Overview and Specification of the Built-In Types in Little Smalltalk

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Abstract
This document informally specifies the behavior of most of the key data types in the Little Smalltalk system.

Keywords
Smalltalk, class, subclass, inheritance, instance, method, message passing, specification, sub-type, pre-condition, post-condition

Disciplines
Programming Languages and Compilers | Systems Architecture

Comments
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Overview and Specification of the Built-In Types in Little Smalltalk

Gary T. Leavens and Yoonsik Cheon

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This document informally specifies the behavior of most of the key data types in the Little Smalltalk system. This is done partly because the protocols differ from those found in Smalltalk-80[GR83] and also because for version three of Little Smalltalk, the documentation in [Bud87] is hopelessly out of date and the description in [Bud91] lacks detail. Since our specifications emphasize the client’s point of view, many specialized or private methods of a class are suppressed. The system itself may be used to discover and examine the behavior of such methods.

In the first section we explain our notation for specifying methods. The next sections give type specifications for groups of related types. Section 2 describes protocol for all classes; i.e., the methods of the type Class. Section 3 gives protocol for all Smalltalk objects; i.e., the methods defined in the type Object, the ultimate supertype of all other types. In Section 4, the type Smalltalk is discussed, whose sole instance is used for saving the state of the interpreter, as well as for terminal I/O. Section 5 specifies methods for such primitive types as Boolean, Char, Number, and Symbol. The type String, along with other collection types (Array, List, etc.), is explained in Section 6. Smalltalk control structures (blocks) are specified in Section 7. The type File is described in Section 8. Section 9 presents a table that can be used to find methods in the implementation of Little Smalltalk.

1 Notation for Method Specifications

Specifications of methods are given informally, but in a stylized manner, following [LG86]. A specification consists of a header, a requires clause, and an ensures clause. The header describes the signature of the operation and gives formal names to the arguments and the result. These names are used in the requires and ensures clauses. The requires clause states a pre-condition on the operation’s arguments; that is, a property of the arguments that the caller is expected to satisfy. The requires clause is omitted if the condition is vacuous (i.e., always true). The ensures clause states a post-condition on the results, described in terms of the arguments and the formal result identifier. The post-condition is a property of the result that the method establishes.

Consider the following simple example, the at: operation on arrays.

\[
\text{at:} \quad \text{self: Array, } i: \text{ Integer} \rightarrow o: \text{ Object}
\]

**Requires:** \(i\) is greater than 0, and less than or equal to the size of \(self\).

**Ensures:** \(o\) is the \(i\)th element of \(self\).

The header says that at: is a message that can be sent to an instance of the class Array or a subtype\(^1\) of Array. The receiver, the object to which the message is sent, is given the name self. The at: message also needs an additional argument, which must be an Integer (or a subtype); this additional argument is denoted by \(i\). The object returned by the at: method must be an Object (or one of its subtypes, which is not restrictive), and this object is represented by \(o\). The requires clause says that, the value of \(i\) must be a legal index into the array \(self\). If this condition is true, the operation behaves as described in the ensures clause. Otherwise, the operation does not need to behave as specified in the ensures clause, and may instead do something else, such as printing an error message. The ensures clause says that the value returned is the \(i\)th element of the receiver (\(self\)). This is a termination semantics, that is to say, the operation must not loop forever or encounter an error when the requires clause is satisfied. If the operation does not return, those cases will be made explicitly described.

A slightly different format is used for operations that mutate their arguments and for those that have no return value. For operations that mutate their arguments, a modifies clause is included to state which objects are allowed to be modified. Most operation specifications omit this clause, which means no objects are mutated by that operation. For some operations, especially those that mutate their arguments, the return value is irrelevant. Therefore for such operations, the arrow (\(\rightarrow\)) and the information about the result is omitted from the header; this is interpreted as follows: if the requires clause is satisfied, the receiving object itself will be returned. For such operations the post-condition is stated in an effect clause instead of

\(^1\)A “subtype of Array” is a type whose instances behave like arrays in the sense that each instance of the subtype simulates some array. At the least, an object \(y\) simulates \(r\) if a sequence of message sends cumulating in a boolean or integer result would yield the same final result for both \(y\) and \(r\). See [IWi90] and [Lea91] for more details.
an ensures clause. Logically the meaning is the same, however such a post-condition only states side effects, because there is no return object to refer to.

In the specification of an operation that mutates its arguments, it is sometimes necessary to refer the value of an object in two different states; the states before and after the call. It is also necessary to refer the identity of the object (i.e., its address), that is to say, the object itself not its value. These distinctions are made by qualifying formal argument names. Consider, for example, an object named self. The value of this object before the call is denoted by \texttt{pre(self)} while the value after the call is represented by \texttt{post(self)}. The object's identity is denoted by \texttt{obj(self)}. Qualifications are often redundant. This leads us to adopt certain defaults depending on the context in which a name appears. In the modifies clause, one always refers to object identities, so the object qualification is the default. An unqualified formal argument name \texttt{arg} is, by default, qualified as \texttt{pre(arg)}. A formal result name \texttt{res} is, by default, qualified as \texttt{post(res)}. For example, consider the following description of the \texttt{at:put} operation for arrays, which stores an object at a given index in the receiver.

\begin{verbatim}
\textbf{at:put: } \texttt{self. Array, i: Integer, o: Object}

\textbf{Requires: } i is greater than 0, and less than or equal to the size of \texttt{self}.

\textbf{Modifies at most: } \texttt{self}.

\textbf{Effect: } makes \texttt{o} the element of \texttt{post(self)} at index \texttt{i}.
\end{verbatim}

The input formal \texttt{i} appearing in the requires and effect clauses, is a short form of \texttt{pre(i)}, and the input formal \texttt{o} in the effect clause is short for \texttt{pre(o)}. The receiver \texttt{self} in the modifies clause is also short for \texttt{obj(self)}.

The major conceptual difference of our notation from Liskov and Guttag's is that we omit from a type's specification formalizations for operations defined in the type's supertypes. For instance, since all types are subtypes of the type \texttt{Object}, all have a method \texttt{class} that returns the class of the receiving object. However this method is not repeatedly specified in each type, since repeating it would be redundant and uninformative. It is only specified in the type \texttt{Object} once and for all. Therefore one can think of subtyping as inheritance of specifications (as opposed to code inheritance, which is subclassing in Smalltalk). Because of this, it is worthwhile to refer to the specifications of supertypes if the desired operation seems to be missing.

A set of method specifications are collected together to give a specification of an abstract data type. An abstract data type, which will be called a \texttt{type} for short, is an abstraction of a set of Smalltalk classes characterized by their behavior. A type is usually implemented by a single Smalltalk class. However it may be implemented by several classes, as in the case of type \texttt{Boolean} which is implemented by three Smalltalk classes, \texttt{Boolean}, \texttt{True}, and \texttt{False}. Figure 1 shows the subtype relationships among the types specified in this paper. Figure 2 gives the actual class hierarchy of the Little Smalltalk system.

