 Methods on singleton(<sequence>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

Mutable Collections

`<mutable-collection>` [Open Abstract Class]

The class of collections that may be modified.

Superclasses: `<collection>`

Init-keywords: None.

Description: The class of collections that may be modified.

Every mutable collection is required to allow modification by implementing `element-setter`.

The element type of `<mutable-collection>` is `indefinite` ⇐ `<object>`.

Operations: The class `<mutable-collection>` provides the following operations:

Table 11-24 Functions on <mutable-collection>

Function	Description	Page
`map-into`	Iterates over one or more collections and collects the results in an existing mutable collection.	317

Table 11-25 Generic Functions on <mutable-collection>

Function	Description	Page
`last-setter`	Sets the last element of a mutable sequence.	293

Table 11-26 Methods on <mutable-collection>

Function	Description	Page
`type-for-copy`	Returns an appropriate type for creating mutable copies of its argument.	279

Table 11-27 Methods on singleton(<mutable-collection>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

`<mutable-explicit-key-collection>` [Open Abstract Class]

The class of explicit-key-collections that can have elements replaced.

Superclasses: `<explicit-key-collection>` `<mutable-collection>`

Init-keywords: None.

Description: The class of explicit-key-collections that can have elements replaced.

The element type of `<mutable-explicit-key-collection>` is `indefinite` ⇐ `<object>`.

Operations: The class `<mutable-explicit-key-collection>` provides the following operations:

Table 11-28 Methods on singleton(<mutable-explicit-key-collection>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

`<mutable-sequence>` [Open Abstract Class]

The class of sequences that may be modified.

Superclasses: `<sequence>` `<mutable-collection>`

Init-keywords: None.

Description: The class of sequences that may be modified.

The element type of `<mutable-sequence>` is `indefinite` ⇐ `<object>`.

Operations: The following operations are provided on `<mutable-sequence>`:

Table 11-29 Generic Functions on <mutable-sequence>

Function	Description	Page
`first-setter`	Sets the first element of a mutable sequence.	291
`second-setter`	Sets the second element of a mutable sequence.	292
`third-setter`	Sets the third element of a mutable sequence.	292

Table 11-30 Methods on <mutable-sequence>

Function	Description	Page
`first-setter`	Sets the first element of a mutable sequence.	291
`second-setter`	Sets the second element of a mutable sequence.	292
`third-setter`	Sets the third element of a mutable sequence.	292

Table 11-31 Methods on singleton(<mutable-sequence>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

Stretchy Collections

`<stretchy-collection>` [Open Abstract Class]

The class of collections that may grow or shrink to accomodate adding or removing elements.

Superclasses: `<collection>`

Init-keywords: None.

Description: The class of collections that may grow or shrink to accomodate adding or removing elements.

Stretchy collections allow `element-setter` to be called with a key that is not present in the collection, expanding the collection as necessary to add a new element in that case. Each concrete subclass of `<stretchy-collection>` must provide or inherit a method for `element-setter` that behaves as follows when there is not already an element present for the indicated key:

- If the class is a subclass of `<explicit-key-collection>`, adds a new element to the collection with the indicated key.
- If the class is a subclass of `<sequence>`, first calls `size-setter` on the key + 1 and the collection to expand the sequence. The key must be a non-negative integer.

The element type of `<stretchy-collection>` is `indefinite` ⇐ `<object>`.

Operations: The following operations are provided on `<stretchy-collection>`:

Table 11-32 Methods on singleton(<stretchy-collection>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

Arrays

`<array>` **[Open Abstract Instantiable Class]**

The class of sequences whose elements are arranged according to a Cartesian coordinate system.

Superclasses: `<mutable-sequence>`

Init-keywords: The make method on `singleton(<array>)` accepts the following keyword arguments. Note that these are not inherited by subclasses of `<array>`.

`dimensions:`	An instance of `<sequence>` with elements that are instances of `<integer>`. This argument specifies the dimensions of the array. The size of the sequence specifies the rank (number of dimensions) of the array, and each integer in the sequence specifies the size of a dimension. This argument is required.
`fill:`	An instance of `<object>` specifying an initial value for each element of the array. The default value is `#f`.

Description: The class of collections whose elements are arranged according to a Cartesian coordinate system.

An array element is referred to by a (possibly empty) series of indices. The length of the series must equal the rank of the array. Each index must be a non-negative integer less than the corresponding dimension. An array element may alternatively be referred to by an integer, which is interpreted as a row-major index.

Arrays typically use space efficient representations, and the average time required to access a randomly chosen element is typically sublinear to the number of elements.

Whe a multi-dimensional array is created, the concrete class that is actually instantiated cannot be any of the specified subclasses of `<array>`, which are all one-dimensional. Every implementation must have one or more concrete subclasses of `<array>` that are used for this purpose. These concrete subclasses have no specified names, and their names are not exported by the Dylan module.

When a single-dimensional array is created, the array created will be an instance of `<vector>`.

Each concrete subclass of `<array>` must either provide or inherit implementations of the functions `element`, `element-setter`, and `dimensions`.

The element type of `<array>` is `indefinite` ⇐ `<object>`.

Operations: The class `<array>` provides the following operations::

Table 11-33 Generic Functions on <array>

Function	Description	Page
`rank`	Returns the number of dimensions of an array.	283
`row-major-index`	Returns the row-major-index position of an array element.	284
`aref`	Returns the array element indicated by a set of indices.	289
`aref-setter`	Sets the array element indicated by a set of indices.	289
`dimensions`	Returns the dimensions of an array.	284
`dimension`	Returns the size of a specified dimension of an array.	285

Table 11-34 Methods on <array>

Function	Description	Page
`size`	Returns the size of its argument.	281
`rank`	Returns the number of dimensions of an array.	283
`row-major-index`	Returns the row-major-index position of an array element.	284

Table 11-34 Methods on <array> (continued)

Function	Description	Page
`aref`	Returns the array element indicated by a set of indices.	289
`aref-setter`	Sets the array element indicated by a set of indices.	289
`dimension`	Returns the size of a specified dimension of an array.	285

Table 11-35 Methods on singleton(<array>)

Function	Description	Page
`make`	Returns a general instance of its first argument.	246
`limited`	Returns a limited subtype of a class.	251

Vectors

<vector> [Open Abstract Instantiable Class]

The class of arrays of rank one (i.e. exactly one dimension).

Superclasses: `<array>`

Init-keywords: The make method on `singleton(<vector>)` accepts the following keyword arguments. Note that these are not inherited by subclasses of `<vector>`.

`size:`	An instance of `<integer>` specifying the size of the vector.
`fill:`	An instance of `<object>` specifying an initial value for each element of the vector. The default value is `#f`.

Description: The class of one-dimensional arrays.

`<vector>` has no direct instances; calling `make` on `<vector>` returns an instance of `<simple-object-vector>`.

Each concrete subclass of `<vector>` must either provide or inherit an implementation of `size` that shadows the method provided by `<array>`.

The element type of `<vector>` is `indefinite` ⇐ `<object>`.

Operations: The class `<vector>` provides the following operations:

Table 11-36 Constructors for <vector>

Function	Description	Page
`vector`	Creates and returns a freshly allocated vector.	254

Table 11-37 Methods on <vector>

Function	Description	Page
`dimensions`	Returns the dimensions of an array.	284
`element`	Returns the collection element associated with a particular key.	286

Table 11-38 Methods on singleton(<vector>)

Function	Description	Page
`make`	Returns a general instance of its first argument.	246
`limited`	Returns a limited subtype of a class.	251

`<simple-vector>` [Sealed Abstract Instantiable Class]

A predefined subclass of `<vector>` which provides an efficient implementation of fixed-length vectors.

Superclasses: `<vector>`

Init-keywords: The make method on `singleton(<simple-vector>)` accepts the following keyword arguments. Note that these are not inherited by subclasses of `<simple-vector>`.

`size:`	An instance of `<integer>` specifying the size of the vector.
`fill:`	An instance of `<object>` specifying an initial value for each element of the vector. The default value is `#f`.

Description: The class of simple and efficient vectors.

The class `<simple-vector>` provides a constant time implementation for the `element` and `element-setter` functions. This property is shared by all subtypes of `<simple-vector>`.

Calling `make` on a `<simple-vector>` returns an instance of `<simple-object-vector>`. The size of a simple vector cannot be changed after the simple vector has been created.

Vector literals (created with the `#[…]` syntax) are general instances of `<simple-vector>`.

The element type of `<simple-vector>` is `indefinite` ⇐ `<object>`.

The class `<simple-object-vector>` and the type `limited(<simple-vector>, of: <object>)` have exactly the same instances, but neither is a subtype of the other. The relationship between them is simply that the `make` method for the type returns an instance of the class.

Operations: The class `<simple-vector>` provides the following operations:

Table 11-39 Methods on <simple-vector>

Function	Description	Page
`element`	Returns the collection element associated with a particular key.	286
`element-setter`	Sets the collection element associated with a particular key.	287

Table 11-40 Methods on singleton(<simple-vector>)

Function	Description	Page
`make`	Returns a general instance of its first argument.	246
`limited`	Returns a limited subtype of a class.	251

`<simple-object-vector>` [Sealed Instantiable Class]

The class of simple vectors that may have elements of any type.

Superclasses: `<simple-vector>`

Init-keywords: The class `<simple-object-vector>` supports the following init-keywords:

`size:`	An instance of `<integer>` specifying the size of the vector. The default value is `0`.
`fill:`	An instance of `<object>` specifying the initial value for each element. The default value is `#f`.

Description: The class `<simple-object-vector>` represents vectors that may have elements of any type. It provides a constant time implementation for the `element` and `element-setter` functions.

The element type of `<simple-object-vector>` is `<object>`.

Operations: None.

`<stretchy-vector>` [Open Abstract Instantiable Primary Class]

The class of vectors that are stretchy.

Superclasses: `<vector> <stretchy-collection>`

Init-keywords: The class `<stretchy-vector>` supports the the following init-keywords:

`size:`	An instance of `<integer>` specifying the initial size of the stretchy vector. The default value is `0`.
`fill:`	An instance of `<object>` specifying the initial value for each element. The default value is `#f`.

Description: The class of vectors that are stretchy.

Because `<stretchy-vector>` is abstract and instantiable but has no specified subclasses, every implementation must provide one or more concrete subclass to instantiate. These concrete subclasses have no specified names, and their names are not exported by the Dylan module.

The element type of `<simple-vector>` is `indefinite` ⇐ `<object>`.

Operations: The class `<stretchy-vector>` provides the following operations:

Table 11-41 Methods on <stretchy-vector>

Function	Description	Page
`add!`	Adds an element to a sequence.	296
`remove!`	Removes an element from a sequence.	300

Table 11-42 Methods on singleton(<stretchy-vector>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

Deques

<deque> [Open Abstract Instantiable Primary Class]

The class of double-ended queues.

Superclasses: `<mutable-sequence> <stretchy-collection>`

Init-keywords: The class `<deque>` supports the following init-keywords:

`size:`	An instance of `<integer>` specifying the initial size of the deque. The default value is `0`.

`fill:`	An instance of `<object>` specifying the initial value for each element. The default value is `#f`.

Description: A subclass of sequence that supports efficient forward and backward iteration, and efficient addition and removal of elements from the beginning or end of the sequence.

Because `<deque>` is abstract and instantiable but has no specified subclasses, every implementation must provide one or more concrete subclass to instantiate. These concrete subclasses have no specified names, and their names are not exported by the Dylan module.

The element type of `<deque>` is `indefinite` ⇐ `<object>`.

Operations: The class `<deque>` provides the following operations:

Table 11-43 Generic Functions on <deque>

Function	Description	Page
`push`	Adds an element to the front of a deque.	302
`pop`	Removes and returns the first element of a deque.	302
`push-last`	Adds an element to the end of a deque.	302
`pop-last`	Removes and returns an element from the end of a deque.	303

Table 11-44 Methods on <deque>

Function	Description	Page
`add!`	Adds an element to a sequence.	296
`remove!`	Removes an element from a sequence.	300

Table 11-45 Methods on singleton(<deque>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

Lists

Lists are constructed by linking together instances of `<pair>`. The head of a list contains an element, and the tail of the list contains a pointer to the next pair in the list. The list ends when the tail of a pair contains something besides another pair.

A **proper list** has a final pair with a tail containing the empty list.

An **improper list** does not have a final pair with a tail containing the empty list, either because the tail of its final pair is not the empty list, or because the list is circular and thus does not have a final pair. Except when their behavior on improper lists is documented explicitly, collection or sequence functions are not guaranteed to return an answer when an improper list is used as a collection or a sequence. At the implementation's option, these functions may return the correct result, signal a `<type-error>`, or (in the case of a circular list) fail to return.

When treated as a collection, the elements of a list are the heads of successive pairs in the list.

`<list>` [Sealed Instantiable Abstract Class]

The class of linked lists.

Superclasses: `<mutable-sequence>`

Init-keywords: The make method on `singleton(<list>)` accepts the following keyword arguments. Note that these are not inherited by subclasses of `<list>`.

`size:`	An instance of `<integer>` specifying the size of the list. The default value is `0`.
`fill:`	An instance of `<object>` specifying the initial value for each element. The default value is `#f`.

Description: The class of linked lists.

The `<list>` class is partitioned into two concrete subclasses, `<pair>` and `<empty-list>`. Calling make on `<list>` will return a linked list made from pairs and terminated with the empty list.

The element type of `<list>` is `<object>`.

Operations: The class `<list>` provides the following operations:

Table 11-46 Constructors for <list>

Function	Description	Page
`list`	Creates and returns a freshly allocated list.	249
`pair`	Creates and returns a freshly allocated pair.	249

Table 11-47 Functions on <list>

Function	Description	Page
`head`	Returns the head of a list.	294
`tail`	Returns the tail of a list.	294

Table 11-48 Methods on <list>

Function	Description	Page
`size`	Returns the size of its argument.	281
`=`	Compares two objects for equality.	256
`add!`	Adds an element to a sequence.	296
`remove!`	Removes an element from a sequence.	300

Table 11-49 Methods on singleton(<list>)

Function	Description	Page
`make`	Returns a general instance of its first argument.	246

`<pair>` **[Sealed Instantiable Class]**

The class of lists that can have new values assigned to their heads and tails.

Superclasses: `<list>`

Init-keywords: None.

Description: The class of lists that can have new values assigned to their heads and tails.

The element type of `<pair>` is `<object>`.

Operations: The following operations are provided on `<pair>`:

Table 11-50 Functions on <pair>

Function	Description	Page
`head-setter`	Sets the head of a pair.	295
`tail-setter`	Sets the tail of a pair.	295

Table 11-51 Constructors for <pair>

Function	Description	Page
`pair`	Creates and returns a freshly allocated pair.	249

`<empty-list>` **[Sealed Instantiable Class]**

The class with only one instance, the empty list.

Superclasses: `<list>`

Init-keywords: None.

Description: The class `<empty-list>` has only one instance, the empty list. The empty list is a direct instance of `<empty-list>` and an indirect instance of `<list>`. Note that `<empty-list>` is not == to `singleton (#())`.

The element type of `<empty-list>` is `<object>`.

Operations: None.

Ranges

<range> [Open Abstract Instantiable Primary Class]

The class of arithmetic sequences.

Superclasses: `<sequence>`

Init-keywords: The class `<range>` supports the the following init-keywords:

`from:`	An instance of `<real>` specifying the first value in the range. The default value is `0`.
`by:`	An instance of `<real>` specifying the step between consecutive elements of the range. The default value is `1`.
`to:`	An instance of `<real>` specifying an inclusive bound for the range. If `by:` is positive, the range will include numbers up to and including this value. If `by:` is negative, the range will include numbers down to to and including this value. `to:` cannot be specified with `above:` or `below:`.
`above:`	An instance of `<real>` specifying an exclusive lower bound for the range. The range will only include numbers above this value, regardless of the sign of `by:`. `above:` cannot be specified with `to:` or `below:`.

`below:`	An instance of `<real>` specifying an exclusive upper bound for the range. The range will only include numbers below this value, regardless of the sign of `by:`. `below:` cannot be specified with `to:` or `above:`.
`size:`	An instance of `<integer>` specifying the size of the range.

Description: The class `<range>` is used for creating sequences of numbers. Ranges may be infinite in size, and may run from higher numbers to lower numbers.

Because `<range>` in abstract and instantiable but has no specified subclasses, every implementation must provide one or more concrete subclass to instantiate. These concrete subclasses have no specified names, and their names are not exported by the Dylan module.

The element type of `<range>` is `indefinite` $\Leftarrow$ `<real>`.

Operations: The class `<range>` provides the following operations:

Table 11-52 Methods on <range>

Function	Description	Page
`member?`	Returns true if a collection contains a particular value.	322
`size`	Returns the size of its argument.	281
`copy-sequence`	Returns a freshly allocated copy of some subsequence of a sequence.	311
`=`	Compares two objects for equality.	256
`reverse`	Returns a sequence with elements in the reverse order of its argument sequence.	303
`reverse!`	Returns a sequence with elements in the reverse order of its argument sequence.	303
`intersection`	Returns the intersection of two sequences.	307
`type-for-copy`	Returns an appropriate type for creating mutable copies of its argument.	279

Table 11-53 Methods on singleton(<range>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

Strings

`<string>` [Open Abstract Instantiable Class]

The class of sequences with elements that are characters.

Superclasses: `<mutable-sequence>`

Init-keywords: The class `<string>` supports the following init-keywords:

`size:`	An instance of `<integer>` specifying the size of the string. The default value is `0`.
`fill:`	An instance of `<character>` specifying the initial value for each element. The default value is `' '` (space).

Description: The class `<string>` is used for holding sequences of characters.

`<string>` has no direct instances; calling `make` on `<string>` will return an instance of a concrete subclass of `<string>`.

The element type of `<string>` is `indefinite` ⇐ `<character>`.

Operations: The class `<string>` provides the following operations:

Table 11-54 Methods on <string>

Function	Description	Page
`<`	Returns true if its first operand is less than its second operand.	258
`as-lowercase`	Coerces an object to lowercase.	278

Table 11-54 Methods on <string> (continued)

Function	Description	Page
`as-lowercase!`	Coerces an object to lowercase in place.	278
`as-uppercase`	Coerces an object to uppercase.	277
`as-uppercase!`	Coerces an object to uppercase in place.	277

Table 11-55 Methods on singleton(<string>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

`<byte-string>` [Sealed Instantiable Class]

The class of vectors with elements that are eight-bit characters.

Superclasses: `<string> <vector>`

Init-keywords: The class `<byte-string>` supports the following init-keywords:

`size:`	An instance of `<integer>` specifying the size of the byte string. The default value is `0`.
`fill:`	An instance of `<character>` specifying the initial value for each element. The default value is `' '` (space).

Description: The class `<byte-string>` represents strings with elements that are eight bit characters. It provides constant time `element` and `element-setter` methods.

The element type of `<byte-string>` is `indefinite` $\Leftarrow K_2$ (where K_2 is a subtype of `<character>`).

Operations: The class `<byte-string>` provides the following operations:

Table 11-56 Methods on <byte-string>

Function	Description	Page
`element`	Returns the collection element associated with a particular key.	286
`element-setter`	Sets the collection element associated with a particular key.	287

`<unicode-string>` [Sealed Instantiable Class]

The class of vectors with elements that are sixteen-bit Unicode characters.

Superclasses: `<string> <vector>`

Init-keywords: The class `<unicode-string>` supports the following init-keywords:

`size:`	An instance of `<integer>` specifying the size of the unicode string. The default value is `0`.
`fill:`	An instance of `<character>` specifying the initial value for each element. The default value is `' '` (space).

Description: The class `<unicode-string>` represents strings with elements that are sixteen bit Unicode characters. It provides constant time `element` and `element-setter` methods.

The element type of `<unicode-string>` is `indefinite` $\Leftarrow K_1$ (where K_1 is a subtype of `<character>`).

Operations: The class `<unicode-string>` provides the following operations:

Table 11-57 Methods on <unicode-string>

Function	Description	Page
`element`	Returns the collection element associated with a particular key.	286
`element-setter`	Sets the collection element associated with a particular key.	287

Tables

Also called a hash table, a table is an unordered mapping between arbitrary keys and elements. Tables are the only predefined collections that are unstable under iteration.

Tables are stretchy in that they allow the addition and removal of keys. `<table>` and its subclasses are the only predefined classes that are stretchy but are not stretchy sequences.

For a complete description of tables, see “Tables” on page 120.

`<table>` [Open Abstract Instantiable Primary Class]

The class of tables (also known as hash tables).

Superclasses: `<mutable-explicit-key-collection> <stretchy-collection>`

Init-keywords: The class `<table>` supports the following init-keyword:

`size:`	An instance of <integer>. If specified, this value provides a hint to the implementation as to the expected number of elements to be stored in the table, which might be used to control how much space to initially allocate for the table. The default value is unspecified.

Description: The class `<table>` is the only predefined instantiable subclass of `<explicit-key-collection>`.

Every concrete subclass of `<table>` must provide or inherit a method for `table-protocol`. For details, see “Tables” on page 120.

`<table>` has no direct instances; calling `make` on `<table>` will return an instance of `<object-table>`.

The element type of `<table>` is `indefinite` ⇐ `<object>`.

Operations: The class `<table>` provides the following operations:

Table 11-58 Generic Functions on <table>

Function	Description	Page
`table-protocol`	Returns functions used to implement the iteration protocol for a tables.	329

Table 11-59 Methods on <table>

Function	Description	Page
`forward-iteration -protocol`	Returns a group of functions used to iterate over the elements of a collection.	326
`table-protocol`	Returns functions used to implement the iteration protocol for a tables.	329
`remove-key!`	Modifies an explicit key collection so it no longer has a particular key.	324
`element`	Returns the collection element associated with a particular key.	286
`element-setter`	Sets the collection element associated with a particular key.	287
`size`	Returns the size of its argument.	281
`key-test`	Returns the function used by its collection argument to compare keys.	285

Table 11-60 Methods on singleton(<table>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

`<object-table>` **[Open Abstract Instantiable Class]**

The class of tables that compare keys using `==`.

Superclasses: `<table>`

Init-keywords: None.

Description: Calling `make` on `<table>` will return a general instance of `<object-table>`. Because `<object-table>` is abstract and instantiable but has no specified subclasses, every implementation must provide one or more concrete subclasses to instantiate. These concrete subclasses have no specified names, and their names are not exported by the Dylan module.

The element type of `<object-table>` is `indefinite` ⇐ `<object>`.

Operations: The class `<object-table>` provides the following operations:

Table 11-61 Methods on <object-table>

Function	Description	Page
`table-protocol`	Returns functions used to implement the iteration protocol for a tables.	329

Table 11-62 Methods on singleton(<object-table>)

Function	Description	Page
`limited`	Returns a limited subtype of a class.	251

Functions

Functions

`<function>` [Sealed Abstract Class]

The class of objects that can be applied to arguments.

Superclasses: `<object>`

Init-keywords: None.

Description: All functions are instances of `<function>`. Functions are described in Chapter 6, "Functions."

Operations: The class `<function>` provides the following operations:

Table 11-63 Functions on <function>

Function	Description	Page
`compose`	Returns the composition of one or more functions.	334
`complement`	Returns a function that expresses the complement of a predicate.	335
`disjoin`	Returns a function that expresses the disjunction of one or more predicates.	335
`conjoin`	Returns a function that expresses the conjunction of one or more predicates.	336
`curry`	Returns a function based on an existing function and a number of default initial arguments.	336

Table 11-63 Functions on <function> (continued)

Function	Description	Page
`rcurry`	Returns a function based on an existing function and a number of default final arguments.	337
`function-specializers`	Returns the specializers of a function.	341
`function-arguments`	Returns information about the arguments accepted by a function.	342
`function-return-values`	Returns information about the values returned by a function.	343
`applicable-method?`	Tests if a function is applicable to sample arguments.	343
`apply`	Applies a function to arguments.	339
`do`	Iterates over one or more collections for side effect.	315
`map`	Iterates over one or more collections and collects the results in a freshly allocated collection.	316
`map-as`	Iterates over one or more collections and collects the results in a freshly allocated collection of a specified type.	316
`map-into`	Iterates over one or more collections and collects the results in an existing mutable collection.	317
`any?`	Returns the first true value obtained by iterating over one or more collections.	318
`every?`	Returns true if a predicate returns true when applied to all corresponding elements of a set of collections.	319
`reduce`	Combines the elements of a collection and a seed value into a single value by repeatedly applying a binary function.	320

Table 11-63 Functions on <function> (continued)

Function	Description	Page
`reduce1`	Combines the elements of a collection into a single value by repeatedly applying a binary function, using the first element of the collection as the seed value.	321
`find-key`	Returns the key in a collection such that the corresponding collection element satisfies a predicate.	323
`replace-elements!`	Replaces collection elements that satisfy a predicate.	324
`choose`	Returns those elements of a sequence that satisfy a predicate.	321
`choose-by`	Returns those elements of a sequence that correspond to those in another sequence that satisfy a predicate.	322
`do-handlers`	Applies a function to all dynamically active handlers.	351

Generic Functions

`<generic-function>` [Sealed Instantiable Class]

The class of functions that are made up of a number of individual methods.

Superclasses: `<function>`

Init-keywords: The class `<generic-function>` supports the following init-keywords:

`required:` An instance of `<number>` or `<sequence>`.

This argument represents the required arguments that the generic function accepts. If a sequence is supplied, the size of the sequence is the number of required arguments, and the elements of the sequence are the specializers. If a number is supplied, it is the number of required arguments, and the

	specializers default to `<object>`. If the argument is not supplied, or the supplied argument is neither a sequence nor a non-negative integer, an error is signaled.
`rest?:`	An instance of `<boolean>`. A true value indicates that the generic function accepts a variable number of arguments. The default value is `#f`.
`key:`	`#f` or an instance of `<collection>` whose elements are keywords. If the value is a collection, then the generic function accepts keyword arguments, and the collection specifies the set of mandatory keywords for the generic function. A value of `#f` indicates that the generic function does not accept keyword arguments. The default value is `#f`.
`all-keys?:`	An instance of `<boolean>`. A true value indicates that the generic function accepts all keyword arguments. The default value is `#f.`

Description: The class of generic functions. Generic functions are described in Chapter 6, “Functions.”

The arguments describe the shape of the generic function’s parameter list, and thereby control which methods can be added to the generic function. See the section “Kinds of Parameter Lists” on page 84 and the section “Parameter List Congruency” on page 91 for the implications of these choices.

An error is signaled if the value of `rest?:` is true and the value of `key:` is a collection. While a method parameter list may specify both `#rest` and `#key`, a generic function parameter list cannot.

An error is signaled if the value of `all-keys?:` is true and the value of `key:` is `#f`.

A new generic function initially has no methods. An error will be signaled if a generic function is called before methods are added to it. Once a generic function is created, you can give it behavior by adding methods to it with `add-method` or `define method`.

Generic functions are not usually created by calling `make` directly. Most often they are created by `define generic` or implicitly by `define method`.

Operations: The class `<generic-function>` provides the following operations:

Table 11-64 Functions on <generic-function>

Function	Description	Page
`generic-function-methods`	Returns the methods of a generic function.	340
`add-method`	Adds a method to a generic function.	340
`generic-function-mandatory-keywords`	Returns the mandatory keywords of a generic function, if any.	341
`sorted-applicable-methods`	Returns all the methods in a generic function that are applicable to sample arguments, sorted in order of specificity.	344
`find-method`	Returns the method in a generic function that has particular specializers.	345
`remove-method`	Removes a method from a generic function.	345

Methods

`<method>` [Sealed Class]

The class of functions that are applicable to arguments of a specified type.

Superclasses: `<function>`

Init-keywords: None.

Description: The class of methods. Methods are described in Chapter 6, “Functions.”

Operations: The class `<method>` provides the following operations:

Table 11-65 Functions on <method>

Function	Description	Page
`add-method`	Adds a method to a generic function.	340
`remove-method`	Removes a method from a generic function.	345

Conditions

Conditions

<condition> [Open Abstract Class]

The class of objects used by the condition system to connect a signaler with an appropriate handler.

Superclasses: `<object>`

Init-keywords: None.

Description: The class of condition objects. A complete description of conditions is given in Chapter 7, "Conditions."

Operations: The class `<condition>` provides the following operations::

Table 11-66 Functions on <condition>

Function	Description	Page
`signal`	Signals a condition.	346
`error`	Signals a non-recoverable error.	346
`cerror`	Signals a correctable error.	347
`break`	Invokes the debugger.	348

Table 11-67 Generic functions on <condition>

Function	Description	Page
`default-handler`	Called if no dynamic handler handles a condition.	349
`return-query`	Called to query the user and return.	350
`return-allowed?`	Returns true if a condition's recovery protocol allows returning values.	351
`return-description`	Returns a description of a condition's returned values.	352

Table 11-68 Methods on <condition>

Function	Description	Page
`default-handler`	Called if no dynamic handler handles a condition.	349

Serious Conditions

`<serious-condition>` [Open Abstract Class]

The class of conditions that cannot safely be ignored.

Superclasses: `<condition>`

Init-keywords: None.

Description: The class of conditions that cannot safely be ignored.

Operations: The following operations are defined on `<serious-condition>`.:

Table 11-69 Methods on <serious-condition>

Function	Description	Page
`default-handler`	Called if no dynamic handler handles a condition.	349

Errors

`<error>` [Open Abstract Class]

The class of conditions that represent something invalid about the program.

Superclasses: `<serious-condition>`

Init-keywords: None.

Description: The class of serious conditions that represent program errors.

`<error>` is distinct from `<serious-condition>` so one can establish a handler for errors that does not also trap unpredictable environmental exceptions such as network problems.

Operations: None.

`<simple-error>` **[Sealed Instantiable Class]**

The class of error conditions that consist of just an error message constructed from a format string and arguments.

Superclasses: `<error>`

Init-keywords: `format-string:`
An instance of `<string>`. A format string describing the error.

`format-arguments:`
An instance of `<sequence>`. Format arguments to splice into the format string to describe the error.

Description: The class of error conditions that consist of just an error message constructed from a format string and arguments.

The recovery protocol of `<simple-error>` is empty.

Operations: The class <simple-error> provides the following operations:

Table 11-70 Functions on <simple-error>

Function	Description	Page
`condition-format-string`	Returns the format string of a simple condition.	352
`condition-format-arguments`	Returns the format arguments of a simple condition.	353

`<type-error>` **[Sealed Instantiable Class]**

The class of error conditions generated by type checks.

Superclasses: `<error>`

Init-keywords: `value:` An instance of `<object>`. The object whose type was checked.

`type:` An instance of `<type>`. The type which was expected. The error was signaled because the object was not of this type.

