The Cyan Language

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Foreword

This is the manual of Cyan, a prototype-based statically-typed object-oriented language. The language introduces several novelties that makes it easy to implement domain specific languages, reuse the code of methods and nested prototypes (the equivalent of nested classes), blend dynamic and static code, reuse exception treatment, and do several other common tasks. However, the reader should be aware that:

1. the design of Cyan has not finished. There are a lot of things to be designed, the metalevel being one of them (although we cite metaobjects a lot in the text, the compile-time metaobject protocol has not been defined). It is possible that the definition of some language features will be modified, although it is improbable that they will be great changes;

2. many language features need a more detailed description. Probably there are ambiguities in the description of some constructs. That will be corrected in due time;

3. Cyan is a big language, maybe a huge language (unfortunately). But this is fine since Cyan is an academic language. Its main goal is to publish articles. However, there are many small details that were added thinking in the programmer, such as nested if-else statements, while statement, Elvis operator, literal objects, etc;

4. the compiler for a subset of the language is being built. It creates the AST (Abstract Syntax Tree) generates code for a small subset of the language. Cyan code will be able to use Java classes. Since the Cyan compiler produces Java code, this will not be difficult. Java code will be able to use Cyan prototypes (which is a little bit tricker). However, nowhere in this text we talk about interrelations between the two languages;

5. I have thought in how to implement some parts of the language in an efficient way (whenever possible). There was no time to put the ideas in this report. We believe that many flexible constructs, such as considering methods as objects, can be efficiently implemented (they would not be considered objects unless necessary);

6. If you have any suggestions on anything, please email me.

The main novelties of Cyan are, in order of importance:

(a) grammar methods, Chapter 9
(b) an object-oriented exception handling system, Chapter 12
(c) context objects, Chapter 11
(d) statically-typed blocks, Chapter 10
(e) many ways of mixing dynamic and static typing, Chapter 6
(f) codegs, Section 5.4;
(g) context blocks, Section 10.11;
(h) literal objects delimited by user-defined symbols, Chapter 13. This feature is being defined;
(i) generic objects with variable number of parameters, Chapter 7.
(j) a restricted form of multi-methods (search for methods in the textually-declared order), Section 4.12
(k) compilation considers previous version of the source code (source code in XML), Chapter 2.
The address of the Cyan home page is http://www.cyan-lang.org.
Other features will probably be added to Cyan and its libraries. They are:
(a) optional use of “;” at the end of a statement;
(b) non-null types. If a variable is declared with type “T”, then nil cannot be assigned to it. To allow that, the variable should be declared with a type “T?”;
(c) metaobjects in the project program (a file that describes all source codes and libraries used in a program). So a metaobject can be applied to all prototypes of a program or to all prototypes of a package;
(d) enumerated constants;
(e) concurrent constructs;
(f) a library of patterns for parallel programming implemented as grammar methods
(g) a library of Domain Specific Languages for Graphical User Interface made using grammar methods and based on Swing of Java (an initial version has been done already);
(h) a library for XML and HTML handling using DSL’s made using grammar methods;
(i) grammar methods with user-defined symbols. That would allow small parsers of arbitrary languages to be implemented as grammar methods;
(j) a library of patterns implemented using codegs, regular metaobjects, and literal objects;
(k) doc metaobject to document objects, methods, variables, and so on;
(l) literal regular expressions (implemented as literal objects);
(m) generic prototypes defined as metaobjects. Then “P<T1, T2, ... Tn>” would be a call to a method of metaobject P which would produce a real prototype that replaces “P<T1, T2, ... Tn>” in the source code. Tuples will be implemented in this way by the Cyan compiler;
(n) generic methods.
Chapter 1

An Overview of Cyan

Cyan is a statically-typed prototyped-based object-oriented language. As such, there is no class declaration. Objects play the role of classes and the cloning and new operations are used to create new objects. Although there is no class, objects do have types which are used to check the correctness of message sending. Cyan supports single inheritance, mixin objects (similar to mixin classes with mixin inheritance), interfaces, a completely object-oriented exception system, statically-typed closures, optional dynamic typing, user-defined literal objects (an innovative way of creating objects), context objects (which are a generalization of closures and one of the biggest innovations of the language), and grammar methods and message sends (which makes it easy to define Domain Specific Languages). The language will have a compile-time metaobject protocol in a not-so-near future.

Although the language is based in prototypes, it is closest in many aspects to class-based languages like C++ and Java than some prototype-based languages such as Self [19] or Omega [1]. For example, there is no workspace which survives program execution, objects have a new method that creates a new object similar to another one (but without cloning it), and a Cyan program is given textually. In Omega, for example, a method is added to a class through the IDE. Cyan is close to Java and C++ in another undesirable way: its size is closer to these languages than to other prototype-based languages (which are usually small). However, several concepts were unified in Cyan therefore reducing the amount of constructs in relation to the amount of features. For example, methods are objects, the exception system is completely object-oriented (it does not need many ad-hoc keywords found in other languages), and closures are just a kind of context objects.

In this Chapter we give an overview of the language highlighting some of its features. An example of a program in Cyan is shown in Figure 1.1. The corresponding Java program is shown in Figure 1.2. It is assumed that there are classes In and Out in Java that do input and output (they are in package inOut). The Cyan program declares objects Person and Program. Object Person declares a variable name and methods getName and setName. Keywords var and fun are used before an instance variable and a method declaration. var is optional. Method getName takes no argument and returns a String. Symbol -> is used to indicate the return value type. Inside a method, self refers to the object that received the message that caused the execution of the method (same as self of Smalltalk and this of Java). A package is a collection of objects and interfaces — it is the same concept of Java packages and modules of other languages. All the public identifiers of a package become available after a “import” declaration. Package inOut is automatically imported by every Cyan program. Therefore the line “import inOut” can be removed from this example.

Object Program declares a run method. Assume that this will be the first method of the program to be executed. The first statement of run is

:p = Person clone;

“Person clone” is the sending of message clone to object Person. “clone” is called the “selector” of
package program
import inOut

private object Person
  private var :name String = ""
  public fun getName -> String [
    " self.name
  ]
  public fun setName: :name String [
    self.name = name
  ]
end

public object Program
  public fun run [
    :p = Person clone;
    :name String;
    name = In readString;
    p setName: name;
    Out println: (p getName);
  ]
end

Figure 1.1: A Cyan program
package program;
import inOut;

private class Person {
    private String name;
    public String getName() {
        return this.name;
    }
    public Void setName( String name ) {
        this.name = name;
    }
}

public class Program {
    public void run() {
        Person p;
        String name;
        p = new Person();
        name = In.readString();
        p.setName(name);
        Out.println( p.getName() );
    }
}

Figure 1.2: A Java program
the message. All objects have a clone method. This statement declares a variable called p and assigns to it a copy of object Person. The code

```ruby
:variableName = expr
```
declares a variable with the same compile-time type as expr and assigns the result of expr to the variable. The type of expr should have been determined by the compiler using information of previous lines of code. The next line,

```ruby
:name String;
```
declares name as a variable of type String. This is also considered a statement. In

```ruby
name = In readString;
```
there is the sending of message readString to object In, which is an object used for input. Statement

```ruby
p setName: name;
```
is the sending of message “setName: name” to the object referenced to by p. The message selector is “setName:” and “name” is the argument. Finally

```ruby
Out println: (p getName);
```
is the sending of message “println: (p getName)” to object Out. The message selector is “println:” and the argument is the object returned by “p getName”.