\section{Protocol for all Classes}

A class is a module that implements an abstract data type. The code and other information kept about each class definition is stored in the Smalltalk system as an object, called a \texttt{class object}. Since each class definition is represented by a single class object, classes and class objects are identified; hence class objects are often called \texttt{classes} for short. Each object in Smalltalk is an instance of a class; hence a class can also be thought of as a set (or class) of objects. Classes (i.e., class objects) are important in Smalltalk because they store Smalltalk code; thus a programmer must master the protocol of class objects to read and write code. Each class object in Smalltalk is named by a global variable that denotes it. The name of this global variable is the name of the class. In what follows we use these names to refer to particular class objects. For example the class \texttt{Object} is named by the global variable \texttt{Object}. Since classes are represented by class objects, these objects must also be instances of some class. That class is called \texttt{Class}. It is the protocol of the class \texttt{Class} that is described in this section.

Classes are related to one another by \texttt{subclass} (or inheritance) relationships. Each class is a \texttt{proper subclass} of exactly one other class, called its \texttt{proper superclass}, and may be a proper superclass of any number of other classes. A class, \texttt{C}, its proper superclass, its proper superclass's proper superclass, and so on are collectively called the \texttt{superclasses} (or ancestors) of \texttt{C}. A class \texttt{C}, its proper subclasses, its proper subclass's proper subclasses, and so on are collectively called the \texttt{subclasses} (or descendents) of \texttt{C}. See Figure 2 for the class
Figure 1: The hierarchy of types

Figure 2: The class hierarchy of the Little Smalltalk
hierarchy of the Little Smalltalk. The operations described below allow one to create new classes, traverse
the inheritance hierarchy, access the instance methods defined in a class or its ancestors, create and edit
methods, save and restore one's work, and create instances of given class. One can also use the messages in
Section 2.2 to traverse the hierarchy of classes.

2.1 Creation of New Classes
New classes can also be created using the methods described in Section 2.5.

addSubClass:instanceVariableNames: 
   self: Class, cn: Symbol, ivn: String

Modifies at most: self, the global dictionary symbols.

Effect: creates a new class named cn as a proper subclass of self with its instance variables names
those words appearing in ivn. (Words in ivn are separated by blanks.)

2.2 Subclass and Superclass Access
The methods described below allow one to traverse the class hierarchy.

superClass
   self: Class → c: Class

Ensures: c is the proper superclass of self.

subClasses
   self: Class → subs: List

Ensures: subs contains all of the proper subclasses of self without repetition and no other classes.

upSuperclassChain:
   self: Class, b: Block

Requires: b is a one-argument block that takes a class object as its argument.

Modifies at most: the objects modified by the execution of b.

Effect: invokes the block b with argument self, the proper superclass of self, and so on for each ancestor
of self (in that order).

To better traverse the class hierarchy, one can add additional methods to the class Class. For example,
the following method would invoke a block on each subclass of the receiver (in depth first order).

allSubclassesDo: aBlock
   aBlock value: self.
   self subClasses do: [:c | c allSubclassesDo: aBlock ]

2.3 Instance Method Access
An instance is said to respond to a given message if its class defines or inherits a method for that message.
This is no guarantee that something useful will happen when that message is sent to it; in some cases an
error will be produced. See also messages for method creation and editing in Section 2.4 the methods in
Section 3.2, and the methods in Section 5.2.

respondsTo
   self: Class → d: Dictionary

Ensures: d is a new dictionary that describes the messages to which instances of self respond. That
is, d maps each method name (a Symbol) to the method object (a Method) that implements that
method. Inherited methods are included.

methods
   self: Class → d: Dictionary

Ensures: d is a new dictionary that describes the messages that are defined in the class self. Inherited
methods are not included.

viewMethod:
   self: Class, s: Symbol

Effect: If instances of self respond to the message s, then the name of the class where the instance
method for s is defined and the code that implements that method are printed; otherwise an error
message is printed.

methodNamed:
   self: Class, s: Symbol → m: Object

Ensures: If there is a method named s implemented in self or its superclasses, then m is the Method
object that implements s; otherwise m is nil.
2.4 Method Creation and Editing

Method creation in Little Smalltalk is either done interactively (as described in this section) or through the use of external files and the methods described in Section 2.5. One can create a method interactively using the editor named by the global variable editor (which is "emacs" by default at ISU). Once editing is finished, it is compiled by the system into an executable code. If there are any errors, one gets a chance to correct them.

```
addMethod self: Class
Modifies at most: self.
Effect: allows you to add a new method to the class self, using the editor whose name is the value of the global variable editor.
```

```
readMethods self: Class
Modifies at most: self.
Effect: allows you to add several method to the class self. You are prompted as to whether you want to add a method or not, and if so you add it as in addMethod. When you are done, you are again asked whether you want to add a method or not, etc.
```

```
editMethod: self: Class, s: Symbol
Modifies at most: self.
Effect: if instances of self respond to the message s, then you are allowed to edit the method definition named s; otherwise an error message is printed.
```

2.5 Saving and Restoring Class Descriptions

Smalltalk code can be saved to and restored from the operating system’s files using the methods described in this section. It is a good idea to save methods to files fairly often; it is especially important to save them before running any tests, because if the Smalltalk system gets into an inconsistent state, you may be forced to restart from files.

The “file out” methods write a description into a file, which can be read back in by the “filing in” methods. Among the methods listed below, some are actually those messages that should be sent to File objects (see Section 8). It is also possible to save the state of the entire system (see Section 4).

```
fileOut self: Class
Effect: write a description of self in a file named “cn.st”, where cn is the name of the class self.
```

```
fileOutOn: self: Class, f: File
Modifies at most: f.
Effect: write a description of self into the file f.
```

```
fileOutMethodsOn: self: Class, f: File
Modifies at most: f.
Effect: write a description of all instance methods of the class self into the file f.
```

```
fileIn: self: File, fn: String
Modifies at most: self, the global dictionary symbols, and existing class objects.
Effect: reads class and/or method descriptions stored in the file named fn, and installs them in the system.
```

```
fileIn self: File
Modifies at most: self, the global dictionary symbols, and existing class objects.
Effect: reads class or method descriptions stored in the file self, and installs them in the system.
```

2.6 Instance Creation

Most objects (other than class objects) in Smalltalk are created (ultimately) by sending some class object a new message. However, arrays and strings are created with new message (see Section 6).
new self: Class → o: Object

Requires: self is neither Array nor String.