Description: The class of errors indicating that an object was not of the expected type.

The recovery protocol is empty.

Operations: The class `<type-error>` provides the following operations::

Table 11-71 Functions on <type-error>

Function	Description	Page
`type-error-value`	Returns the value which was not of the expected type.	353
`type-error-expected-type`	Returns the expected type of the type check that led to the type error.	353

`<sealed-object-error>` [Sealed Class]

The class of errors that are generated by sealing violations.

Superclasses: `<error>`

Init-keywords: None.

Description: The class of errors that indicate the violation of a sealing restriction.

Operations: None.

Warnings

`<warning>` [Abstract Class]

The class of conditions that are interesting to users but can safely be ignored.

Superclasses: `<condition>`

Init-keywords: None.

Operations: The following operations are defined on `<warning>`:

Table 11-72 Methods on <warning>

Function	Description	Page
`default-handler`	Called if no dynamic handler handles a condition.	349

Description: The class of conditions that can be safely ignored.

There is a default handler for `<warning>` that displays the warning in a user-interface dependent way and then returns `#f`. The recovery protocol is that any value can be returned and will be ignored.

`<simple-warning>` **[Sealed Instantiable Class]**

A default class of warnings which are described by a warning string.

Superclasses: `<warning>`

IInit-keywords: `format-string:`
An instance of `<string>`. A format string describing the warning.

`format-arguments:`
An instance of `<sequence>`. Format arguments to splice into the format string to describe the warning.

Description: The class of warnings described by a format string and arguments.

The recovery protocol is that any value can be returned and will be ignored.

Operations: The class <simple-warning> provides the following operations:

Table 11-73 Functions on <simple-warning>

Function	Description	Page
`condition-format-string`	Returns the format string of a simple condition.	352
`condition-format-arguments`	Returns the format arguments of a simple condition.	353

Restarts

`<restart>` [Open Abstract Class]

The class of conditions used for restarting a computation.

Superclasses: `<condition>`

Init-keywords: `condition:` `#f` or an instance of `<condition>`. This argument is accepted and ignored by `<restart>`; some subclasses save the value of this initialization argument and use it to associate a restart with a particular condition from which the restart can recover. No such subclasses are defined as part of the language. Other restarts do not care; they can recover from any condition.

Description: The class of conditions used to correct an unusual situation.

There is a default handler for `<restart>` that signals an error reporting an attempt to use a restart for which no restart handler was established. The recovery protocol concept is not applicable to restarts.

Operations: The class `<restart>` provides the following operations:

Table 11-74 Generic functions on <restart>

Function	Description	Page
`restart-query`	Called to query the user and restart.	350

Table 11-75 Methods on <restart>

Function	Description	Page
`default-handler`	Called if no dynamic handler handles a condition.	349

`<simple-restart>` [Sealed Instantiable Class]

A default class of restarts.

Superclasses: `<restart>`

Init-keywords: `format-string:`

An instance of `<string>`. A format string describing the restart.

`format-arguments:`

An instance of `<sequence>`. Format arguments to splice into the format string to describe the restart.

Description: A default class of restarts.

Typical implementations will use the format string and format arguments to produce a description of the restart.

Operations: The class <simple-restart> provides the following operations:

Table 11-76 Functions on <simple-warning>

Function	Description	Page
`condition-format-string`	Returns the format string of a simple condition.	352
`condition-format-arguments`	Returns the format arguments of a simple condition.	353

Aborts

`<abort>` **[Sealed Instantiable Class]**

The class of conditions used to terminate a computation.

Superclasses: `<restart>`

Init-keywords: None.

Description: The class of conditions used to terminate a computation.

Handlers are expected to terminate execution of the current application command, or similar unit of execution, and return control to something like an application command loop. This is comparable to command-period on the Macintosh. The exact details of this feature depend on the particular environment, of course, but signaling an instance of `<abort>` is a uniform way to "get out."

Operations: None.

C H A P T E R 1 2

The Built-In Functions

Contents

The Built-In Functions

Overview

This chapter contains an entry for each function defined by Dylan.

The functions described below are annotated either as an **open generic function** or as a **function**.

A function specified as an open generic function can be extended through the addition of programmer defined methods. The signature of the generic function constrains which methods can be added through the congruency rules described on page 91. The signature does not imply a set of predefined methods. For example, the signature of `+` is `(<object>, <object>)`, but the predefined methods on `+` only cover subtypes of `<number>`. Particular behavior of the function is given in its description and in the description of its methods.

A function specified as a function cannot portably be extended through the addition of methods. Implementations are free to implement these functions as open generic functions, but programs that take advantage of such liberality will not be portable. The signature of such a function specifies the type domain of the function, but does not necessarily imply that the function is applicable to all instances of the types. The exact behavior of the function is given in its description.

Implementations are allowed to define these generic functions and functions with signatures that are less restrictive than those given below. However, programs that take advantage of this liberality will not be portable.

Where a sealed domain is specified, implementations are free to seal the domain or leave the domain unsealed. Portable programs should not rely on the domain being unsealed.

When a method is specified, it describes the behavior of a generic function when applied to arguments of particular types. It does not imply that this behavior is implemented by a single method.

Constructing and Initializing Instances

General Constructor

`make` **[Open Generic Function]**

Returns a general instance of its first argument.

Signature: `make` *type* `#rest` *supplied-init-args* `#key #all-keys` ⇒ *instance*

Arguments:

type	An instance of `<type>`.
supplied-init-args	Keyword/argument pairs.

Values:

instance	An `<object>`, which must be a general instance of *type*.

Description: Returns an instance of *type*, with characteristics specified by keyword arguments.

The *instance* returned is guaranteed to be a general instance of *type* but not necessarily a direct instance of *type*. This liberality allows `make` to be called on an abstract class or other type; it can instantiate and return a direct instance of one of the concrete subtypes of the abstract class or type.

The *instance* returned may or may not be newly allocated. If a new instance is allocated, `make` will call `initialize` on the instance before returning it.

Programmers may customize `make` for particular classes by defining methods specialized by singleton specializers. These methods may obtain the default `make` behavior, if desired, by calling next-method.

Note that the `<class>` method on `make` returns a newly allocated direct instance of its first argument.

make ***class*** **#rest** ***supplied-init-args*** **#key** ⇒ ***object*** **[G.F. Method]**

The method on `<class>` creates an instance of *class*, calls `initialize` on the instance, and then returns the instance. An error is signaled if *class* is abstract.

A complete description of this method and its role in the initialization protocol is given in "Instance Creation and Initialization" on page 63.

make `(singleton <array>)`
#key ***dimensions fill*** ⇒ ***array*** **[G.F. Method]**

A method on `singleton(<array>)` accepts *dimensions* and *fill* keyword arguments, and instantiates a concrete subclass of `<array>`. These arguments are described with the <array> class on page 210.

make `(singleton <vector>)`
#key ***size fill*** ⇒ ***simple-object-vector*** **[G.F. Method]**
make `(singleton <simple-vector>)`
#key ***size fill*** ⇒ ***simple-object-vector*** **[G.F. Method]**

Methods on `singleton(<vector>)` and `singleton(<simple-vector>)` accept *size* and *fill* keyword arguments, and return an instance of `<simple-object-vector>`. These arguments are described with the `<vector>` class on page 212 and with the `<simple-vector>` class on page 213.

make `(singleton <list>)`
#key ***size fill*** ⇒ ***list*** **[G.F. Method]**

A method on `singleton(<list>)` accepts *size* and *fill* keyword arguments. These arguments are described with the `<list>` class on page 218.

Initialization

`initialize` **[Open Generic Function]**

Performs instance initialization that cannot be specified declaratively by a class definition.

Signature: `initialize` *instance* `#key #all-keys` ⇒ `#rest` *objects*

Arguments: *instance* An instance of `<object>`.

Values: *objects* Instances of `<object>`. The return values are ignored by `make`.

Description: Provides a way for users to handle initialization of instances which cannot be expressed simply by init specifications. This is typically needed when a computation requires inputs from multiple initialization arguments or slot values, or a single computation needs to be used to initialize multiple slots.

By convention, all `initialize` methods should call next-method very early, to make sure that any initializations from less specific classes are performed first.

The `initialize` generic function permits all keywords and requires none. It does this because the keyword argument checking is performed by the default method on `make`.

`initialize` *object* #key ⇒ *object* **[G.F. Method]**

This method does nothing. It is present so that it is always safe for `initialize` methods to call next method, and so that it is safe for the default `make` method to call `initialize`.

`slot-initialized?` **[Open Generic Function]**

Tests whether a slot has been initialized

Signature: `slot-initialized?` *instance getter* ⇒ *boolean*

Arguments: *instance* An instance of of `<object>`.

getter An instance of `<generic-function>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if the slot in *instance* that would be accessed by the *getter* generic function is initialized. If the slot is not initialized, then false is returned.

`slot-initialized?` will signal an error if the *getter* does not access a slot in the *instance*.

To support `slot-initialized?` for a virtual slot, programmers must define a method for `slot-initialized?` which shares a protocol with the getter of the slot.

Specific Constructors

`list` **[Function]**

Creates and returns a freshly allocated list.

Signature: `list #rest` *arguments* ⇒ *list*

Arguments: *arguments* The elements of the *list*. Instances of `<object>`.

Values: *list* A freshly allocated instance of `<list>`.

Description: Returns a freshly allocated list containing the *arguments,* in order.

`pair` **[Function]**

Creates and returns a freshly allocated pair.

Signature: `pair` *object1*`,`*object2* ⇒ *pair*

Arguments: *object1* An instance of `<object>`.

object2 An instance of `<object>`.

Values: *pair* A freshly allocated instance of `<pair>`.

Description: Creates a freshly allocated pair whose head value is *object1* and tail value is *object2*.

```
pair (1, 2)
  ⇒ #(1 . 2)
pair (1, #(2, 3, 4, 5))
  ⇒ #(1, 2, 3, 4, 5)
```

Note that while the pair returned by `pair` is freshly allocated, it may be the beginning of a list, portions of which are not freshly allocated.

```
define variable *preexisting-list* = list(2, 3, 4)
define variable *new-list* = pair(1, *preexisting-list*)
*new-list*
  ⇒ #(1, 2, 3, 4)
tail(*new-list*) == *preexisting-list*
  ⇒ #t
third(*new-list*) := 'x'
*new-list*
  ⇒  #(1, 2, x, 4)
*preexisting-list*
  ⇒  #(2, x, 4)
```

`range` **[Function]**

Creates and returns a range.

Signature: `range #key` *from to above below by size* ⇒ *range*

Arguments:

from	An instance of `<real>`. The default value is `0`.
to	An instance of `<real>`.
above	An instance of `<real>`.
below	An instance of `<real>`.
by	An instance of `<real>`. The default value is `0`.
size	An instance of `<real>`.

Values:

range	An instance of `<range>`.

Description: Creates an instance of `<range>`. The arguments correspond to the initialization arguments of `<range>`, described on page 221.

`singleton` **[Function]**

Creates and returns a singleton.

Signature: `singleton` *object* ⇒ *singleton*

Arguments: *object* An instance of `<object>`.

Values: *singleton* An instance of `<singleton>`. The singleton for *object*.

Description: Returns a singleton for *object*. `singleton(`*object*`)` is equivalent to `make(<singleton>, object:` *object*`)`. If a singleton for the specified object already exists, implementations are free to return it rather than allocate a new singleton.

`limited` **[Function]**

Returns a limited subtype of a class.

Signature: `limited` *class* `#key` ⇒ *type*

Arguments: *class* An instance of `<class>`.

Values: *type* An instance of `<type>`.

Description: Returns a limited subtype of *class*. The available keyword arguments depend on the class. Not all classes support `limited`; the methods for `limited` are documented individually.

`limited` `(singleton <integer>)` **#key** ***min max*** ⇒ ***type*** **[G.F. Method]**

Returns a limited integer type, which is a subtype of `<integer>` whose instances are integers greater than or equal to *min* (if `min:` is specified) and less than or equal to *max* (if `max:` is specified). If no keyword arguments are specified, the result type is equivalent to `<integer>`. Limited integer types are not instantiable.

`limited` `(singleton <collection>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**
`limited` `(singleton <explicit-key-collection>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**
`limited` `(singleton <mutable-collection>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**
`limited` `(singleton <stretchy-collection>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**

limited `(singleton <mutable-explicit-key-collection>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**
limited `(singleton <sequence>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**
limited `(singleton <mutable-sequence>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**

These methods return uninstantiable limited collection types.

limited `(singleton <table>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**
limited `(singleton <object-table>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**

These two methods return types that support a `size:` initialization keyword with the same behavior as `<table>`.

limited `(singleton <array>)`
#key ***of size dimensions*** ⇒ ***type*** **[G.F. Method]**

This method returns a type that supports `dimensions:` and `fill:` initialization keywords with the same behavior as `<array>`. The default for fill is `#f` so if `instance?(#f,` *of*`)` is not true and the product of the *dimensions* is nonzero, the `fill:` initialization keyword is required because the default would cause a type error.

Instantiating *type* with a value of *dimensions* that has one element will return an instance of `limited(<simple-vector>, of:` *of*`)`.

limited `(singleton <vector>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**

This method returns the same types as the method on `singleton(<simple-vector>)`.

limited `(singleton <simple-vector>)`
#key ***of size*** ⇒ ***type*** **[G.F. Method]**
limited `(singleton <stretchy-vector>)`
#key ***of*** ⇒ ***type*** **[G.F. Method]**
limited `(singleton <deque>)`
#key ***of*** ⇒ ***type*** **[G.F. Method]**

These three methods return types that support `size:` and `fill:` initialization keywords with the same behavior as the collection-class argument. The default for fill is `#f` so if `instance?(#f,` *of*`)` is not true and *size* is nonzero, the `fill:` initialization keyword is required because the default would cause a type error.

All general instances of `<simple-vector>` provide a constant time implementation of `element` and `element-setter`.

`limited` `(singleton <string>)`
    #key ***of size*** ⇒ ***type*** **[G.F. Method]**

The *of* argument must be a subtype of `<character>`. This method returns a type that supports `size:` and `fill:` initialization keywords with the same behavior as `<string>`. The default for `fill`: is `' '` so if `instance?(' ',` *of*`)` is not true and *size* is nonzero, the `fill:` initialization keyword is required because the default would cause a type error.

There are no specified subtypes of `<character>`, except for unions of singletons, which makes this method rather useless for portable programs. However the method is provided because there might be useful subtypes of `<character>` in a particular implementation or in future versions of Dylan.

`limited` `(singleton <range>)`
    #key ***of*** ⇒ ***type*** **[G.F. Method]**

The *of* argument must be a subtype of `<real>`. This method returns a type that supports `from:`, `to:`, `below:`, `above:`, `by:`, and `size:` initialization keywords with the same behavior as `<range>`. Make of this type signals a `<type-error>` if any element of the range is not an instance of *of*.

`type-union` **[Function]**

Returns the union of two types.

Signature: `type-union` *type1* `#rest` *more-types* ⇒ *type*

Arguments:

type1	An instance of `<type>`.
more-types	Instances of `<type>`.

Values:

type	An instance of `<type>`.

Description: Returns a type whose instances are the instances of *type1* and all the *more-types*. The type returned is not instantiable. A complete description of union types is given in “Union Types” on page 71.

```
define constant $my-enumerated-type =
                    type-union(singleton(#"one"),
                               singleton(#"two"),
                               singleton(#"three"),
                               singleton(#"four"),
                               singleton(#"five"))
```

`vector` [Function]

Creates and returns a freshly allocated vector.

Signature: `vector #rest` *arguments* ⇒ *vector*

Arguments:

arguments	Instances of `<object>`.

Values:

vector	A freshly allocated instance of `<simple-object-vector>`. Its elements are the *arguments*, in order.

Description: Returns a vector whose elements are the *arguments*, in order.

Equality and Comparison

Dylan provides an identity function, as well as a group of equality and magnitude comparison functions that can be extended for user classes. The functions ~=, ~==, >, <=, >=, `min` and `max` are defined in terms of == or = and <. By extending the behavior of = and <, programs can extend the behavior of the other functions.

For the protocol to work, user-defined methods on = and < must preserve the following properties:

Identity:	If (a = b), then (a = b).
Transitivity:	If (a < b) and (b < c), then (a < c).

	If (a = b) and (b = c), then (a = c).
Trichotomy:	Exactly one of: (a < b), (a = b), (b < a) always holds (on the assumption that these two operations are defined for the objects in question).

In the general case, the behavior of comparison operators when applied to instances of `<complex>` is implementation defined. This is to allow implementations to support IEEE floating point when comparing NaNs. However, when instances of `<rational>` and instances of `<float>` are compared, it is defined that the instance of `<float>` is first converted to a rational and then an exact comparison is performed.

Not and Identity

~ [Function]

Returns true if its argument is false; otherwise returns false.

Signature: ~ *thing* ⇒ *boolean*

Arguments:

thing	An instance of `<object>`.

Values:

boolean	An instance of `<boolean>`.

Description: Returns true if *thing* is false. Returns false if *thing* is true.

Equality Comparisons

== [Function]

Compares two objects for identity.

Signature: *object1* == *object2* ⇒ *boolean*

Arguments:

object1	An instance of `<object>`.
object2	An instance of `<object>`.

Values:	*boolean*	An instance of `<boolean>`.

Description: Returns true if *object1* and *object2* are identical. Otherwise, it returns false.

Objects are considered identical if they are computationally equivalent. That is, there is no way for any possible Dylan program to distinguish them.

At an implementation level, this will usually mean that the objects are pointers to the same storage or are the same immediate value. An extension is made for built-in number classes and characters. Because these objects are not mutable (i.e. cannot be changed), two with the same value will always be the same (and will thus be indistinguishable to programs).

`~==` **[Function]**

Compares two objects for nonidentity.

Signature: *object1* `~==` *object2* ⇒ *boolean*

Arguments:	*object1*	An instance of `<object>`.
	object2	An instance of `<object>`.
Values:	*boolean*	An instance of `<boolean>`.

Description: Returns true if *object1* and *object2* are not identical. It returns false if they are identical.

If both arguments are instances of `<complex>` then the result is computed in an implementation-defined way. Otherwise, the result is computed by `~(object1 == object2)`.

`=` **[Open Generic Function]**

Compares two objects for equality.

Signature: *object1* `=` *object2* ⇒ *boolean*

Arguments:	*object1*	An instance of `<object>`.
	object2	An instance of `<object>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if *object1* and *object2* are equal. Otherwise, it returns false.

Programmers may define methods for = specialized on classes they define. A programmer may be required to provide an = method when defining subclasses of some predefined classes in order to fullfill the protocol of the class, as described below. For objects which do not have a more specific = method, = returns the same as ==.

= is not guaranteed to return. For example, it may not return when called on circular structures or otherwise unbounded structures.

The generic function = is inert over the domain `(<complex>, <complex>)`.

object1* = *object2* ⇒ *boolean **[G.F. Method]**

The default method on = calls == and returns the result returned by ==.

complex1* = *complex2* ⇒ *boolean **[G.F. Method]**

Complex numbers are equal if they have the same mathematical value.

collection1* = *collection2* ⇒ *boolean **[G.F. Method]**

Two collections are equal if they have identical `key-test` functions, they have the same keys (as determined by their `key-test` functions), the elements at corresponding keys are =, and neither collection is a dotted list.

$sequence_1$* = *$sequence_2$* ⇒ *boolean **[G.F. Method]**

For sequences, = returns true if *$sequence_1$* and *$sequence_2$* have the same size and elements with = keys are =, and returns false otherwise.

$list_1$* = *$list_2$* ⇒ *boolean **[G.F. Method]**

For lists, = returns true if the two lists are the same size, corresponding elements of *$list_1$* and *$list_2$* are = and the final tails are =. It returns false otherwise.

list = sequence ⇒ boolean **[G.F. Method]**
sequence = list ⇒ boolean **[G.F. Method]**

For mixed lists and sequences, = returns true if the *list* is not a dotted list, both have the same size, and elements with = keys are =. It returns false otherwise.

range1 =range2 ⇒ boolean **[G.F. Method]**

When called with two ranges, = always terminates, even if one or both ranges are unbounded in size.

`~=` **[Function]**

Compares two objects for inequality.

Signature: *object1* `~=` *object2* ⇒ *boolean*

Arguments:	*object1*	An instance of `<object>`.
	object2	An instance of `<object>`.
Values:	*boolean*	An instance of `<boolean>`.

Description: Returns true if *object1* and *object2* are not equal. It returns false if they are equal.

If both arguments are instances of `<complex>` then the result is computed in an implementation-defined way. Otherwise, the result is computed by the expression `~(`*object1* `=` *object2*`)`.

Magnitude Comparisons

`<` **[Open Generic Function]**

Returns true if its first operand is less than its second operand.

Signature: *object1* `<` *object2* ⇒ *boolean*

Arguments:	*object1*	An instance of `<object>`.
	object2	An instance of `<object>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if *object1* is less than *object2*.

The generic function < is inert over the domain `(<complex>, <complex>)`.

real1* < *real2* ⇒ *boolean **[G.F. Method]**

Built-in real numbers are compared by mathematical value.

character1* < *character2* ⇒ *boolean **[G.F. Method]**

Characters are compared by the ordinal value of the underlying character set. Character case is significant.

***string1* < *string2* ⇒** *boolean* **[G.F. Method]**

When both arguments are strings, < compares strings by comparing elements from left to right, using < and = on corresponding elements, and stopping when the elements are not =. If one string is a strict prefix of the other, the shorter string is considered the "smaller" one.

For variations on string comparison (such as comparisons that ignore case), different comparison operators must be used.

> [Function]

Returns true if its first operand is greater than its second operand.

Signature: *object1* > *object2* ⇒ *boolean*

Arguments:

object1	An instance of `<object>`.
object2	An instance of `<object>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if *object1* is greater than *object2*.

If both arguments are instances of `<complex>` then the result is computed in an implementation-defined way. Otherwise, the result is computed by the expression `(`*object2* `<` *object1*`)`.

`<=` **[Function]**

Returns true if its first operand is less than or equal to its second operand.

Signature: *object1* `<=` *object2* ⇒ *boolean*

Arguments:

object1	An instance of `<object>`.
object2	An instance of `<object>`.

Values:

boolean	An instance of `<boolean>`.

Description: Returns true if *object1* is less than or equal to *object2*.

If both arguments are instances of `<complex>` then the result is computed in an implementation-defined way. Otherwise, the result is computed by the expression `~(`*object2* `<` *object1*`)`.

`>=` **[Function]**

Returns true if its first operand is greater than or equal to its second operand.

Signature: *object1* `>=` *object2* ⇒ *boolean*

Arguments:

object1	An instance of `<object>`.
object2	An instance of `<object>`.

Values:

boolean	An instance of `<boolean>`.

Description: Returns true if *object1* is greater than or equal to *object2*.

If both arguments are instances of `<complex>` then the result is computed in an implementation-defined way. Otherwise, the result is computed by the expression `~(`*object1* `<` *object2*`)`.

`min` **[Function]**

Returns the least of its arguments.

Signature: `min` *object1* `#rest` *objects* ⇒ *object2*

Arguments:	*object1*	An instance of `<object>`.
	objects	Zero or more instances of `<object>`.
Values:	*object2*	An instance of `<object>`.

Description: Returns the least of its arguments.

`min` operates by calling `<`, and therefore is applicable to any objects for which `<` is defined.

`max` **[Function]**

Returns the greatest of its arguments.

Signature: `max` *object1* `#rest` *objects* $\Rightarrow$ *object2*

Arguments:	*object1*	An instance of `<object>`.
	objects	Zero or more instances of `<object>`.
Values:	*object2*	An instance of `<object>`.

Description: Returns the greatest of its arguments.

`max` operates by calling `<`, and therefore is applicable to any objects for which `<` is defined.

Arithmetic Operations

When instances of `<rational>` and instances of `<float>` are combined by a numerical function, the instance of `<rational>` is first converted to an instance of `<float>` of the same format as the original instance of `<float>`.

Properties

`odd?` **[Function]**

Tests for the property of being an odd number.

Signature: `odd?` *integer* ⇒ *boolean*

Arguments: *integer* An instance of `<integer>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if its argument is an odd number.

`even?` **[Function]**

Tests for the property of being an even number.

Signature: `even?` *integer* ⇒ *boolean*

Arguments: *integer* An instance of `<integer>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if its argument is an even number.

`zero?` **[Open Generic Function]**

Tests for the property of being equal to zero.

Signature: `zero?` *object* ⇒ *boolean*

Arguments: *object* An instance of `<object>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if its argument is equal to zero.

zero? ***complex*** ⇒ ***boolean*** **[G.F. Method]**

A method is defined for the class `<complex>`.

`positive?` **[Open Generic Function]**

Tests for the property of being positive.

Signature: `positive?` *object* ⇒ *boolean*

Arguments:	*object*	An instance of `<object>`.
Values:	*boolean*	An instance of `<boolean>`.

Description: Returns true if its argument is positive.

positive? ***real*** ⇒ ***boolean*** **[G.F. Method]**

A method is defined for the class `<real>`.

`negative?` **[Open Generic Function]**

Tests for the property of being negative.

Signature: `negative?` *object* ⇒ *boolean*

Arguments:	*object*	An instance of `<object>`.
Values:	*boolean*	An instance of `<boolean>`.

Description: Returns true if its argument is negative.

negative? ***real*** ⇒ ***boolean*** **[G.F. Method]**

A method is defined for the class `<real>`.

`integral?` **[Open Generic Function]**

Tests for the property of being integral.

Signature: `integral?` *object* ⇒ *boolean*

Arguments:	*object*	An instance of `<object>`.
Values:	*boolean*	An instance of `<boolean>`.

Description: Returns true if its argument is an integer.

`integral?` ***object*** **⇒** ***false*** **[G.F. Method]**

A method is defined for the class `<object>` which returns `#f`.

`integral?` ***real*** **⇒** ***boolean*** **[G.F. Method]**

A method is defined for real numbers which is equivalent to *real* `=` `round(`*real*`)`.

Arithmetic Operations

`+` **[Open Generic Function]**

Returns the sum of its arguments.

Signature: *object1* `+` *object2* ⇒ `#rest` *objects*

Arguments:	*object1*	An instance of `<object>`.
	object2	An instance of `<object>`.
Values:	*objects*	Instances of `<object>`.

Description: Adds two objects and returns the sum.

complex1 **+** ***complex2*** **⇒** ***complex*** **[G.F. Method]**

A predefined method returns the sum of two complex numbers.

`*` **[Open Generic Function]**

Returns the product of its arguments.

Signature: *object1* `*` *object2* ⇒ `#rest` *objects*

Arguments:

object1	An instance of `<object>`.
object2	An instance of `<object>`.

Values:

objects	Instances of `<object>`.

Description: Multiplies two objects and returns the product.

complex1* * *complex2* ⇒ *complex **[G.F. Method]**

A predefined method returns the product of two complex numbers.

`-` **[Open Generic Function]**

Returns the difference of its arguments.

Signature: *object1* `–` *object2* ⇒ `#rest` *objects*

Arguments:

object1	An instance of `<object>`.
object2	An instance of `<object>`.

Values:

objects	Instances of `<object>`.

Description: Subtracts *object2* from *object1* and returns the difference.

complex1* - *complex2* ⇒ *complex **[G.F. Method]**

A predefined method returns the difference of two complex numbers.

`/` **[Open Generic Function]**

Returns the quotient of its arguments.

Signature: *object1* `/` *object2* ⇒ `#rest` *objects*

Arguments: *object1* An instance of `<object>`.

object2 An instance of `<object>`.

Values: *objects* Instances of `<object>`.

Description: Divides *object2* into *object1* and returns the quotient.

complex1* / *complex2* ⇒ *complex **[G.F. Method]**

A predefined method returns the quotient of two complex numbers.

Division by zero signals an error.

The result of dividing two integers with / is implementation defined. Portable programs should use `floor/`, `ceiling/`, `round/`, or `truncate/` to divide two integers.

`negative` [Open Generic Function]

Returns the negation of an object.

Signature: `negative` *object1* ⇒ `#rest` *objects*

Arguments: *object1* An instance of `<object>`.

Values: *objects* Instances of `<object>`.

Description: Returns the negation of its argument. The unary minus operator is equivalent to a call to the `negative` in the current binding environment.

`negative` *real1* ⇒ *real2* **[G.F. Method]**

A predefined method returns the additive inverse of a real number.

`floor` [Function]

Truncates a real number towards negative infinity.

Signature:	`floor` *real1* ⇒ *integer real2*	
Arguments:	*real1*	An instance of `<real>`.
Values:	*integer*	An instance of `<integer>`.
	real2	An instance of `<real>`.

Description: Truncates *real1* towards negative infinity. The integer part is returned as *integer*, the remainder is returned as *real2*.

`ceiling` **[Function]**

Truncates a real number towards positive infinity.

Signature:	`ceiling` *real1* ⇒ *integer real2*	
Arguments:	*real1*	An instance of `<real>`.
Values:	*integer*	An instance of `<integer>`.
	real2	An instance of `<real>`.

Description: Truncates *real1* towards positive infinity. The integer part is returned as *integer*, the remainder is returned as *real2*.

`round` **[Function]**

Rounds a real number towards the nearest mathematical integer.

Signature:	`round` *real1* ⇒ *integer real2*	
Arguments:	*real1*	An instance of `<real>`.
Values:	*integer*	An instance of `<integer>`.
	real2	An instance of `<real>`.

Description: Rounds *real1* towards towards the nearest mathematical integer. The integer part is returned as *integer*, the remainder is returned as *real2*.

`truncate` **[Function]**

Truncates a real number towards zero.

Signature: `truncate` *real1* ⇒ *integer real2*

Arguments:

real1	An instance of `<real>`.

Values:

integer	An instance of `<integer>`.
real2	An instance of `<real>`.

Description: Truncates *real1* towards zero. The integer part is returned as *integer,* the remainder is returned as *real2*.

`floor/` **[Function]**

Returns the floor of the quotient of two numbers.

Signature: `floor/` *real1 real2* ⇒ *integer real3*

Arguments:

real1	An instance of `<real>`.
real2	An instance of `<real>`.

Values:

integer	An instance of `<integer>`.
real3	An instance of `<real>`.

Description: Divides *real2* into *real1* and truncates the result towards negative infinity. The integer part of the result is returned as *integer,* the remainder is returned as *real3*.

`ceiling/` **[Function]**

Returns the ceiling of the quotient of two numbers.

Signature: `ceiling/` *real1 real2* ⇒ *integer real3*

Arguments:

real1	An instance of `<real>`.
real2	An instance of `<real>`.

Values:	*integer*	An instance of `<integer>`.
	real3	An instance of `<real>`.