The parameters that follow a selector in a method declaration may be surrounded by ( and ). So method setName: could have been declared as

```ruby
public fun setName: (:name String) [ self.name = name ]
```
This is allowed to increase the legibility of the code.

**Definition and Declaration of Variables**

Statement

```ruby
:p = Person clone;
```
could have been defined as

```ruby
:p Person;
```
```ruby
p = Person clone;
```
Variable p is declared in the first line and its type is the object Person. When an object is used where a type is expected, as in a variable or parameter declaration, it means “the type of the object”. By the type rules of Cyan, explained latter, p can receive in assignments objects whose types are Person or sub-objects of Person (objects that inherit from Store, a concept equivalent to inheritance of classes).

**Inheritance**

The type system of Cyan is close to that of Java although the first language does not support classes. There are interfaces, single inheritance, and implementation of interfaces. The inheritance of an object Person from Worker is made with the following syntax:

```ruby
object Worker extends Person
```
```ruby
  private :company String
  // other instance variables and methods
end
```

If a method is redefined in a sub-object (be it public or protected), keyword “override” should appear just after “public” or “protected”. Methods of the sub-object may call methods of the super-object using keyword super as the message receiver:

---

1In this report, we will use parameter and argument as synonymous.
Cyan has runtime objects, created with new and clone methods, and objects such as Person, Program, and Worker, which are created before the program execution. To differentiate them, most of the time the last objects will be called prototypes. However, when no confusion can arise, we may call them objects too.

It is important to bear in mind the dual rôle of a prototype in Cyan: it is a regular object when it appears in an expression and it is a type when it appears as the type of a variable, parameter, or return value of methods.

Interfaces

Interfaces are similar to those of Java. One can write

```caym
interface Savable
    fun save
end

object Person
    public :name String
    public :age Int
end

object Worker extends Person implements Savable
    private :company String
    public fun save [
        // save to a file
    ]
    ... // elided
end
```

Here prototype Worker should implement method save. Otherwise the compiler would sign an error. Unlike Java, interfaces in Cyan are objects too. They can be passed as parameters, assigned to objects, and receive messages.

Values

The term “variable” in Cyan is used for local variable, instance variable (attribute of a prototype), and parameter. A variable in Cyan is a reference to an object. The declaration of the variable does not guarantee that an object was created. To initialize the variable one has to use a literal object such as 1, 3.1415, "Hello" or to created an object with clone or new. There is a special object called nil with one special property: it can be assigned to any variable. nil plays the rôle of nil in Smalltalk. As in Smalltalk, nil knows how to answer some messages — it is an object. Value null of Java or NULL of C++ are not objects. These values correspond to the value noObject of Cyan, the only value of the basic prototype Void. It cannot answer any messages.

Object String is a pre-defined object for storing sequences of characters. A literal string can be given enclosed by " as usual: "Hi, this is a string", "um", "ended by newline\n".
Any

All prototypes in Cyan inherit from prototype Any which has some basic methods such as eq: (reference comparison), == (is the content equal?), asString, and methods for computational reflection (add methods, get object information, and so on). Method
eq: (:other Any) -> Boolean
tests whether self and other reference the same object. Method == is equal to eq: by default but it should be redefined by the user. Method eq: cannot be redefined in sub-prototypes. Method neq: returns the opposite truth value of eq:

Basic Types

Cyan has the following basic types: Byte, Short, Int, Long, Float, Double, Char, and Boolean. Since Cyan will be targeted to the Java Virtual Machine, the language has exactly the same basic types as Java. Unlike Java, all basic types in Cyan inherit from prototype Any. Therefore there are not two separate hierarchies for basic types, that obey value semantics and all other types, which obey reference semantics.

However, methods eq: and == of all basic types have the same semantics: they return true if the contents of the objects are equal:

:I Int = 1;
:J Int = 1;
if ( I == J && I eq: J ) [
    Out println: "This will be printed"
]

Since the basic prototypes cannot be inherited and methods eq: and == cannot be changed or intercepted, not even by reflection, the compiler is free to implement basic types as if they obey value semantics. That is, a basic type Int is translated to int of Java (Cyan is translated to Java or to the JVM). There are cases in which this should not be done:

(a) when a basic type variable is passed as parameter to a method that accepts type Any:

    object IntHashTable
        public fun key: (:aKey String) value: (:aValue Any) [ ... ]
        ...
    end
    ...
    IntHashTable key: "one" value: 1;

    In this case the compiler will create a dynamic object of prototype Int for the 1 literal;

(b) when a basic type variable receives a message that correspond to a method of Any such as prototypeName:

    // prints "Int"
    Out println: (1 prototypeName);

    But even in this case the compiler will be able to optimize the code since it knows which method should be called;

---

The declaration of a variable allocates memory for the “object”. Variables really contains the object, it is stack allocated. In reference semantics, variables are pointers. Objects are dynamically allocated.
(c) when the variable of a basic type receives nil in an assignment:

```
:n Int; n = nil;
```

In practice, the compiler will implement basic types as the basic types of Java almost all of the time. The overhead should be minimal.

There is also another basic type, Void, which has only one value, noObject, which is not an object. Any messages sent to noObject causes a runtime error. Every method that does not return anything in fact return value noObject.

**Constructors and Inheritance**

Constructors have the name `init` and may have any number of parameters. The return value should be Void or none. For each method named `init` the compiler (in fact, a metaobject) adds to the prototype a method named `new` with the same parameter types. Each `new` method creates an object and calls the corresponding `init` method. If the prototype does not define any `init` or `new` methods, the compiler supplies an empty `init` method that does not take parameters. Consequently, a `new` method is created too. A sub-prototype should call one of the `init` methods of the super-prototype (if one was defined by the user) using keyword `super`:

```object
object Person
  public fun init: (:name String) [ self.name = name ]
  private :name String
  ...
end

object Worker extends Person
  public fun init: (:name String, :job String) [
    // this line is demanded
    super init: name;
    self.job = job;
  ]
  private :job String
  ...
end
```

All `new` methods return an object of the prototype. Therefore, `Person` has a method

```
  “ new: (:name String) -> Person”
```

and `Worker` has a method

```
  “ new: (:name String, :job String) -> Worker”
```

To make it easy to create objects, there is an alternative way of calling methods `new` and `new:`.

```
P(p1, p2, ..., pn) is a short form for
(P new: p1, p2, ..., pn)
```

Therefore we can write either

```
:prof = Worker("John", "Professor")
```
or

```
:prof = Worker new: "John", "Professor"
```

Of course, if a prototype P has a `new` method that does not take parameters we can write just “P()” to create an object.
Public and Protected Instance Variables

An instance variable can be declared private, protected, or public. In the last two cases, the compiler will create public or protected get and set methods for a hidden variable that can only be accessed, in the source code, by these methods. For a user-declared public instance variable instVar of type T, the compiler creates two methods and one hidden instance variable. For example, suppose University is declared as

```
object University
  public :name String = ""
end
```

Then the compiler considers that this prototype were declared as

```
object University
  public name -> String [ return _name ]
  public name: (: _newName String ) [ _name = _newName ]
  private : _name String
end
```

The source code is not modified. The compiler only changes the abstract syntax tree used internally.