Ensures: o is a new instance of the class self, and this new instance has, itself, also been sent the message new (unless self is Class, in which case the new class object is sent the message initialize instead).

new self: Class, i: Integer → o: Object

Requires: self is either Array or String.

Ensures: o is a new instance of self, with size i.

3 Protocol for all Objects

The type Object is a supertype of all other types, just as the class Object is a superclass of all other classes. Its methods provide a consistent basic functionality and default behavior that is useful for debugging. With these methods one can observe all objects in the Little Smalltalk system, including class objects.

The methods of the type Object described below can be used to test the class of an object, test the instance methods to which an object responds, to print and display objects, and to compare the identity of objects. Also included below are methods of the type MutableObject, which is a fictitious subtype of Object. A mutable object is one whose state can be changed. The methods of type MutableObject can be used to copy mutable objects.

3.1 Class access and Membership Tests

The proper way to test if an object is a member of a certain class is with the messages whose specification is given below. (There are also messages, such as isFraction and isInteger, that should be regarded as private to various classes.)

class self: Object → c: Class

Ensures: c is the class of self.

isMemberOf self: Object, c: Class → b: Boolean

Ensures: b is true if and only if c is the class of self.

isKindOf self: Object, c: Class → b: Boolean

Ensures: b is true if c is the class of self or a superclass of self; b is false if c is not an ancestor of the class of self. For example, 1 isKindOf: Object is true, but 1 isKindOf: Boolean is false.

3.2 Instance Method Testing

The messages to which an object responds can be discovered in two ways. One can use the respondsTo: message specified below, or one can first obtain the object’s class and use the message respondsTo specified in Section 2.3. Note that the respondsTo: message can be sent to any object, while the respondsTo message are limited to class objects. Furthermore, these messages differ in the number of arguments and the kind of value returned. (The inverse of this kind of test is described in Section 5.2.)

respondsTo self: Object, s: Symbol → b: Boolean

Ensures: b is true if self responds to the message s; otherwise b is false.

3.3 Printing and Displaying

The message printString is used in preparing formatted output. For debugging the other messages are more useful.

printString self: Object → s: String

\(^{2}\)That is, MutableObject only exists for purposes of specification and there is no class called MutableObject in Little Smalltalk.


Ensures: $s$ is a string describing $self$. The exact result depends on the class of $self$ and its value. (By default, $s$ is just the class name of $self$.)

print $self$: Object

Modifies at most: the standard output.

Effect: prints the string that results from sending $self$ the message printString.

display $self$: Object

Modifies at most: the standard output.

Effect: prints a description of $self$ on the standard output device. The exact result depends on the class of $self$ and its value. (By default, this prints the class name in parentheses and the value of sending $self$ the message printString.)

3.4 Object Identity Comparisons

Object identity is a useful concept only for mutable types (types whose instances have time-varying state) and should not be used for comparing instances of immutable types. The major exception to this rule is for testing to see if an object is defined or nil. In most circumstances one should use the $=$ message to compare the abstract values of objects instead of comparing their identity (address). However, the specification for $=$ cannot be given here, as it varies from type to type and is not meaningful for some types (e.g., Block).

$==$  

$$
es: Object, o: Object \rightarrow b: Boolean$$

Ensures: $b$ is true if $obj(self)$ is equal to $obj(o)$; otherwise $b$ is false. Hence, true is returned if and only if $self$ and $o$ are the same object.

$\neq$

$$
es: Object, o: Object \rightarrow b: Boolean$$

Ensures: $b$ is false if $obj(self)$ is equal to $obj(o)$; otherwise $b$ is true. Hence, true is returned if and only if $self$ and $o$ are different objects.

isNil  

$$
es: Object \rightarrow b: Boolean$$

Ensures: $b$ is true if and only if $obj(self)$ is the object nil, which is the sole instance of the class UndefinedObject.

notNil  

$$
es: Object \rightarrow b: Boolean$$

Ensures: $b$ is false if and only if $obj(self)$ is equal to $obj(nil)$.

3.5 Protocol for Mutable Objects

The type MutableObject is considered to be a supertype of all mutable types. The methods described below are implemented in class Object in Little Smalltalk, but do not work for objects of all types and hence cannot be specified as methods of type Object. The methods of Section 3.4 are also principally useful for mutable objects, but they also work for immutable objects and so are considered methods of type Object.

3.5.1 Copying

Copying an instance of a mutable type is useful as a way to preserve an object’s state from side-effects and to avoid aliasing. The usual way to copy an object is to use the copy operation, which is defined for many types. However, its specification cannot be given here, as it varies from type to type.

shallowCopy  

$$
es: MutableObject \rightarrow o: MutableObject$$

Ensures: $o$ is a new object that has the same value as $self$, $o$ is not the same object as $self$ (i.e., $obj(o) \neq obj(self)$), but $o$ shares all the objects contained in $self$ with $self$.

deepCopy  

$$
es: MutableObject \rightarrow o: MutableObject$$

Ensures: $o$ is a new object that has the same value as $self$, is not the same object as $self$ (i.e., $obj(o) \neq obj(self)$), and does not share any objects contained in $self$. That is, none of the objects contained in $o$ is equal ($==$) to any of the objects contained in $self$. 
4 Smalltalk

The type Smalltalk handles terminal input and output, as well as saving the state of the interpreter. The class Smalltalk has as its only instance the value of the pseudo-variable smalltalk.

4.1 Saving System State

See also the methods in Section 2.5.

saveImage: self: Smalltalk
  Effect: prompt the user for a file name (e.g., “systemImage”, typed without the quotes) and save the current system state in that file.

saveImage: self: Smalltalk, s: String
  Effect: save the current system state in a file named s.

4.2 Terminal I/O

getPrompt: self: Smalltalk, p: String -> s: String
  Modifies at most: standard input and output.
  Ensures: s is a string consisting of a line read from the standard input, after p is printed as a prompt on the standard output with no carriage return. The line read from standard input is terminated by a carriage return, which is not included in s.

inquire: self: Smalltalk, p: String -> b: Boolean
  Modifies at most: standard input and output.
  Ensures: b is true if the first character on a line read from standard input is either “y” or “Y”; b is false otherwise. Before reading the line, the string p is printed as a prompt (i.e., with no carriage return) on the standard output.

error: self: Smalltalk, s: String
  Modifies at most: standard error output.
  Effect: print s as an error message on the standard error output, followed by a trace of the run-time stack, and terminate current execution (so this operation never returns).

5 Primitive Types

The type UndefinedObject has as its only instance the object that is the value of the pseudo-variable nil. It is sometimes useful as a placeholder or a default value.