Description: Divides *real2* into *real1* and truncates the result towards positive infinity. The integer part of the result is returned as *integer*, the remainder is returned as *real3*.

`round/` [Function]

Rounds off the quotient of two numbers.

Signature: `round/` *real1 real2* ⇒ *integer real3*

Arguments:	*real1*	An instance of `<real>`.
	real2	An instance of `<real>`.
Values:	*integer*	An instance of `<integer>`.
	real3	An instance of `<real>`.

Description: Divides *real2* into *real1* and rounds the result towards the nearest mathematical integer. The integer part of the result is returned as *integer*, the remainder is returned as *real3*.

`truncate/` [Function]

Returns the truncated quotient of two numbers.

Signature: `truncate/` *real1 real2* ⇒ *integer real3*

Arguments:	*real1*	An instance of `<real>`.
	real2	An instance of `<real>`.
Values:	*integer*	An instance of `<integer>`.
	real3	An instance of `<real>`.

Description: Divides *real2* into *real1* and truncates the result towards zero. The integer part of the result is returned as *integer*, the remainder is returned as *real3*.

`modulo` [Function]

Returns the second value of `floor/`.

Signature: `modulo` *real1 real2* ⇒ *real3*

Arguments:	*real1*	An instance of `<real>`.
	real2	An instance of `<real>`.
Values:	*real3*	An instance of `<real>`.

Description: Returns the second value of `floor/(`*real1* `,` *real2*`)`.

`remainder` [Function]

Returns the second value of `truncate/`.

Signature: `remainder` *real1 real2* ⇒ *real3*

Arguments:	*real1*	An instance of `<real>`.
	real2	An instance of `<real>`.
Values:	*real3*	An instance of `<real>`.

Description: Returns the second value of `truncate/(`*real1* `,` *real2*`)`.

`^` [Open Generic Function]

Raises an object to a specified power.

Signature: *object1* `^` *object2* ⇒ `#rest` *objects*

Arguments:	*object1*	An instance of `<object>`.
	object2	An instance of `<object>`.
Values:	*objects*	Instances of `<object>`.

Description: Returns *object1* raised to the power *object2*.

complex1* ^ *complex2* ⇒ *number **[G.F. Method]**

A predefined method raises a complex number to the power of another complex number and returns the result.

`abs` [Open Generic Function]

Returns the absolute value of its argument.

Signature: `abs` *object1* ⇒ `#rest` *objects*

Arguments: *object1* An instance of `<object>`.

Values: *objects* Instances of `<object>`.

Description: Returns the absolute value of *object1*.

abs *complex1* ⇒ *complex* **[G.F. Method]**

A predefined method returns the absolute value of a complex number.

`logior` [Function]

Returns the bitwise inclusive or of its integer arguments.

Signature: `logior #rest` *integers* ⇒ *integer*

Arguments: *integers* Zero or more instances of `<integer>`.

Values: *integer* An instance of `<integer>`..

Description: Returns the bitwise inclusive or of the *integers*.

`logxor` [Function]

Returns the bitwise exclusive or of its integer arguments.

Signature: `logxor #rest` *integers* ⇒ *integer*

Arguments:	*integers*	Zero or more instances of `<integer>`.
Values:	*integer*	An instance of `<integer>`.

Description: Returns the bitwise exclusive or of the *integers*.

`logand` **[Function]**

Returns the bitwise and of its integer arguments.

Signature: `logand #rest` *integers* ⇒ *integer*

Arguments:	*integers*	Zero or more instances of `<integer>`.
Values:	*integer*	An instance of `<integer>`.

Description: Returns the bitwise and of the *integers*.

`lognot` **[Function]**

Returns the bitwise not of its integer argument.

Signature: `lognot` *integer1* ⇒ *integer2*

Arguments:	*integer1*	An instance of `<integer>`.
Values:	*integer2*	An instance of `<integer>`.

Description: Returns the bitwise not of the *integer1*.

`logbit?` **[Function]**

Tests the value of a particular bit in its integer argument.

Signature: `logbit?` *index integer* ⇒ *boolean*

Arguments:	*index*	An instance of `<integer>`.
	integer	An instance of `<integer>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if the *index*th bit in *integer* is a one-bit; otherwise it returns false.

Negative *integers* are treated as if they were in two's-complement notation.

`ash` **[Function]**

Performs an arithmetic shift on its first argument.

Signature: `ash` *integer1 count* ⇒ *integer2*

Arguments:

integer1	An instance of `<integer>.`
count	An instance of `<integer>.`

Values: *integer2* An instance of `<integer>`.

Description: Performs an arithmetic shift on the binary representation of *integer1*.

`ash` shifts *integer1* arithmetically left by *count* bit positions if *count* is positive, or right *count* bit positions if *count* is negative. The shifted value of the same sign as *integer1* is returned.

When `ash` moves bits to the left, it adds zero-bits at the right. When it moves them to the right, it discards bits.

`ash` is defined to behave as if *integer1* were represented in two's complement form, regardless of how integers are represented by the implementation.

```
ash(8, 1)
  ⇒  16
ash(32, -1)
  ⇒  16
```

`lcm` **[Function]**

Returns the least common multiple of two integers.

Signature: `lcm` *integer1 integer2* ⇒ *integer*

Arguments: *integer1* An instance of `<integer>`.

	integer2	An instance of `<integer>`.
Values:	*integer*	An instance of `<integer>`.

Description: Returns the least common multiple of *integer1* and *integer2.*

`gcd` [Function]

Returns the greatest common divisor of two integers.

Signature: `gcd` *integer1 integer2* ⇒ *integer*

Arguments:	*integer1*	An instance of `<integer>`.
	integer2	An instance of `<integer>`.
Values:	*integer*	An instance of `<integer>`.

Description: Returns the greatest common divisor of *integer1* and *integer2.*

Coercing and Copying Objects

`identity` [Function]

Returns its argument.

Signature: `identity` *object* ⇒ *object*

Arguments:	*object*	An instance of `<object>`.
Values:	*object*	An instance of `<object>`; the same object that was passed in as an argument.

Description: Returns *object* unaltered.

`values` **[Function]**

Returns its arguments as multiple values.

Signature: `values #rest` *the-values* ⇒ `#rest` *the-values*

Arguments:	*the-values*	Zero or more instances of `<object>`.
Values:	*the-values*	Zero or more instances of `<object>`; the objects that were passed as arguments.

Description: Returns *the-values* as multiple values.

```
values(1, 2, 3);
 ⇒ 1   // first value returned
   2   // second value returned
   3   // third value returned
```

General Coercion Function

`as` **[Open Generic Function]**

Coerces an object to a type.

Signature: `as` *type object* ⇒ *instance*

Arguments:	*type*	An instance of `<type>`.
	object	An instance of `<object>`.
Values:	*instance*	An instance of `<object>`. It must be an instance of *type*.

Description: Coerces *object* to *type*. That is, it returns an instance of *type* that has the same contents as *object*. If *object* is already an instance of *type*, it is returned unchanged. In general, the value returned may or may not be freshly allocated.

Predefined methods allow coercion between integers and characters, between strings and symbols, and between collection types. No methods are predefined for other classes. Programs may define additional methods.

as ***collection-type collection*** ⇒ ***instance-of-collection-type*** **[G.F. Method]**

When converting between collection types, the return value will have the same number of elements as *collection*. If the *collection* is an instance of `<sequence>` and the *collection-type* is a subtype of `<sequence>`, the elements will be in the same order. The individual elements may also undergo some conversion. The specific collection types for which `as` is defined is implementation defined.

as `(singleton <integer>)` ***character*** ⇒ ***integer*** **[G.F. Method]**

This method on `as` returns a numeric equivalent for *character*. The integer returned is implementation dependent.

as `(singleton <character>)` ***integer*** ⇒ ***character*** **[G.F. Method]**

This method on `as` returns the character equivalent to *integer*. The meaning of *integer* is implementation dependent.

as `(singleton <symbol>)` ***string*** ⇒ ***symbol*** **[G.F. Method]**

This method on `as` returns the symbol that has the name *string*. If the symbol does not yet exist, it is created. This method on `as` will always return the same symbol for strings of the same characters, without regard to alphabetic case.

```
as (<symbol>, "foo")
 ⇒  #"foo"
#"FOO" == as (<symbol>, "foo")
 ⇒  #t
#"Foo"
 ⇒  #"foo"
```

as `(singleton <string>)` ***symbol*** ⇒ ***string*** **[G.F. Method]**

This method on `as` returns the name of the symbol, which will be a string.

```
as (<string>, #"Foo")
 ⇒  "Foo"
```

Coercing Case

`as-uppercase` **[Open Generic Function]**

Coerces an object to uppercase.

Signature: `as-uppercase` *object1* ⇒ *object2*

Arguments: *object1* An instance of `<object>`.

Values: *object2* An instance of `<object>`.

Description: Coerces an object to uppercase and returns the resulting new object.

object1 is not modified by this operation.

as-uppercase ***character*** ⇒ ***uppercase-character*** **[G.F. Method]**

This method returns the upper-case equivalent for *character*. If *character* already is uppercase or does not exist in two cases, it is returned unchanged.

as-uppercase ***string*** ⇒ ***new-string*** **[G.F. Method]**

This method is equivalent to `map(as-uppercase,` *string*`)`.

`as-uppercase!` **[Open Generic Function]**

Coerces an object to uppercase in place.

Signature: `as-uppercase!` *object* ⇒ *object*

Arguments: *object* An instance of `<object>`.

Values: *object* An instance of `<object>`; the same object that was passed in as an argument.

Description: Coerces an object to uppercase in place and returns the modified object.

object may be modified by this operation, and the result will be `==` to the *object*.

`as-uppercase!` ***string* ⇒ *string*** **[G.F. Method]**

This method is equivalent to `map-into(`*string* `, as-uppercase ,`*string*`)`.

`as-lowercase` [Open Generic Function]

Coerces an object to lowercase.

Signature: `as-lowercase` *object1* ⇒ *object2*

Arguments: *object1* An instance of `<object>`.

Values: *object2* An instance of `<object>`.

Description: Coerces an object to lowercase and returns the resulting new object.

object1 will not be modified by this operation.

`as-lowercase` ***character* ⇒ *lowercase-character*** **[G.F. Method]**

The `<character>` method on `as-lowercase` returns the lower-case equivalent for *character*. If *character* already is lowercase or does not exist in two cases, it is returned unchanged.

`as-lowercase` ***string* ⇒ *new-string*** **[G.F. Method]**

This method is equivalent to `map(as-lowercase,` *string*`)`.

`as-lowercase!` [Open Generic Function]

Coerces an object to lowercase in place.

Signature: `as-lowercase!` *object* ⇒ *object*

Arguments: *object* An instance of `<object>`.

Values: *object* An instance of `<object>`; the same object that was passed in as an argument.

Description: Coerces an object to lowercase in place and returns the modified object.

object may be modified by this operation, and the result will be `==` to the *object*.

`as-lowercase!` ***string*** **⇒** ***string*** **[G.F. Method]**

This method is equivalent to `map-into(`*string* `, as-lowercase,` *string*`)`.

Copying Objects

`shallow-copy` [Open Generic Function]

Returns a copy of its argument.

Signature: `shallow-copy` *object1* ⇒ `#rest` *objects*

Arguments: *object1* An instance of `<object>`.

Values: *objects* Instances of `<object>`.

Description: Returns a new object that has the same contents as *object1*. The contents are not copied but are the same objects contained in *object1*.

There is a predefined method for instances of `<collection>`. For other classes, the programmer must provide a method.

`shallow-copy` ***collection*** **⇒** ***new-collection*** **[G.F. Method]**

The method for `<collection>` creates a new object by calling `make` on the `type-for-copy` of *collection* and filling it with the same elements as *collection*.

`type-for-copy` [Open Generic Function]

Returns an appropriate type for creating mutable copies of its argument.

Signature: `type-for-copy` *object* ⇒ *type*

Arguments: *object* An instance of `<object>`.

Values: *type* An instance of `<type>.`

Description: Returns an appropriate type for creating mutable copies of *object*.

The `type-for-copy` value of a collection must be an instantiable subtype of `<mutable-collection>`. For collections that are themselves mutable, the collection's actual class is generally the most appropriate (assuming it is instantiable). The `type-for-copy` value for a sequence should be a subtype of `<sequence>`, and the `type-for-copy` value of an explicit-key-collection should be a subtype of `<explicit-key-collection>`.

`type-for-copy` ***object*** ⇒ ***type*** **[G.F. Method]**

The method on `<object>` returns the result of calling `object-class` on the *object*.

`type-for-copy` ***mutable-collection*** ⇒ ***type*** **[G.F. Method]**

The method on `<mutable-collection>` returns the result of calling `object-class` on the *mutable-collection*.

`type-for-copy` ***limited-collection*** ⇒ ***type*** **[G.F. Method]**

For a type L_1 created by `limited(`*C*`, of: `*T*`, size: `*S*`)` where *C* is not `<range>`, `type-for-copy` of an object made by instantiating L_1 returns a type L_2 that satisfies each of the following:

- L_2 is either a class or a limited collection type.
- L_2 is a subtype of *C*.
- L_2's element type is equivalent to *T*.
- If L_2 is a limited collection type, its size attribute is `#f`.

`type-for-copy` ***range*** ⇒ **`<list>`** **[G.F. Method]**

The method on `<range>` returns `<list>`.

`type-for-copy` ***limited-range*** ⇒ **`<list>`** **[G.F. Method]**

The method on instances of `limited(singleton(<range>)…)` returns `<list>`, the same as for any instance of `<range>`.

Collection Operations

Note to implementors:

Functions such as `map`, `map-as` that return a new collection cannot rely on the type they instantiate having a valid default for `fill:`. Therefore when the size of the result is non-zero these functions should compute the first element of the result before making the collection, and specify that element as the `fill:` value. Otherwise a spurious type error could occur when making the collection.

Collection Properties

`empty?` **[Open Generic Function]**

Returns true if its argument is empty.

Signature: `empty?` *object* ⇒ *boolean*

Arguments: *object* An instance of `<object>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if *object* is empty. Otherwise returns `#f`.

`empty?` *collection* ⇒ *boolean* **[G.F. Method]**

A set of methods defined for the class `<collection>` return true if the collection has zero elements.

`size` **[Open Generic Function]**

Returns the size of its argument.

Signature: `size` *object* ⇒ `#rest` *objects*

Arguments: *object* An instance of `<object>`.

Values: *objects* Instances of `<object>`.

Description: Returns the size of *object*.

size *collection* ⇒ *integer-or-false* **[G.F. Method]**

When called on a collection, `size` returns the numbers of keys in the collection. This default method simply counts while iterating through the collection. `size` may return `#f` for collections of unbounded size.

size *array* ⇒ *size* **[G.F. Method]**

The method for `<array>` is equivalent to

```
reduce(\*, 1, dimensions (array))
```

size *list* ⇒ *integer-or-false* **[G.F. Method]**

For circular lists, `size` is guaranteed to terminate and return `#f`. For non-circular lists, `size` returns an integer size value.

size *range* ⇒ *size* **[G.F. Method]**

For unbounded ranges, `size` always terminates and returns `#f`. For finite ranges, `size` returns an integer.

size *table* ⇒ *size* **[G.F. Method]**

The class `<table>` provides an implementation of `size` for use by its subclasses. The method returns an instance of `<integer>`.

`size-setter` **[Open Generic Function]**

Sets the size of an object.

Signature: `size-setter` *new-size object* ⇒ *new-size*

Arguments:

new-size	An instance of `<object>`.
object	An instance of `<object>`.

Values: *new-size* An instance of `<object>`.

Description: Sets the size of *object* to *new-size*.

object is modified by this operation.

`size-setter` ***integer stretchy-sequence*** ⇒ ***integer*** **[G.F. Method]**

Methods are provided for stretchy sequences, that is, for collections which are instances both of `<stretchy-collection>` and of `<sequence>`.

`size-setter` sets the size of *stretchy-sequence* to be *integer*. *stretchy-sequence* is modified by this operation. If *integer* is less than or equal to the original size of *stretchy-sequence*, then the first *integer* elements of *stretchy-sequence* are retained at the same positions. If *integer* is greater than the original size of *stretchy-sequence*, then the previous elements of the *stretchy-sequence* are retained at the same positions, and enough new elements are added to reach the new size. The value of each new element is the same as would have been used if *stretchy-sequence* had been created with `make`, specifying `size:` *integer* but not `fill:`.

It is not specified how `size-setter` adds new elements to a *stretchy-sequence*. In particular, it is not required to call `add!` or any other predefined function.

`rank` **[Open Generic Function]**

Returns the number of dimensions of an array.

Signature: `rank` *array* ⇒ *rank*

Arguments: *array* An instance of `<array>`.

Values: *rank* An instance of `<integer>`.

Description: Returns the number of dimensions (the rank) of *array*.

rank ***array*** ⇒ ***rank*** **[G.F. Method]**

The method for `<array>` computes `rank` by calling `size` on the `dimensions` of `array`.

`row-major-index` **[Open Generic Function]**

Returns the row-major-index position of an array element.

Signature: `row-major-index` *array* `#rest` *subscripts* ⇒ *index*

Arguments:

array	An instance of `<array>`.
subscripts	Instances of `<integer>`.

Values:

index	An instance of `<integer>`.

Description: Computes the position according to the row-major ordering of `array` for the element that is specified by `subscripts`, and returns the position of that element.

An error is signaled if the number of subscripts is not equal to the rank of the array. An error is signaled if any of the subscripts are out of bounds for array.

`row-major-index` *array* `#rest` *subscripts* ⇒ *index* **[G.F. Method]**

The method for `<array>` computes the `index` using the result of calling `dimensions` on the `array`.

`dimensions` **[Open Generic Function]**

Returns the dimensions of an array.

Signature: `dimensions` *array* ⇒ *sequence*

Arguments:

array	An instance of `<array>`.

Values:

sequence	An instance of `<sequence>`. The elements of this sequences will be instances of `<integer>`.

Description: Returns the dimensions of *array,* as a sequence of integers. The consequences are undefined if the resulting sequence is modified. This function forms the basis for all the other array operations. Each concrete subclass of `<array>` must either provide or inherit an implementation of this function.

`dimensions` *vector* ⇒ *sequence* **[G.F. Method]**

Returns a sequence whose single element is the size of the vector.

`dimension` [Open Generic Function]

Returns the size of a specified dimension of an array.

Signature: `dimension` *array axis* ⇒ *dimension*

Arguments:

array	An instance of `<array>`.
axis	An instance of `<integer>`.

Values:

dimension	An instance of `<integer>`.

Description: Returns the *axis* dimension of `array`.

axis must be a non-negative integer less than the rank of `array`. An error is signaled if *axis* is out of bounds for `array`.

`dimension` *array axis* ⇒ *dimension* **[G.F. Method]**

The method for `<array>` calls `element` on the result of calling `dimensions` on the `array`, using the `axis` number as the key.

`key-test` [Open Generic Function]

Returns the function used by its collection argument to compare keys.

Signature: `key-test` *collection* ⇒ *test-function*

Arguments:

collection	An instance of `<collection>`.

Values:

test-function	An instance of `<function>`. The function used by the collection to compare keys.

Description: Returns the function used by *collection* to compare keys.

All collection classes must provide or inherit a method that returns a result consistent with their iteration protocol and `element` methods. A given method for `key-test` must return the same value (compared with `==`) each time it is called.

`key-test` *sequence* ⇒ *test-function* **[G.F. Method]**

The method of `key-test` for sequences returns the function `==`.

`key-test` *table* ⇒ *test-function* **[G.F. Method]**

The method of `key-test` for instances of `<table>` returns the first value of `table-protocol(`*table*`)`.

`key-sequence` **[Open Generic Function]**

Returns a sequence containing the keys of its collection argument.

Signature: `key-sequence` *collection* ⇒ *keys*

Arguments: *collection* An instance of `<collection>`.

Values: *keys* An instance of `<sequence>` containing the keys of *collection*.

Description: Returns a sequence containing the keys of *collection*.

Although elements may be duplicated in a collection, keys, by their nature, must be unique; two different elements in a collection may not share a common key, even though distinct keys may yield identical elements.

The order in which the keys from *collection* appear in the key sequence is unspecified if *collection* is unstable under iteration. In particular, different calls to `key-sequence` with the same argument may yield differently ordered key sequences. If *collection* is stable under iteration, however, the resulting sequence of keys will be in the natural order for *collection*.

Selecting Elements

`element` **[Open Generic Function]**

Returns the collection element associated with a particular key.

Signature: `element` *collection key* `#key` *default* ⇒ *element*

Arguments:

collection	An instance of `<collection>`.
key	An instance of `<object>`.
default	An instance of `<object>`.

Values:

element	An instance of `<object>`.

Description: Returns the element associated with *key* in *collection*. If no element is associated with *key*, then the behavior of `element` depends on whether it was called with a *default* argument: if a *default* argument was passed, its value is returned; otherwise, an error is signaled.

All collections are required to implement `element`.

`element` ***simple-vector index*** **#key** ***default*** ⇒ ***element*** **[G.F. Method]**

There is a constant time implementation of `element` for all general instances of `<simple-vector>`.

`element` ***unicode-string index*** **#key** ***default*** ⇒ ***character*** **[G.F. Method]**

The class `<unicode-string>` provides a constant time implementation for the `element` function.

`element` ***byte-string index*** **#key** ***default*** ⇒ ***character*** **[G.F. Method]**

The class `<byte-string>` provides a constant time implementation for the `element` function.

`element` ***table key*** **#key** ***default*** ⇒ ***element*** **[G.F. Method]**

The class `<table>` provides a default implementation for the `element` function.

`element-setter` **[Open Generic Function]**

Sets the collection element associated with a particular key.

Signature: `element-setter` *new-value mutable-collection key* ⇒ *new-value*

Arguments:	*new-value*	An instance of `<object>`.
	mutable-collection	An instance of `<mutable-collection>`.
	key	An instance of `<object>`.
Values:	*new-value*	Zero or more instances of `<object>`.

Description: Alters *mutable-collection* so that the value associated with *key* will subsequently be *new-value*. If *mutable-collection* is stretchy, `element-setter` may also change its size (for example, by adding new keys with values).

An error is signaled if a program calls `element-setter` with a key that is not already a key to *collection*, unless the collection is stretchy.

Stretchy collections allow `element-setter` to be called with a key that is not present in the collection, expanding the collection as necessary to add a new element in that case. Each concrete subclass of `<stretchy-collection>` must provide or inherit a method for `element-setter` that behaves as follows when there is not already an element present for the indicated key:

- If the class is a subclass of `<explicit-key-collection>`, adds a new element to the collection with the indicated key.
- If the class is a subclass of `<sequence>`, first calls `size-setter` on the key + 1 and the collection to expand the sequence. The key must be a non-negative integer.

`element-setter` ***new-element simple-vector index*** **[G.F. Method]**
⇒ ***new-element***

There is a constant time implementation of `element-setter` for all general instances of `<simple-vector>`.

`element-setter` ***new-value table key*** **[G.F. Method]**

The class `<table>` provides an implementation of `element-setter` for use by its subclasses. If no element with the given *key* exists, `element-setter` will add the *key* and *new-value* to the table.

`element-setter` ***character unicode-string index*** **⇒** ***character*** **[G.F. Method]**

The class `<unicode-string>` provides a constant time implementation for the `element-setter` function.

`element-setter` ***character byte-string index*** **⇒** ***character*** **[G.F. Method]**

The class `<byte-string>` provides a constant time implementation for the `element-setter` function.

`aref` [Open Generic Function]

Returns the array element indicated by a set of indices.

Signature: `aref` *array* `#rest` *indices* ⇒ *element*

Arguments:

array	An instance of `<array>`.
indices	Instances of `<integer>`.

Values:

element	An instance of `<object>`.

Description: Returns the element of *array* indicated by *indices*.

An error is signaled if the number of *indices* is not equal to the rank of the *array*. An error is signaled if any of the *indices* are out of bounds for the *array*.

`aref` ***array*** **`#rest`** ***indices*** **⇒** ***element*** **[G.F. Method]**

The method for `<array>` calls `element` on the *array,* using as the key the result of applying `row-major-index` to the *array* and *indices*.

`aref-setter` [Open Generic Function]

Sets the array element indicated by a set of indices.

Signature: `aref-setter` *new-value array* `#rest` *indices* ⇒ *new-value*

Arguments:

new-value	An instance of `<object>`.
array	An instance of `<array>`.
indices	Instances of `<integer>`.

Values: *new-value* An instance of `<object>`.

Description: Sets the element of *array* indicated by *indices* to the *new-value* and returns the *new-value*.

array is modified by this operation.

An error is signaled if the number of *indices* is not equal to the rank of the *array*. An error is signaled if any of the *indices* are out of bounds for *array*. An error is signaled if the *array* is limited to hold objects of a particular type and the new value is not an instance of that type.

`aref-setter` *new-value* *array* `#rest` *indices* ⇒ *new-value* **[G.F. Method]**

The method for `<array>` calls `element-setter` on the array and new value, using as the key the result of applying `row-major-index` to the `array` and *indices*.

`first` **[Function]**

Returns the first element of a sequence.

Signature: `first` *sequence* `#key` *default* ⇒ *value*

Arguments:	*sequence*	An instance of `<sequence>`.
	default	An instance of `<object>`.

Values: *value* An instance of `<object>`.

Description: Returns the first element of the *sequence* by calling `element` with the supplied arguments and the corresponding index.

Note that because `element` is zero-based, `first(seq)` is equivalent to `element(seq, 0)` and `seq[0]`.

`second` **[Function]**

Returns the second element of a sequence.

Signature: `second` *sequence* `#key` *default* ⇒ *value*

Arguments:	*sequence*	An instance of `<sequence>`.
	default	An instance of `<object>`.
Values:	*value*	An instance of `<object>`.

Description: Returns the second element of the *sequence* by calling `element` with the supplied arguments and the corresponding index.

`third` [Function]

Returns the third element of a sequence.

Signature: `third` *sequence* `#key` *default* ⇒ *value*

Arguments:	*sequence*	An instance of `<sequence>`.
	default	An instance of `<object>`.
Values:	*value*	An instance of `<object>`.

Description: Returns the third element of the *sequence* by calling `element` with the supplied arguments and the corresponding index.

`first-setter` [Function]

Sets the first element of a mutable sequence.

Signature: `first-setter` *new-value mutable-sequence* ⇒ *new-value*

Arguments:	*new-value*	An instance of `<object>`.
	mutable-sequence	An instance of `<mutable-sequence>`.
Values:	*new-value*	An instance of `<object>`.

Description: Sets the first element of the *mutable-sequence* and returns the *new-value*, by calling `element-setter` with the supplied arguments and the corresponding index.

Note that because `element-setter` is zero-based, `first-setter(val, seq)` is equivalent to `element-setter(val, seq, 0)` and `seq[0] := val`.

`second-setter` **[Function]**

Sets the second element of a mutable sequence.

Signature: `second-setter` *new-value mutable-sequence* ⇒ *new-value*

Arguments:

new-value	An instance of `<object>`.
mutable-sequence	An instance of `<mutable-sequence>`.

Values:

new-value	An instance of `<object>`.

Description: Sets the second element of the *mutable-sequence* and returns the *new-value*, by calling `element-setter` with the supplied arguments and the corresponding index.

`third-setter` **[Function]**

Sets the third element of a mutable sequence.

Signature: `third-setter` *new-value mutable-sequence* ⇒ *new-value*

Arguments:

new-value	An instance of `<object>`.
mutable-sequence	An instance of `<mutable-sequence>`.

Values:

new-value	An instance of `<object>`.

Description: Sets the third element of the *mutable-sequence* and returns the *new-value*, by calling `element-setter` with the supplied arguments and the corresponding index.

`last` **[Open Generic Function]**

Returns the last element of a sequence.

Signature: `last` *sequence* `#key` *default* ⇒ *value*

Arguments:

sequence	An instance of `<sequence>`.
default	An instance of `<object>`.

Values:

value	Zero or more instances of `<object>`.

Description: Returns the last element of *sequence*.

If the sequence is empty, then the behavior of `last` depends on whether it was called with a *default* argument. If the *default* argument was supplied, its value is returned; otherwise, an error is signaled.

```
last (#("emperor", "of", "china"))
 ⇒  "china"
```

`last-setter` **[Open Generic Function]**

Sets the last element of a mutable sequence.

Signature: `last-setter` *new-value* *mutable-sequence* ⇒ *new-value*

Arguments:

new-value	An instance of `<object>`.
mutable-sequence	An instance of `<mutable-sequence>`.

Values:

new-value	An instance of `<object>`.

Description: Replaces the last element of *mutable-sequence* with *new-value*.

mutable-sequence is modified by this operation.

new-value must obey any type restrictions for elements of *mutable-sequence* . An error is signaled if *mutable-sequence* is empty or unbounded.

```
define variable my-list = list (1, 2, 3)
my-list
 ⇒  #(1, 2, 3)
last (my-list) := 4
 ⇒  4
my-list
 ⇒  #(1, 2, 4)

define variable my-empty-vector = vector()
my-empty-vector
 ⇒  #[]
last (my-empty-vector) := 4
{error}
```

`head` **[Function]**

Returns the head of a list.

Signature: `head` *list* ⇒ *object*

Arguments:	*list*	An instance of `<list>`.
Values:	*object*	An instance of `<object>`.

Description: Returns the head of *list*.

If *list* is a pair, `head` returns the value of the head slot. If *list* is the empty list, `head` returns the empty list.

```
head (#(4, 5, 6))
 ⇒  4
head (#())
 ⇒  #()
```

`tail` **[Function]**

Returns the tail of a list.

Signature: `tail` *list* ⇒ *object*

Arguments:	*list*	An instance of `<list>`.
Values:	*object*	An instance of `<object>`.

Description: Returns the tail of *list*.

If *list* is a pair, `tail` returns the value of the tail slot. If *list* is the empty list, `tail` returns the empty list.

```
tail (#(4, 5, 6))
 ⇒  #(5, 6)
tail (#())
 ⇒  #()
```

`head-setter` [Function]

Sets the head of a pair.

Signature: `head-setter` *object pair* ⇒ *object*

Arguments:	*object*	An instance of `<object>`.
	pair	An instance of `<pair>`.
Values:	*object*	An instance of `<object>`.

Description: Sets the head of *pair* to contain *object* and returns *object*.

pair is modified by this operation.

Example

```
define variable x = list (4, 5, 6)
head (x) := 9
 ⇒  9
x
 ⇒  #(9, 5, 6)
```

`tail-setter` [Function]

Sets the tail of a pair.

Signature: `tail-setter` *object pair* ⇒ *object*

Arguments:

object	An instance of `<object>`.
pair	An instance of `<pair>`.

Values:

object	An instance of `<object>`.