Note that methods name and name: are considered different. The hidden instance variable _name cannot be directly accessed in the source file. However, it can be accessed through the reflection library (yet to be made). It is as if the compiler replaced the declaration

```
public :name String
```

by the above code. The same applies to protected variables. The instance variable should be used through methods:

```
University.name = "Universidade Federal de São Carlos";
Out println: University.name;
```

Future versions of Cyan may allow the use of dot to access public and protected instance variables. It is only necessary a syntax for grouping the get and set methods associated to a public or protected variable. As it is, this syntax in unnecessary. To replace a public instance variable by methods it is only necessary to delete the variable declaration and replace it by methods.

As an example of that, consider a prototype Point:

```
object Point
  public :dist Float
  public :angle Float
end
```

```
aPoint = Point new;
aPoint dist: 100;
aPoint angle: 30;
r = aPoint dist;
angle = aPoint angle;
...
Later we may be like to use cartesian coordinates. No problem:

```plaintext
object Point
    public dist -> Float [ return Math.sqrt: (x*x + y*y) ]
    public dist: (:newDist Float) [ // calculate x and y with this new distance
        ... 
    ]
    public angle -> Float [ ... ]
    public :angle (:newAngle Float) [ ... ]
    private :x Float
    private :y Float
end
```

```
// no changes here
aPoint = Point new;
aPoint dist: 100;
aPoint angle: 30;
r = aPoint dist;
angle = aPoint angle;
```

**Keyword Messages and Methods**

Since Cyan is a descendent of Smalltalk, it supports keywords messages, a message with multiple selectors (or keywords) as in

```
:p = Point dist: 100.0 angle: 20.0;
```

Method calls become documented without further effort. Prototype `Point` should have been declared as

```plaintext
object Point
    public fun dist: (:newDist Float) angle: (:newAngle Float) -> Point [ 
        :p = self clone;
        p dist: newDist;
        p angle: newAngle;
        return p
    ]
    public :dist Float
    public :angle Float
end
```

Unlike Smalltalk, after a single keyword there may be multiple parameters:

```plaintext
object Quadrilateral
    public fun p1: (:x1, :y1 Int)
        p2: (:x2 Int, :y2 Int)
        p3: :x3, :y3 Int
        p4: :x4 Int, :y4 Int [ 
```
self.x = x1;
...
self.y4 = y4
]
...  
private :x1, :y1, :x2, :y2, :x3, :y3, :x4, :y4 Int
end
...
:r = Quadrilateral p1: 0, 0 p2: 100, 10
   p3: 20, 50 p4: 120, 70;

This example declares the parameters after the selectors in all possible ways.

Abstract Prototypes

An abstract prototype should be declared with keyword `abstract` and it may have zero or more public abstract methods:

```
public abstract object Shape
   public abstract fun draw
end
```

An abstract prototype does not have any `new` methods even if it declares `init` methods. Abstract methods can only be declared in abstract objects. A sub-prototype of an abstract object may be declared abstract or not. However, if it does not define the inherited abstract methods, it must be declared as abstract too.

To call an object “abstract” seem to be a contradiction in terms since “objects” in prototype-based languages are concrete entities. However, this is no more strange than to have “abstract” classes in class-based languages: classes are already an abstraction. To say “abstract class” is to refer to an abstraction of an abstraction.

Final Prototypes and Methods

A prototype declared as final meaning that it cannot be inherited.

```
public final object Int
...
end
...
public object MyInt extends Int
...
end
```

There would be a compile-time error in the inheritance of the final prototype `Int` by `MyInt`.

A final method cannot be redefined. This allows the compiler to optimize code generation for these methods.

```
public object Person
   public final fun name -> String [ ^_name ]
   public final fun name: (:newName String) [ _name = newName ]
...
end
```
Public instance variables may be declared final. That means the get and set methods of the variable are final.

Decision and Loop Methods and Statements

Since Cyan is a descendent of Smalltalk, statements if and while are not necessary. They can be implemented as message sends:

```plaintext
( n%2 == 0 ) ifTrue: [ s = "even" ] ifFalse: [ s = "odd" ];
:i = 0;
[^ i < 5 ] whileTrue: [  
    Out println: i;
    ++i
]
```

However, if and while statements were added to the language to make programming easier and cascaded if’s efficient. The code above can be written as

```plaintext
if ( n%2 == 0 ) [  
    s = "even"
]  
else [ // the else part is optional  
    s = "odd"
];
:i = 0;
while ( i < 5 ) [  
    Out println: i;
    ++i
]
```

Cascaded if’s are possible:

```plaintext
if ( age < 3 ) [  
    s = "baby"
]  
else if ( age <= 12 ) [  
    s = "child"
]  
else if ( age <= 19 ) [  
    s = "teenager"
]  
else [  
    s = "adult"
];
```

Without the if statement, the above code would be much greater and would demand a lot of message sends and parameter passing which would require a lot of optimizations from the compiler.
There is also a short form of if that returns an expression:

```plaintext
oddOrEven = (n%2 == 0) t: "even" f: "odd";
// or
oddOrEven = (n%2 != 0) f: "even" t: "odd";
```

Unnecessary to say that this is a message send and that the arguments of both selectors should be of the same type.

Every prototype inherits a grammar method from Any that implements the switch “statement”. There is a metaobject attached to this method that checks whether the expressions after case: have the same type as the receiver. The block after do: is of type Block (no parameters or return value).

```plaintext
:n = In readInt;
if ( n >= 0 && n <= 6 ) [
    n switch:
        case: 0 do: [
            Out println: "zero"
        ]
        case: 1 do: [
            Out println: "one"
        ]
        case: 2, 3, 5 do: [
            Out println: "prime"
        ]
        else: [
            Out println: "four or six"
        ]
];
```

**Cyan Symbols**

There is a sub-prototype of String called CySymbol (for Cyan Symbol) which represents strings with an special eq: operator: it returns true if the argument and self have the same contents. This is the same concept as Symbols of Smalltalk. There are two types of literal symbols. The first one starts by a # followed, without spaces, by letters, digits, underscores, and “:”, starting with a letter or digit. The second type is a string preceded by a #, as #"a symbol". These are valid symbols in Cyan:

```plaintext
#name #name:
#"this is a valid symbol; ok? ! &)"
#at:put: #1 #711
"1 + 2" "Hello world"
```

A symbol can be assigned to a string variable since CySymbol inherits from String.