5.1 Boolean

The type Boolean provides conditionals and logical connectives. It is implemented by three classes named Boolean, True, and False. There are two boolean objects, true and false, which are bound to the pseudo globals true and false respectively. The class of true is True, and that of false is False. Both of these classes are subclassed of the class Boolean. Having two classes provides an interesting demonstration of the technique of using the class of an object to select the algorithm used in the implementation of a message.

5.1.1 Conditionals

The messages ifTrue:ifFalse: and ifFalse:ifTrue: can be used both as expressions and statements.

ifTrue:ifFalse: self: Boolean, c: Block, a: Block -> o: Object
  Requires: c and a take no arguments.
  Modifies at most: the objects modified by the execution of c or a.
  Ensures: o is the result of evaluating c if self is true; otherwise o is that of evaluating a.
ifFalse: ifTrue:  
  self: Boolean, a: Block, c: Block → o: Object  
  Requires: a and c take no arguments.
  Modifies at most: the objects modified by the execution of c or a.
  Ensures: o is the result of evaluating a if self is false; otherwise o is that of evaluating c.

ifTrue:  
  self: Boolean, c: Block  
  Requires: c takes no arguments
  Modifies at most: the objects modified by the execution of c.
  Effect: Evaluates c if self is true; otherwise does nothing.

ifFalse:  
  self: Boolean, a: Block  
  Requires: a takes no arguments
  Modifies at most: the objects modified by the execution of a.
  Effect: Evaluates a if self is false; otherwise does nothing.

5.1.2 Logical connectives

To achieve short-circuit evaluation, the connectives or: and and: take as their second argument a block that should return a boolean.

and:  
  self: Boolean, aBlock: Block → b: Boolean  
  Requires: aBlock takes no arguments and returns a Boolean.
  Modifies at most: the objects modified by the execution of aBlock.
  Ensures: b is false if self is false; otherwise b is the result of evaluating aBlock.

or:  
  self: Boolean, aBlock: Block → b: Boolean  
  Requires: aBlock takes no arguments and returns a Boolean.
  Modifies at most: the objects modified by the execution of aBlock.
  Ensures: b is true if self is true; otherwise b is the result of evaluating aBlock.

not  
  self: Boolean → b: Boolean  
  Ensures: b is true if self is false; otherwise b is false.

xor:  
  self: Boolean, b2: Boolean → b: Boolean  
  Ensures: b is true if self is not equal to b2; otherwise b is false.

5.2 Symbol

Symbols, such as #foo:#bar:, are used for message selectors and in dictionaries. They can be created by the compiler from literals (#aSymbolLiteral), or by sending the message asSymbol to a String object. Symbols cannot be created using new. Abstractly a symbol is a string of characters. Hence, its identity is determined by its string of characters. As a result, there is only one symbol with a given string of characters. Symbols are immutable.

In addition to the methods described below, the methods apply: and apply:ifError: can be used to send a message when the name of the message is not known until run-time.

respondsTo  
  self: Symbol → s: Set  
  Ensures: s is a new set that contains all classes whose instances respond to the message named self.

asString  
  self: Symbol → s: String  
  Ensures: s is the string of characters that form the abstract value of self.

5.3 Magnitude

The type Magnitude defines a general comparison protocol followed by its subtypes: Char, Number, and some subtypes of Collection. The messages <=, <, >, >=, ^= (not equal), =, min:, and max: can be sent to objects of type Magnitude (or a subtype) and have the usual meanings. They should only be considered defined when the second argument has the same subtype as the receiver (e.g., both numbers or both characters). The only unusual message is the following.
between:and: self: Magnitude, low: Magnitude, high: Magnitude → b: Boolean

Requires: self, low, and high are instances of classes that have a common ancestor which is a proper subclass of Magnitude.

Ensures: b is true if self is greater than or equal to low and self is less than or equal to high; otherwise b is false.

5.4 Char

Characters can be created using literals (such as $c$) by sending the asCharacter message to a (small) Integer. The type Char is a subtype of Magnitude; thus characters can be compared with the usual comparison operations (see Section 5.3).

asInteger self: Char → i: Integer

Ensures: i is the ASCII code for self.

isAlphabetic self: Char → b: Boolean

Ensures: b is true just when self is an alphabetic character (a-z or A-Z).

isDigit self: Char → b: Boolean

Ensures: b is true just when self is a digit (0-9).

isAlphaNumetric self: Char → b: Boolean

Ensures: b is true just when self is an alphabetic character (a-z or A-Z) or a digit (0-9).

isBlank self: Char → b: Boolean

Ensures: b is true just when self is the space character ($\]$).

isUppercase self: Char → b: Boolean

Ensures: b is true just when self is an upper case letter (A-Z).

isLowercase self: Char → b: Boolean

Ensures: b is true just when self is a lower case letter (a-z).

5.5 Numbers

The type Number has three subtypes: Integer, Fraction, and Float. Integers and floating point numbers can be created using literals. Integers can also be created by sending the message asInteger to a String object. Fractions are created by division of integers using the message \(/\). The numerator and denominator of a fraction can be obtained by using the messages \(\text{top}\) and \(\text{bottom}\).

Definite iteration over numbers is possible by creating intervals using the methods \(\text{to:}\) or \(\text{to-by:}\) sent to a number (see Section 7.2). For example the following expression prints the odd numbers from 1 to 10.

\(\text{(1 to: 10 by: 2 do: [:i | i print]}\)

The timesRepeat: message (see Section 5.5.2) can also express definite iteration. Protocol for comparing numbers is inherited from the type Magnitude (see Section 5.3).

5.5.1 Arithmetic Operations

The protocol for arithmetic, given in Smalltalk’s syntax, is fairly standard. Most of it is implemented in the class Number. See Figure 3.

5.5.2 Integer Specific operations

In addition to the following operations, integers also have several operations that can be used to manipulate bit-fields: bitShift:, bitAnd:, bitOr:, bitXor:, bitAt:, bitInvert, anyMask, and allMask.

even self: Integer → b: Boolean

Ensures: b is true if self is divisible by 2; otherwise b is false.