Description: Sets the tail of *pair* to contain *object* and returns *object*.

pair is modified by this operation.

```
define variable x = list (4, 5, 6)
tail (x) := #(9, 8, 7)
 ⇒  #(9, 8, 7)
x
 ⇒  #(4, 9, 8, 7)
tail (x) := "dot"
 ⇒  "dot"
x
 ⇒  #(4, 9, 8 . "dot")
```

Adding and Removing Elements

`add` **[Open Generic Function]**

Adds an element to a sequence.

Signature: `add` *source-sequence new-element* ⇒ *result-sequence*

Arguments:

source-sequence	An instance of `<sequence>`.
new-element	An instance of `<object>`.

Values:

result-sequence	An instance of `<sequence>`.

Description: Returns a sequence that contains *new-element* and all the elements of *source-sequence*. The *result-sequence* may or may not be freshly allocated. It may share structure with a preexisting sequence.

source-sequence is not modified by this operation.

The *result-sequence*'s size is one greater than the size of *source-sequence*. The generic function `add` doesn't specify where the new element will be added, although individual methods may do so.

```
define variable *numbers* = #(3, 4, 5)
add (*numbers*, 1)
  ⇒  #(1, 3, 4, 5)
*numbers*
  ⇒  #(3, 4, 5)
```

`add!` **[Open Generic Function]**

Adds an element to a sequence.

Signature: `add!` *source-sequence new-element* ⇒ *result-sequence*

Arguments:

source-sequence	An instance of `<sequence>`.
new-element	An instance of `<object>`.

Values:

result-sequence	An instance of `<sequence>`.

Description: Returns a sequence that contains *new-element* and all the elements of *source-sequence*. The *result-sequence* may or may not be freshly allocated. It may share structure with a preexisting sequence. *source-sequence* and *result-sequence* may or may not be `==`.

source-sequence may be modified by this operation.

result-sequence's size is one greater than the size of *source-sequence*. The generic function `add!` doesn't specify where the new element will be added, although individual methods may do so.

```
define variable *numbers* = list (3, 4, 5)
add! (*numbers*, 1)
  ⇒  #(1, 3, 4, 5)
*numbers*
  ⇒ {undefined}
```

add! ***deque new-value*** ⇒ ***deque*** **[G.F. Method]**

The result of `add!` on a deque is `==` to the *deque* argument, which is modified by this operation.

add! ***stretchy-vector new-element*** ⇒ ***stretchy-vector*** **[G.F. Method]**

The result of `add!` on a stretchy vector is `==` to the *stretchy-vector* argument, and the argument is modified by this operation. `add!` adds *new-element* at the end of the *stretchy-vector*.

add! ***list element*** ⇒ ***pair*** **[G.F. Method]**

The result of `add!` on a list is equivalent to `(pair` *element list*`)`. The result will share structure with the *list* argument, but it will not be `==` to the argument, and the argument will not be modified.

`add-new` **[Open Generic Function]**

Adds a new element to a sequence.

Signature: `add-new` *source-sequence new-element* `#key` *test* ⇒ *result-sequence*

Arguments:

source-sequence	An instance of `<sequence>`.
new-element	An instance of `<object>`.
test	An instance of `<function>`. The default is `==`.

Values:

result-sequence	An instance of `<sequence>`.

Description: Adds *new-element* to source-sequence if it is not already an element of *source-sequence*, as determined by the *test* function. If *new-element* is already a member of *source-sequence*, then *source-sequence* is returned unmodified.

If an element is added, `add-new` operates just as `add` would.

The *test* function may be non-commutative: it is always called with an element from *source-sequence* as its first argument and *new-element* as its second argument.

```
add-new (#(3, 4, 5), 1)
  ⇒  #(1, 3, 4, 5)
add-new (#(3, 4, 5), 4)
  ⇒  #(3, 4, 5)
```

`add-new!` **[Open Generic Function]**

Adds a new element to a sequence.

Signature: `add-new!` *source-sequence new-element* `#key` *test* ⇒ *result-sequence*

Arguments:

source-sequence	An instance of `<sequence>`.
new-element	An instance of `<object>`.
test	An instance of `<function>`. The default is `==`.

Values:

result-sequence	An instance of `<sequence>`.

Description: Adds *new-element* to source-sequence if it is not already an element of *source-sequence*, as determined by the *test* function. If *new-element* is already a member of *source-sequence*, then *source-sequence* is returned unmodified.

If an element is added, `add-new!` operates just as `add!` would.

The *test* function may be non-commutative: it is always called with an element from *sequence* as its first argument and *new-element* as its second argument.

```
add-new! (list (3, 4, 5), 1)
  ⇒  #(1, 3, 4, 5)
add-new! (list (3, 4, 5), 4)
  ⇒  #(3, 4, 5)
```

`remove` **[Open Generic Function]**

Removes an element from a sequence.

Signature: `remove` *source-sequence value* `#key` *test count* ⇒ *result-sequence*

Arguments:

source-sequence	An instance of `<sequence>`.
value	An instance of `<object>`.
test	An instance of `<function>`. The default is `==`.
count	An instance of `<integer>` or `#f`. The default is `#f`.

Values:

result-sequence	An instance of `<sequence>`.

Description: Returns a sequence consisting of the elements of *source-sequence* not equal to *value*. The *result-sequence* may or may not be freshly allocated. However, the *source-sequence* is never modified by `remove`.

test is a function which determines whether an element is equal to *value*. The *test* function may be non-commutative: it is always called with an element from *source-sequence* as its first argument and *value* as its second argument.

If *count* is `#f`, then all copies of *value* are removed. Otherwise, no more than *count* copies of *value* are removed (so additional elements equal to *value* might remain in *result-sequence*).

```
define variable *old-list* = list(1, 2, 3)
define variable *new-list* = remove(*old-list* 1)
*new-list*
 ⇒  #(2, 3)
*new-list* == tail(*old-list*)
 ⇒  {undefined}
```

`remove!` **[Open Generic Function]**

Removes an element from a sequence.

Signature: `remove!` *source-sequence value* `#key` *test count* ⇒ *result-sequence*

Arguments:	*source-sequence*	An instance of `<sequence>`.
	value	An instance of `<object>`.
	test	An instance of `<function>`. The default is `==`.
	count	An instance of `<integer>` or `#f`. The default is `#f`.
Values:	*result-sequence*	An instance of `<sequence>`.

Description: Returns a sequence consisting of the elements of *source-sequence* not equal to *value*. The *result-sequence* may or may not be freshly allocated, may or may not be `==` to the *source-sequence*, and may or may not share structure with the *source-sequence*. The *source-sequence* may be modified by `remove!`.

test is a function which determines whether an element is equal to *value*. The *test* function may be non-commutative: it is always called with an element from *source-sequence* as its first argument and *value* as its second argument.

If *count* is `#f`, then all copies of *value* are removed. Otherwise, no more than *count* copies of *value* are removed (so additional elements equal to *value* might remain in *result-sequence*).

`remove!` ***deque value* #key *test count*** ⇒ ***deque*** **[G.F. Method]**

The result of `remove!` on a deque is `==` to the *deque* argument. The argument is modified by this operation.

`remove!` ***stretchy-vector element* #key *test count*** ⇒ ***stretchy-vector*** **[G.F. Method]**

The result of `remove!` on a stretchy vector is `==` to the *stretchy-vector* argument. The argument is modified by this operation.

`remove!` ***list element* #key *test count*** ⇒ ***list*** **[G.F. Method]**

The result of `remove!` on a list may or may not be `==` to the *list* argument. The argument may be modified by this operation.

`push` [Open Generic Function]

Adds an element to the front of a deque.

Signature:	`push` *deque new-value* ⇒ *new-value*	
Arguments:	*deque*	An instance of `<deque>`.
	new-value	An instance of `<object>`.
Values:	*new-value*	An instance of `<object>`. The same object that was passed in as an argument.

Description: Augments *deque* by adding *new-value* to its front.

deque is modified by this operation.

`pop` [Open Generic Function]

Removes and returns the first element of a deque.

Signature:	`pop` *deque* ⇒ *first-element*	
Arguments:	*deque*	An instance of `<deque>`.
Values:	*first-element*	An instance of `<object>`.

Description: Removes the first element from *deque* and returns it.

deque is modified by this operation.

`push-last` [Open Generic Function]

Adds an element to the end of a deque.

Signature:	`push-last` *deque new-value* ⇒ *new-value*	
Arguments:	*deque*	An instance of `<deque>`.
	new-value	An instance of `<object>`.

Values: *new-value* An instance of `<object>`. The same object that was passed in as an argument.

Description: Augments *deque* by adding *new-value* to its end.

deque is modified by this operation.

`pop-last` **[Open Generic Function]**

Removes and returns an element from the end of a deque.

Signature: `pop-last` *deque* ⇒ *last-element*

Arguments: *deque* An instance of `<deque>`.

Values: *last-element* An instance of `<object>`.

Description: Removes the last element from *deque* and returns it.

deque is modified by this operation.

Reordering Elements

`reverse` **[Open Generic Function]**

Returns a sequence with elements in the reverse order of its argument sequence.

Signature: `reverse` *source-sequence* ⇒ *result-sequence*

Arguments: *source-sequence*
An instance of `<sequence>`.

Values: *result-sequence*
An instance of `<sequence>`.

Description: Returns a sequence containing the same elements as *source-sequence*, but in reverse order. The *result-sequence* is generally of the same class as the *source-sequence*.

The *result-sequence* may or may not be freshly allocated. The *source-sequence* is not modified by this operation.

The consequences are undefined if the *source-sequence* is unbounded (circular or infinite).

```
define variable *x* = list("bim", "bam", "boom")
*x*
  ⇒  #("bim", "bam", "boom")
reverse(*x*)
  ⇒  #("boom", "bam", "bim")
*x*
  ⇒  #("bim", "bam", "boom")
```

reverse ***range*** ⇒ ***new-range*** **[G.F. Method]**

Reversing a range produces another range. An unbounded range cannot be reversed.

`reverse!` **[Open Generic Function]**

Returns a sequence with elements in the reverse order of its argument sequence.

Signature: `reverse!` *source-sequence* ⇒ *result-sequence*

Arguments: *source-sequence*

An instance of `<sequence>`.

Values: *result-sequence*

An instance of `<sequence>`.

Description: Returns a sequence containing the same elements as *source-sequence*, but in reverse order. The *result-sequence* is generally of the same class as the *source-sequence*.

The *source-sequence* may be modified by this operation. The *result-sequence* may or may not be freshly allocated. The *source-sequence* and the *result-sequence* may or may not be `==`. Programs should never rely on this operation performing a side-effect on an existing sequence, but should instead use the value returned by the function.

The consequences are undefined if the *source-sequence* is unbounded (circular or infinite).

```
define variable *x* = list("bim", "bam", "boom")
*x*
  ⇒  #("bim", "bam", "boom")
reverse!(*x*)
  ⇒  #("boom", "bam", "bim")
*x*
  ⇒ {undefined}
```

reverse! ***range*** ⇒ ***range*** **[G.F. Method]**

The result of `reverse!` on a range is `==` to the *range* argument. An unbounded range cannot be reversed.

sort [Open Generic Function]

Returns a sequence containing the elements of its argument sequence, sorted.

Signature: `sort` *source-sequence* `#key` *test stable* ⇒ *result-sequence*

Arguments:

source-sequence	An instance of `<sequence>`.
test	An instance of `<function>`. The default is `<`.
stable	An instance of `<object>`, treated as a boolean.

Values:

result-sequence	An instance of `<sequence>`.

Description: Returns a sequence containing the elements of *source-sequence* sorted into ascending order. The *result-sequence* may or may not be freshly allocated. The *source-sequence* is not modified by this operation.

`sort` determines the relationship between two elements by giving elements to the *test*. The first argument to the *test* function is one element of *source-sequence*; the second argument is another element of *source-sequence*. *test* should return true if and only if the first argument is strictly less than the second (in some appropriate sense). If the first argument is greater than or equal to the second (in the appropriate sense), then the *test* should return `#f`.

If *stable* is supplied and not `#f`, a possibly slower algorithm will be used that will leave in their original order any two elements, *x* and *y*, such that *test(x, y)* and *test(y, x)* are both false.

```
define variable *numbers* = vector(3, 1, 4, 1, 5, 9)
*numbers*
  ⇒ #[3, 1, 4, 1, 5, 9]
sort (*numbers*)
  ⇒  #[1, 1, 3, 4, 5, 9]
*numbers*
  ⇒  #[3, 1, 4, 1, 5, 9]
```

`sort!` **[Open Generic Function]**

Returns a sequence containing the elements of its argument sequence, sorted.

Signature: `sort!` *source-sequence* `#key` *test stable* ⇒ *result-sequence*

Arguments:

source-sequence	An instance of `<sequence>`.
test	An instance of `<function>`. The default is `<`.
stable	An instance of `<object>`, treated as a boolean.

Values:

result-sequence	An instance of `<sequence>`.

Description: Returns a sequence containing the elements of *source-sequence* sorted into ascending order. The *result-sequence* may or may not be freshly allocated. The *source-sequence* may be modified by this operation. The *result-sequence* may or may not be `==` to *source-sequence*. After this operation, the contents of *source-sequence* are undefined.

Programs should never rely on this operation performing a side-effect on an existing sequence, but should instead use the value returned by the function.

`sort!` determines the relationship between two elements by giving elements to the *test*. The first argument to the *test* function is one element of *source-sequence*; the second argument is another element of *source-sequence*. *test* should return true if and only if the first argument is strictly less than the second (in some appropriate sense). If the first argument is greater than or equal to the second (in the appropriate sense), then the *test* should return `#f`.

If *stable* is supplied and not `#f`, a possibly slower algorithm will be used that will leave in their original order any two elements, *x* and *y*, such that *test(x, y)* and *test(y, x)* are both false.

```
define variable *numbers* = vector(3, 1, 4, 1, 5, 9)
*numbers*
  ⇒ #[3, 1, 4, 1, 5, 9]
sort! (*numbers*)
  ⇒  #[1, 1, 3, 4, 5, 9]
*numbers*
  ⇒  {undefined}
```

Set Operations

`intersection` **[Open Generic Function]**

Returns the intersection of two sequences.

Signature: `intersection` *sequence1 sequence2* #key *test* ⇒ *new-sequence*

Arguments:

sequence1	An instance of `<sequence>`.
sequence2	An instance of `<sequence>`.
test	An instance of `<function>`. The default is `==`.

Values:

new-sequence	An instance of `<sequence>`.

Description: Returns a new sequence containing only those elements of *sequence1* that also appear in *sequence2*.

test is used to determine whether an element appears in *sequence2*. It is always called with an element of *sequence1* as its first argument and an element from *sequence2* as its second argument. The order of elements in the result sequence is not specified.

new-sequence may or may not share structure with the *sequence1* and *sequence2*.

```
? intersection (#("john", "paul", "george", "ringo"),
                #("richard", "george", "edward", "charles"),
                test: \=)
#("george")
```

intersection ***range1 range2*** **#key *test*** ⇒ ***range*** **[G.F. Method]**

`intersection` applied to two ranges and a test of `==` (the default) will produce another range as its result, even though the `type-for-copy` of a range is not `<range>`. If either *range1* or *range2* is unbounded, this method is guaranteed to terminate only if the *test* is `==`.

`union` **[Open Generic Function]**

Returns the union of two sequences.

Signature: `union` *sequence1 sequence2* #key *test* ⇒ *new-sequence*

Arguments:

sequence1	An instance of `<sequence>`.
sequence2	An instance of `<sequence>`.
test	An instance of `<function>`. The default is `==`.

Values:

new-sequence	An instance of `<sequence>`.

Description: Returns a sequence containing every element of *sequence1* and *sequence2*.

If the same element appears in both argument sequences, this will not cause it to appear twice in the result sequence. However, if the same element appears more than once in a single argument sequence, it may appear more than once in the result sequence.

test is used for all comparisons. It is always called with an element from *sequence1* as its first argument and an element from *sequence2* as its second argument. The order of elements in the *new-sequence* is not specified.

new-sequence may or may not share structure with *sequence1* or *sequence2*.

```
union (#("butter", "flour", "sugar", "salt", "eggs"),
       #("eggs", "butter", "mushrooms", "onions", "salt"),
       test: \=)
 ⇒  #("salt", "butter", "flour", "sugar", "eggs",
       "mushrooms", "onions")
```

`remove-duplicates` **[Open Generic Function]**

Returns a sequence without duplicates.

Signature: `remove-duplicates` *source-sequence* #key *test* ⇒ *result-sequence*

Arguments:

source-sequence	An instance of `<sequence>`.
test	An instance of `<function>`. The default is `==`.

Values:

result-sequence	An instance of `<sequence>`.

Description: Returns a sequence that contains all the unique elements from *source-sequence* but no duplicate elements.

test is the function used to determine whether one element is a duplicate of another. The *test* argument may be non-commutative; it will always be called with its arguments in the same order as they appear in *source-sequence*.

The *result-sequence* may or may not be freshly allocated. However, the *source-sequence* will not be modified by this operation.

```
remove-duplicates (#("spam", "eggs", "spam",
                     "sausage", "spam", "spam"),
                    test: \=)
 ⇒  #("spam", "eggs", "sausage")
or
 ⇒  #("eggs", "spam", "sausage")
or
 ⇒  #("eggs", "sausage", "spam")
```

`remove-duplicates!` **[Open Generic Function]**

Returns a sequence without duplicates.

Signature: `remove-duplicates!` *source-sequence* #key *test* ⇒ *result-sequence*

Arguments:

source-sequence
An instance of `<sequence>`.

test An instance of `<function>`. The default is `==`.

Values:

result-sequence
An instance of `<sequence>`.

Description: Returns a sequence that contains all the unique elements from *source-sequence* but no duplicate elements.

test is the function used to determine whether one element is a duplicate of another. The *test* argument may be non-commutative; it will always be called with its arguments in the same order as they appear in *source-sequence*.

The *result-sequence* may or may not be freshly allocated, may or may not share structure with the *source-sequence*, and may or may not be == to the *source-sequence*. The *source-sequence* may or may not be modified by the operation.

```
define variable *menu* = #("spam", "eggs", "spam",
                           "sausage", "spam", "spam")
remove-duplicates! (*menu*, test: \=)
  ⇒  #("spam", "eggs", "sausage")
or
 ⇒  #("eggs", "spam", "sausage")
or
 ⇒  #("eggs", "sausage", "spam")
*menu*
  ⇒  {undefined}
```

Subsequence Operations

`copy-sequence` **[Open Generic Function]**

Returns a freshly allocated copy of some subsequence of a sequence.

Signature: `copy-sequence` *source* `#key` *start end* ⇒ *new-sequence*

Arguments:

source	An instance of `<sequence>`.
start	An instance of `<integer>`. The default is `0`.
end	An instance of `<integer>`. The default is the size of *source*.

Values: *new-sequence*

A freshly allocated instance of `<sequence>`.

Description: Creates a freshly allocated sequence containing the elements of *source* between *start* and *end*.

```
define constant hamlet = #("to", "be", "or", "not", "to", "be")
hamlet == copy-sequence (hamlet)
 ⇒  #f
copy-sequence (hamlet, start: 2, end: 4)
 ⇒  #("or", "not")
```

copy-sequence ***range*** **#key** ***start end*** **⇒** ***new-range*** **[G.F. Method]**

When applied to a range, `copy-sequence` returns another range, even though the `type-for-copy` of a range is the `<list>` class.

`concatenate` **[Function]**

Returns the concatenation of one or more sequences in a sequence of a type determined by the `type-for-copy` of its first argument.

Signature: `concatenate` *first-sequence* `#rest` *more-sequences* ⇒ *result-sequence*

Arguments: *first-sequence*

An instance of `<sequence>`.

more-sequences
Instances of `<sequence>`.

Values: *result-sequence*
An instance of `<sequence>`.

Description: Returns a sequence containing all the elements of all the sequences, in order.

The *result-sequence* will be an instance of the `type-for-copy` value for *first-sequence*. It may or may not be freshly allocated. The *result-sequence* may be created by calling `make` on the indicated type, with a `size:` initialization argument whose value is the sum of the sizes of the argument sequences. (For this reason, the `type-for-copy` value of *first-sequence* must support the `size:` init-keyword.)

new-sequence may share structure with any of the argument sequences, but it is not guaranteed to do so. The argument sequences will not be modified by this operation.

```
concatenate ("low-", "calorie")
 ⇒  "low-calorie"
```

`concatenate-as` **[Function]**

Returns the concatenation of one or more sequences in a sequence of a specified type.

Signature: `concatenate-as` *type first-sequence* `#rest` *more-sequences* ⇒ *result-sequence*

Arguments: *type* An instance of `<type>`, which must be a subtype of `<mutable-sequence>`

first-sequence
An instance of `<sequence>`.

more-sequences
Instances of `<sequence>`.

Values: *result-sequence*
An instance of *type*, and therefore also an instance of `<sequence>`.

Description: Returns a sequence containing all the elements of all the sequences, in order.

The *result-sequence* will be an instance of *type*. It may or may not be freshly allocated.

type must be a subtype of `<mutable-sequence>` and acceptable as the first argument to `make`. `size:` with a non-negative integer value must be an acceptable initarg for `make` of *type*. The *result-sequence* may be created by calling `make` on *type*, with a `size:` initialization argument whose value is the sum of the sizes of the arguments.

Example

```
concatenate-as (<string>, #('n', 'o', 'n'), #('f', 'a', 't'))
 ⇒  "nonfat"
```

`replace-subsequence!` **[Open Generic Function]**

Replaces a portion of a sequence with the elements of another sequence.

Signature: `replace-subsequence!` *source-sequence insert-sequence* `#key` *start end* ⇒ *result-sequence*

Arguments:

source-sequence	An instance of `<sequence>`.
insert-sequence	An instance of `<sequence>`.
start	An instance of `<integer>`. The default is `0`.
end	An instance of `<integer>`. The default is the size of *sequence*.

Values: *result-sequence* An instance of `<sequence>`.

Description: `replace-subsequence!` returns a sequence with the same elements as *source-sequence*, except that elements of the indicated subsequence are replaced by all the elements of *insert-sequence*. The subsequence to be overridden begins at index *start* and ends at index *end*.

result-sequence may or may not share structure with *source-sequence* or *insert-sequence*, and it may or may not be `==` to *source-sequence* or *insert-sequence*. *source-sequence* may or may not be modified by the operation. *insert-sequence* will not modified by this operation.

Example

```
define variable x = list ("a", "b", "c", "d", "e")
abcde := replace-subsequence! (x, #("x", "y", "z"), end: 1))
 ⇒  #("x", "y", "z", "b", "c", "d", "e")
abcde := replace-subsequence! (x, #("x", "y", "z"), start: 4))
 ⇒  #("x", "y", "z", "b", "x", "y", "z")
abcde := replace-subsequence! (x, #("a", "b", "c"),
                                      start: 2, end: 4))
 ⇒  #("x", "y", "a", "b", "c", "x", "y", "z")
```

`subsequence-position` **[Open Generic Function]**

Returns the position where a pattern appears in a sequence.

Signature: `subsequence-position` *big pattern* `#key` *test count* ⇒ *index*

Arguments:

big	An instance of `<sequence>`.
pattern	An instance of `<sequence>`.
test	An instance of `<function>`. The default is `==`.
count	An instance of `<integer>`. The default is `1`.

Values:

index	`#f` or an instance of `<integer>`.

Description: Searches *big* for a subsequence that is element-for-element equal to *pattern*, as determined by the *test* argument.

test is applied to elements of successive subsequences of *big* and corresponding elements of the *pattern* to determine whether a match has occurred. If a subsequence is found, `subsequence-position` returns the index at which the subsequence starts; otherwise, it returns `#f`. If there is more than one match, *count* determines which subsequence is selected. A *count* of 1 (the default) indicates that the first match should be returned.

```
subsequence-position ("Ralph Waldo Emerson", "Waldo")
 ⇒  6
```

Mapping and Reducing

Simple Mapping

The following mapping functions (`do`, `map`, `map-as`, `map-into`, `any?`, `every?`) iterate over a number of source collections. Each time through the iteration, a function is applied to one element from each of the source collections. The number of arguments to the function is equal to the number of source collections.

The functions vary in how they handle the results of each function application.

`do` **[Function]**

Iterates over one or more collections for side effect.

Signature: `do` *function collection* `#rest` *more-collections* ⇒ *false*

Arguments:

function	An instance of `<function>`.
collection	An instance of `<collection>`.
more-collections	Instances of `<collection>`.

Values: *false* `#f`.

Description: Applies *function* to corresponding elements of all the *collections* and returns `#f`. If all the *collections* are sequences, `do` guarantees that they will be processed in their natural order.

```
do (method (a b) print (a + b) end,
    #(100, 100, 200, 200),
    #(1, 2, 3, 4))
101
102
203
204
 ⇒  #f
```

`map` [Function]

Iterates over one or more collections and collects the results in a freshly allocated collection.

Signature: `map` *function collection* `#rest` *more-collections* ⇒ *new-collection*

Arguments:

function	An instance of `<function>`.
collection	An instance of `<collection>`.
more-collections	Instances of `<collection>`.

Values:

new-collection	A freshly allocated instance of `<collection>`.

Description: Creates a freshly allocated collection whose elements are obtained by calling *function* on corresponding elements of all the *collections*. If all the *collections* are sequences, processing is performed in the natural order.

`map` returns a collection whose value is an instance of the `type-for-copy` value of *collection*. The new collection is created by calling `make` on that type, with a `size:` initialization argument whose value is the number of corresponding elements in the *collections*.

```
map (\+,
     #(100, 100, 200, 200),
     #(1, 2, 3, 4))
  ⇒  #(101, 102, 203, 204)
```

`map-as` [Function]

Iterates over one or more collections and collects the results in a freshly allocated collection of a specified type.

Signature: `map-as` *type function collection* `#rest` *more-collections* ⇒ *new-collection*

Arguments:

type	An instance of `<type>`. It must be an instantiable subtype of `<mutable-collection>`.
function	An instance of `<function>`.
collection	An instance of `<collection>`.

more-collections
Instances of `<collection>`.

Values: *new-collection* A freshly allocated instance of `<mutable-collection>`.

Description: Creates a freshly allocated collection of type *type* whose elements are obtained by applying *function* to corresponding elements of the *collection* arguments. *type* must be acceptable as the first argument to `make`. `size:` with a non-negative integer value must be an acceptable initarg for `make` of *type*. *new-collection* is created by calling `make` on *type,* with a `size:` initialization argument whose value is the number of corresponding elements in the *collections*. If all the *collections* are sequences (including *new-collection*), processing is done in the natural order.

```
map-as (<vector>, \+,
        #(100, 100, 200, 200),
        #(1, 2, 3, 4))
 ⇒  #(101, 102, 203, 204)
```

`map-into` [Function]

Iterates over one or more collections and collects the results in an existing mutable collection.

Signature: `map-into` *mutable-collection function collection* `#rest` *more-collections* ⇒ *mutable-collection*

Arguments:

mutable-collection
An instance of `<mutable-collection>`.

function An instance of `<function>`.

collection An instance of `<collection>`.

more-collections
Instances of `<collection>`.

Values:

mutable-collection
An instance of `<mutable-collection>`.

Description: Returns the *mutable-collection* argument after modifying it by replacing its elements with the results of applying *function* to corresponding elements of *collection* and *more-collections*.

If *mutable-collection* and all the other *collections* are sequences, processing is done in the natural order.

When *mutable-collection* is an instance of `<stretchy-collection>`, the usual alignment requirement (described in "Collection Alignment" on page 118) is relaxed. In this case, the key sequence of *mutable-collection* is not considered during alignment. Rather, only the key sequences for the source *collections* are aligned, with *function* called on the corresponding elements. The result of each call to *function* is then stored into *mutable-collection* with the corresponding key (possibly stretching *mutable-collection* in the process), using `element-setter`. Other keys in *mutable-collection* remain undisturbed.

mutable-collection may be the same object as *collection* or any of the *more-collections*.

An error is signalled if *mutable-collection* does not have the same `key-test` function as the rest of the *collections*. This is true even if it is a `<stretchy-collection>` and therefore does not get aligned.

```
define variable x = list (10, 9, 8, 7)
map-into (x, \+, #(1, 2, 3, 4), #(100, 100, 200, 200))
 ⇒  #(101, 102, 203, 204)
x
 ⇒  #(101, 102, 203, 204)
```

`any?` **[Function]**

Returns the first true value obtained by iterating over one or more collections.

Signature: `any?` *function collection* `#rest` *more-collections* ⇒ *value*

Arguments:

function	An instance of `<function>`.
collection	An instance of `<collection>`.
more-collections	Instances of `<collection>`.

Values:

value	An instance of `<object>`.

Description: Applies *function* to groups of corresponding elements of *collection* and *more-collections*. If an application of *function* returns true, then `any?` returns that true value. Otherwise *function* returns `#f` when applied to every such group, and `any?` returns `#f`.

If all the *collections* are sequences, `any?` operates in natural order. In all cases, `any?` stops on the first true value returned by *function*.

```
any? (\>, #(1, 2, 3 ,4), #(5, 4, 3, 2))
 ⇒  #t
any? (even?, #(1, 3, 5, 7))
 ⇒  #f
```

`every?` [Function]

Returns true if a predicate returns true when applied to all corresponding elements of a set of collections.

Signature: `every?` *function collection* `#rest` *more-collections* ⇒ *value*

Arguments:

function	An instance of `<function>`.
collection	An instance of `<collection>`.
more-collections	Instances of `<collection>`.

Values:

value	An instance of `<boolean>`.

Description: Applies *function* to groups of corresponding elements of *collection* and *more-collections*. If an application of *function* returns false, then `every?` returns `#f`. Otherwise *function* returns a true value when applied to every such group, and `every?` returns `#t`.

If all the *collections* are sequences, `every?` operates in natural order. In all cases, `every?` stops on the first false value returned by *function*.

```
every? (\>, #(1, 2, 3, 4), #(5, 4, 3, 2))
 ⇒  #f
every? (odd?, #(1, 3, 5, 7))
 ⇒  #t
```

Extensible Mapping Functions

`reduce` **[Open Generic Function]**

Combines the elements of a collection and a seed value into a single value by repeatedly applying a binary function.

Signature: `reduce` *function initial-value collection* ⇒ *value*

Arguments:

function	An instance of `<function>`.
initial-value	An instance of `<object>`.
collection	An instance of `<collection>`.

Values:

value	An instance of `<object>`.

Description: Returns the result of combining the elements of *collection* and *initial-value* according to *function*.