```plaintext
:s String;
:s = #at:put:;
    // prints at:put:
Out println: s;
:s = #"Hello world"
    // prints Hello world
Out println: s;
```
We call the “name of a method” the concatenation of all of its selectors. For example, methods

```kotlin
public fun key: (:aKey String) value: (:aValue Int) -> String
public fun name: (:aName String) age: (:aAge Int) salary: (aSalary Float) -> Worker
```

have names `key:value:` and `name:age:salary:`.

### Overloading

There may be methods with the same name but with different number of parameters and parameter types (method overloading). For example, one can declare

```kotlin
object MyBlackBoard
    public fun draw: :f Square [ ... ]
    public fun draw: :f Triangle [ ... ]
    public fun draw: :f Circle [ ... ]
    public fun draw: :f Shape [ ... ]
    private :name String
end
```

There are four `draw` methods that are considered different by the compiler. In a message send

```kotlin
MyBlackBoard draw: fig
```

the runtime system searches for a `draw` method in prototype `MyBlackBoard` in the textual order in which the methods were declared. It first checks whether `fig` references a prototype which is a sub-prototype from `Square` (that is, whether the prototype extends `Square`, assuming `Square` is a prototype and not an interface). If it is not, the searches continues in the second method,

```kotlin
draw: :f Triangle
```

and so on. If an adequate method were not found in this prototype, the search would continue in the super-prototype.

### Subtyping and Method Search

The definition of subtyping in Cyan considers that prototype `S` is a subtype of `T` if `S` inherits from `T` (in this case `T` is a prototype) or if `S` implements interface `T`. An interface `S` is a subtype of interface `T` if `S` extends `T`. This is a pretty usual definition of subtyping.

In the general case, in a message send

```kotlin
p draw: fig
```

the algorithm searches for an adequate method in the object the variable `p` refer to and then, if this search fails, proceeds up in the inheritance hierarchy. Suppose `C` inherits from `B` that inherits from `A`. Variable `x` is declared with type `B` and refers to a `C` object at runtime. Consider the message send

```kotlin
x first: expr1 second: expr2
```

At runtime a search is made for a method of object `C` such that:

(a) the method has selectors `first:` and `second:` and;

(b) selector `first:` of the method takes a single parameter of type `T` and the runtime type of `expr1` is subtype of `T`. The same applies to selector `second:` and `expr2`;

The methods are searched for in object `C` in the *textually* declared order. The return value type is not considered in this search. If no adequate method is found in object `C`, the search continues at object `B`. If again no method is found, the search continues at object `A`. 
The compiler makes almost exactly this search with just one difference: the search for the method starts at the declared type of \( x, B \).

This unusual runtime search for a method is used for two reasons:

(a) it can be employed in dynamically-typed languages. Cyan was designed to allow a smooth transition between dynamic and static typing. Cyan will not demand the declaration of types for variables (including parameters and instance variables). After the program is working, types can be added.

The algorithm that searches for a method described above can be used in dynamically and statically-typed languages;

(b) it is used in the Cyan exception system. When looking for an exception treatment, the textual order is the correct order to follow. Just like in Java/C++/etc in which the catch clauses after a try block are checked in the order in which they were declared after an exception is thrown in the try block.

The programmer should be aware that to declare two methods such that:

(a) they have the same selectors and;

(b) for each selector, the number of parameters is the same.

will make message send much slower than the normal.

Methods that differ only in the return value type cannot belong to the same prototype. Then it is illegal to declare methods \( \text{id} \rightarrow \text{Int} \) and \( \text{id} \rightarrow \text{String} \) in the same prototype (even if one of them is inherited).

The search for a method in Cyan makes the language supports a kind of multi-methods. The linking “message”-“method” considers not only the message receiver but also other parameters of the message (if they exist). Unlike other object-oriented languages, the parameter types are inspected at runtime in order to discover which method should be called.

### Arrays

Array prototypes are declared using the syntax: \( \text{Array}<\text{A}> \) in which \( \text{A} \) is the array element type. Only one-dimensional arrays are supported. A literal array object is created using \{# element list #\}, as in the example:

\[
:n = 5;
:anIntArray = \{# 1, 2, (\text{Math} \text{ sqr: n}) \#\};
:anStringArray \text{ Array<String>};
\]

\[
\text{anStringArray} = \{# "one", "t" + "wo" \#\};
\]

This code creates two literal arrays. \text{anIntArray} will have elements 1, 2, and 25, assuming the existence of a \text{Math} prototype with a \text{sqr} method (square the argument). And \text{anStringArray} will have elements "one" and "two". The array objects are always created at runtime. So a loop

\[
1..10 \text{ foreach: [ |:i \text{ Int}|}

\text{Out println: \{# i-1, i, i + 1 \#\]}\]

Creates ten different literal arrays at runtime. The type of a literal array is \( \text{Array}<\text{A}> \) in which \( \text{A} \) is the type of the first element of the literal array. Therefore

\[
:fa = \{# 1.0, 2, 3 \#\};
\]

declares \text{fa} as a \text{Array<Float>}.
Figure 1.3: The resulting Window prototype after the mixin inheritance is applied

**Mixin Objects**

A prototype can inherit from any number of mixin prototypes. A mixin prototype is declared as in the example:

```plaintext
mixin(Window) object Border
    public :borderColor Int;
    ...
    public override fun draw [ drawBorder; super draw; ]
    public fun drawBorder [ ... ]
end
```

Here `Border` is a mixin prototype that may be inherited by prototype `Window` or its sub-prototypes (`Window` could be an interface too). Inside this mixin prototype, methods of `Border` may send messages to `super` or `self` as if `Border` inherited from `Window` (or as if `Border` inherited from some class implementing interface `Window`). Code

```plaintext
object Window mixin Border
    public fun draw [ ... ]
    ...
end
```

makes `Window` inherit from `Border`. The word “inherits” here is misleading. In fact, the compiler creates a prototype `Window'` with the contents of `Window`, creates a prototype `Window` with the contents of `Border`, and makes `Window` inherit from `Window'`. What the compiler does is a textual copy of the text of `Window` to a new text create for `Window'`. Then it deletes the text of `Window` putting in its place the text of `Border`. Figure [1.3] illustrates the resulting Window prototype.

A mixin declared as

```plaintext
mixin(A) object B
    ...
end
```

should obey the same restrictions as a prototype that inherits from `A`. In particular, if `B` declares a method

```plaintext
public override fun get -> T
```

Window’ is just a new name.
that is already defined in A, it should be declared with the keyword override and its return value type
should be equal to the return value type of method get of A or it should be a subtype of it:

```csharp
object A
  public fun get -> Person [ ... ]
end

mixin(A) object B
  public override fun get -> Worker [ ... ]
end
```

Prototype Border may add behavior to object Window. For example, it defines a draw method that
draws a border and calls draw of Window using super — see the example. Then,

```csharp
Window draw
first calls draw of Border. This method calls method drawBorder of Border and then draw of Window
using super.