odd self: Integer → b: Boolean
<table>
<thead>
<tr>
<th>Message Name</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>abs</td>
<td>absolute value</td>
</tr>
<tr>
<td>negated</td>
<td>unary negation</td>
</tr>
<tr>
<td>positive</td>
<td>test if receiver is greater than or equal to 0</td>
</tr>
<tr>
<td>strictlyPositive</td>
<td>test if receiver is greater than 0</td>
</tr>
<tr>
<td>negative</td>
<td>test if receiver is less than 0</td>
</tr>
<tr>
<td>sign</td>
<td>return -1, 0, or 1 depending on sign of receiver</td>
</tr>
<tr>
<td>rounded</td>
<td>integer nearest the receiver</td>
</tr>
<tr>
<td>truncated</td>
<td>integer part of receiver</td>
</tr>
<tr>
<td>fractionalPart</td>
<td>fractional part of receiver</td>
</tr>
<tr>
<td>floor</td>
<td>largest integer not greater than receiver</td>
</tr>
<tr>
<td>ceiling</td>
<td>smallest integer not less than receiver</td>
</tr>
<tr>
<td>exp</td>
<td>$e$ to power of receiver</td>
</tr>
<tr>
<td>ln</td>
<td>logarithm base $e$</td>
</tr>
<tr>
<td>log</td>
<td>logarithm at base of argument</td>
</tr>
<tr>
<td>sqrt</td>
<td>square root of receiver</td>
</tr>
<tr>
<td>squared</td>
<td>receiver multiplied by itself</td>
</tr>
<tr>
<td>raisedTo</td>
<td>multiply receiver by itself argument times</td>
</tr>
<tr>
<td>reciprocal</td>
<td>1 divided by receiver</td>
</tr>
<tr>
<td>+</td>
<td>addition</td>
</tr>
<tr>
<td>-</td>
<td>subtraction</td>
</tr>
<tr>
<td>*</td>
<td>multiplication</td>
</tr>
<tr>
<td>/</td>
<td>division (preserves accuracy)</td>
</tr>
<tr>
<td>//</td>
<td>division truncated towards $-\infty$</td>
</tr>
<tr>
<td>\</td>
<td>modulo (remainder truncated towards $-\infty$)</td>
</tr>
<tr>
<td>rem:</td>
<td>remainder truncated towards 0</td>
</tr>
<tr>
<td>quo:</td>
<td>quotient truncated towards 0</td>
</tr>
</tbody>
</table>
Ensures: \( b \) is true if \( \text{self} \) is not divisible by 2; otherwise \( b \) is false.

factorial

\[ \text{self}: \text{integer} \rightarrow i: \text{integer} \]

Requires: \( \text{self} \) is not negative.

Ensures: \( i \) is the factorial of \( \text{self} \); that is, \( i = \text{self} \times (\text{self} - 1) \times \cdots \times 2 \times 1 \).

timesRepeat

\[ \text{self}: \text{integer}, \text{aBlock}: \text{block} \]

Requires: \( \text{self} \) is not negative and \( \text{aBlock} \) has no arguments.

Modifies at most: the objects modified by the execution of \( \text{aBlock} \).

Effect: evaluate \( \text{aBlock} \) \( \text{self} \) times.

gcd

\[ \text{self}: \text{integer}, j: \text{integer} \rightarrow i: \text{integer} \]

Ensures: \( i \) is the largest integer that divides both \( \text{self} \) and \( j \).

radix

\[ \text{self}: \text{integer}, \text{base}: \text{integer} \rightarrow s: \text{string} \]

Requires: \( \text{base} \) is between 2 and 36 (inclusive).

Ensures: \( s \) represents the value of \( \text{self} \) as a numeral in base \( \text{base} \) digits.

6 Collections

The type Collection is the supertype of types, like List and Array, whose instances contain a “bunch” of other objects. The major subtypes of Collection are List and Array. Arrays are much like those in Smalltalk-80, but lists are quite different. Other subtypes of Collection are Set, Dictionary, String, and Interval. Common protocol for Dictionary, Array and String is implemented by the type IndexedCollection (See Figure 1 on page 23 for more detail). Protocol for all collections (i.e., those methods defined in the type Collection) is described in the next subsection. The following sub-sections describe the subtypes.

6.1 Protocol for all Collections

Objects of a subtype of Collection are mutable, and thus Collection is a subtype of MutableObject (see Section 3.5). As such collections can be copied. A deep copy of a collection generally copies each element, while a shallow copy shares elements with the original. By default copy gives a shallow copy.

It is best to think of a collection as homogeneous, that is, a collection should contain elements that have a common supertype (e.g., Object) if nothing else. Following this view, one can think of Collection as a type generator, which can be instantiated for various element types; for example, sets of integers or arrays of objects.

The type of a collection of objects that are magnitudes (e.g., lists of integers) is a subtype of Magnitude and hence supports the comparison protocol of the type Magnitude (see Section 5.3). In implementation terms, the comparison protocol that the class Collection inherits from the class Magnitude only works if the elements also support the protocol. The basic “magnitude” of a collection in this view is how many times an element occurs in the collection. For example, if \( c1 \) and \( c2 \) are lists, then \( c1 \leq c2 \) if every element of \( c1 \) occurs at least as many times in \( c2 \) as it occurs in \( c1 \). (See the message occurrencesOf: below.)

6.1.1 Testing

isEmpty

\[ \text{self}: \text{collection} \rightarrow b: \text{boolean} \]

Ensures: \( b \) is true if \( \text{self} \) contains no elements, and false otherwise.

size

\[ \text{self}: \text{collection} \rightarrow i: \text{integer} \]

Ensures: \( i \) is the number of elements in \( \text{self} \).

occurrencesOf

\[ \text{self}: \text{collection}, o: \text{object} \rightarrow i: \text{integer} \]

Ensures: \( i \) is the number of elements in \( \text{self} \) that are equal (=) to \( o \).

includes

\[ \text{self}: \text{collection}, o: \text{object} \rightarrow b: \text{boolean} \]

Ensures: \( b \) is true if \( \text{self} \) contains an element that is equal (=) to \( o \), and false otherwise.
6.1.2 Iteration

See also the methods for the type Interval in Section 7.2.

do: self: Collection, aBlock: Block
  Requires: aBlock takes one argument.
  Modifies at most: the objects modified by the execution of aBlock.
  Effect: evaluate aBlock for each element of self.
select: self: Collection, aBlock: Block → c: Collection
  Requires: aBlock takes one argument, returns a Boolean, and has no side-effects.
  Ensures: c is a new collection with the same class as self, that contains just those elements e of self
  for which the expression aBlock value: e is true (See Section 7.1).
inject:into: self: Collection, v: Object, aBlock: Block → o: Object
  Requires: aBlock takes two arguments and has no side-effects.
  Ensures: o is the reduction of self by aBlock with initial value v. That is, if self has no elements,
  then o is v. If self has an element e, then o is aBlock value: x value: e, where x is the reduction
  of the remaining elements of self. For example, one can sum the elements of a collection c by the
  following expression.

  c inject: 0 into: [:x :y | x + y ]

6.1.3 Conversions among Collection Types

asArray self: Collection → a: Array
  Ensures: a is a new Array that contains just the elements of self.
asSet self: Collection → s: Set
  Ensures: s is a new Set that contains just the elements of self, such that no two elements of s are
  equal (=).
sort: self: Collection, aBlock: Block → lst: List
  Requires: aBlock takes two arguments, returns a Boolean, and has no side-effects; furthermore, the
  elements of self are totally ordered by aBlock.
  Ensures: lst contains just the elements of self, sorted so that for all i < j that are indexes of lst,
  aBlock value: (lst at: i) value: (lst at: j) returns true.
sort self: Collection → lst: List
  Requires: the elements of self are totally ordered by <=.
  Ensures: lst contains just the elements of self in increasing order.