If *collection* is empty, `reduce` returns *initial-value*; otherwise, *function* is applied to *initial-value* and the first element of *collection* to produce a new value. If more elements remain in the *collection*, then *function* is called again, this time with the value from the previous application and the next element from *collection*. This process continues until all elements of *collection* have been processed.

function is a binary function used to combine all the elements of *collection* into a single value. Processing is always done in the natural order for *collection*.

Example

```
define variable high-score = 10
reduce (max, high-score, #(3, 1, 4, 1, 5, 9))
 ⇒  10
reduce (max, high-score, #(3, 12, 9, 8, 8, 6))
 ⇒  12
```

`reduce1` **[Open Generic Function]**

Combines the elements of a collection into a single value by repeatedly applying a binary function, using the first element of the collection as the seed value.

Signature: `reduce1` *function collection* ⇒ *value*

Arguments:

function	An instance of `<function>`.
collection	An instance of `<collection>`.

Values:

value	An instance of `<object>`.

Description: Returns the combination of the elements of *collection* according to *function*.

An error is signaled if *collection* is empty.

`reduce1` is similar to `reduce`, except that the first element of *collection* is taken as the initial value, and all the remaining elements of *collection* are processed as if by `reduce`. (In other words, the first value isn't used twice.)

For unstable collections, "first" element effectively means "an element chosen at random." Processing is done in the natural order for *collection*.

```
reduce1 (\+, #(1, 2, 3, 4, 5))
 ⇒  15
```

`choose` **[Open Generic Function]**

Returns those elements of a sequence that satisfy a predicate.

Signature: `choose` *predicate source-sequence* ⇒ *result-sequence*

Arguments:

predicate	An instance of `<function>`.
source-sequence	An instance of `<sequence>`.

Values:

result-sequence	An instance of `<sequence>`.

Description: Returns a sequence containing those elements of *source-sequence* that satisfy *predicate*. The *result-sequence* may or may not be freshly allocated.

```
choose (even?, #(3, 1, 4, 1, 5, 8, 9))
  ⇒  #(4, 8)
```

`choose-by` **[Open Generic Function]**

Returns those elements of a sequence that correspond to those in another sequence that satisfy a predicate.

Signature: `choose-by` *predicate test-sequence value-sequence* ⇒ *result-sequence*

Arguments:

predicate	An instance of `<function>`.
test-sequence	An instance of `<sequence>`.
value-sequence	An instance of `<sequence>`.

Values: *result-sequence*
An instance of `<sequence>`.

Description: Returns a sequence containing the elements from *value-sequence* which correspond to elements in *test-sequence* that satisfy *predicate*. The *result-sequence* may or may not be freshly allocated.

```
choose-by (even?, range (from: 1),
             #("a", "b", "c", "d", "e", "f", "g", "h", "i"))
  ⇒  #("b", "d", "f", "h")
```

Other Mapping Functions

`member?` **[Open Generic Function]**

Returns true if a collection contains a particular value.

Signature: `member?` *value collection* #key *test* ⇒ *boolean*

Arguments:

value	An instance of `<object>`.

	collection	An instance of `<collection>`.
	test	An instance of `<function>`. The default is `==`.
Values:	*boolean*	An instance of `<boolean>`.

Description: Returns true if *collection* contains *value* as determined by *test*. Otherwise returns false.

The *test* function may be non-commutative: it is always called with *value* as its first argument and an element from *collection* as its second argument.

```
define constant flavors = #(#"vanilla", #"pistachio", #"ginger")
member? (#"vanilla", flavors)
 ⇒  #t
member? (#"banana", flavors)
 ⇒  #f
```

`member?` *val range* #key *test* ⇒ *boolean* **[G.F. Method]**

If *range* is unbounded, this method is guaranteed to terminate if *test* is `==`.

`find-key` [Open Generic Function]

Returns the key in a collection such that the corresponding collection element satisfies a predicate.

Signature: `find-key` *collection function* #key *skip failure* ⇒ *key*

Arguments:	*collection*	An instance of `<collection>`.
	predicate	An instance of `<function>`.
	skip	An instance of `<integer>`. The default is `0`.
	failure	An instance of `<object>`. The default is `#f`.
Values:	*key*	An instance of `<object>`.

Description: Returns a key value such that `(`*predicate* `(element` *collection key*`))` is true. If no element in *collection* satisfies *predicate*, `find-key` returns *failure*.

The *skip* argument indicates that the first *skip* matching elements should be ignored. If *skip* or fewer elements of *collection* satisfy *predicate*, then *failure* is returned. If collection is not stable under iteration, then skip is only useful for finding out whether collection contains at least *skip* elements which satisfy *predicate*; it is not useful for finding a particular element.

```
flavors
 ⇒  #(#"vanilla", #"pistachio", #"ginger")
find-key (flavors, has-nuts?)
 ⇒  1
flavors[1]
 ⇒  #"pistachio"
```

`remove-key!` **[Open Generic Function]**

Modifies an explicit key collection so it no longer has a particular key.

Signature: `remove-key!` *collection key* ⇒ *boolean*

Arguments:

collection	An instance of `<mutable-explicit-key-collection>`.
key	An instance of `<object>`.

Values:

boolean	An instance of `<boolean>`.

Description: Modifies *collection* so that it no longer has a key equal to *key*. Equality is determined by *collection*'s key-test function.

The *boolean* return value will be `#t` if the *key* was present and removed, or `#f` if the key was not present and hence not removed.

`remove-key!` ***table key*** **⇒** ***table*** **[G.F. Method]**

There is a predefined method on `<table>`.

`replace-elements!` **[Open Generic Function]**

Replaces collection elements that satisfy a predicate.

Signature: `replace-elements!` *mutable-collection predicate new-value-fn* `#key` *count* ⇒ *mutable-collection*

Arguments:

mutable-collection	An instance of `<mutable-collection>`.
predicate	An instance of `<function>`.
new-value-fn	An instance of `<function>`.
count	An instance of `<integer>` or `#f`. The default is `#f`.

Values: *mutable-collection* An instance of `<mutable-collection>`.

Description: Replaces those elements of *mutable-collection* for which *predicate* returns true. The elements are replaced with the value of calling *new-value-fn* on the existing element. If *count* is `#f`, all of the matching elements are replaced. Otherwise, no more than *count* elements are replaced.

mutable-collection may be modified by this operation.

```
define variable numbers = list (10, 13, 16, 19)
replace-elements! (numbers, odd?, double)
 ⇒  #(10, 26, 16, 38)
```

`fill!` **[Open Generic Function]**

Fills a collection with a specified value.

Signature: `fill!` *mutable-collection value* `#key` *start end* ⇒ *mutable-collection*

Arguments:

mutable-collection	An instance of `<collection>`.
value	An instance of `<object>`.
start	An instance of `<integer>`.
end	An instance of `<integer>`.

Values: *mutable-collection* An instance of `<collection>`.

Description: Modifies *mutable-collection* so that `(element` *mutable-collection key*`)` returns *value* for every *key*.

If *mutable-collection* is a sequence, then *start* and *end* keywords may be specified to indicate that only a part of the sequence should be filled. *start* is considered an inclusive bound and defaults to `0`; *end* is an exclusive bound and defaults to the length of the sequence.

```
define variable numbers = list (10, 13, 16, 19)
fill! (numbers, 3, start: 2)
 ⇒  #(10, 13, 3, 3)
```

The Iteration Protocol

`forward-iteration-protocol` **[Open Generic Function]**

Returns a group of functions used to iterate over the elements of a collection.

Signature: `forward-iteration-protocol` *collection*
⇒ *initial-state limit next-state finished-state? current-key current-element current-element-setter copy-state*

Arguments:

collection	An instance of `<collection>`.

Values:

initial-state — An instance of `<object>`. The initial iteration state object.

limit — An instance of `<object>` that is used by the *finished-state?* function to determine whether the iteration has been completed.

next-state — An instance of `<function>`. Its signature is

`next-state` *collection state* ⇒ *new-state*

This function steps the iteration by producing a new state from the associated *collection* and *state*. The *next-state* function may or may not modify the *state* argument; it is an error to use a state value after it has been passed to the associated *next-state* function. The *copy-state* function provides a mechanism for saving a particular state in an iteration for later resumption.

finished-state? — An instance of `<function>`. Its signature is

`finished-state?` *collection state limit* ⇒ *boolean*

This function returns `#t` if the iteration of the collection has been completed, i.e., there are no other elements of the collection to consider. It returns `#f` otherwise. It is an error to use a finished state in a call to the associated *next-state*, *current-element*, *current-key* or *current-element-setter* functions.

current-key An instance of `<function>`. Its signature is

`current-key` *collection state* ⇒ *key*

This function returns the unique key associated with *state* in the *collection*. If the *current-key* function were called once with each *state* value produced during an iteration over a collection, the resulting sequence of values would contain every key from the collection exactly once; it would be the key-sequence of the collection.

current-element

An instance of `<function>`. Its signature is

`current-element` *collection state* ⇒ *element*

This function returns the element of *collection* currently indicated by *state*.

current-element-setter

An instance of `<function>`. Its signature is

`current-element-setter` *value collection state* ⇒ *value*

This function sets the element of *collection* indicated by *state* to *value* and returns *value.* If *collection* is not an instance of `<mutable-collection>`, or if the *value* is not of a type acceptable to the collection, an error is signaled.

copy-state An instance of `<function>`. Its signature is

`copy-state` *collection state* ⇒ *new-state*

This function returns a state which represents the same point in the iteration over *collection* as is represented by *state.*

Description: Returns eight values used to implement iteration over the *collection* argument.

Only the *collection* argument this function was called with may be used as the *collection* argument to functions returned by this function. Only the *initial-state* object and state objects returned by the *next-state* and *copy-state* functions may be used as the *state* argument to functions returned by this function. Only the *limit* object may be used as the *limit* argument to the *finished-state?* function.

An example of the use of the iteration protocol is the following definition of a single-argument version of the `do` function:

```
define method do1 (f :: <function>, c :: <collection>)
  let (init, limit, next, end?, key, elt) =
                     forward-iteration-protocol(c);
  for (state = init then next(c, state),
    until end?(c, state, limit))
    f(elt(c, state));
  end for;
end method do1;
```

`forward-iteration-protocol` ***table***
⇒ *initial-state limit next-state finished-state? current-key current-element current-element-setter copy-state* **[G.F. Method]**

The method for `<table>` implements the iteration protocol in terms of the function `table-protocol`.

`backward-iteration-protocol` [Open Generic Function]

Returns a group of functions used to iterate over the elements of a collection in reverse order.

Signature: `backward-iteration-protocol` *collection*
⇒ *initial-state limit next-state finished-state? current-key current-element current-element-setter copy-state*

Arguments:

collection	An instance of `<collection>`.

Values:

initial-state	An instance of `<object>`.
limit	An instance of `<object>`.
next-state	An instance of `<function>`.
finished-state?	An instance of `<function>`.
current-key	An instance of `<function>`.
current-element	An instance of `<function>`.
current-element-setter	An instance of `<function>`.

copy-state An instance of `<function>`.

Description: Returns eight values used to implement reverse iteration over the *collection* argument.

Some collection classes that are stable under iteration support the ability to iterate in the reverse of the natural order, by providing a method on the generic function `backward-iteration-protocol`. The eight values returned by this function are analogous to the corresponding values returned by `forward-iteration-protocol`.

The Table Protocol

The class `<table>` provides an implementation of the iteration protocol, using the function `table-protocol`. Every concrete subclass of `<table>` must provide or inherit a method for `table-protocol`. A complete description of the table protocol is given in "Tables" on page 120.

`table-protocol` **[Open Generic Function]**

Returns functions used to implement the iteration protocol for a tables.

Signature: `table-protocol` *table* ⇒ *test-function hash-function*

Arguments: *table* An instance of `<table>`.

Values: *test-function* An instance of `<function>`. Its signature is

`test-function` *key1 key2* ⇒ *boolean*

test-function is used to compare keys. It returns true if the keys are members of the same equivalence class according to the table's equivalence predicate.

hash-function

An instance of `<function>`. Its signature is

`hash-function` *key* ⇒ *id state*

hash-function computes the hash code of the *key*, using the hash function associated with the table's equivalence predicate. The hash code is returned as two values, *id* (an integer) and *state* (a hash state).

Description: Returns the test-function and hash-function for the `<table>`. These functions are in turn used to implement the other collection operations on `<table>`.

`table-protocol` ***object-table*** ⇒ ***test-function hash-function*** **[G.F. Method]**

The method for `<object-table>` returns `==` as the *test-function* and `object-hash` as the *hash-function*.

The method for `<object-table>` could be written as

```
define method table-protocol (table :: <object-table>)
      => test-function :: <function>,
         hash-function :: <function>;
  values(\==, object-hash);
end method table-protocol;
```

`merge-hash-codes` [Function]

Returns a hash-code created from the merging of two argument hash codes.

Signature: `merge-hash-codes` *id1 state1 id2 state2* `#key` *ordered* ⇒ *merged-id merged-state*

Arguments:

id1	An instance of `<integer>`.
state1	An instance of `<object>`.
id2	An instance of `<integer>`.
state2	An instance of `<object>`.
ordered	An instance of `<boolean>`.

Values:

merged-id	An instance of `<integer>`.
merged-state	An instance of `<object>`.

Description: Computes a new hash code by merging the argument hash codes in some implementation dependent way.

id1, *id2*, and *merged-id* are all integers. *state1*, *state2*, and *merged-state* are all hash states. *ordered* is a boolean and determines whether the algorithm used to perform the merge is permitted to be order dependent. If false, which is the default, then the merged result must be independent of the order in which the argument pairs are provided. If true, then the order of the argument pairs matters because the algorithm used need not be either commutative or associative. Providing a true value for *ordered* is recommended when doing so will not cause the hash function to violate the second constraint on hash functions, because it may result in a better distribution of hash ids.

state1 and *state2* should be the value of `$permanant-hash-state` or hash-states returned from previous calls to `merge-hash-codes` or `object-hash`.

`object-hash` **[Function]**

The hash function for the equivalence predicate `==`.

Signature: `object-hash` *object* ⇒ *hash-id hash-state*

Arguments:	*object*	An instance of `<object>`.
Values:	*hash-id*	An instance of `<integer>`.
	hash-state	An instance of `<object>`.

Description: Returns a hash-code for *object* which corresponds to the equivalence predicate `==`. It is made available as a tool for writing hash functions in which the object identity of some component of a key is to be used in computing the hash code. It returns a hash id (an integer) and associated hash state for the object, computed in some implementation dependent manner. The values returned by `object-hash` when called repeatedly on the same object might not be the same for each call. If the *hash-id* value changes then the *hash-state* value will also change.

Reflective Operations on Types

`instance?` **[Function]**

Tests whether an object is an instance of a type.

Signature: `instance?` *object type* ⇒ *boolean*

Arguments: *object* An instance of `<object>`.

type An instance of `<type>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if *object* is a general instance of *type*.

`subtype?` [Function]

Tests whether a type is a subtype of another type.

Signature: `subtype?` *type1 type2* ⇒ *boolean*

Arguments: *type1* An instance of `<type>`.

type2 An instance of `<type>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if *type1* is a subtype of *type2*. Subtype rules are given in “The Type Protocol” on page 47

`object-class` [Function]

Returns the class of an object.

Signature: `object-class` *object* ⇒ *class*

Arguments: *object* An instance of `<object>`.

Values: *class* An instance of `<class>`.

Description: Returns the class of which *object* is a direct instance.

`all-superclasses` [Function]

Returns all the superclasses of a class.

Signature: `all-superclasses` *class* ⇒ *sequence*

Arguments: *class* An instance of `<class>`.

Values: *sequence* An instance of `<sequence>`. Each element in the sequence is an instance of `<class>`.

Description: Returns all the superclasses of *class* in a sequence. The order of the classes in the sequence will correspond to the class precedence list of *class*.

The result *sequence* should never be destructively modified. Doing so may cause unpredictable behavior. If *class* is sealed, an implementation may choose to signal an error of type `<sealed-object-error>` rather than returning the sequence of all superclasses.

`direct-superclasses` [Function]

Returns the direct superclasses of a class.

Signature: `direct-superclasses` *class* $\Rightarrow$ *sequence*

Arguments: *class* An instance of `<class>`.

Values: *sequence* An instance of `<sequence>`. Each element in the sequence is an instance of `<class>`.

Description: Returns the direct superclasses of *class* in a sequence. These are the classes that were passed as arguments to `make` or `define class` when the *class* was created. The order of the classes in the sequence is the same as the order in which they were passed to `define class` or `make` when *class* was created.

The result *sequence* should never be destructively modified. Doing so may cause unpredictable behavior. If *class* is sealed, an implementation may choose to signal an error of type `<sealed-object-error>` rather than returning the direct superclasses.

`direct-subclasses` [Function]

Returns the direct subclasses of a class.

Signature: `direct-subclasses` *class* $\Rightarrow$ *sequence*

Arguments:	*class*	An instance of `<class>`.
Values:	*sequence*	An instance of `<sequence>`. Each element in the sequence is an instance of `<class>`.

Description: Returns the direct subclasses of *class* in a sequence. These are the classes that have *class* as a direct superclass. The order of the classes in the sequence is not significant.

The result *sequence* should never be destructively modified. Doing so may cause unpredictable behavior. If *class* is sealed, an implementation may choose to signal an error of type `<sealed-object-error>` rather than returning the direct subclasses.

Functional Operations

The following operations are used to create new functions from other functions or objects. Often the Dylan compiler will have special knowledge of these operations, to allow for efficient in-line compilation.

`compose` **[Function]**

Returns the composition of one or more functions.

Signature: `compose` *function1* `#rest` *more-functions* ⇒ *function*

Arguments:	*function1*	An instance of `<function>`.
	more-functions	Instances of `<function>`.
Values:	*function*	An instance of `<function>`.

Description: When called with just a single argument, `compose` returns that argument.

When called with two arguments, `compose` returns a function that applies the second function to its arguments and then applies the first function to the (single) result value.

With three or more arguments, `compose` composes pairs of argument functions, until a single composite function is obtained. (It doesn't matter if the pairings are done from the left or from the right, as long as the order of application is preserved.)

```
define constant number-of-methods =
  compose(size, generic-function-methods)

define constant root-position = compose(position, root-view)
```

`complement` [Function]

Returns a function that expresses the complement of a predicate.

Signature: `complement` *predicate* ⇒ *function*

Arguments: *predicate* An instance of `<function>`.

Values: *function* An instance of `<function>`.

Description: Returns a function that applies *predicate* to its arguments. If the *predicate* returns `#f`, the complement returns `#t`; otherwise, the complement returns `#f`. For example, `odd?` could be defined as `complement(even?)`.

```
choose(complement(zero?), #(1, 3, 0, 4, 0, 0, 3))
  ⇒  #(1, 3, 4, 3)
```

`disjoin` [Function]

Returns a function that expresses the disjunction of one or more predicates.

Signature: `disjoin` *predicate1* `#rest` *more-predicates* ⇒ *function*

Arguments: *predicate1* An instance of `<function>`.

more-predicates Functions.

Values: *function* An instance of `<function>`.

Description: Returns a single function, termed the disjunction of its argument functions. The disjunction accepts any number of arguments and operates by applying the predicates, in order, to the arguments. If any of the predicates returns true, the remaining predicates (if any) are not applied, and the true result is returned. Otherwise, all the predicates will be applied, and `#f` returned.

A disjunction is similar to an `|` expression of calls to the predicates.

```
define constant nonzero? = disjoin(positive?, negative?);
nonzero?(4)
 ⇒  #t
```

`conjoin` [Function]

Returns a function that expresses the conjunction of one or more predicates.

Signature: `conjoin` *predicate1* `#rest` *more-predicates* ⇒ *function*

Arguments:

predicate1	An instance of `<function>`.
more-predicates	Instances of `<function>`.

Values:

function	An instance of `<function>`.

Description: Returns a single function, termed the conjunction of its argument functions. The conjunction accepts any number of arguments and operates by applying the predicates, in order, to the arguments. If any of the predicates returns `#f`, the remaining predicates (if any) are not applied and `#f` is immediately returned. Otherwise, all the predicates will be applied, and the result of the last application is returned.

A conjunction is similar to an & expression of calls to the predicates.

```
choose(conjoin(positive?, integral?), #(-1, -3, 5, -3.7, 3.5, 7))
  ⇒ #(5, 7)
```

`curry` [Function]

Returns a function based on an existing function and a number of default initial arguments.

Signature: `curry` *function* `#rest` *curried-arguments* ⇒ *new-function*

Arguments:

function	An instance of `<function>`.
curried-arguments	Instances of `<object>`.

Values:

new-function	An instance of `<function>`.

Description: Returns a function that applies *function* to *curried-arguments* plus its own arguments, in that order. For example `curry (\>, 6)` is a predicate that returns true for values less than 6; `curry (\=, "x")` is a predicate that tests for equality with the string `"x"`; `curry (\+, 1)` is an incrementing function; `curry (concatenate, "set-")` is a function that concatenates the string `"set-"` to any additional sequences it is passed.

```
define constant all-odd? = curry(every?, odd?)
all-odd?(list(1, 3, 5))
 ⇒ #t

define constant less-than-10? = curry(\>, 10)
less-than-10?(4)
 ⇒ #t
```

`rcurry` [Function]

Returns a function based on an existing function and a number of default final arguments.

Signature: `rcurry` *function* `#rest` *curried-arguments* ⇒ *new-function*

Arguments:

function	An instance of `<function>`.
curried-arguments	Instances of `<object>`.

Values:

new-function	An instance of `<function>`.

Description: Returns a function that applies *function* to *curried-arguments* plus its own arguments, with the *curried-arguments* occuring last.

`rcurry` ("right" curry) operates just like `curry`, except it allows the rightmost arguments of *function* to be specified in advance, rather than the leftmost arguments. For example, `rcurry (\>, 6)` is a predicate that returns true for values greater than 6.

```
define constant number? = rcurry(instance?, <number>)
number?(4)
  ⇒ #t
number?("string")
  ⇒ #f

define constant greater-than-10? = rcurry(\>, 10)
greater-than-10?(4)
  ⇒ #f
```

`always` **[Function]**

Returns a function that always returns a particular object.

Signature: `always` *object* ⇒ *function*

Arguments: *object* An instance of `<object>`.

Values: *function* An instance of `<function>`.

Description: Returns a function that can be called with any number of arguments. The function ignores its arguments and always returns *object*.

```
define constant menu = always("spam!")
menu("today")
  ⇒ "spam!"
menu("tomorrow")
  ⇒ "spam!"
menu(4, 5, 6)
  ⇒ "spam!"
```

Function Application

`apply` **[Function]**

Applies a function to arguments.

Signature: `apply` *function argument* `#rest` *more-arguments* ⇒ `#rest` *values*

Arguments:

function	An instance of `<function>`.
argument	An instance of `<object>` or, if there are no *more-arguments*, an instance of `<sequence>`.
more-arguments	Instances of `<object>`. The last *more-arguments* must be an instance of `<sequence>`.

Values:

values	Instances of `<object>`.

Description: Calls *function* and returns the values which *function* returns. The *argument* and *more-arguments* supply the arguments to *function*. All but the last of *argument* and *more-arguments* are passed to *function* individually. The last of *argument* and *more-arguments* must be a sequence. This sequence is not passed as a single argument to *function*. Instead, its elements are taken individually as arguments to *function*.

```
apply(max, list(3, 1, 4, 1, 5, 9))
  ⇒  9
apply(min 5, 7 list(3, 1, 4))
  ⇒  1

define constant make-string =
       method (#rest init-args) => string :: <string>;
         apply(make, <string>, init-args)
       end;
make-string(fill: 'a', size: 10)
  ⇒  "aaaaaaaaaa"
```

Reflective Operations on Functions

`generic-function-methods` **[Function]**

Returns the methods of a generic function.

Signature: `generic-function-methods` *generic-function* ⇒ *sequence*

Arguments: *generic-function*
An instance of `<generic-function>`.

Values: *sequence* An instance of `<sequence>`. Each element in the sequence is an instance of `<method>`.

Description: Returns a sequence of all of the methods in *generic-function*. The order of the methods in the sequence is not significant. The sequence returned should never be destructively modified. Doing so may cause unpredictable behavior.

If *generic-function* is sealed, an implementation may choose not to return a sequence of methods, but instead signal an error of type `<sealed-object-error>`.

`add-method` **[Function]**

Adds a method to a generic function.

Signature: `add-method` *generic-function method* ⇒ *new-method old-method*

Arguments: *generic-function*
An instance of `<generic-function>`.

method An instance of `<method>`.

Values: *new-method* An instance of `<method>`.

old-method `#f` or an instance of `<method>`.

Description: Adds *method* to *generic-function*, thereby modifying the *generic-function*.

Programs do not commonly call `add-method` directly. It is called by `define method`.

If you add a method to a generic function, and the generic function already has a method with the exact same specializers, then the old method is replaced with the new one.

A single method may be added to any number of generic functions.

`add-method` returns two values. The first is the new *method*. The second will be either the method in *generic-function* which is being replaced by *method*, or it will be `#f` if no method is being replaced.

`add-method` may signal an error of type `<sealed-object-error>` if adding the method or replacing an existing method would cause a sealing violation.

`generic-function-mandatory-keywords` **[Function]**

Returns the mandatory keywords of a generic function, if any.

Signature: `generic-function-mandatory-keywords` *generic-function* ⇒ *keywords*

Arguments: *generic-function*
An instance of `<generic-function>`.

Values: *keywords* The object `#f` or an instance of `<collection>`.

Description: If *generic-function* accepts keyword arguments, returns a collection of the mandatory keywords for *generic-function.* This collection will be empty if the generic function accepts keywords but does not have any mandatory keywords. It returns `#f` if *generic-function* does not accept keyword arguments.

The collection returned should never be destructively modified. Doing so may cause unpredictable behavior.

`function-specializers` **[Function]**

Returns the specializers of a function.

Signature: `function-specializers` *function* ⇒ *sequence*

Arguments: *function* An instance of `<function>`.

Values: *sequence* An instance of `<sequence>`. The elements of the sequence are instances of `<type>`.

Description: Returns a sequence of the specializers for *function*. The length of the sequence will equal the number of required arguments of *function*. The first element of the sequence will be the specializer of the first argument of *function*, the second will be the specializer of the second argument, etc.

The sequence returned should never be destructively modified. Doing so may cause unpredictable behavior.

`function-arguments` [Function]

Returns information about the arguments accepted by a function.

Signature: `function-arguments` *function* ⇒ *required-number rest-boolean kwd-sequence*

Arguments: *function* An instance of `<function>`.

Values:

required-number An instance of `<integer>`.

rest-boolean An instance of `<boolean>`.

kwd-sequence Either `#f` or the symbol `#"all"` or an instance of `<collection>` whose elements are instances of `<keyword>`.

Description: Returns three values:

- *required-number* is the number of required arguments accepted by the function.
- *rest-boolean* indicates whether the function accepts a variable number of arguments.
- *kwd-sequence* indicates whether the function accepts keyword arguments. If the value is `#f` then the function does not accept keyword arguments. Otherwise, the function does accept keyword arguments, and the value is either a collection of the keywords which are permissible for any call to the

function, or the symbol `#"all"` if all keywords are permitted by the function.

Note that particular calls to a generic function may accept additional keywords not included in the third value returned by `function-arguments`, by virtue of their being recognized by applicable methods.

`function-return-values` [Function]

Returns information about the values returned by a function.

Signature: `function-return-values` *function* ⇒ *return-value-types rest-return-value*

Arguments:

function	An instance of `<function>`.

Values:

return-value-types
An instance of `<sequence>`. The elements of the sequence are instances of `<type>`.

rest-return-value
An instance of `<type>` or `#f`.

Description: Returns two values:

- *return-value-types* is a sequence of the types of values returned by the function. The length of the sequence equals the number of required return values of the function. The first element of the sequence is the type of the first return value, the second is the type of the second return value, etc. This sequence returned should never be destructively modified. Doing so may cause unpredictable behavior.
- *rest-return-value* is a indicates whether the function returns a variable number of values and, if so, the type of values which may be returned after the required return values. If the function does not return a variable number of values, `#f` is returned; otherwise a type is returned.

`applicable-method?` [Function]

Tests if a function is applicable to sample arguments.

Signature: `applicable-method?` *function* `#rest` *sample-arguments* ⇒ *boolean*

Arguments: *function* An instance of `<function>`.

sample-arguments Instances of `<object>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns true if *function* is a method or contains a method that would be applicable to *sample-arguments*.

`sorted-applicable-methods` [Function]

Returns all the methods in a generic function that are applicable to sample arguments, sorted in order of specificity.

Signature: `sorted-applicable-methods` *generic-function* `#rest` *sample-arguments* ⇒ *sorted-methods unsorted-methods*

Arguments: *generic-function* An instance of `<generic-function>`.

sample-arguments Instances of `<object>`.

Values: *sorted-methods* An instance of `<sequence>`. Elements of the sequence are instances of `<method>`.

unsorted-methods An instance of `<sequence>`. Elements of the collection are instances of `<method>`.

Description: Returns two sequences that, taken together, contain the methods in *generic-function* that are applicable to the *sample-arguments*. *sorted-methods* contains methods that are more specific than every method that follows them. *unsorted-methods* begins at the first point of ambiguity; it contains the methods that cannot be sorted.

The sequences returned should never be destructively modified. Doing so may cause unpredictable behavior.

`find-method` **[Function]**

Returns the method in a generic function that has particular specializers.

Signature: `find-method` *generic-function specializers* ⇒ *found-method*

Arguments:

generic-function	An instance of `<generic-function>`.
specializers	An instance of `<sequence>`. Elements of the sequence are instances of `<type>`.

Values:

found-method	`#f` or an instance of `<method>`.

Description: Returns the method in *generic-function* that has the specializers in *specializers* as its specializers. The specializers must match exactly for a method to be returned.

If *generic-function* is sealed, an implementation may choose to signal an error of type `<sealed-object-error>` rather than return a value.

`remove-method` **[Function]**

Removes a method from a generic function.

Signature: `remove-method` *generic-function method* ⇒ *method*

Arguments:

generic-function	An instance of `<generic-function>`.
method	An instance of `<method>`.

Values:

method	An instance of `<method>`.

Description: Removes *method* from *generic-function* and returns *method*.

This operation modifies the *generic-function*.

`remove-method` will signal an error if *method* is not in *generic-function*. If *generic-function* is sealed, or if *method* is in an inert domain of *generic-function* , then an error of type `<sealed-object-error>` is signaled.

Operations on Conditions

Signaling Conditions

`signal` **[Function]**

Signals a condition.

Signatures: `signal` *condition* ⇒ *values*
`signal` *string* `#rest` *arguments* ⇒ *values*

Arguments (1):

condition	An instance of `<condition>`.

Arguments (2):

string	An instance of `<string>`.
arguments	Instances of `<object>`.