Mixin prototypes can also be dynamically attached to objects. Suppose mixin Border is not inherited
from prototype Window. A mixin object of Border may be dynamically attached to a Window object using
the attachMixin: method inherited from Any:

```csharp
:w = Window new;
  // other initializations of w
  ...
  // calls draw of Window: no border
  w draw;
  w attachMixin: Border;
    // calls draw of Border
  w draw;
```

Border works like a runtime metaobject with almost the same semantics as shells of the Green
language [12]. Any messages sent to Window will now be searched first in Border and then in Window.
When Window is cloned or a new object is created from it using new, a new Border object is created too.

**Dynamic Typing**

Although Cyan is statically-typed, it supports some features of dynamically-typed languages. A message
send whose selectors are preceded by ? is not checked at compile-time. That is, the compiler does not
check whether the static type of the expression receiving that message declares a method with those
selectors. For example, in the code below, the compiler does not check whether prototype Person defines
a method with selectors name: and age: that accepts as parameters a String and an Int.

```csharp
:p Person;
  ...
  p ?name: "Peter" ?age: 31;
```

This non-checked message send is useful when the exact type of the receiver is not known:
The array could have objects of any type. At runtime, a message `printObj` is sent to all of them. If all objects of the array implemented a `Printable` interface, then we could declare parameter `anArray` with type `Array<Printable>`. However, this may not be the case and the above code would be the only way of sending message `printObj` to all array objects.

The compiler does not do any type checking using the returned value of a dynamic method. That is, the compiler considers that

```plaintext
if( obj ?get ) [ ... ]
```

is type correct, even though it does not know at compile-time if `obj ?get` returns a boolean value.

Dynamic checking with `?` plus the reflective facilities of Cyan can be used to create objects with dynamic fields. Object `DTuple` of the language library allows one to add fields dynamically:

```plaintext
:t = DTuple new;
// add field "name" to t
:t ?name: "Carolina";
// prints "Carolina"
Out println: (t ?name);
// if uncommented the line below would produce a runtime error
//Out println: (t ?age);
:t ?age: 1;
// prints 1
Out println: (t ?age);
// if uncommented the line below would produce a
// **compile-time** error because DTuple does not
// have an "age" method
Out println: (t age);
```

Here fields `name` and `age` were dynamically added to object `t`.

Metaobject `@dynOnce` used before a prototype makes types optional in the declaration of variables and return value types.

```plaintext
@dynOnce object Person
public :name
public :age
public fun addAge: (:n) [
  // unnecessary and didactic code
  :sum;
  sum = age + n;
  age = sum
]
public fun print [
  Out println: name + " (#{age} years old)"
]
end
```

With `@dynOnce`, types become optional in `Person`. Suppose that in the first run of the program, the following code is executed.

```plaintext
:p Person;
p name: "Turing";
p age: 100;
p print;
```
Then at the end of program execution, the compiler adds some of the missing types in the declaration of
Person:

```plaintext
@dynOnce object Person
    public :name String
    public :age Int
    public fun addAge: (:n) [  // unnecessary and didactic code
        :sum;
        sum = age + n;
        age = sum
    ]
    public fun print [  // unnecessary and didactic code
        Out println: name + " (#{age} years old)"
    ]
end
```

However, `addAge:` was not used in this run of the program and its parameter `n` does not have a type yet. In the next run, suppose statement

```plaintext
Person addAge: 1
```

is executed. Then all the missing types of `Person` have been established. Again the compiler changes the
source code of `Person` to

```plaintext
object Person
    public :name String
    public :age Int
    public fun addAge: (:n Int) [  // unnecessary and didactic code
        :sum Int;
        sum = age + n;
        age = sum
    ]
    public fun print [  // unnecessary and didactic code
        Out println: name + " (#{age} years old)"
    ]
end
```

Since all variables and return value types are known, the call to metaobject `@dynOnce` is removed from
the source code.

There is also a metaobject `@dynAlways` whose call should precede a prototype declaration. This
prototype should not declare any types for variables or return value methods. The compiler will not issue
an error because of the missing types. This prototype becomes a dynamically-typed piece of code. The
source code is not changed afterwards by the compiler.

### Expressions in Strings

In a string, a `#` not preceded by a `\` should be followed either by a valid identifier or an expression between
`{` and `}`. The identifier should be a parameter, local variable, or unary method of the current object.
The result is that the identifier or the expression between `{` and `}` is converted at runtime to a string
(through the `asString` method) and concatenated to the string. Let us see an example:
:name = "Johnson";
:n = 3;
:johnsonSalary Float = 7000.0;
Out println: "Person name = #name, id = #{n*n+1}, salary = #johnsonSalary";

This code prints
  Person name = Johnson,  id = 10, salary = 7000.0
The last line is completely equivalent to
Out println: "Person name = " + name + " , id = " + (n*n+1) + " ,
salary = " + johnsonSalary;

Generic Prototypes

Cyan also supports generic prototypes in a form similar to other languages but with some important differences. First, a family of generic prototypes may share a single name but different parameters. For example, there is a single name UTuple that is used for tuples of any number of parameters (as many as there are in the library):

:aName UTuple<String>;
:p UTuple<String, Int>;
aName f1: "Lívia"
  // prints Lívia
Out println: (aName f1);
p f1: "Carol"
p f2: 1
  // prints "name: Carol age: 1". Here + concatenates strings
Out println: "name: " + (p f1) + " age: " + (p f2);

Second, it is possible to used field names as parameters:

:aName Tuple<name, String>;
:p Tuple<name, String, age, Int>;
aName name: "Lívia"
  // prints Lívia
Out println: (aName name);
p name: "Carol"
p age: 1
  // prints "name: Carol age: 1"
Out println: "name: " + (p name) + " age: " + (p age);

A generic prototype is considered different from the prototype without parameters too:

object Box
  public :value Any
end

object Box<:T>
  public :value T
end

...
A unnamed literal tuple is defined between [. and .] as in

:p = [. "Lívia", 4 .];
Out println: (p f1), " age ", (p f2);
    // or
:q UTuple<String, Int>;
q = [. "Lívia", 4 .];

A named literal tuple demands the name of the fields:

:p = [. name:"Lívia", age:4 .];
Out println: (p name), " age ", (p age);
    // or
:q UTuple<name, String, age, Int>;
q = [. name:"Lívia", age:4 .];

**Multiple Assignments**

Multiple assignments can be used to extract the values of literal tuples:

:Livia = [. "Lívia", 4 .];
:Carol = [. name:"Carolina", age:1 .];
:name String;
:age Int;

    // multiple assignment
name, age = Livia;
name, age = Carol;

The same applies to return value of methods:

object Person
...
  public fun getInfo -> UTuple<String, Int> [
      return [. name, age .]
  ]
private :name String
private :age Int
end
:Myself = Person new;
name, age = Myself getInfo;

Both unnamed and named tuples can be used in multiple assignments. If there are less tuple fields than the number of variables of the left of symbol “=”, then the compiler issues an error. If there are more fields than the number of variables, the extra fields are ignored.
Blocks or Cyan Closures

Cyan supports statically-typed closures, which are called blocks in Smalltalk and Cyan. A block is a literal object that can access local variables and instance variables. It is delimited by [ and ] and can have parameters which should be put between vertical bars:

```cy
:b = [ |:x Int| ^x*x ];
   // prints 25
Out println: (b eval: 5);
```

Here [ |:x Int| ^x*x ] is a block with one `Int` parameter, `x`. The return value of the block is the expression following the symbol `^`. The return value type may be omitted in the declaration — it will be deduced by the compiler. This block takes a parameter and returns the square of it. A block is a literal object with a method `eval` or `eval:` (if it has parameters as the one above). The statements given in the block can be called by sending message `eval` or `eval:` to it, as in `"b eval: 5"`.