6.2 List

A List object is, abstractly, a mutable, ordered sequence of objects. Elements can be added and taken off
the list at both ends; there is a first element and a last element in every non-empty list. The objects in the
sequence are the list’s elements. Empty instances of List are created by sending the new message to the class
object List.

6.2.1 Adding and Removing Elements

The various ways that elements can be added to a list can be exploited to implement stacks, queues, priority
queues, and other data structures. Note, however, that there is no removeFirst operation that corresponds
to the removeLast operation.

add: self: List, o: Object
  Modifies at most: self.
  Effect: makes post(self) contain o as its last element; the other elements of post(self) are those of
  pre(self), in their original order.
addLast: \[ \text{self: List, } o: \text{Object} \]
Modifies at most: self.
Effect: makes post(self) contain \( o \) as its last element; the other elements of post(self) are those of pre(self), in their original order.

addFirst: \[ \text{self: List, } o: \text{Object} \]
Modifies at most: self.
Effect: makes post(self) contain \( o \) as its first element; the remaining elements of post(self) are those of pre(self), in their original order.

addAll: \[ \text{self: List, } c: \text{Collection} \]
Modifies at most: self.
Effect: makes post(self) contain all the elements of \( c \) as its last elements (in the ordering of \( c \), if \( c \) has an order), and the elements of pre(self) as its first elements, in their original order.

add:ordered: \[ \text{self: List, } o: \text{Object, } b: \text{Block} \]
Requires: \( b \) takes two arguments, returns a Boolean, and has no side-effects.
Modifies at most: self.
Effect: makes post(self) contain all the elements of pre(self) in their original order, except that \( o \) appears in post(self) just before the first element of pre(self) \( v \) such that the expression \( b \text{ value: } v \) value: \( o \) is false. For example, if list is a list with elements 1, 1, and 3 (in that order), the result of
\[
\text{list add: } 2 \text{ ordered: } [ \text{:x :y | x < y } ]
\]
is to insert 2 just before the 3 in list, so that the elements of list are (in order): 1, 1, 2, and 3.

remove: \[ \text{self: List, } o: \text{Object} \]
Modifies at most: self.
Effect: makes post(self) contain all the elements of pre(self) in their original order, except for the first occurrence of an element that is equal (=) to \( o \).

removeFirst \[ \text{self: List} \]
Modifies at most: self.
Effect: makes post(self) contain all the elements of pre(self) in their original order, except for the first element of pre(self).

6.2.2 Accessing Elements

Surprisingly, there is only one operation available to access elements directly. The other way to access the elements of a list is by using the iteration operations described below and in Section 6.1.2.

first \[ \text{self: List } \rightarrow o: \text{Object} \]
Ensures: \( o \) is the first element of \( self \).

6.2.3 Mapping and Filtering

In addition to those operations described in Section 6.1.2, List also defines following iteration operations.

collect: \[ \text{self: List, } a\text{Block: Block } \rightarrow \text{lst: List} \]
Requires: \( a\text{Block} \) takes one argument.
Modifies at most: the objects modified by the execution of \( a\text{Block} \).
Ensures: \( \text{lst} \) is a new list that contains for each element \( e \) of self the result of the expression \( a\text{Block value: } e \), where the results appear in the same order as the elements of pre(self). (The argument \( a\text{Block} \) is invoked on the elements in the order that they appear in pre(self).)

reject: \[ \text{self: List, } a\text{Block: Block } \rightarrow \text{lst: List} \]
Requires: \( a\text{Block} \) takes one argument, returns a Boolean, and has no side-effects.
Ensures: \( \text{lst} \) is a new list that contains the elements \( e \) of self such that the result of the expression \( a\text{Block value: } e \) is false, The elements appear in their original order.
reverseDo:  
   self: List, aBlock: Block
   Requires:  
      aBlock takes one argument.
   Modifies at most:  
      the objects modified by the execution of aBlock.
   Effect:  
      evaluate aBlock once for each element of self, starting with the last element and working back to the first.

6.3 Set

The abstract value of a Set instance is a set of objects with distinct abstract values. The elements of a Set are compared using the equality (=) message. That is, two objects \( x \) and \( y \) have the same abstract value if and only if the result of the equality (=) message is true. It is assumed that equality (=) can be applied to any two objects and that it is an equivalence relation on all objects.

Instances of class Set are partially ordered by set inclusion; that is, \( s_1 \) is a subset of \( s_2 \) if for each element \( e_1 \) of \( s_1 \), there is some element in \( s_2 \) with the same abstract value (i.e., that is equal (=) to \( e_1 \)). Two instances of Set have the same abstract value if each is a subset of the other. Furthermore \( s_1 \) is a proper subset of \( s_2 \) if \( s_1 \) is a subset but they do not have the same abstract value. The = message tests sets for the same abstract value, while the <== message tests the subset relation.

New instances of Set are created with by sending the new message to the class object Set, which returns an empty set.

6.3.1 Adding and Removing Elements

add:  
   self: Set, o: Object
   Modifies at most:  
      self.
   Effect:  
      makes post(self) contain just the elements of pre(self) and o.

addAll:  
   self: Set, c: Collection
   Modifies at most:  
      self.
   Effect:  
      makes post(self) contain just the elements of pre(self) plus all the elements of c.

remove:  
   self: Set, o: Object
   Modifies at most:  
      self.
   Effect:  
      makes post(self) contain the elements of pre(self) except o.

6.3.2 Iteration

In addition to those messages described in Section 6.1.2, Set also defines following iteration protocol.

collect:  
   self: Set, k: Block \rightarrow s: Set
   Requires:  
      k takes one argument.
   Modifies at most:  
      the objects modified by the execution of k.
   Ensures:  
      s is a new set that contains for each element \( e \) of self the value of the expression aBlock value: e. (The set \( s \) is constructed by invoking k once for each element of self in arbitrary order.)

reject:  
   self: Set, k: Block \rightarrow s: Set
   Requires:  
      k is a one-argument block that returns a Boolean and has no side-effects.
   Ensures:  
      s is a new set that contains just those elements, \( e \), of self for which k value: e is false. Note that this is the opposite of select:.

6.4 Array

The abstract value of an Array is an ordered sequences of elements. This ordering is used to index the elements. The first element has index 1, the second 2, and so on. A legal index is thus the one between 1 and the size of the collection (inclusive).