Values:

values	Instance of `<object>`.

Description: Signals the *condition*, trying each active dynamic handler, the most recent first. If all dynamic handlers decline, `signal` calls `default-handler(`*condition*`)`. If a handler returns, all the values that it returned are returned from `signal`. If `signal` returns when *condition*'s recovery protocol does not allow returning, some handler has violated protocol; `signal` does not check for this error. If *condition* is a restart, the caller of `signal` should always assume that it might return.

The second form signals a condition of type `<simple-warning>`.

`error` **[Function]**

Signals a non-recoverable error.

Signatures: `error` *condition* ⇒ *{will never return}*
`error` *string* `#rest` *arguments* ⇒ *{will never return}*

Arguments (1):

condition	An instance of `<condition>`.

Arguments (2):

string	An instance of `<string>`.
arguments	Instances of `<object>`.

Values: None. `error` will never return.

Description: `error` is similar to `signal` but never returns; if a handler returns, `error` invokes the debugger immediately. `error` is used to make it clear that a program does not expect to receive control again after signaling a condition and might enable the compiler to generate slightly more compact code.

The second form signals a condition of type `<simple-error>`.

`cerror` **[Function]**

Signals a correctable error.

Signatures:

`cerror` *restart-description condition* ⇒ *false*
`cerror` *restart-description string* `#rest` *arguments* ⇒ *false*

Arguments (1):

restart-description	An instance of `<string>`, interpreted as a format string.
condition	An instance of `<condition>`.

Arguments (2):

restart-description	An instance of `<string>`, interpreted as a format string.
string	An instance of `<string>`.
arguments	Instances of `<object>`.

Values:

false	`#f`.

Description: `cerror` is the same as `error` but first establishes a handler for `<simple-restart>`, with a format string of *restart-description* and format arguments of a sequence containing the *arguments*.

If the restart handler is invoked, `cerror` returns `#f`; otherwise, `cerror` never returns. If `cerror` returns, the program should take the corrective actions promised in the *restart-description*. `cerror` is the standard way to signal correctable errors when no special class of restart condition is required.

`break` **[Function]**

Invokes the debugger.

Signatures: `break` *condition* ⇒ *false*
`break` *string* `#rest` *arguments* ⇒ *false*
`break` ⇒ *false*

Arguments (1):

condition	An instance of `<condition>`.

Arguments (2):

string	An instance of `<string>`, interpreted as a format string.
arguments	Instances of `<object>`, interpreted as format arguments.

Arguments (3): None.

Values:

false	`#f`.

Description: Obtains a condition in the same way as `signal` but then invokes the debugger immediately without signaling first. `break` establishes a `<simple-restart>` so the debugger can continue execution. This is useful for breakpoints. `break` always returns `#f`. With no arguments, a default message string is used.

`check-type` **[Function]**

Checks an object to ensure that it is an instance of a specified type.

Signature: `check-type` *value type* ⇒ *value*

Arguments:

value	An instance of `<object>`.
type	An instance of `<type>`.

Values:

value	An instance of `<object>`.

Description: Checks *value* to ensure that it is an instance of *type*, and signal an error of type `<type-error>` if it is not.

`abort` **[Function]**

Aborts and never returns.

Signature: `abort`

Arguments: None.

Values: None. `abort` will never return.

Description: Performs `error(make (<abort>))`.

This function is provided as a convenient shortcut. The call is to `error`, rather than to `signal`, to guarantee that `abort` will never return.

Handling Conditions

`default-handler` **[Open Generic Function]**

Called if no dynamic handler handles a condition.

Signature: `default-handler` *condition* ⇒ *values*

Arguments: *condition* An instance of `<condition>`.

Values: *values* Instances of `<object>`.

Description: Called if no dynamic handler handles a condition.

`default-handler` ***condition*** **⇒** ***false*** **[G.F. Method]**

A predefined method on `<condition>` simply returns `#f`.

`default-handler` ***serious-condition*** **⇒ {does not return}** **[G.F. Method]**

A predefined method on `<serious-condition>` invokes an implementation-defined debugger.

`default-handler` *warning* ⇒ *false* **[G.F. Method]**

A predefined method on `<warning>` prints the warning's message in an implementation-defined way and then returns `#f`.

`default-handler` *restart* ⇒ {does not return} **[G.F. Method]**

A predefined method on `<restart>` signals an error.

`restart-query` **[Open Generic Function]**

Called to query the user and restart.

Signature: `restart-query` *restart* ⇒ *values*

Arguments: *restart* An instance of `<restart>`.

Values: *values* Instances of `<object>`.

Description: Engages the interactive user in a dialog and stores the results in slots of *restart*.

This function is designed to be called from a handler, after making a restart and before signaling it. The debugger uses `restart-query`, for example. There is a default method for `<restart>` which does nothing.

`return-query` **[Open Generic Function]**

Called to query the user and return.

Signature: `return-query` *condition* ⇒ *values*

Arguments: *condition* An instance of `<condition>`.

Values: *values* Instances of `<object>`.

Description: If the recovery protocol of *condition* allows returning values, this engages the program user in a dialog and returns the results as any number of values, which the handler should return.

`return-query` should not be called if `return-allowed?` returns `#f`. Programs which define condition classes whose recovery protocol allows returning values should ensure that there is an appropriate method for this function defined on or inherited by the condition class.

Introspection on Conditions

`do-handlers` **[Function]**

Applies a function to all dynamically active handlers.

Signature: `do-handlers` *function* ⇒ *false*

Arguments: *function* An instance of `<function>`.

Values: *false* `#f`.

Description: Applies *function* to all dynamically active handlers, the most recently established first. *function* receives four arguments: *type*, *test*, *function*, and *init-arguments*. The arguments describe a dynamically active handler. All arguments have dynamic extent and must not be modified. *test* defaults to a function that always returns `#t`. *init-arguments* will be an empty sequence if it was not supplied by the handler.

`return-allowed?` **[Open Generic Function]**

Returns true if a condition's recovery protocol allows returning values.

Signature: `return-allowed?` *condition* ⇒ *boolean*

Arguments: *condition* An instance of `<condition>`.

Values: *boolean* An instance of `<boolean>`.

Description: Returns `#t` if the recovery protocol of *condition* allows returning values, or `#f` if it does not.

There is a default method for `<condition>` that returns `#f`. Programs which define condition classes whose recovery protocol allows returning values should ensure that there is an appropriate method for this function defined on or inherited by the condition class.

`return-description` **[Open Generic Function]**

Returns a description of a condition's returned values.

Signature: `return-description` *condition* ⇒ *description*

Arguments: *condition* An instance of `<condition>`.

Values: *description* `#f` or an instance of `<string>` or an instance of `<restart>`.

Description: If the recovery protocol of this condition allows returning values, `return-description` returns a description of the meaning of returning values.

This *description* can be a restart, a string, or `#f`. `return-description` should not be called if `return-allowed?` returns `#f`. If you define your own condition class whose recovery protocol allows returning values, you need to define a method for `return-description` unless the inherited method is suitable.

`condition-format-string` **[Function]**

Returns the format string of a simple condition.

Signature: `condition-format-string` *simple-condition* ⇒ *format-string*

Arguments: *simple-condition*
An instance of `<simple-error>`, `<simple-warning>`, or `<simple-restart>`.

Values: *format-string* An instance of `<string>`.

Description: Returns the format string that was supplied as an initialization argument when the *simple-condition* was created.

`condition-format-arguments` [Function]

Returns the format arguments of a simple condition.

Signature: `condition-format-arguments` *simple-condition* ⇒ *format-args*

Arguments: *simple-condition*

An instance of `<simple-error>`, `<simple-warning>`, or `<simple-restart>`.

Values: *format-args* An instance of `<sequence>`.

Description: Returns the sequence of format arguments that was supplied as an initialization argument when the *simple-condition* was created.

`type-error-value` [Function]

Returns the value which was not of the expected type.

Signature: `type-error-value` *type-error* ⇒ *object*

Arguments: *type-error* An instance of `<type-error>`.

Values: *object* An instance of `<object>`.

Description: Returns the value which was not of the expected type, and thereby led to the type error.

`type-error-expected-type` [Function]

Returns the expected type of the type check that led to the type error.

Signature: `type-error-expected-type` *type-error* ⇒ *type*

Arguments: *type-error* An instance of `<type-error>`.

Values: *type* An instance of `<type>`.

Description: Returns the expected type of the type check that led to the type error.

C H A P T E R 1 3

Other Built-In Objects

Contents

Other Built-In Objects

#t **[<boolean>]**

The canonical true value.

#f **[<boolean>]**

The false value.

$permanent-hash-state **[<object>]**

A hash state that is always valid.

This is an implementation-dependent hash state that indicates that the associated hash id is always valid, and does not depend on any mutable property of the object that can be changed without a visible modification to the object.

#() **[<empty-list>]**

The empty list.

C H A P T E R 1 4

The Built-In Macros and Special Operators

Contents

Overview

This chapter contains descriptions of the built-in macros, special definitions, and special operators defined by Dylan.

The syntax used in this chapter is described in "Manual Notation" on page 6.

Definitions

Definitions are used to declare the overall structure of a program. They often define one or more module bindings, but do not always do so. Definitions can only appear at top level in a program. Definitions do not return values.

Table 14-1 Definitions

Macro	Description	Page
`define variable`	Defines and initializes a variable binding in the current module.	362
`define constant`	Defines and initializes a constant binding in the current module.	363
`define generic`	Defines a constant binding in the current module and initializes it to a new generic function.	364
`define method`	Adds a method to a generic function, and potentially defines a constant binding in the current module containing a new generic function.	365
`define class`	Defines a constant binding in the current module and initializes it to a new class.	366
`define module`	Defines and names a module, describing the imports and exports of the module.	369

Table 14-1 Definitions (continued)

Macro	Description	Page
`define library`	Defines and names a library, describing the imports and exports of the library.	374
`define domain`	Restricts the ways in which a generic function and set of types can be extended, thereby enabling additional error checking and compiler optimization.	376
`define macro`	Defines a constant module binding containing a macro.	377

`define variable` [Definition]

Defines and initializes a variable binding in the current module.

Macro Call: `define` { *adjective* }* `variable` *variables* = *init*

Arguments:

adjective	unreserved-name$_{bnf}$. The adjectives allowed are implementation dependent.
variables	variable$_{bnf}$ | (variable-list$_{bnf}$)
init	expression$_{bnf}$

Description: `define variable` creates variable bindings in the current module.

The values returned by *init* are used to initialize the bindings. The first value returned is bound to the first *variable*, the second value to the second *variable*, etc. The last *variable* may be preceded by `#rest`, in which case it is bound to a sequence containing all the remaining values.

If more than one binding is defined, the *variables* are enclosed in parentheses and separated by commas.

```
define variable *elapsed-time* = 0;

define variable (*whole-part*, *remainder*) = truncate(*amount*);

define variable (*first-value*, #rest *rest-values*)
                 = get-inital-orders();
```

Module bindings may be specialized. This ensures that their value will always be of a given type. An attempt to initialize or assign the binding to a value not of that type will signal an error of type `<type-error>`.

```
define variable *elapsed-time* :: <integer> = 0;

define variable *front-window* :: union (<window>, singleton(#f))
                 = initial-front-window();

define variable (*whole-part* :: <integer>, *remainder* ::
<real>)
                 = truncate(*amount*);
```

define constant [Definition]

Defines and initializes a constant binding in the current module.

Macro Call: `define` { *adjective* }* `constant` *constants* = *init*

Arguments:

adjective	unreserved-name$_{bnf}$. The adjectives allowed are implementation dependent.
constants	variable$_{bnf}$ | (variable-list$_{bnf}$)
init	expression$_{bnf}$

Description: Creates constant bindings in the current module.

The values returned by *init* are used to initialize the constant bindings. The first value returned is bound to the first *constant*, the second value to the second *constant*, etc. The last *constant* may be preceded by `#rest`, in which case it is bound to a sequence containing all the remaining values.

If more than one *constant* is defined, the *constants* are enclosed in parentheses and separated by commas.

```
define constant $start-time = get-current-time();

define constant $pi = 3.14159;

define constant ($whole-pie, $piece-pie) = truncate($pi);
```

Module constants may be specialized. This ensures that their value is of a given type. An attempt to initialize the constant to a value not of that type will signal an error of type `<type-error>`.

```
define constant $start-time :: <integer> = get-current-time();
```

A constant binding cannot be assigned a new value. However, the object which is the value of the constant binding is not necessarily itself immutable. For example, if a constant binding contains a sequence, the elements of the the sequence may be settable.

define generic [Definition]

Defines a constant binding in the current module and initializes it to a new generic function.

Macro Call: `define` { *adjective* }* `generic` *name parameter-list* [*options*]

Arguments:

adjective	unreserved-name$_{bnf}$. The allowed adjectives are `sealed` and `open`. These adjectives are mutually exclusive. The default is `sealed`. Additional implementation-defined adjectives may be supported.
name	variable-name$_{bnf}$
parameter-list	([parameters$_{bnf}$]) [=> *values*]
options	comma-property-list$_{bnf}$
values	variable$_{bnf}$ | ([values-list$_{bnf}$])

Description: `define generic` is used to define generic functions.

It creates a constant module binding with the name *name*, and initializes it to a new generic function described by the *adjectives*, *parameter-list* and *options*.

The *adjectives* specify whether the generic function is sealed. A complete description of generic function sealing is given in“Declaring Characteristics of Generic Functions” on page 133.

The *parameter-list* specifies the parameters and return values of the generic function and thereby constrains which methods may be added to it. For a complete description of these constraints, see “Parameter List Congruency” on page 91.

The *options* are alternating keywords and values. No options are defined by the language. They may be supplied by individual implementations.

The following example defines a generic function of two required arguments and one return value. All methods added to the generic function must also take two arguments and return one value. The first argument will always be specialized to a subtype of `<animal>`, the second argument will always be specialized to a subtype of `<number>`, and the return value will always be specialized to a subtype of `<number>`.

```
define generic cut-hair (subject :: <animal>, new-length ::
<number>)
                              => (new-length :: <number>)
```

The use of the same name for a parameter and return value indicates that the parameter is returned as the value. This is only a convention; it is not enforced by the language.

The following example defines a generic function with one required parameter and one mandatory keyword parameter, `strength:`. Methods added to the generic function must have one required parameter, they must accept keyword arguments, and they must permit the keyword argument `strength:`.

```
define generic brew (brand :: <coffee-brand>, #key strength)
                                 => (coffee :: <coffee>)
```

define method [Definition]

Adds a method to a generic function, and potentially defines a constant binding in the current module containing a new generic function.

Macro Call: `define` { *adjective* }* `method` *name parameter-list*
  [*body*]
`end` [`method`] [*name*]

Arguments:	*adjective*	unreserved-name$_{bnf}$. The allowed adjective is `inert`. Additional implementation-defined *adjectives* may be supported.
	name	variable-name$_{bnf}$

parameter-list	$\text{parameter-list}_{bnf}$
body	body_{bnf}

Description: `define method` creates a method and adds it to the generic function in *name*. If the module binding *name* is not already defined, it is defined as with `define generic`. Thus, `define method` will create a new generic function or extend an old one, as needed.

The *adjective* allows a sealing declaration to be made about the generic function to which the method is added. The effect of this adjective is described in “Abbreviations for Define Inert Domain” on page 136.

The *parameter-list* describes the parameters and return values of the method, including their number and type. The method can be called only with arguments that match the types of the parameters, and the method will always return values in the quantity and typed declared. Methods added to a generic function must have parameter lists that are congruent with the generic function’s parameter list. A complete description of parameter lists is given in “Parameter Lists” on page 82.

When the method is called, new local bindings are created for the parameters, initialized to the arguments of the call. The *body* is then executed in the environment containing these bindings.

```
define method tune (device :: <radio>) => (station :: <station>)
  // method body goes here
end method tune
```

`define class` [Definition]

Defines a constant binding in the current module and initializes it to a new class.

Macro Call: `define` { *class-adjective* }* `class` *name* `(` { *superclass* } `,+` `)`
  { *slot-spec* `|` *init-arg-spec* `|` *inherited-slot-spec* } `;*`
`end` [`class`] [*name*]

Arguments: *class-adjective*	unreserved-name$_{bnf}$. The allowed adjectives are `abstract`, `concrete`, `primary`, `free`, `sealed`, and `open`. Additional implementation-dependent class-adjectives may be supported.
name	variable-name$_{bnf}$
superclass	expression$_{bnf}$
slot-spec	{ *slot-adjective* }* [*allocation*] `slot` *getter-name* [`::` *type*] [*init-expression*] { `,` *slot-option* }*
init-arg-spec	[`required`] `keyword` symbol$_{bnf}$ [*init-expression*] { `,` *init-arg-option* }*
inherited-slot-spec	`inherited slot` *getter-name* [*init-expression*] { `,` *inherited-option* }*
slot-adjective	unreserved-name$_{bnf}$. Supported slot-adjectives are `constant` and `inert`. Additional implementation-dependent slot-adjectives may be supported.
allocation	unreserved-name$_{bnf}$. Supported allocations are `instance`, `class`, `each-subclass`, and `virtual`. Additional implementation-defined allocations may be supported.
getter-name	variable-name$_{bnf}$
type	operand$_{bnf}$
init-expression	= expression$_{bnf}$
slot-option	*setter-option* | *init-keyword-option* | *required-init-keyword-option* | *init-value-option* | *init-function-option* | *type-option*
init-arg-option	*type-option* | *init-value-option* | *init-function-option*
inherited-option	*init-value-option* | *init-function-option*
setter-option	`setter:` { variable-name$_{bnf}$ | `#f` }

init-keyword-option
`init-keyword:` symbol$_{bnf}$

required-init-keyword-option
`required-init-keyword:` symbol$_{bnf}$

init-value-option
`init-value:` expression$_{bnf}$

init-function-option
`init-function:` expression$_{bnf}$

type-option `type:` expression$_{bnf}$

Description: `define class` is used to define classes.

It creates a constant module binding with the name *name*, and initializes it to a new class.

The *class-adjectives* provide sealing information about the class. Among the adjectives, `abstract` and `concrete` are mutually exclusive, `primary` and `free` are mutually exclusive, and `sealed` and `open` are mutually exclusive. Additional implementation-defined adjectives may be supported. See "Declaring Characteristics of Classes" on page 132 for a complete description of these adjectives.

The *superclasses* are the classes from which the new class directly inherits. The rules of inheritance are described in "Class Inheritance" on page 51 and "Computing the Class Precedence List" on page 52.

The *init-expression*, *required-init-keyword-option*, *init-value-option*, and *init-function-option* are all mutually exclusive in a single *slot-spec*, *init-arg-spec*, or *inherited-slot-spec*.

Each *slot-spec* describes a slot specification in the class. Slot specifications are described in "Slot Specifications" on page 57

Each *init-arg-spec* describes the handling of an initialization argument specification of the class. Initialization argument specifications are described in "Initialization Argument Specifications" on page 67.

Each *inherited-slot-spec* describes an inherited slot specification of the class. Inherited slot specifications are described in "Inherited Slot Specifications" on page 66.

`define module` [Definition]

Defines and names a module, describing the imports and exports of the module.

Macro Call: `define module` *module-name*
{ *export-clause* | *create-clause* | *use-clause* } `;`*
`end` [`module`] [*module-name*]

Arguments:

module-name	name_{bnf}
export-clause	`export` { $\text{ordinary-name}_{bnf}$ } `,`*
create-clause	`create` { $\text{ordinary-name}_{bnf}$ } `,`*
use-clause	`use` *used-module* { `,` *option* }*
used-module	$\text{ordinary-name}_{bnf}$
option	*import-option* |
	exclude-option |
	prefix-option |
	rename-option |
	export-option
import-option	`import: all` | { { *variable-spec* } `,`* }
variable-spec	name_{bnf} [=> name_{bnf}]
exclude-option	`exclude:` { { name_{bnf} } `,`* }
prefix-option	`prefix:` $\text{string-literal}_{bnf}$
rename-option	`rename:` { { name_{bnf} => name_{bnf} } `,`* }
export-option	`export: all` | { { name_{bnf} } `,`* }

Description: `define module` defines a module with the given name. It describes which modules are used by the module being defined, which bindings are imported from the used modules, and which bindings are exported by the module being defined.

Circular use relationships among modules are not allowed. The graph of the module-uses-module relation must be directed and acyclic.

Like other definitions, module definitions are only allowed at top level. Like all constituents, module definitions are contained in a module. The names of bindings being imported and exported in a module definition refer to bindings in the module being defined and the modules being used. These are not affected by the module which contains the module definition.

There is no prohibition against macros which expand into module definitions.

- *module-name* is the name of the module being defined. Note that no binding is created for this name. The namespaces of modules, libraries, and bindings are distinct. The module name is scoped within the library containing the module.
- An *export-clause* specifies bindings that are to be exported from the module being defined. Each name is the name of one such binding. These bindings must be defined by a definition in the module being defined. It is an error if any of the bindings were imported from other modules. It is allowed for the same name to appear more than once, since this is sometimes useful for documentation purposes.
- A *create-clause* specifies that the named bindings are to be declared owned by and exported from the module being defined. Each name is the name of a binding to declare and export. These bindings must not be defined by a definition in the module being defined, and they must not be imported from another module. They must be defined by a definition in a module which uses the module being defined. It is allowed for the same name to appear more than once, since this is sometimes useful for documentation purposes.
- Each *use-clause* describes a set of bindings to be imported from another module. There may be multiple use clauses and there may even be multiple use clauses importing from the same module. If there are multiple use clauses importing from the same module, the bindings imported are the sum of the binding imported by each use clause. Because of renaming, it is possible for the same binding to imported multiple times under different names. This is not an error.
  Within a use clause, the *used-module* is the name of the module being used, and the options control which bindings are to be imported from that module, whether and how they should be renamed, and whether they should be rexported from the module being defined. Each of these options applies within the scope of the particular use clause, and does not affect the behavior of other use clauses (even if the other use clauses indicate the same module). The various options may each appear no more than once in a single use clause. They may appear in any order.

- An *import-option* describes which bindings should be imported. It can be the name `all`, or a series of comma-delimited *variable-specs* enclosed in curly braces. The default is `all`, indicating that all bindings should be imported. If a series of *variable-specs* is specified, only the indicated variables are imported.
- A *variable-spec* is a name, or two names separated by an arrow. In the first form, the binding has the same name in the module being used and the module being defined. In the second form the binding is renamed as it is imported. The name preceding the arrow is the name of the binding in the module being used, and the name following the arrow is the name of the binding in the module being defined.
- An *exclude-option* indicates bindings which should not be imported from the module being used. The default is the empty set. This option may only specify a non-empty set if the import option is `all`.
- A *prefix-option* indicates a prefix to be given to all binding names as they are imported. This option can be overriden for individual bindings by supplying a renaming in a rename option or import option. The default prefix option is the empty string.
- A *rename-option* indicates how individual bindings should be renamed as they are imported. It is a comma-delimited series of entries surrounded by curly braces. Each entry is a pair of names separated by an arrow. The name preceding the arrow is the name of the binding in the module being used, and the name following the arrow is the name of the binding in the module being defined. The default for this option is the empty set.
- An *export-option* indicates which imported bindings should be rexported from the module being defined. It can be the name `all`, or a series of comma-delimited names enclosed in curly braces. Each name is the name of the binding in the module being defined as well as the name under which it will be exported. (There is no option to rename on export) Each binding indicated must have been imported by this use clause. It is allowed for the same name to appear more than once, as this is sometimes useful for documentation purposes. `all` indicates that all the bindings imported by this use clause should be exported. The default value for this option is the empty set.

```
define module graphics
  use dylan;
  create draw-line,
         erase-line,
         invert-line,
         skew-line
         frame-rect,
         fill-rect,
         erase-rect,
         invert-rect;
end module graphics;

define module lines
  use dylan;
  use graphics,
    import: {draw-line,
             erase-line,
             invert-line,
             skew-line};
end module lines;

define module rectangles
  use dylan;
  use graphics,
    prefix: "graphics$",
    exclude: {skew-line};
end module rectangles;

define module dylan-gx
  use dylan, export: all;
  use graphics,
    rename: {skew-line => warp-line},
      export: all;
end module dylan-gx;
```

The modules created by these module declarations would have access to bindings with the following names:

```
graphics
       draw-line
       erase-line
       invert-line
```

```
        skew-line
        frame-rect
        fill-rect
        erase-rect
        invert-rect
        plus all the bindings in the Dylan module

lines
        draw-line
        erase-line
        invert-line
        skew-line
        plus all the bindings in the Dylan module

rectangles
        graphics$draw-line
        graphics$erase-line
        graphics$invert-line
        graphics$frame-rect
        graphics$fill-rect
        graphics$erase-rect
        graphics$invert-rect
        plus all the bindings in the Dylan module

dylan-gx
        draw-line
        erase-line
        invert-line
        warp-line
        frame-rect
        fill-rect
        erase-rect
        invert-rect
        plus all the bindings in the Dylan module
```

The `lines` and `rectangles` modules do not export any variables. They are presumably used to provide definitions for the variables created and exported by the `graphics` modules. The difference between the `graphics` module and the `dylan-gx` module is that one variable is renamed, and the `dylan-gx` module exports the variables which it imports from the `dylan` module, while the `graphics` module does not.

`define library` [Definition]

Defines and names a library, describing the imports and exports of the library.

Macro Call: `define library` *library-name*
{ *export-clause* | *use-clause* } `;*`
`end` [`library`] [*library-name*]

Arguments:

library-name	name_{bnf}
use-clause	`use` *used-library* { `,` *option* }*
export-clause	`export` { $\text{ordinary-name}_{bnf}$ } `,*`
used-library	$\text{ordinary-name}_{bnf}$
option	*import-option* |
	exclude-option |
	prefix-option |
	rename-option |
	export-option
import-option	`import: all` | `{` { *module-spec* } `,*` `}`
module-spec	name_{bnf} [=> name_{bnf}]
exclude-option	`exclude:` `{` { name_{bnf} } `,*` `}`
prefix-option	`prefix:` $\text{string-literal}_{bnf}$
rename-option	`rename:` `{` { name_{bnf} => name_{bnf} } `,*` `}`
export-option	`export: all` | `{` { name_{bnf} } `,*` `}`

Description: `define library` defines a library with the given name. It describes which libraries are used by the library being defined, which modules are imported from the used libraries, and which modules are exported by the library being defined.

Circular use relationships among libraries are not allowed. The graph of the library-uses-library relation must be directed and acyclic.

Like other definitions, library definitions are only allowed at top level. Like all constituents, library definitions are contained in a module. The names of modules being imported and exported by a library definition do not refer to bindings, and are not affected by the environment in which the library definition occurs.

There is no prohibition against macros which expand into library definitions.

- *library-name* is the name of the library being defined. Note that no binding is created for this name. The namespaces of libraries, modules, and bindings are distinct. The library name is scoped along with the other library names in the program.
- An *export-clause* specifies modules that are to be exported from the library being defined. Each name is the name of one such module. It is an error if any of the modules were imported from other libraries. It is allowed for the same name to appear more than once, since this is sometimes useful for documentation purposes.
- Each *use-clause* describes a set of modules to be imported from another library. There may be multiple use clauses and there may even be multiple use clauses importing from the same library. If there are multiple use clauses importing from the same library, the modules imported are the sum of the modules imported by each use clause. Because of renaming, it is possible for the same module to imported multiple times under different names. This is not an error.
  Within a use clause, the *used-library* is the name of the library being used. The mechanism by which this name is associated with another library is implementation defined.
  The *options* control which modules are to be imported from that library, whether and how they should be renamed, and whether they should be rexported from the library being defined. Each of these options applies within the scope of the particular use clause, and does not affect the behavior of other use clauses (even if the other use clauses indicate the same library). The various options may each appear no more than once in a single use clause. They may appear in any order.
  - An *import-option* describes which modules should be imported. It can be the name `all`, or a series of comma-delimited *module-specs* enclosed in curly braces. The default is `all`, indicating that all modules should be imported. If a series of *module-specs* is specified, only the indicated modules are imported.

- A *module-spec* is a name, or two names separated by an arrow. In the first form, the module has the same name in the library being used and the library being defined. In the second form the module is renamed as it is imported. The name preceding the arrow is the name of the module in the library being used, and the name following the arrow is the name of the module in the library being defined.
- An *exclude-option* indicates modules which should not be imported from the library being used. The default is the empty set. This option may only specify a non-empty set if the import option is `all`.
- A *prefix-option* indicates a prefix to be given to all module names as they are imported. This option can be overriden for individual modules by supplying a renaming in the rename option or import option. The default prefix option is the empty string.
- A *rename-option* indicates how individual modules should be renamed as they are imported. It is a comma-delimited series of entries surrounded by curly braces. Each entry is a pair of names separated by an arrow. The name preceding the arrow is the name of the module in the library being used, and the name following the arrow is the name of the module in the library being defined. The default for this option is the empty set.
- An *export-option* indicates which imported modules should be rexported from the library being defined. It can be the name `all`, or a series of comma-delimited names enclosed in curly braces. Each name is the name of the module in the library being defined as well as the name under which it will be exported. (There is no option to rename on export) Each module indicated must have been imported by this use clause. It is allowed for the same name to appear more than once, as this is sometimes useful for documentation purposes. `all` indicates that all the modules imported by this use clause should be exported. The default value for this option is the empty set.

define inert domain [Definition]

Restricts the ways in which a generic function and set of types can be extended, thereby enabling additional error checking and compiler optimization.

Macro Call: `define inert domain` *generic-function* `(` { *type* } `,*` `)`

Arguments: *generic-function* variable-name$_{bnf}$

type expression$_{bnf}$

Description: `define inert domain` seals the specified *generic-function* over the domain indicated by the *types*. For a complete description of the rules governing `define inert domain` and the implications of a `define inert domain` definition, see “Define Inert Domain” on page 133.

- *generic-function* is the name of a module binding containing an explicitly defined generic function.
- Each *type* is an expression, the value of which must be a type. The number of *types* must be the same as the number of required arguments accepted by *generic-function.*

define macro [Special Definition]

Defines a constant module binding containing a macro.

Macro Call: `define macro` *macro-definition*

Arguments: *macro-definition* macro-definition$_{bnf}$

Description: See Chapter 10, “Macros,” for a complete description of the macro system.

Note that `define macro` is not a defining macro but a special definition. It is not named by a binding, and so it cannot being excluded or renamed using module operations.

Local Declarations

Local declarations are used to create bindings or install handlers that are active for the remainder of the innermost body containing the declaration. Bindings created by local declarations can be referenced only in the remaining program text of the body. Handlers installed are active while the execution of the remainder of the body is active, which includes the time during which any functions called from the remainder of the body are active.