A block can also access a local variable:

```cy
:y = 2;
:b = [ |:x Int| ^ x + y ];
   // prints 7
Out println: (b eval: 5);
```

As full objects, blocks can be passed as parameters:

```cy
object Loop
    public fun until: (:test Block<Boolean>) do: (:b Block) [
        b eval;
        (test eval) ifTrue: [ until: test do: b ]
    ]
end
...
```

Here prototype `Loop` defines a method `until:do:` which takes as parameters a a block that returns a Boolean value (`Block<Boolean>`) and a block that returns nothing (`Block`). The second block is evaluated until the first block evaluated to `false` (and at least one time). Notation "i = #i" is equivalent to ("i = " + i). If an expression should come after #, then we should do "i = #{i + 1}"; which is the same as ("i = " + (i+1)). Note that both blocks passed as parameters to method `until:do:` use the local variable `i`, which is a local variable.

Blocks are useful to iterate over collections. For example,

```cy
:v = {# 1, 2, 3, 4, 5, 6 #};
   // sum all elements of vector v
:sum = 0;
v foreach: [ |:x Int|
    sum = sum + x
];
```
Method `foreach`: of the array `v` calls the block (as in "b eval: 5") for each of the array elements. The sum of all elements is then put in variable `sum`.

Sometimes we do not want to change the value of a local variable in a block. In these cases, we should precede the variable by `%`:

```plaintext
:y = 2;
:b = [ |:x Int| y = y + 1; ^ x + y ];
  // prints 8
Out println: (b eval: 5);
  // prints 3
Out println: y;
y = 4;
  // prints 10
Out println: (b eval: 5);
  // prints 5
Out println: y;

:y = 2;
:c = [ |:x Int| %y = %y + 1; ^ x + %y ];
  // prints 8
Out println: (c eval: 5);
  // prints 2
Out println: y;
y = 4;
  // prints 8
Out println: (c eval: 5);
  // prints 4
Out println: y;
```

The value of local variable `y` is copied to a variable called `y` that is local to the block. This copy is made at the creation of the block, when the value of `y` is assigned to an instance variable of the block object. Changes to this variable are not reflected into the original local variable.

However, both the original variable and the `%`-variable refer to the same object. Message sends to this object using the `%`-variable or the original variable will produce the same result. The variables are different but they refer to the same object.

```plaintext
:p = Person name: "Newton" age: 370;
[ // here %p and p DO refer to the same object
    %p = Person new;
    // here %p and p do NOT refer to the same object
    %p name: "Gauss" age: 235
] eval;
  // prints "Newton"
Out println: (p name);
[ // here %p and p DO refer to the same object
    %p name: "Gauss";
    // the name of the object Person was
    // changed to "Gauss"
] eval;
  // prints "Gauss"
```
Out println: (p name);

There are two kinds of blocks: those that accesses local variables (without the \% qualifier) or have a return statement and those that do not have any of these things. They are called restricted and unrestricted blocks, respectively (for short, r-blocks and u-blocks). r-blocks cannot be stored in instance variables. If this were allowed, the block could be used after the local variables it uses ceased to exist. There are special rules for type checking of r-blocks. The rules make sure an r-block will not outlive the local variables it uses in its body. An u-block can be assigned to a variable whose type is an r-block. Since parameter passing is a kind of assignment, r-blocks can be passed as parameters — it is only necessary that the formal parameters have r-blocks as types. In this way, closures (blocks) in Cyan are statically-typed and retain almost all functionalities of closures of dynamic languages such as Smalltalk.

Context Objects

Context objects are a generalization of blocks and internal (or inner) classes. Besides that, they allow a form of language-C-like safe pointers. The variables external to the block are made explicit in a context object, freeing it from the context in which it is used. For example, consider the block

\[
[ | :x \text{ Int} | \text{sum} = \text{sum} + x ]
\]

It cannot be reused because it uses external (to the block) variable sum and because it is a literal object. Using context objects, the dependence of the block to this variable is made explicit:

```cpp
// Block<Int><Void> is a block that takes an Int
// as parameter and returns Void
object Sum(:sum &Int) implements UBlock<Int><Void>
    public fun eval: :x Int [
        sum = sum + x
    ]
end

... // sum the elements of array v
:s = 0;
v foreach: Sum(s)
```

Context objects may have one or more parameters given between ( and ) after the object name. These correspond to the variables that are external to the block (sum in this case). This context object implements interface Block<Int><Void> which represents blocks that take an Int as a parameter and returns nothing. Method eval: contains the same code as the original block. In line

```
v foreach: Sum(s)
```

expression “Sum(s)” creates at runtime an object of Sum in which sum represents the same variable as s. When another object is assigned to sum in the context object, this same object is assigned to s. It is as if sum and s were exactly the same variable.

Prototype Sum can be used in other methods making the code of eval: reusable. Reuse is not possible with blocks because they are literals. Context objects can be generic, making them even more useful:

```cpp
object Sum<T>(:sum &T) implements UBlock<T><Void>
    public fun eval: :x T [
        sum = sum + x
    ]
end
```
...  

// concatenate the elements of array v
:v = #{"but", "ter", "fly"};;
:s String;
v foreach: Sum<String>(s)

Now context object Sum is used to concatenate the elements of vector v (which is a string array).

The type of a context-object parameter may be preceded by % to mean that the parameter is a copy parameter. That means changes in the context-object parameter are not propagated to the real argument:

```context
object Sum(:sum %Int) implements UBlock<Int><Void>
    public fun eval: (:x Int) [
        sum = sum + x
    ]
end
```

...  

// do not sum the elements of array v
:s = 0;
v foreach: Sum(s);
assert: (s == 0);

Method assert: of Any checks whether its argument returns true. It ends the program otherwise. In this example, the final value of s will be 0.

A context-object parameter may be preceded by * to indicate that the real argument to the context object should be an instance variable. This kind of parameter is called instance variable parameter. Parameters whose types are preceded by & are called reference parameters (see first example). Context objects that have at least one reference parameter are called restricted context objects and have the same restrictions as r-blocks. All the other are unrestricted context objects and there is no restriction on their use.