An array is created using a literal of the form #(1 aSymbol 3.3) or by the new: message sent to the class object Array where the argument is the desired size.
6.4.1 Fetching and Storing

Some messages not described below give the programmer more control over error conditions through the use of zero-argument exception blocks. These include at:ifAbsent: and indexOf:ifAbsent:.

at:  
\[ \text{self: Array, i: Integer} \rightarrow o: Object \]
\textbf{Requires:} \( i \) is greater than 0, and less than or equal to the size of self.
\textbf{Ensures:} \( o \) is the \( i^{\text{th}} \) element of self.

indexOf:  
\[ \text{self: Array, b: Block} \rightarrow i: \text{Integer} \]
\textbf{Requires:} \( b \) takes one argument, returns a Boolean, and has no side-effects; furthermore self contains some element \( x \) such that \( b \text{ value: } x \) is true.
\textbf{Ensures:} \( i \) is the smallest index of self such that the expression \( b \text{ value: } (\text{self at: } i) \) returns true.

at:put:  
\[ \text{self: Array, i: Integer, o: Object} \]
\textbf{Requires:} \( i \) is greater than 0, and less than or equal to the size of self.
\textbf{Modifies at most:} self.
\textbf{Effect:} makes \( o \) the element of \( \text{post}(\text{self}) \) at index \( i \); the other elements of \( \text{pre}(\text{self}) \) are unchanged.

with:  
\[ \text{self: Array, o: Object} \rightarrow a: \text{Array} \]
\textbf{Ensures:} \( a \) is a new array that has as its elements the elements of self in order, followed by \( o \).

addAll:  
\[ \text{self: Array, a2: Array} \]
\textbf{Requires:} \( a2 \) has no more elements than self.
\textbf{Modifies at most:} self.
\textbf{Effect:} makes the first \( s2 \) elements of \( \text{post}(\text{self}) \) the elements of \( a2 \) in the order of \( a2 \), where \( s2 \) is the size of \( a2 \); the elements of \( \text{post}(\text{self}) \) whose indexes are greater than \( s2 \), if any, are unchanged from \( \text{pre}(\text{self}) \).

exchange:  
\[ \text{self: Array, i: Integer, j: Integer} \]
\textbf{Requires:} \( i \) and \( j \) are greater than 0, and less than or equal to the size of self.
\textbf{Modifies at most:} self.
\textbf{Effect:} the element of \( \text{post}(\text{self}) \) at index \( i \) is that of \( \text{pre}(\text{self}) \) at index \( j \) and vice versa; the other elements of \( \text{pre}(\text{self}) \) are unchanged.

6.4.2 Iteration

As a subtype of Collection, Array also supports all the iteration operations described in Section 6.1.2. In addition to the above, there are also several other interesting operations that have been omitted for lack of space. The messages binaryDo: and binaryInject:into: enable one to operate on both elements and indexes. The messages with:do: and with:ifAbsent:do: allow one to operate on the elements of two arrays at once.

collect:  
\[ \text{self: Array, aBlock: Block} \rightarrow a: \text{Array} \]
\textbf{Requires:} aBlock takes one argument.
\textbf{Modifies at most:} the objects modified by the execution of aBlock.
\textbf{Ensures:} \( a \) is a new array that contains for each element \( e \) of self the result of the expression aBlock value: \( e \), where the results appear in the same order as the elements of \( \text{pre}(\text{self}) \). (The argument aBlock is invoked on the elements in the order they appear in \( \text{pre}(\text{self}) \).)

reverseDo:  
\[ \text{self: Array, aBlock: Block} \]
\textbf{Requires:} aBlock takes one argument.
\textbf{Modifies at most:} the objects modified by the execution of aBlock.
\textbf{Effect:} evaluates aBlock once for each element of self, starting with element at the greatest index, and working back to the element with index 1.
6.5 Dictionary

Abstractly, a Dictionary object is a mutable mapping from keys to values. The mapping is generally partial. The elements of a dictionary are the values, i.e., the range of the map. As a subtype of Collection, Dictionary also supports the iteration operations described in Section 6.1.2. Some messages not described below give the programmer more control over error conditions through the use of zero-argument exception blocks, for example, ifAbsent: and indexOf:ifAbsent:.

at:  
    self: Dictionary, key: Object -> v: Object
    Requires: self is defined at key.
    Ensures: v is the value associated with key in self.

indexOf:  
    self: Dictionary, b: Block -> key: Object
    Requires: b takes one argument, returns a Boolean, and has no side-effects; furthermore, self contains some element x such that b value: x is true.
    Ensures: key is one of the keys of self such that b value: (self at: key) returns true.

includesKey:  
    self: Dictionary, key: Object -> b: Boolean
    Ensures: b is true if self is defined at key, otherwise b is false.

at:put:  
    self: Dictionary, key: Object, value: Object
    Modifies at most: self.
    Effect: makes value the element of post(self) at key key; the rest of the mapping is unchanged.

addAll:  
    self: Dictionary, d2: Dictionary
    Modifies at most: self.
    Effect: makes post(self) map the keys of d2 to the values associated by d2; other keys defined in pre(self) are mapped to their values in pre(self).

removeKey:  
    self: Dictionary, key: Object
    Requires: self is defined at the key key.
    Modifies at most: self.
    Effect: makes post(self) not defined at key; the mapping is unchanged for all other keys.

6.6 String

A String object is an ordered collection of characters. Strings are mutable, and are a subtype of the type array of characters. As such they inherit copying protocol (see Section 3.5) and the fetching and storing protocol of Array (see Section 6.4.1), but with the restriction that only Char objects can be fetched and stored.

As a subtype of Collection whose elements are magnitudes, String supports a lexicographic ordering messages of type Magnitude (see Section 5.3), and the iteration messages described in Section 6.1.2. The iteration protocol of Arrays also applies (see Section 6.4.2).

Strings cannot be created by sending the new message to the class object String. Instead they are created by literals ("a String, don't laugh").

words:  
    self: String, aBlock: Block -> a: Array
7 Control Structures

Conditionals, which are messages sent to Booleans, are described in Section 5.1.1.

7.1 Block

The class Block provides the essential control structures of Smalltalk. Technically a block is a closure; that is, a block contains some parameterized code and an environment used to look up variables that occur in the block but which are not parameters.

Blocks may have up to three arguments. Zero argument blocks are invoked with the value message. The main use of a zero-argument block is to delay evaluation of code. One argument blocks are invoked with the value: message while two argument blocks are with the value:value: message. Finally, the value:value:value: message is used to invoke a three-argument blocks are invoked with the value:value:value: message. For example, the following expressions all have a value of 7.

\[
[5 + 2] \text{value} \\
[ :x \mid x + 2 ] \text{value: 5} \\
[ :x :y \mid x + y ] \text{value: 5 value: 2} \\
[ :x :y :z \mid x + y + (z - z)] \text{value: 5 value: 2 value: 8}
\]

In addition to the following, there are also messages (fork, forkWith:, and newProcess) that can be used to create multiple threads of control (parallelism).