Table 14-2 Local Declarations

Macro	Description	Page
`let`	Creates and initializes new local bindings within the smallest enclosing implicit body.	378
`local`	Creates new local bindings within the smallest enclosing implicit body and initializes them to local methods which can be self-recursive and mutually-recursive.	379
`let handler`	Establishes a condition handler for the duration of the execution of smallest enclosing implicit body.	380

`let` [Local Declaration]

Creates and initializes new local bindings within the smallest enclosing implicit body.

Macro Call: `let` *variables* = *init* `;`

Arguments:

variables	variable$_{bnf}$ `|` `(` variable-list$_{bnf}$ `)`
init	expression$_{bnf}$

Description: `let` creates local bindings for the *variables*, and initializes them to the values returned by *init*. The bindings are visible for the remainder of the smallest enclosing implicit body.

The first value returned by the *init* is bound to the first *variable*, the second value to the second *variable*, etc. The last *variable* may be preceded by `#rest`, in which case it is bound to a sequence containing all the remaining values.

Each *variable* is a variable-name or a variable-name followed by a specializer.

If more than one binding is defined, the *variables* are enclosed in parentheses and separated by commas.

```
let start = 0;

let (whole-part, remainder) = truncate(amount);

let (first-value, #rest rest-values) = get-inital-values();
```

Local variables may be specialized. This ensures that their value will always be of a given type. An attempt to initialize or assign the variable to a value not of that type will signal an error of type `<type-error>`.

```
let elapsed-time :: <integer> = 0;

let the-front-window :: <window> = front-window();

let(whole-part :: <integer>, remainder :: <real>) =
truncate(amount);
```

local **[Local Declaration]**

Creates new local bindings within the smallest enclosing implicit body and initializes them to local methods which can be self-recursive and mutually-recursive.

Macro Call: `local{[method]`*name parameter-list* `[`*body*`] end[method][`*name*`]},`$^+$

Arguments:	*name*	variable-name$_{bnf}$
	parameter-list	parameter-list$_{bnf}$
	body	body$_{bnf}$

Description: `local` is creates local methods which may be mutually recursive and self-recursive.

Each *name* creates a new local binding. The binding is initialized to a new method specified by the *parameter-list* and *body*. In addition to being visible for the remainder of the smallest enclosing implicit body, the bindings created for the *names* are visible to the *parameter-lists* and *bodies* of all the methods created by the `local` declaration.

The *parameter-list* is a standard method parameter list. A complete description of parameter lists is given in “Parameter Lists” on page 82.

The *body* is an implicit body.

`let handler` [Local Declaration]

Establishes a condition handler for the duration of the execution of smallest enclosing implicit body.

Macro Call: `let handler` *condition* `=` *handler*

Arguments:

condition	*type* | `(` *type* `{` `,` *option* `}*` `)`
type	expression$_{bnf}$
option	*test-option* | *init-option*
test-option	`test:` expression$_{bnf}$
init-option	`init-arguments:` expression$_{bnf}$
handler	expression$_{bnf}$

Description: `let handler` establishes a new condition handler which is in effect for the duration of the execution of the remainder of the smallest enclosing implicit body. Unlike the local declarations `let` and `local`, `let handler` does not create any bindings.

- The *condition* describes the conditions for which the handler is applicable.
  - The *type* is the type of the applicable conditions. The handler will be applicable to conditions that are general instances of *type*.
  - The *test-option* is a function which is called to further test the applicability of the handler. When a condition of type *type* is signaled, the test function will be called with that condition as an argument. If the test returns true, the handler is considered applicable to the condition. If the test returns false, the handler is considered to be inapplicable to the condition. The default value of this option is a function that always returns true. There can be at most one *test-option*.
    An example use for this feature is a restart handler for restarting only from a particular condition object, for example restarting from an

unbound-slot error by setting the slot and retrying the invocation of the accessor. The `<set-and-continue>` restart condition will have the signaled `<unbound-slot>` condition in a slot, and the handler's test will check for it. (These class names are invented for this example and are not part of the specification.)

- The *init-option* is a sequence of alternating keywords and objects which can be used as initialization arguments to construct a condition to which the handler is applicable. It defaults to an empty sequence. For example, if the handler is a restart handler, a program could use the initialization arguments to construct a restart. (The program would retrieve the keyword/value pairs by calling `do-handler`.) There can be at most one *init-option*.

- The *handler* is function called to handle a condition that matches *type* and passes *test-option*. The function should accept two arguments. The first argument will be the condition being signaled, and the second argument will be a next-handler function. The handler handles the condition by taking a non-local exit, returning values according to the condition's recovery protocol, or tail-recursively calling `signal` of a restart. The function can decline to handle the condition by tail-recursively calling the next-handler function with no arguments.

test-option and *handler* are distinct so that handler applicability can be tested without actually handling (which might take a non-local exit). One use for this is constructing a list of available restart handlers.

There is no "condition wall," i.e., when executing *handler* the set of available handlers is not reset to the handlers that were in effect when the `let handler` was entered.

Implementations are encouraged to implement `let handler` in a way that optimizes establishing a handler for both speed and space, even if that increases the cost of signaling. The assumption is that most of the time a handler will never be used, because the exception it is looking for will never occur.

type, *handler*, *test-option*, and *init-option* are executed before execution of the rest of the enclosing body begins.

Statements

Statements are used to implement a variety of program constructs.

Many statements include an optional implicit body, which may contain one or more constintuents separated by semicolons. When an implicit body is executed, the expressions in the implicit body are executed in order (left to right). The values of the implicit body are the values of the last expression. If the optional implicit body is not present or contains no expressions, the return value is `#f`.

Table 14-3 Statements

Macro	Description	Page
`if`	Executes an implicit body if the value of a test is true or an alternate if the test is false.	383
`unless`	Executes an implicit body unless the value of a test is true.	385
`case`	Executes a number of tests until one is true, and then executes an implicit body associated with the true test.	385
`select`	Compares a target object to a series of potential matches, and executes an implicit body associated with the first match found.	386
`while`	Repeatedly executes a body until a test expression is false.	388
`until`	Repeatedly executes a body until a test expression is true.	388
`for`	Performs general iteration over a body, updating bindings and performing end tests on each iteration.	389

Table 14-3 Statements (continued)

Macro	Description	Page
`begin`	Executes expressions in a body, in order.	392
`block`	Executes a body with several options for non-standard flow of control.	392
`method`	Creates and returns a method.	396

Conditionals

The following statements are used to perform conditional execution.

`if` [Statement]

Executes an implicit body if the value of a test is true or an alternate if the test is false.

Macro Call: `if` `(` *test* `)` [*consequent*]
 { `elseif` `(` *elseif-test* `)` [*elseif-consequent*] }*
 [`else` [*alternate*]]
`end` [`if`]

Arguments:

test	expression$_{bnf}$
consequent	body$_{bnf}$
elseif-test	expression$_{bnf}$
elseif-consequent	body$_{bnf}$
alternate	body$_{bnf}$

Values: Zero or more instances of `<object>`.

Description: `if` executes one or more expressions, executing and returning the values of a body following the first test which returns true.

test is the first expression to be executed. If its value is true, `if` executes and returns the values of the *consequent*. If the value of *test* is false, `if` proceeds with the optional elseif-tests and alternate.

First the elseif clauses are tried in order. The first *elseif-test* is executed. If its value is true, the corresponding *elseif-consequent* is executed and its values are returned as the value of the `if` statement. If its value is false, the next *elseif-test* is tried. This continues until a true *elseif-test* is found, or until there are no more elseif clauses.

If the *test* and all the *elseif-tests* are false, the *alternate* is executed and its values are returned as the value of the `if` statement. If there is no alternate, the `if` statement returns `#f`.

```
if ( x < 0 )
  - x;
end if;

if ( heads?(flip(coin)) )
  start(black);
else
  start(white);
end if

if (player1.money <= 0)
  end-game(player1)
elseif (player2.money <= 0)
  end-game(player2)
else
  move(player1);
  move(player2);
end if

if ( camel.humps = 1 )
  "dromedary"
elseif ( camel.humps = 2 )
  "bactrian"
else
  "not a camel"
end if;
```

`unless` [Statement]

Executes an implicit body unless the value of a test is true.

Macro Call:

`unless` (*test*)
 [*body*]
`end` [`unless`]

Arguments:

test	expression$_{bnf}$
body	body$_{bnf}$

Values: Zero or more instances of `<object>`.

Description: `unless` executes *test*. If the value of *test* is false, then the *body* is executed and its values are returned by `unless`. If the value of *test* is true, the *body* is not executed and `unless` returns `#f`.

If there are no expressions in the *body*, then `#f` is returned.

```
unless(detect-gas? (nose))
   light(match)
end unless
```

`case` [Statement]

Executes a number of tests until one is true, and then executes an implicit body associated with the true test.

Macro Call:

`case`
{ *test* `=>` *consequent* } *
[`otherwise` [`=>`] *alternate*]
`end` [`case`]

Arguments:

test	expression$_{bnf}$
consequent	[constituents$_{bnf}$] `;`
alternate	[constituents$_{bnf}$] `;`

Values: Zero or more instances of `<object>`.

Description: `case` executes the *test* in order, until it reaches a test which returns true. When it reaches a test which returns true, it executes the corresponding *consequent* and returns its values. Subsequent tests are not executed. If the corresponding consequent is empty, the first value of the successful test is returned.

As a special case, the name `otherwise` may appear as a *test*. This *test* always succeeds if there is no preceding successful *test*.

If no *test* is true, then `case` returns `#f`.

```
case
   player1.money <= 0
     => end-game(player1);
   player2.money <= 0
     => end-game(player2);
   otherwise
     => move(player1);
        move(player2);
end case;
```

`select` [Statement]

Compares a target object to a series of potential matches, and executes an implicit body associated with the first match found.

Macro Call: `select` (*target* [`by` *test*])
{ *matches* `=>` *consequent* }*
[`otherwise` [`=>`] *alternate*]
`end` [`select`]

Arguments:

target	expression_{bnf}
test	expression_{bnf}
matches	{ expression_{bnf} } `,`$^{+}$ | ({ expression_{bnf} } `,`$^{+}$)
consequent	[$\text{constituents}_{bnf}$] `;`
alternate	[$\text{constituents}_{bnf}$] `;`

Values: Zero or more instances of `<object>`.

Description: `select` generates a target object and then compares it to a series of potential matches, in order. If it finds a match, it executes the corresponding consequent and returns the values of the consequent. If no match is found, an error is signaled.

The *target* is executed to produce the match object.

The *test*, if supplied, is a function used to compare the target object to the potential matches. The default *test* is `==`.

One at a time, each *match* is executed and its value compared to *target*, in order. If a match is found, the corresponding *consequent* is executed and its values are returned. If the corresponding *consequent* is empty, `#f` is returned.

Once a match is found, subsequent *matches* and the corresponding bodies are not executed.

As a special case, the name `otherwise` may appear instead of a *matches*. This will be considered a match if no other match is found.

If there is no matching clause, an error is signaled. Because an `otherwise` clause matches when no other clause matches, a `select` form that includes an `otherwise` clause will never signal an error for failure to match.

Since testing stops when the first match is found, it is irrelevant whether the test function would also have returned true if called on later matches of the same clause or on matches of later clauses.

```
select ( career-choice(student) )
   art:, music:, drama:
     => "Don’t quit your day job";
   literature:, history:, linguistics:
     => "That really is fascinating";
   science:, math:, engineering:
     => "Say, can you fix my VCR?";
   otherwise => "I wish you luck";
end select;

select ( my-object by instance? )
  <window>, <view>, <rectangle> => "a graphical object";
  <number>, <string>, <list> => "a computational object";
  otherwise => "I don’t know";
end select
```

Iteration Constructs

while [Statement]

Repeatedly executes a body until a test expression is false.

Macro Call:

```
while ( test )
  [ body ]
end [ while ]
⇒ #f
```

Arguments:

test	expression$_{bnf}$
body	body$_{bnf}$

Values: `#f`

Description: `while` loops over *body* until *test* returns false.

Each pass through the loop begins by executing *test*. If *test* returns a true value, the expressions in the *body* are executed and the looping continues. If *test* returns false, the loop terminates and `while` returns `#f`.

until (*test*) [Statement]

Repeatedly executes a body until a test expression is true.

Macro Call:

```
until ( test )
  [ body ]
end [until]
⇒ #f
```

Arguments:

test	expression$_{bnf}$
body	body$_{bnf}$

Values: `#f`

Description: `until` loops over *body* until *test* returns true.

Each pass through the loop begins by executing *test*. If *test* returns false, the expressions in the *body* are executed and the looping continues. If *test* returns true, the loop terminates and `until` returns `#f`.

`for` **[Statement]**

Performs general iteration over a body, updating bindings and performing end tests on each iteration.

Macro Call: `for (` { *for-clause* } `,* |`
    { { *for-clause* `,` }* *end-clause* } `)`
  [*loop-body*]
  [`finally` [*result-body*]]
`end` [`for`]

Arguments:

for-clause	*explicit-step-clause* | *collection-clause* | *numeric-clause*
end-test	expression$_{bnf}$
loop-body	body$_{bnf}$
result-body	body$_{bnf}$
explicit-step-clause	variable$_{bnf}$ `=` *init-value* `then` *next-value*
collection-clause	variable$_{bnf}$ `in` *collection*
numeric-clause	variable$_{bnf}$ `from` *start* [{ `to` | `above` | `below` } *bound*] [`by` *increment*]
end-clause	{ `until:` | `while:` } *end-test*
init-value	expression$_{bnf}$
next-value	expression$_{bnf}$
collection	expression$_{bnf}$
start	expression$_{bnf}$
bound	expression$_{bnf}$

increment	expression$_{bnf}$

Values: Zero or more instances of `<object>`.

Description: `for` iterates over *loop-body*, creating and updating iteration bindings on each iteration according to the *for-clauses*. Iteration ends when one of the *for-clauses* is exhausted, or when the optional *end-test* is satisfied.

Each *for-clause* controls one iteration binding. The optional *end-test* does not control any iteration bindings.

There are three kinds of for-clauses: *explicit-step-clauses*, *collection-clauses*, and *numeric-clauses*: An *explicit-step-clause* creates bindings for the results of executing an expression. A *collection-clause* creates bindings for successive elements of a collection. A *numeric-clause* creates bindings for a series of numbers.

Execution of a `for` statement proceeds through the following steps:

1. Execute the expressions that are executed just once, in left to right order as they appear in the `for` statement. These expressions include the types of all the bindings, and the expressions *init-value*, *collection*, *start*, *bound*, and *increment*. If the value of *collection* is not a collection, an error is signaled. The default value for *increment* is `1`.
2. Create the iteration bindings of explicit step and numeric clauses.
   - □ For each explicit step clause, create the binding for the value of *init-value*. If the binding is typed and the value is not of the specified type, signal an error.
   - □ For each numeric clause, create the binding for the value of *start*. If the binding is typed and the value is not of the specified type, signal an error.
3. Check numeric and collection clauses for exhaustion. If a clause is exhausted, go to step 9.
   - □ A collection clause is exhausted if its collection has no next element.
   - □ A numeric clause is exhausted if a *bound* is supplied and the value of the clause is no longer in bounds. If `above` is specified, the clause will be in bounds as long as the value is greater than the *bounds*. If `below` is specified, the clause will be in bounds as long as the value is less than the *bounds*. If `to` is specified with a positive or zero *increment*, the clause will be in bounds as long as it is less than or equal to the *bounds*. If `to` is

specified with a negative *increment*, the clause will be in bounds as long as it is greater than or equal to the *bounds*.

4. For each collection clause create the iteration binding for the next element of the collection for that clause. Fresh bindings are created each time through the loop (i.e., the binding is not assigned the new value). If the binding is typed and the value is not of the specified type, signal an error.
5. If *end-test* is supplied, execute it. If the value of *end-test* is false and the symbol is `while:`, go to step 9. If the value of *end-test* is true and the symbol is `until:`, go to step 9.
6. Execute the expressions in the *body* in order. The expressions in the *body* are used to produce side-effects.
7. Obtain the next values for explicit step and numeric clauses. Values are obtained in left to right order, in the environment produced by step 6.
   - For each explicit step clause, execute *next-value*.
   - For each numeric clause, add the *increment* to the current value of the binding, using `+`.
8. Create the iteration bindings of explicit step and numeric clauses for the values obtained in step 7. For each clause, if a binding type is supplied and the next value for that clause is not of the specified type, signal an error. Fresh bindings are created each time through the loop (i.e., the binding is not assigned the new value). After the bindings have been created, go to step 3.
9. Execute the expressions in the *result-body* in order. Bindings created in step 2 and 8 are visible during the execution of *result-body*, but bindings created in step 4 (the iteration bindings of collection clauses) are not visible during the execution of *result-body*. The values of the last expression in the *result-body* are returned as the values of the `for` statement. If there are no expressions in the *result-body*, `for` returns `#f`.

```
for ( thing = first-thing then next(thing),
      until: done?(thing) )
  do-some(thing)
end;

for (j :: <integer> from 0 to height)
  for (i :: <integer> from 0 to width)
   erase(i,j);
   plot (i,j);
  end for;
end for;

for (city in olympic-cities,
     year from start-year by 4)
  schedule-olympic-game(city, year)
  finally: notify(press);
           sell(tickets);
end;

for (i from 0 below 100,
     zombies from 0 below 100,
     normals from 100 above 0 by -1)
   population[i] := zombies + normals
end;
```

begin [Statement]

Executes expressions in a body, in order.

Macro Call: `begin` [*body*] `end`

Arguments: *body* body$_{bnf}$

Values: Zero or more instances of `<object>`.

Description: Begin executes the expressions in a body, in order. The values of the last expression are returned. If there are no expressions in the body, `#f` is returned.

block [Statement]

Executes a body with several options for non-standard flow of control.

Macro Call: `block` ([*exit-variable*])
[*block-body*]
[`afterwards` [*afterwards-clause*]]

`[ cleanup [` *cleanup-clause* `] ]`
`{ exception` *exception-clause* `}*`
`end [ block ]`

Arguments:

exit-variable	variable-name$_{bnf}$
block-body	body$_{bnf}$
afterwards-clause	body$_{bnf}$
cleanup-clause	body$_{bnf}$
exception-clause	`( [` *name* `:: ]` *type* `{ ,` *exception-options* `}* )` `[` body$_{bnf}$ `]`
name	variable-name$_{bnf}$
type	expression$_{bnf}$
exception-options	`{ test:` expression$_{bnf}$ `}	{ init-arguments:` expression$_{bnf}$ `}`

Values: Zero or more instances of `<object>`.

Description: `block` executes the expressions in the *block-body* in order, and then the executes the optional *afterwards-clause* and *cleanup-clause*. Unless there is a non-local exit, block returns the values of the *block-body*, or `#f` if there is no *block-body*.

If *exit-variable* is provided, it is bound to an exit procedure (an object of type `<function>`) which is valid during the execution of the block body and the clauses. At any point in time before the last clause returns, the exit procedure can be called. Calling the exit procedure has the effect of immediately terminating the execution of the block, and returning as values the arguments to the exit procedure.

The body of the *afterwards-clause*, if provided, is executed after the *block-body*. The values produced by the *afterwards-clause* are ignored.

The body of the *cleanup-clause*, if provided, is executed after the *block-body* and *afterwards-clause*. Its values are also ignored. The cleanup clause differs from the afterwards clause in that its body is guaranteed to be executed, even if the execution of the block is interrupted by a non-local exit. There is no such guarantee for the afterwards clauses.

For example, the following code fragment ensures that files are closed even in the case of an error causing a non-local exit from the block body:

```
block (return)
  open-files();
  if (something-wrong)
    return("didn't work");
  end if;
  compute-with-files()
cleanup
  close-files();
end block
```

The *exception-clauses*, if supplied, install exception handlers during the execution of the *block-body*, *afterwards-clause*, and *cleanup-clause*. If one of these handlers is invoked, it never declines but immediately takes a non-local exit to the beginning of the block, executes the expressions in its body and returns the values of the last expression or `#f` if the body is empty. Note that when the expressions in an exception body are executed, all handlers established by the `block` are no longer active. Note also that the cleanup clause of the block will be executed before the expressions of the handler body are executed.

The *type* and *exception-options* are as for `let handler`. If present, *name* is bound to the condition during the execution of the handler's body.

The exception clauses are checked in the order in which they appear. That is, the first handler will take precedence over the second, the second over the third, etc.

The following is a trivial use of an exception clause.

```
block (return)
  open-files();
  compute-with-files()
exception (<error>)
  "didn't work")
cleanup
  close-files();
end block
```

Dynamic Extent of Block Features

A block installs features which are active for different portions of the execution of the block.

- During the execution of the block body and the afterwards clause the exit procedure, exception clauses, and cleanup clauses are active.
- During the execution of the cleanup clause, the exit procedure and exception clauses are active.
- During the execution of a handler installed by an exception clause, the exit procedure is active.

Intervening Cleanup Clauses

When an exit procedure is called, it initiates a non-local exit out of its establishing block. Before the non-local exit can complete, however, the cleanup clauses of intervening blocks (blocks that have been entered, but not exited, since the establishing block was entered) must be executed, beginning with the most recently entered intervening block. Once the cleanup clauses of an intervening block have been executed, it is an error to invoke the exit procedure established by that block. The cleanup clauses of the establishing block are executed last. At that point, further invocation of the exit procedure becomes invalid, and the establishing block returns with the values that were passed to the exit procedure.

Note that a block statement may also be exited due to the execution of a handler clause. Before the exception clause is executed, intervening cleanup clauses are executed as described above (including any clause for the establishing block.) The exit procedure may be invoked during execution of exception clauses, in which case the argument values are immediately returned from the block (the cleanup clause already having been executed).

During the process of executing the cleanup clauses of the intervening blocks, any valid exit procedure may be invoked and may interrupt the current non-local exit.

All exception clauses are executed in the same dynamic environment. None of the handlers established in the block are visible during the execution of one of the handlers. This can be thought of as parallel installation of the handlers.

Restrictions on the use of exit procedures

The exit procedure is a first-class object. Specifically, it can be passed as an argument to functions, stored in data structures, etc. Its use is not restricted to the lexical body of the block in which it was established. However, invocation of the exit procedure is valid only during the execution of the establishing block. It is an error to invoke an exit procedure after its establishing block has returned, or after execution of the establishing block has been terminated by a non-local exit.

In the following example, the `block` establishes an exit procedure in the binding `bar`. The `block` returns a method containing a call to `bar`, and the method is stored in the binding `foo`. Calling `foo` is an error because it is no longer valid to invoke `bar` after its establishing `block` has returned.

```
define constant foo =
  block (bar)
     method (n) bar(n) end;
  end block;
foo(5)
  {error or other undefined consequences}
```

`method` **[Statement]**

Creates and returns a method.

Macro Call: `method` *parameter-list* [*body*] `end` [`method`]

Arguments:

parameter-list	parameter-list$_{bnf}$
body	body$_{bnf}$

Values: An instance of `<method>`.

Description: `method` creates and returns a method specified by the *parameter-list* and *body*. For a complete description of methods, see “Methods” on page 78.

Special Operators

Special operators provide syntax for assignment and for conditional execution.

Table 14-4 Special Operators

Operator	**Description**	**Page**
`:=`	Stores a new value in a location.	397
`|`	Returns the value of the first of two operands which is true.Returns the value of the first of two operands which is true.	399
`&`	Executes a second operand and returns its values if the value of the first operand is true.	400

Assignment

`:=` **[Special Operator]**

Stores a new value in a location.

Operator Call: *place* `:=` *new-value*

Arguments:

place	operand$_{bnf}$
new-value	operand$_{bnf}$

Values: *new-value*, an instance of `<object>`.

Description: `:=` stores *new-value* in *place* and returns *new-value*.

place may be a variable, a getter function or macro with a corresponding setter, a slot access, or an element reference.

new-value may be any operand. It is executed, and its value is stored in *place*.

In all cases, *new-value* must be an appropriate type for *place* or an error is signaled.

The *new-value* of an assignment statement is executed first, followed by the *place* (assuming the *place* requires any execution, which will only be true if it is not a binding name).

Assignment to a binding

If *place* is a binding name, then *new-value* is stored in the binding. It is an error if there is no binding corresponding to *place*. (`:=` cannot be used to create bindings, only to change their values.) An error is also signaled if *place* is a binding specialized to a type and the *new-value* is not of that type.

```
define variable *number* = 10;
*number*
 ⇒  10
*number* := *number* + 10;
 ⇒  20
*number*
 ⇒  20
```

Assignment to a function or function macro

If *place* has the syntax of a function call, then `:=` will invoke the corresponding setter function. Given a binding named *fun*, the corresponding setter is the binding named *fun*`-setter` in the current environment.

`:=` maps *place* to *place*`-setter` without regard for whether *place* is a function or a macro. It does not expand a macro call on the left-hand side before determining the setter.

With the exception of the order of execution and a guaranteed return value, the following three expressions are equivalent:

```
*top-view*.subviews := generate-subviews()
subviews(*top-view*) := generate-subviews()
subviews-setter(generate-subviews(), *top-view*)
```

(The differences are as follows: the execution time of `subviews-setter` is undefined in the first two expressions but defined in the last; the first two expressions will return the value of the call to `generate-subviews` while the last will return the value of the call to `subviews-setter`.)

```
name(arg1,…argn ) := new-value
```

behaves exactly the same as

```
begin
  let temp = new-value;
  name-setter(temp, arg1,…argn );
  temp
end
```

This is true regardless of whether `name` and `name-setter` are functions or macros. Here *temp* stands for a variable with a unique name. If `name-setter` is a macro, it is responsible for the order of executation of `arg1,…argn`.

The same considerations apply to `arg.name := new-value`.

Assignment to element references

Just as `[]` can be used as syntax for `element` and `aref`, `[]` and `:=` can be used as syntax for `element-setter` and `aref-setter`. For example, the following three expressions are equivalent:

```
foo[2] := "quux"
element (foo, 2) := "quux"
element-setter ("quux", foo, 2).
```

Conditional Execution

| [Special Operator]

Returns the value of the first of two operands which is true.

Macro Call: *one* | *another*

Arguments:

one	operand$_{bnf}$
another	operand$_{bnf}$

Values: Zero or more instances of `<object>`.

Description: `|` (logical or) executes *one*. If the first value of *one* is true, that value is returned. Otherwise *another* is executed and its values are returned.

& **[Special Operator]**

Executes a second operand and returns its values if the first value of the first operand is true.

Macro Call: *one* `&` *another* $\Rightarrow$ *values*

Arguments:

one	operand$_{bnf}$
another	operand$_{bnf}$

Values: Zero or more instances of `<object>`.

Description: & (logical and) executes *one*. If the first value returned by *one* is false, `#f` is returned and *another* is not executed. Otherwise, *another* is executed and its values are returned.

A P P E N D I X   A

BNF

General Notes

Dylan syntax can be parsed with an LALR(1) grammar.

This appendix uses some special notation to make the presentation of the grammar more readable.

- The $_{opt}$ suffix means that the preceding item is optional.
- A trailing ellipsis (...) is used in two different ways to signal possible repetition.
  - If there is only one item on the line preceding the ellipsis, the item may appear one or more times.
  - If more than one item precedes the ellipsis, the last of these items is designated a separator; the rest may appear one or more times, with the separator appearing after each occurrence but the last. (When only one item appears, the separator does not appear.)
- Identifiers for grammar rules are written with uppercase letters when the identifier is used in the phrase grammar but defined in the lexical grammar.
- The grammar does not use distinct identifiers for grammar rules that differ only in alphabetic case.

Lexical Notes

In the lexical grammar, the various elements that come together to form a single token on the right-hand sides of rules must *not* be separated by white-space, so that the end result will be a single token. This is in contrast to the phrase grammar, where each element is already a complete token or a series of complete tokens.

Arbitrary white-space is permitted between tokens, but it is required only as necessary to separate tokens that might otherwise blend together.

A P P E N D I X A

BNF

Case is not significant except within character and string literals. The grammars do not reflect this, using one case or the other, but it is still true.