Context objects are a generalization of both blocks and nested objects, a concept similar to nested or inner classes. That is, a class declared inside other class that can access the instance variables and method of it. However, class B declared inside class A is not reusable with other classes. Class B will always be attached to A. In Cyan, B may be implemented as a context object that may be attached to an object A (that play the rôle of class A) or to any other prototype that has instance variables of the types of the parameters of B. Besides that, both referenced parameters and instance variable parameters implement a kind of language-C like pointers. In fact, it is as if the context-object parameter were a pointer to the real argument:

```context
// C
int *sum;
int s = 0;
sum = &s;
*sum = *sum + 1;
    // value of s was changed
printf("%d\n", s);
```
**Context Blocks**

A context block is a kind of method that can be plugged to more than one prototype. It is also a kind of literal context object with a single `eval` or `eval:` method. A context block was created to allow a method to be attached to all objects of a prototype. This concept is very similar to an object that represent a “class method” in class-based object-oriented languages.

A context block that returns the name of a color is declared as

```plaintext
:colorNameCB = (:self IColor) [ | -> String |
    // colorTable takes an integer and returns
    // a string with the name of the color of
    // that integer
    return colorTable[ self color ]
];
```

`self` appears as a parameter declaration before the block. Its type is `IColor`:

```plaintext
interface IColor
    fun color -> Int
    fun color: Int
end
```

Inside the block, `self` has type `IColor`. Message sends to `self` should match methods declared in the `IColor` interface. The only message send in this example is “`self color`”, which calls method `color` of `self`.

The context block referenced by `colorNameCB` may be added to any object that implements interface `IColor` using method `addMethod:` of `Any`.

```plaintext
private object Shape implements IColor
    public fun color -> Int [ ^_color ]
    public fun color: (:newColor Int) [ _color = newColor ]
    ...
end
```

```plaintext
:colorNameCB = (:self IColor) [
    return colorTable[ self color ]
];
Shape addMethod:
    selector: #colorName
    returnType: String
    body: colorNameCB;
Out println: (Shape ?colorName);  
```

Of course, the method added to `Shape`, `colorName -> String` should be called using `?` because it is not in the `Shape` signature. We could also have written

```plaintext
private object Button implements IColor
    ...
end
```
... 

Button addMethod:
    selector: #colorName
    returnType: String
    body: (:self IColor) [
        return colorTable[ self color ]
    ];
:b = Button();
Out println: (b ?colorName);

Since a context block has a self parameter, it cannot be called as a regular block:
:s = colorNameCB eval;
The compiler will not complain but there will be a runtime error (message send to nil).

Grammar Methods

A method declared with selectors s1:s2 can only be called through a message send s1: e1 s2: e2 in which e1 and e2 are expressions. Grammar methods do not fix the selectors of the message send. Using operators of regular expressions a grammar method may specify that some selectors can be repeated, some are optional, there can be one or more parameters to a given selector, there are alternative selectors and just one of them can be used.

A method that takes a variable number of Int arguments is declared as shown below.

    // a set of integers
    object IntSet
        public fun (add: (Int)+) :t [ ... ]
    ...
end

The + after (Int) indicates that after add: there may be one or more integer arguments:

IntSet add: 0, 2, 4;
:odd = IntSet new;
odd add: 1, 3;

Maybe we would like to repeat the selector for each argument. That can be made:

    // a set of integers
    object IntSet
        public fun (add: Int)+ :t [ ... ]
    ...
end

... 

IntSet add: 0 add: 2 add: 4;
:odd = IntSet new;
odd add: 1 add: 3;

The :t that appears after + is the method parameter. Every grammar method is declared using ( and ) and, after the signature there should appear exactly one parameter. Its type may be omitted. In this case the compiler will assign a type to it — this same type can be given by the programmer. There are
rules for calculating the type of the single parameter of a grammar method (See Chapter 9). This type
dependes on the regular expression used to define the method. In both of the above examples, the type
of \( t \) is

\[
\text{Array<Int>}
\]

So the method could have been declared as

```kotlin
// a set of integers
object IntSet

public fun (add: Int)+ :t Array<Int>[
    // the simplest and inefficient way of
    // inserting elements into intArray
    t foreach: |
        elem Int|
    // inserts elem in intArray
    // create a new array if there is not
    // space in this one
    ...
]
]

private :intArray Array<Int>
end
```

A grammar method may use all of the regular expression operators: \( A^+ \) matches one or more \( A \)'s, \( A^* \)
matches zero or more \( A \)'s, \( A? \) matches \( A \) or nothing (\( A \) is optional), \( A \mid B \) matches \( A \) or \( B \) (but not both),
and \( A \cdot B \) matches \( A \) followed by \( B \). The | operator may be used with types:

```kotlin
public fun (add: Int | String) :t UUnion<Int, String>[
    ...
]
```

Method \( \text{add} \) may receive as parameters an \( \text{Int} \) or a \( \text{String} \).

Grammar methods are useful for implementing Domain Specific Languages (DSL). In fact, every
grammar method can be considered as implementing a DSL. The advantages of using grammar methods
for DSL are that the lexical and syntactical analysis and the building of the Abstract Syntax Tree are
automatically made by the compiler. The parsing is based on the grammar method. The AST of the
grammar message is referenced by the single parameter of the grammar method. Besides that, it is
possible to replace the ugly type of the single parameter of the grammar method by a more meaningful
prototype. Using annotations (Section 5.1) one can annotate a prototype with information and put it as
the type of the grammar method parameter. The compiler will know how to use this prototype in order
to build the AST of a grammar message. See Section 9.7 for more details.

There is one problem left: grammar methods are defined using regular expression operators. Therefore
they cannot define context-free languages. This problem is easily solved by using parenthesis in the
message send and sometimes more than one grammar method. The details are given in Section 9.5
However, we present one example that implements Lisp-like lists:

```kotlin
object GenList

public fun (L: (List | Int)* ) :t UUnion<List, Int>> -> List[
    // here parameter t is converted into a list object
    ...
]
end
```

The grammar defining a Lisp list is not a regular grammar — there is a recursion because a list can be
a list element: \( (1, (2, 3), 4) \)

This list can be built using parenthesis in a grammar message send
Another example of domain specific language implemented using grammar method uses commands given to a radio-controlled car (a toy). The car obeys commands related to movement such as to turn left (a certain number of degrees) right, increase speed, decrease speed, move n centimeters, turn on, and off. Assuming the existence of a prototype `CarRC` with an appropriate grammar method, one could write:

```plaintext
CarRC on:
  left: 30
  move: 100
  right: 20;

CarRC move: 200
  speedUp: 1
  move: 50
  speedDown: 1
  off;
```

These two messages would cause the call of the same grammar method, which is declared as:

```plaintext
object CarRC
  public fun (on: | off: | move: Int | left: Int | right: Int | speedUp: Int |
          speedDown: Int)+
    :t Array<UUnion<Any, Any, Int, Int, Int, Int, Int>>,

    // here should come the implementation of the commands

    // other methods

end
```

The grammar method could really send orders to a real car in the method body, after interpreting the `t` parameter.