**whileTrue:** 
\( \text{self: Block, body: Block} \)

**Requires:** \( \text{self} \) is a zero-argument block that returns a Boolean, and \( \text{body} \) is a zero-argument block.

**Modifies at most:** the objects modified by the execution of \( \text{self} \) and \( \text{body} \).

**Effect:** evaluate \( \text{self} \), if the result is false, return; otherwise evaluate \( \text{body} \) and repeat this process. For example,

\[
i <- 1.3 \\
[1 <= 4] \text{whileTrue: [ i print. i <- i+1]}
\]

prints the numbers 1.3, 2.3, and 3.3 in that order.

**whileFalse:**
\( \text{self: Block, body: Block} \)

**Requires:** \( \text{self} \) is a zero-argument block that returns a Boolean, and \( \text{body} \) is a zero-argument block.

**Modifies at most:** the objects modified by the execution of \( \text{self} \) and \( \text{body} \).

**Effect:** evaluate \( \text{self} \), if the result is true, return; otherwise evaluate \( \text{body} \) and repeat this process.

**whileTrue**
\( \text{self: Block} \)

**Requires:** \( \text{self} \) is a zero-argument block.

**Modifies at most:** the objects modified by the execution of \( \text{self} \).

**Effect:** evaluate \( \text{self} \) repeatedly, so that this operation never returns.

7.2 Interval

The type Interval is a subtype of Collection. An Interval object is, abstractly, an arithmetic sequence of numbers, either ascending or descending. Each Interval has a lower bound, an upper bound, and a step size. Intervals with step size 1 are created by sending the message to: to a number with an number argument;

\[
[5 + 2] \text{value} \\
[ :x \mid x + 2 ] \text{value: 5} \\
[ :x :y \mid x + y ] \text{value: 5 value: 2} \\
[ :x :y :z \mid x + y + (z - z)] \text{value: 5 value: 2 value: 8}
\]
for example, the expression 1.3 to: 4 creates an interval with lower bound 1.3, upper bound 4, and step size 1. The “elements” of this interval are 1.3, 2.3, and 3.3. In general, the elements are numbers of the form \( l + (n \times s) \) where \( l \) is the lower bound, \( s \) is the step size, and \( n \) is an integer that ranges from 0 up to the largest integer \( N \) such that \( l + ((N + 1) \times s) \) is strictly greater than the upper bound if the step size is positive or strictly less than the upper bound if the step size is negative.

The “for loop” of other languages is modeled by the do: message sent to an Interval object. For example,

\[
(1.3 \text{ to } 4) \text{ do: } [i \text{ print } i]
\]

prints the numbers 1.3, 2.3, and 3.3 in that order. Less involved “for loops” can also be constructed by sending an integer the timesRepeat: message with a zero-argument block as an argument (see Section 5.5.2). Collections also provide direct ways to iterate over their elements, using the message do: and others described in Section 6.1.2.

The lower bound, the upper bound, and the step size of an Interval object can be modified by the following methods.

- **lower:** self: Interval, n: Number
  
  **Modifies at most:** self
  
  **Ensures:** \( n \) is the lower bound of \( \text{post}(\text{self}) \).

- **upper:** self: Interval, n: Number
  
  **Modifies at most:** self
  
  **Ensures:** \( n \) is the upper bound of \( \text{post}(\text{self}) \).

- **step:** self: Interval, n: Number
  
  **Modifies at most:** self
  
  **Ensures:** \( n \) is the step size of \( \text{post}(\text{self}) \).

8 Files

A File object is created by new message. The name of the file associated with a File object is set by name: (where the argument must be a string), and accessed by name. A file can be opened in three different modes: read (‘r’), write (‘w’), and read-and-write (‘r+w’). The message open: (with one of the mode strings as its argument) is sent to a file object to open it; if mode is ‘w’, a new file named that of the receiver is created in the current directory, otherwise, the existing file named that of the receiver is opened for reading in the current directory. If no such file exists when the open-mode is ‘r’, an error occurs. A File object is closed by close message. The method readUntil:doing: can be used for complex reading operations (such as parsing).

The main methods for reading and writing to files are described below. See also Section 2.5 for messages that save and read classes and method definitions into and out of files.

- **getString** self: File \( \rightarrow s: \text{Object} \)
  
  **Requires:** self was opened with read mode (‘r’ or ‘r+w’).
  
  **Modifies at most:** self
  
  **Ensures:** \( s \) is the next line of self (terminated by a carriage return) if such is present before the end-of-file; otherwise \( s \) is nil.

- **print** self: File, s: String
  
  **Requires:** self was opened with write mode (‘w’ or ‘r+w’).
  
  **Modifies at most:** self
  
  **Effect:** appends \( s \) at the end of self.

9 Guide to the Implementation

Table 1 lists types specified in this document; it shows which classes implement which operations by methods. The left-hand column gives names of types specified above. The next column, gives the names of the class or
classes that implements each type. For example, the type `Integer` is implemented by the classes `Integer` and `LongInteger`. Operations are mentioned in the column `spec & impl` next to the classes that implement them, provided the operations are also specified above. For example, the operation `radix:` is implemented by the class `Integer`, and we also give a specification for it above under the type `Integer`. The column `re-implemented` gives those operations that are specified for a supertype, implemented by the corresponding superclass, and that are also re-implemented (overridden) by the subclass. For example, the `abs` operation is specified in `Integer`'s supertype `Number`, implemented by a method in `LongInteger`'s superclass `Number`, and that method is re-implemented in the class `LongInteger`.

Notice that we omit from a type's specification operations specified by its supertypes. Therefore, to get all the operations defined for a type, one may need to traverse its supertype chain given in Figure 1 on page 5. For example, the operation `abs` is defined for `Integer` objects, because it is specified in `Integer`'s supertype `Number`. In the implementation, the class `Integer` inherits the method `abs` from its superclass `Number` (see Figure 2 on page 5), because `abs` is not mentioned in the column labeled `re-implemented`.

Operations listed in the column `must be impl` are specified by a type but not implemented by the corresponding class; these operations must be implemented in subclasses of the given class. For example, we specified `do:` as an operation defined on objects of type `Collection`, but the class `Collection` does not implement `do:`. A slightly different case is the operation `=`, which is implemented in the class `Object`, even though its implementation should usually be overridden.

Several operations not specified in this document but implemented in Little Smalltalk are listed below the column with header `not specified`.

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References


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**Table 1: Specified types and their implementations**
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