Lexical Grammar

Comments

comment:
  // …the rest of the line
  /* …everything even across lines… ***/**

Tokens

TOKEN:
  NAME
  SYMBOL
  NUMBER
  CHARACTER-LITERAL
  STRING
  UNARY-OPERATOR
  BINARY-OPERATOR
  punctuation
  #-word

punctuation:
  one of **( ) , . ; [ ] { } :: - = == =>**
  one of **#(#[## ? ?? ?= ...**

#-word:
  one of **#t #f #next #rest #key #all-keys #include**

Reserved Words

reserved-word:
  core-word

BEGIN-WORD
FUNCTION-WORD
DEFINE-BODY-WORD
DEFINE-LIST-WORD

core-word:
one of **`define end handler let local macro otherwise`**

The following reserved words are exported by the Dylan module:

BEGIN-WORD:
one of **`begin block case for if method`**
one of **`select unless until while`**

FUNCTION-WORD:
(none)

DEFINE-BODY-WORD:
one of **`class library method module`**

DEFINE-LIST-WORD:
one of **`constant variable`**

Names, Symbols and Keywords

NAME:
word
\ *word*
operator-name

UNRESERVED-NAME:
any *word* that is not also a *reserved-word*
\ *word*
operator-name

ORDINARY-NAME:
UNRESERVED-NAME
DEFINE-BODY-WORD
DEFINE-LIST-WORD

CONSTRAINED-NAME:
NAME **:** *word*
NAME **:** BINARY-OPERATOR
: *word*

operator-name:
  \ *unary-function-operator*
  \ *binary-function-operator*

SYMBOL:
  word **:**
  # STRING

word:
  leading-alphabetic
  leading-numeric alphabetic-character leading-alphabetic
  leading-graphic leading-alphabetic

leading-alphabetic:
  alphabetic-character
  leading-alphabetic any-character

leading-numeric:
  numeric-character
  leading-numeric any-character

leading-graphic:
  graphic-character
  leading-graphic any-character

any-character:
  alphabetic-character
  numeric-character
  graphic-character
  special-character

alphabetic-character:
  one of **a b c d e f g h i j k l m n o p q r s t u v w x y z**

numeric-character:
  one of **0 1 2 3 4 5 6 7 8 9**

graphic-character:
  one of **! & * < > | ^ $ % @ _**

special-character:
  one of **- + ~ ? / =**

Operators

UNARY-OPERATOR:
unary-function-operator

BINARY-OPERATOR:
binary-function-operator
special-operator

unary-function-operator:
one of **`- ~`**

binary-function-operator:
one of **`+ - * / ^ = == ~= ~== < <= > >=`**

special-operator:
one of **`& | :=`**

Character and String Literals

CHARACTER-LITERAL:
`'` *character* **`'`**

character:
any printing character (including space) except for **`'`** or **`\`**
`\` *escape-character*
`\'`

STRING*:*
`"` *more-string*

more-string:
string-character more-string
`"`

string-character:
any printing character (including space) except for **`"`** or **`\`**
`\` *escape-character*
`\"`

escape-character:
one of **`\ a b e f n r t 0`**
`<` *hex-digits* **`>`**

Numbers

NUMBER:
integer
ratio
floating-point

integer:
binary-integer
octal-integer
sign$_{opt}$ *decimal-integer*
hex-integer

binary-integer:
#b *binary-digit*
binary-integer binary-digit

octal-integer:
#o *octal-digit*
octal-integer octal-digit

decimal-integer:
decimal-digit
decimal-integer decimal-digit

hex-integer:
#x *hex-digit*
hex-integer hex-digit

hex-digits:
hex-digit …

binary-digit:
one of **0 1**

octal-digit:
one of **0 1 2 3 4 5 6 7**

decimal-digit:
one of **0 1 2 3 4 5 6 7 8 9**

hex-digit:
one of **0 1 2 3 4 5 6 7 8 9 A B C D E F**

ratio:
  sign$_{opt}$ *decimal-integer* **/** *decimal-integer*

floating-point:
  sign$_{opt}$ *decimal-integer*$_{opt}$ **.** *decimal-integer* *exponent*$_{opt}$
  sign$_{opt}$ *decimal-integer* **.** *decimal-integer*$_{opt}$ *exponent*$_{opt}$
  sign$_{opt}$ *decimal-integer* *exponent*

exponent:
  E *sign*$_{opt}$ *decimal-integer*

sign:
  one of **+** **-**

Phrase Grammar

Program Structure

source-record:
  body$_{opt}$

body:
  constituents **;**$_{opt}$

constituents:
  constituent **;** …

constituent:
  definition
  local-declaration
  expression

macro:
  definition-macro-call
  statement
  function-macro-call

Property Lists

comma-property-list:
    , *property-list*

property-list:
    property **,** …

property:
    SYMBOL *value*

value:
    basic-fragment

Fragments

body-fragment:
    non-statement-body-fragment
    statement *non-statement-body-fragment*$_{opt}$

list-fragment:
    non-statement-list-fragment
    statement *non-statement-list-fragment*$_{opt}$

basic-fragment:
    non-statement-basic-fragment
    statement *non-statement-basic-fragment*$_{opt}$

non-statement-body-fragment:
    definition *semicolon-fragment*$_{opt}$
    local-declaration *semicolon-fragment*$_{opt}$
    simple-fragment *body-fragment*$_{opt}$
    , *body-fragment*$_{opt}$
    ; *body-fragment*$_{opt}$

semicolon-fragment:
    ; *body-fragment*$_{opt}$

non-statement-list-fragment:
    simple-fragment *list-fragment*$_{opt}$
    , *list-fragment*$_{opt}$

non-statement-basic-fragment:
  simple-fragment *basic-fragment*$_{opt}$

simple-fragment:
  variable-name
  constant-fragment
  BINARY-OPERATOR
  UNARY-OPERATOR
  bracketed-fragment
  function-macro-call
  #-word
  one of **`. :: => ? ?? ?= ... ## otherwise`**

bracketed-fragment:
  `(` *body-fragment*$_{opt}$ **`)`**
  `[` *body-fragment*$_{opt}$ **`]`**
  `{` *body-fragment*$_{opt}$ **`}`**

constant-fragment:
  NUMBER
  CHARACTER-LITERAL
  STRING
  SYMBOL
  `#(` *constants* **`.`** *constant* **`)`**
  `#(` *constants*$_{opt}$ **`)`**
  `#[` *constants*$_{opt}$ **`]`**

Definitions

definition:
  definition-macro-call
  `define macro` *macro-definition*

definition-macro-call:
  `define` *modifiers*$_{opt}$ DEFINE-BODY-WORD *body-fragment*$_{opt}$ *definition-tail*
  `define` *modifiers*$_{opt}$ DEFINE-LIST-WORD *list-fragment*$_{opt}$

modifier:
  UNRESERVED-NAME

modifiers:
  modifier …

definition-tail:
  end DEFINE-BODY-WORD$_{opt}$ NAME$_{opt}$

Local Declarations

local-declaration:
  let *bindings*
  let handler *condition* **=** *handler*
  local *local-methods*

condition:
  type
  (*type* *comma-property-list*$_{opt}$ **)**

handler:
  expression

local-methods:
  method$_{opt}$ *method-definition* **,** …

bindings:
  variable **=** *expression*
  (*variable-list* **)** **=** *expression*

variable-list:
  variables
  variables **, #rest** *variable-name*
  #rest *variable-name*

variables:
  variable **,** …

variable:
  variable-name
  variable-name **::** *type*

variable-name:
  ORDINARY-NAME

type:
  operand

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Expressions

expressions:
  expression **,** …

expression:
  binary-operand BINARY-OPERATOR …

binary-operand:
  SYMBOL
  UNARY-OPERATOR$_{opt}$ *operand*

operand:
  operand **(** *arguments*$_{opt}$ **)**
  operand **[** *arguments* **]**
  operand **.** *variable-name*
  function-macro-call
  leaf

arguments:
  SYMBOL$_{opt}$ *expression* **,** …

function-macro-call:
  FUNCTION-WORD **(** *body-fragment*$_{opt}$ **)**
  FUNCTION-WORD **(** *body-fragment*$_{opt}$ **)** **:=** *expression*

leaf:
  literal
  variable-name
  (*expression* **)**
  statement

literal:
  NUMBER
  CHARACTER-LITERAL
  string-literal
  #t
  #f
  #(*constants* **.** *constant* **)**
  #(*constants*$_{opt}$ **)**
  #[*constants*$_{opt}$ **]**

string-literal:
  STRING …

constants:
  constant **,** …

constant:
  literal
  SYMBOL

Statements

statement:
  BEGIN-WORD *body-fragment*$_{opt}$ *end-clause*

end-clause:
  end BEGIN-WORD$_{opt}$

case-body:
  cases **;**$_{opt}$

cases:
  case-label *constituents*$_{opt}$ **;** …

case-label:
  expressions **=>**
  (*expressions* **) =>**
  otherwise =>$_{opt}$

Methods

method-definition:
  variable-name *parameter-list* *body*$_{opt}$ **end method**$_{opt}$ *variable-name*$_{opt}$

parameter-list :
  (*parameters*$_{opt}$ **) ;**$_{opt}$
  (*parameters*$_{opt}$ **) =>** *variable* **;**
  (*parameters*$_{opt}$ **) => (** *values-list*$_{opt}$ **) ;**$_{opt}$

parameters:
  required-parameters
  required-parameters **,** *next-rest-key-parameter-list*
  next-rest-key-parameter-list

next-rest-key-parameter-list:
  #next *variable-name*
  #next *variable-name* **,** *rest-key-parameter-list*
  rest-key-parameter-list

rest-key-parameter-list:
  #rest *variable-name*
  #rest *variable-name* **,** *key-parameter-list*
  key-parameter-list

key-parameter-list:
  #key *keyword-parameters$_{opt}$*
  #key *keyword-parameters$_{opt}$* **,** **#all-keys**
  #all-keys

required-parameters:
  required-parameter **,** …

required-parameter:
  variable
  variable-name **==** *expression*

keyword-parameters:
  keyword-parameter **,** …

keyword-parameter:
  SYMBOL$_{opt}$ *variable* *default$_{opt}$*

default:
  = *expression*

values-list:
  variables
  variables **,** **#rest** *variable*
  #rest *variable*

Macro Definitions

macro-definition:
  NAME *main-rule-set* *auxiliary-rule-sets$_{opt}$* **end macro**$_{opt}$ NAME$_{opt}$

main-rule-set:
  body-style-definition-rule ...
  list-style-definition-rule ...

statement-rule ...
function-rule ...

body-style-definition-rule :
{ define *definition-head*$_{opt}$ NAME *pattern*$_{opt}$ **;**$_{opt}$ **end }** **=>** *rhs*

list-style-definition-rule :
{ define *definition-head*$_{opt}$ NAME *pattern*$_{opt}$ **}** **=>** *rhs*

rhs:
{ *template*$_{opt}$ **}** **;**$_{opt}$

definition-head :
modifier-pattern ...

modifier-pattern:
modifier
pattern-variable

statement-rule:
{ NAME *pattern*$_{opt}$ **;**$_{opt}$ **end }** **=>** *rhs*

function-rule:
{ NAME **(** *pattern*$_{opt}$ **) }** **=>** *rhs*

Patterns

pattern:
pattern-list **;** ...

pattern-list:
pattern-sequence
property-list-pattern
pattern-sequence **,** *pattern-list*

pattern-sequence:
simple-pattern ...

simple-pattern:
NAME
=>
bracketed-pattern
binding-pattern
pattern-variable

bracketed-pattern:
  (*pattern*$_{opt}$ **)**
  [*pattern*$_{opt}$ **]**
  { *pattern*$_{opt}$ **}**

binding-pattern:
  pattern-variable **::** *pattern-variable*
  pattern-variable **=** *pattern-variable*
  pattern-variable **::** *pattern-variable* **=** *pattern-variable*

pattern-variable:
  ? NAME
  ? CONSTRAINED-NAME
  ...

property-list-pattern:
  #rest *pattern-variable*
  #key *pattern-keywords*$_{opt}$
  #rest *pattern-variable* **,** **#key** *pattern-keywords*$_{opt}$

pattern-keywords:
  #all-keys
  pattern-keyword
  pattern-keyword **,** *pattern-keywords*

pattern-keyword:
  ? NAME *default*$_{opt}$
  ? CONSTRAINED-NAME *default*$_{opt}$
  ?? NAME *default*$_{opt}$
  ?? CONSTRAINED-NAME *default*$_{opt}$

Templates

template:
  template-element ...

template-element:
  NAME
  SYMBOL
  NUMBER
  CHARACTER-LITERAL
  STRING
  UNARY-OPERATOR

separator
#-word
one of **.** **::** **=>**
(*template*$_{opt}$ **)**
[*template*$_{opt}$ **]**
{ *template*$_{opt}$ **}**
#(*template*$_{opt}$ **)**
#[*template*$_{opt}$ **]**
substitution

separator:
one of **;** **,**
BINARY-OPERATOR

substitution:
name-prefix$_{opt}$ **?** *name-string-or-symbol name-suffix*$_{opt}$
?? NAME *separator*$_{opt}$ **...**
...
?= NAME

name-prefix:
STRING **##**

name-suffix:
STRING

name-string-or-symbol:
NAME
STRING
SYMBOL

Auxiliary Rule Sets

auxiliary-rule-sets:
auxiliary-rule-set ...

auxiliary-rule-set:
SYMBOL *auxiliary-rules*

auxiliary-rules:
auxiliary-rule ...

auxiliary-rule:
{ *pattern*$_{opt}$ **}** **=>** *rhs*

APPENDIX A

BNF

Glossary

abstract class
A class that is not intended to have **direct instances**. The opposite of an abstract class is a **concrete class**.

access
1. (a slot) To retrieve (**get**) or replace (**set**) the value of the slot. 2. (a collection element) To retrieve or replace the collection element.

accessor
A **slot accessor** (a **getter** or **setter**).

accessible
(from a module) A binding that is either **owned** by the module or imported into the module from another module.

ambiguous methods
(for a particular function call) Two methods that are both **applicable** for the function call, but neither of which is more specific than the other.

anonymous
1. (~ method) Created by a `method` statement, as opposed to having been created and named by a `define method` or `local` definition, or having been **implicitly defined**. Compare with **bare method**. 2. (~ class) Created by calling the `make` function on the class `<class>`, as opposed to having been created and named by a `define class` definition. 3. (~ generic function) Created by calling the `make` function on the class `<generic-function>`, as opposed to having been created and named by a `define generic` definition.

applicable
1. (~ method, during a generic function call) Having a **parameter list** which matches the supplied arguments. 2. (~ handler, when a condition is signaled) Matching the signaled condition by type and by an optional test function associated with the handler.

apply
1. (a function to arguments) To call the function with the arguments. 2. The function `apply` (see page 339).

argument
An object that is supplied to a function in a function call. In other languages, this is sometimes called an "actual argument" or "actual parameter."

array
An instance of <array>.

assign
1. (a variable) To change the value of the variable. 2. (a slot) To set the value of the slot. 3. (a collection element) To change the value of a collection element.

bare method
1. A method which is not part of a generic function. 2. A method which is used directly, as though it is not part of a generic function.

base type
(of a type): Every type has a base type. The base type for a class is the class itself. The base type of a singleton is the singleton itself. The base type of a union is the union of the base types of its component types. The base type of a limited type `limited(`*C*`, …)` is *C*.

bind
(a variable) To establish a **binding**.

binding
An association between a name and a value.

body
A grammatical element of a Dylan program, consisting of zero or more constituents. If any of the constituents are expressions, the body returns the values of the last expression.

bound
(~ name) Having a **binding** which associates the namewith a value.

call
(a function) To invoke a function on a set of arguments. If the function is a generic function, it will dispatch to an appropriate method. If the function is a method, it will cause the body of the method to be executed within an environment in which the **parameters** of the function are bound to the **arguments**.

circular list
A list that has no last element, because the tail of every pair in the list is another pair in the list. Compare with **improper list**, **dotted list**.

class
1. A **type** that specifies the structure of **instance** and categorizes objects. Each Dylan object is a **direct instance** of exactly one class. 2. (of an object) The class of which the object is a **direct instance**.

class hierarchy
A directed acyclic graph (DAG) which describes the subclass/superclass relationships among classes. Each node represents a class, the children of a node represent the direct subclasses of a class, and the parents of a node represent the direct superclasses of a class.

class precedence list
(of a class) A total ordering on the class and its superclasses that is consistent with the local precedence orders for the class and each of its superclasses. The class precedence list is used in determining method specificity.

cleanup clause
A clause in a `block` statement that is guaranteed to be executed, even if the execution of the `block` statement is terminated by a **non-local exit**.

coerce
(an object to a type) To produce a new object of the specified type, without modifying the original object. The intent is to produce an object that preserves the meaning of the original object, but is an instance of the specified type.

collection
An aggregate data structure such as a list, a table, or an array. A collection is an instance of `<collection>.`

collection alignment
A technique of preparing two or more collections for an iteration over those collections, ensuring that elements are paired in a consistent way.

collection key
(of a collection) An object that can be passed to random-access operations (such as `element` or `element-setter`) to access an element of the collection.

concrete class
A class that is intended to have direct instances. The opposite of a concrete class is an **abstract class**.

condition
An object that is signaled in an exceptional situation, and used to determine which **handlers** are applicable in the situation. Conditions are instances of `<condition>`.

congruent
(two or more ~ parameter lists) Having compatible parameters. The parameter lists of a generic function and its methods must be congruent. See "Parameter List Congruency" on page 91.

constant
1. A **constant binding**. 2. A **literal constant**. 3. (~ binding) Read-only. 4. (~ slot) Not assignable. Constant slots do not have setter functions.

constant binding
A binding which cannot be assigned a new value.

contents
1. (of a collection) The elements of the collection. 2. (of an object) The values stored in the object's slots.

copy
1. (of an object) A new object that has similar structure and **contents** as the original object. A copy may be an instance of the same class as the original object, or it may be an instance of the **type-for-copy** of the object. A copy may or may not share structure with the original object. Compare **fresh copy**, **shallow copy**. 2. (an object) To create a copy of the object.

default method
(of a generic function) The method with the most general parameter specializers for the generic function, intended for use when no more specific method is defined.

definition
A syntax form that denotes a declarative part of a program. Definitions are restricted to be top level expressions, and do not return values.

destructive
(~ function) Capable of modifying its arguments.

direct instance
(of a class C) An object whose class is C itself, rather than some subclass of C.

direct subclass
(of a class C1) A class C2 such that C1 is a direct superclass of C2.

direct superclass
(of a class C1) A class C2 that is listed as a superclass of C1 in the definition of C1, or that was passed as one of the `superclass:` arguments to `make` when C1 was created.

disjoint
(of types): Informally, two types are disjoint if there can be no object that is an instance of both types. A formal definition is given in “Type Disjointness” on page 49.

dotted list
A list that has something other than the **empty list** as the tail of its last pair. Compare **proper list**, **improper list**.

Dylan source code file
A file containing Dylan code in the standard portable file format as described in“Dylan Interchange Format” on page 21.

element
(of a collection) An object that is stored in the collection. It can be identified by a **collection key**.

element reference syntax
The shorthand syntax for accessing an element of an array or of any other collection. `x[y]`,`x[y, z]`

empty list
The list that contains no elements. It is the unique instance of the class `<empty-list>`.

environment
1. A set of **bindings**. 2. The set of **bindings** that are available to a particular part of a program.

equivalence class
(for an **equivalence predicate**) A set of objects, or potential objects, that are all the same under the specified **equivalence predicate** and different under that predicate from all objects not in the equivalence class.

equivalence predicate
A boolean function of two arguments that returns true if and only if the arguments are "the same" according to some specified criteria. For a function to be used as an equivalence predicate, it must be reflexive, commutative, and transitive. See also **hash function**.

equivalent types
Two types, each of which is a subtype of the other.

error
1. A **condition** which represents an **error situation**. 2. An **error situation**.

error situation
A situation in which there is something invalid about the program, in contrast to an environmental condition such as running out of memory or battery power, or inability to establish a network connection.

exceptional situation
A situation that is not conceptually part of the normal execution of the program, but must be handled some other way. Exceptional situations are represented by **conditions**.

exit procedure
A function that can be called explicitly, during the execution of a `block` statement, to terminate the execution of the `block` statement, transfer control to its associated exit point, and return zero or more values.

exit point
A point through which control may be transferred. An exit point established by a `block` statement may have an associated **exit procedure**.

explicit definition
A definition created by `define constant`, `define variable`, `define generic`, `define macro` and the class name in `define class`. See also **implicit definition**.

explicitly defined
(of a class or generic function) defined by an **explicit definition**.

explicitly known
1. (of a class in a library) a class defined by `define class` in the library or in one of the libraries it uses. 2. (of a generic function in a library) a generic function explicitly defined by `define generic` in the library or in one of the libraries it uses, or a generic function implicitly defined by the definition of a method explicitly known in the library or by a slot specification for a class explicitly known in the library. 3. (of a method in a library) a method defined by `define method` in the library or in one of the libraries it uses, or defined by a slot specification for a class explicitly known in the library.

exported binding
(from a module) A binding that is explicitly exported from the module. Exported bindings are available to be imported by other modules that use the module. Unexported bindings are not available to other modules.

expression
A section of program code that represents a value, or the computation of a value. An expression may be part of a larger expression, and it may itself have subexpressions.

false
The unique false object, `#f`.

first-class object
An **object**. The adjective "first-class" is used to emphasize that the object may be stored in a variable or data structure, may be passed as an argument to a function, and may be returned as the value of a function.

free class
A class that may be used freely in multiple inheritance. The opposite of a free class is a **primary class**.

fresh
A collection *C* is fresh if modification of any pre-existing collection's contents can never modify the contents of *C* and if modifications to *C* can never modify the contents of any pre-existing collection. Immutable collections cannot be modified, so a fresh immutable collection can share structure with other immutable collections.

fresh copy
A **copy** that does not share structure. Compare with **shallow copy**.

freshly allocated
See **fresh**.

function
An object used for performing actions and returning values. Functions have a **parameter list** and an optional **return value specification**, which together define the function's **signature**. There are two kinds of functions: **methods** and **generic functions**. A method has a body of code which is executed to compute the method's values when the method is called. A generic function consists of a setof methods,

and computes its values by selecting and calling an appropriate method based on the types of the arguments.

general instance
(of a type) An object that is either a **direct instance** or **indirect instance** of the type.

general superclass
(of a class) A class that is either a **direct superclass** or **indirect superclass** of the class.

generic function
A function consisting of a family of methods with a common calling protocol. A generic function computes its value by selecting and calling an appropriate method based on the types of the arguments. See also **method dispatch**.

generic function dispatch
See **method dispatch**.

get
(the value of a slot) To retrieve the value of the slot.

getter
A function that is applied to an object and returns the value of one of the object's slots.

handler
A function that is used to respond to a signaled **condition**.

hash code
A conceptual object consisting of a **hash id** and its associated **hash state**.

hash function
A function, associated with a table, that computes **hash code**. All hash functions have one argument, a key, and return two values, a **hash id** and a **hash state**, which together represent the **hash code**. See also **equivalence predicate**.

hash id
An integer encoding of an object.

hash table
A **table**.

hash state
An object of implementation-dependent type which is associated with a particular **hash id** and can be used by the implementation to determine whether the **hash id** has been invalidated.

identical
(of two objects) Computationally equivalent. That is, there is no way for any portable Dylan program to distinguish them; they are the same under the **equivalence predicate** `==`.

immutable
Not capable of being modified after it is created. It is an error to attempt to modify an immutable object, though Dylan implementations are not required to detect this error. The opposite of **immutable** is **mutable**.

implicit definition
A definition created by `define method` or by the slot specifications of `define class`.

implicitly defined
1. (of a generic function) Created by an **implicit definition** rather than by `define generic`. 2. (of a method) Created by a slot specification in a `define class` definition, rather than by `define method`.

imported binding
A binding imported from a used module. A binding owned by another module must be imported in order to be visible to code inside the module.

improper list
A list that does not have the **empty list** as the tail of its last pair. An improper list is either a **dotted list** or a **circular list**.

indirect instance
(of a type) A **direct instance** of one of the **proper subclasses** of the type.

indirect superclass
(of a class) A class that is a **general superclass** of one of the class's **direct superclasses**.

infix operator
The name of a function or macro that is normally called using infix notation. Infix operators must be prefixed by the infix operator escape character ("\") in order to be used in any way other than as the operator in an infix function call.

init keyword
A keyword specified in a class definition, used to initialize a slot. An init keyword may be required or optional.

init specification
An init specification provides an initial value for the slot or a default value for an init-keyword. There are three kinds of init specifications. See page 58 for a complete description.

initialization argument
A keyword argument supplied to `make`, used to initialize an **keyword initializable** slot.

initialize
1. (an object) To prepare an object for use, by initializing its slots and calling the initialize function on the object. All Dylan objects are automatically initialized immediately after they are allocated. 2. (a slot) To give the slot its initial value. A program can test to see whether a slot has been initialized by calling the function `slot-initialized?` There is no mechanism for resetting a slot to the uninitialized state. 3. (a variable) To bind the variable to its initial value.

instance
(of a type) A **general instance** of the type.

instantiable class
A class that can be used as the first argument to `make`. The opposite of an instantiable class is an uninstantiable class. Note that an abstract class may be instantiable.

iteration protocol
A protocol that is common to collections, consisting of the functions `forward-iteration-protocol` and `backward-iteration-protocol`. All collections must implement `forward-iteration-protocol`. Some collections that are stable under iteration also implement `backward-iteration-protocol.`

iteration stability
The property of being **stable under iteration**.

iteration binding
A binding associated with a clause in a `for` statement. Each iteration binding is associated with only one clause.

keyword argument list
A sequence containing an even number of **elements** that are alternating keywords and values (i.e. a sequence of **keyword/value pairs**). When there is more than one keyword/value pair with the same keyword, the first such pair determines the value associated with that keyword in the keyword argument list.

keyword initializable
(of a slot) A slot that may be given an initial value by a keyword argument in a call to make. See also **initialization arguments**.

keyword parameter
(of a function) A parameter that corresponds to an optional **keyword/value pair**. Keyword parameters are specified by name rather than position.

keyword/value pair
Two successive arguments (a keyword and a value, respectively) supplied in a function call.

library
A set of modules and code, which is available for use by Dylan programs. Libraries are the unit of compilation, sealing, and optimization.

literal constant
An object that is specified explicitly in program text. Literal constants are immutable.

local precedence order
(of a class and its direct superclasses) An ordering of classes, including the class and its direct superclasses, in which the class precedes its direct superclasses, and each direct superclass precedes all other direct superclasses that follow it in the definition of the class.

local scope
A scope that includes a limited section of program text.

local binding
A binding created by a local declaration. Local bindings are visible within the remainder of the smallest enclosing body containing the declaration which creates the bindings.

mandatory keyword
(of a generic function) A keyword that must be recognized by all of the methods of that generic function. Mandatory keywords are specified in the generic function's parameter list, after `#key` or as the `key:` initialization argument to `make` of `<generic-function>`.

method
A basic callable unit of code. It includes a **parameter list**, a **return value specification** and a **body**.

method dispatch
The process of determining which method to call when a generic function is applied to arguments.

module
A namespace of bindings.

module binding
A binding that can be referenced from any code associated a particular module.

most specific method
The method whose specializers most closely match the arguments of a function call. A method specialized on a subclass is more specific than a method specialized on superclasses.

multimethod
A method that has more than one **specialized** parameter.

multiple inheritance
Inheritance from more than one direct superclass. See also **single inheritance**.

multiple values
Zero or more values returned by an expression. Used in contrast to one value, as in "this function returns multiple values."

mutable
Capable of being modified after it is created. The opposite of mutable is **mutable**.

named value reference
An **expression** which is a reference to a **binding**.

natural order
The order in which elements of a collection are traversed by the iteration protocol for a particular iteration. If a collection is stable under iteration, every iteration over the collection has the same natural order, which defines a natural order for the collection itself.

next method
(during a generic function call) The method that is next most specific, after the method that is currently executing, in the sequence of applicable methods for that generic function call.

next-method parameter
A parameter, usually called `next-method`. The value of the next-method parameter is automatically supplied by the generic function dispatch mechanism. It is either `#f` (if there is no **next method**) or a function that calls the next method after defaulting any unsupplied arguments. There is no way for a user to specify a different next method.

non-local exit
A transfer of control, through an **exit point**, out of a local region of code, that terminates the normal execution of that code and the normal return of values.

normal exit
Completing execution and returning without taking a **non-local exit**.

object
A unit of data in a Dylan program. Objects are instances of classes, may be stored in variables, slots, and collections, may be passed as arguments to functions, and may be returned as values of functions. In Dylan, functions and classes are themselves objects.

open class
A class that may have subclasses that are not explicitly defined in the same library. The opposite of an open class is a **sealed class**.

open generic function
A generic function that may have methods that are not explicitly defined in the same library. The opposite of an open generic function is a **sealed generic function**.

owned
(of a binding, by a module) Created by a `create` clause in the module's `define module` definition, or by a definition associated with the module.

pair
An instance of `<pair>`.

parameter
(of a function) A variable that is declared in the parameter list of a function and specifies part of the function's calling protocol. Parameters are lexically bound within the function body, and are bound to their initial values when the function is called. Dylan supports required parameters, rest parameters, keyword parameters, and next-method parameters.

parameter list
The part of a function definition that specifies the function's calling protocol. See also **signature**.

predicate function
A function that returns a true or false value. The names of predicate functions, by convention, end in a question mark.

primary class
A class that may be used only as the primary superclass in multiple inheritance. A class may not have two primary superclasses unless one is a subclass of the other. The opposite of a primary class is a **free class**.

proper list
A list that has the **empty list** as the tail of its last pair.

proper subclass
(of a class) A class which is a subclass of the class, but is not identical to the class.

proper subtype
(of a type) A type which is a subtype of the type, but is not equivalent to the type. See also **equivalent types**.

protocol
1. (of a class) The methods that all subclasses of the class either implement or inherit. 2. (of a function, esp. a generic function) The **signature** of the function.

pseudosubtype
Arelation between types. The type T_1 is a pseudosubtype of the type T_2 if T_1 is a subtype of the base type of T_2 and T_1 and T_2 are not disjoint.

required parameter
(of a function) A parameter that corresponds to an argument that must be supplied when the function is called. Required parameters are specified in a fixed order before other parameters, and their corresponding arguments must be supplied in the same order. Required parameters may be specialized or unspecialized. Compare **rest parameter**, **keyword parameter**, and **next-method parameter**.

rest parameter
(of a function) A parameter that allows a function to accept a variable number of arguments following those that correspond to the required parameters. The additional arguments are stored in a sequence.

return value specification
An optional part of a function definition that specifies the number and types of the values returned by the function. See also **signature**.

sealed class
A class that cannot have direct subclasses other than those explicitly defined in the same library. The opposite of a sealed class is an **open class**.

sealed generic function
A generic function that cannot have methods that are not explicitly defined in the same library. The opposite of a sealed generic function is an **open generic function**.

sequence
An instance of `<sequence>`, a type of collection which uses successive non-negative integers as keys.

set
(the value of a slot) To replace the value of the slot with a new value.

setter
A function used to set the value of a slot. By convention, the name of a setter is the name of the getter concatenated with the suffix `-setter`.

shadow
(a binding) To hide the binding within a portion of program text, by creating a new local binding with the same name.

shallow copy
(of an object) A new object that has the same **contents** as the object. The contents are not copied, but are the same objects contained in the original object.

signature
(of a function) The **parameter list** and **return value specification** of the function.

single inheritance
Inheritance from only one direct superclass. See also **multiple inheritance**.

singleton
A type used to indicate an individual object. A singleton has only one instance.

slot
A unit of local storage available within an instance or a class, which is used to store state in the instance or class.

slot accessor
A **getter** or **setter**.

specialize
1. (a variable) To restrict the variable to values that are general instances of a particular type. 2. (a generic function) To define a method for the generic function that is applicable only to instances of a particular type or types. 3. (a method) To specify the types of the parameters of the method.

specializer
A type, especially when it is used to specialize a parameter, variable, or slot.

stable under iteration
(of a collection) The proprty of a collection that any two iterations over the collection are guaranteed to produce the same values in the same order (unless, of course, the collection has been modified). See also **natural order** and **sequence**.

stretchy collection
A collection that may grow or shrink to accomodate adding or removing elements.

table
An object, also known as a hashtable, that maps arbitrary keys to objects. Each table has an associated **equivalence predicate** which is used to compare keys. The table maps keys that are equivalent under the predicate to the same table element.

true
1. The canonical true value, `#t`. 2. Any object other than the unique false value, `#f`.

type
A Dylan object that categorizes objects. See "Overview" on page 47.

type equivalent
See **equivalent types**.

type-for-copy
(of an object) An instantiable type suitable for making copies of an object. Instances of the **type-for-copy** must be mutable.

unbounded sequence
A sequence that is infinite or circular.

uninstantiable class
A class that cannot be used as the first argument to `make`. The opposite of an uninstantiable class is an instantiable class.

visible modification
(with respect to an **equivalence predicate**) A modification that changes the equivalence class of the object. The modifications that are visible to an **equivalence predicate** are determined by the definition of the predicate.

white space
Any number of contiguous space, tab, newline, and newpage characters. The amount of contiguous white space is not significant in program code.

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