The uses of grammar methods are endless. They can define optional parameters, methods with variable number of parameters, and mainly DSL’s. One could define methods for SQL, XML (at least part of it!), parallel programming, graphical user interfaces, any small language. It takes minutes to implement a small DSL, not hours.

### Methods as Objects

Methods are objects too. Therefore it is possible to pass a method as parameter. As an example one can use:

```plaintext
P.{s:T1 s2:T2, T3}.
```

to reference the sole method of prototype `P`.

```plaintext
object P
  public fun s1: (:p1 T1) s2: (:p2 T2, :p3 T3) [ /* empty */ ]
end
```

The ability of referring to a method is very useful in graphical user interfaces as the example below shows.
object MenuItem
    public fun onMouseClick: (:b UBlock) [ ...

end

object Help
    public fun show [ ... ]

end

object FileMenu
    public fun open [ ... ]

end

:helpItem = MenuItem new;
helpItem onMouseClick: Help.{show}.;
:openItem = MenuItem new;
openItem onMouseClick: FileMenu.{open}.;
...

We could also have passed u-blocks to method onMouseClick:
openItem onMouseClick: [ self.helpObject show ]

Of course, there can be spaces before ".{" as in:
helpItem onMouseClick: Help .{show}.;

There may even exist a table containing methods and blocks:

:codeTable = Hashtable<String, UBlock<Int><Int>> new;
codeTable key: "square" value: Math.{sqr}.;
codeTable key: "twice" value: [ |:n Int| "n*n ";
codeTable key: "succ" value: [ |:n Int| "n+1 ";
codeTable key: "pred" value: [ |:n Int| "n-1 ";
    // 5.{+ Int}. is method "public fun :other Int) -> Int"
    // of object 5
codeTable key: "add" value: 5.{+ Int}.;
...
    // read the function name from the keyboard
    // and get the u-block of it
:b = codeTable key: (In readString);
    // call the command
Out println: (b eval: 2);

The Exception Handling System

The exception handling system of Cyan was based on that of Green. However, it has important improvements when compared with the EHS of this last language. Both are completely object-oriented, contrary to all systems of languages we know of. An exception is thrown by sending message throw: to
self passing the exception object as parameter. This exception object is exactly the exception objects of other languages. Method throw: is defined in the super-prototype of every one, Any.

The simplest way of catching an exception is to pass the exception treatment as parameters to catch: selectors in a message send to a block.

```latex
:age Int;
[  
  age = In readInt;
  if ( age < 0 ) [
    throw: NegAgeException(age)
  ]
] catch: [ |:e NegAgeException | Out println: "Age #{e age} is negative" ];
```

Here exception NegAgeException is thrown by message send

```latex
  throw: NegAgeException(age)
```
in which “NegAgeException(age)” is a short form of “(NegAgeException new: age)”.

When the exception is thrown the control is transferred to the block passed as parameter to catch:. The error message is then printed. Object NegAgeException should be a sub-prototype of CyException.

```latex
object NegAgeException extends CyException
  // '@init(age)' creates a constructor with
  // parameter age
  @init(age)
  public :age Int
end
```

This example in Java would be

```latex
int age;
try {
  age = In.readInt();
  if ( age < 0 )
     throw new NegAgeException(age);
} catch ( NegAgeException e ) {
    System.out.println("Age " + e.getAge() + " is negative");
}
```

There may be as many catch: selectors as necessary, each one taking a single parameter.

```latex
:age Int;
[  
  age = In readInt;
  if ( age < 0 ) [
    throw: NegAgeException(age);
  ]
  else if ( age > 127 ) [
    throw: TooOldAgeException(age)
  ]
] catch: [ |:e NegAgeException | Out println: "Age #{e age} is negative" ]
  catch: [ |:e TooOldAgeException | Out println: "Age #{e age} is out of limits" ];
```

The catch: parameter may be any object with one or more eval: methods, each of them accepting one parameter whose type is sub-prototype of CyException. So we could write:
:age Int;
[
    age = In readInt;
    if ( age < 0 ) [
        throw: NegAgeException(age);
    ]
    else if ( age > 127 ) [
        throw: TooOldAgeException(age)
    ]
] catch: CatchAgeException;

Consider that CatchAgeException is

object CatchAgeException
    public fun eval: (:e NegAgeException) [
        Out println: "Age #{e age} is negative"
    ]
    public fun eval: (:e TooOldAgeException) [
        Out println: "Age #{e age} is out of limits"
    ]
end

This new implementation produces the same results as the previous one. When an exception E is thrown in the block that reads the age, the runtime system starts a search in the parameter to catch:, which is CatchAgeException. It searches for an eval: method that can accept E as parameter in the textual order in which the methods are declared. This is exactly as the search made after a message send. The result is exactly the same as the code with two blocks passed as parameters to two catch selectors.

The exception handling system of Cyan has several advantages over the traditional approach: exception treatment can be reused, CatchAgeException can be used in many places, exception treatment can be organized in a hierarchy (CatchAgeException can be inherited and some eval: methods can be overridden. Other methods can be added.), the EHS is integrated in the language (it is also object-oriented), one can use metaobjects with the EHS, and there can be libraries of treatment code. For short, all the power of object-oriented programming is brought to exception handling and treatment. Since the Cyan EHS has all of the advantages of the EHS of Green, the reader can know more about its features in an article by José [10].

**Metaobjects**

Compile-time metaobjects are objects that can change the behavior of the program, add information to it, or can inspect the source code. A compile-time metaobject is attached to a prototype using @ as in

@checkStyle object University
    @log public fun name -> String [ return uName ]
    ...
end
...
@singleton object Earth
    ...
end

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object Help
...
end

...
:t = @text(<+ ... +>);
...

Metaobject `checkStyle` is activated at compile-time in the first line of this example. It is attached to specific points of the compiler controlling the compilation of prototype `University`. It could check whether the prototype name, the method names, the instance variable names, and local variables follow some conventions for identifiers (prototype in lower case except the first letter, method selectors, instance variables, and local variables in lower case). The compiler calls methods of the metaobject at some points of the compilation. It is as if the metaobject was added to the compiler. Which method is called at which point is defined by the Meta-Object Protocol (MOP) which has not been defined yet. Initially the Cyan metaobjects will be written in Java because the compiler is written in Java. Afterwards they will be made in Cyan.

There is a call in the example to a metaobject `text`. After the name there may appear a sequence of symbols. The argument to the metaobject call ends with a sequence that mirrors the start sequence. So `(<+ is ended by +>)`. Almost any sequence is valid and different metaobject calls may use the same symbol sequence. The text in between is passed as argument to a call to a specific method of this metaobject (say, `parse`) defined by the MOP. `text` is a pre-defined metaobject. A call to it is replaced by a literal array of `Char`’s with all the characters between the delimiters. Note that to say “metaobject call” is an abuse of language. Metaobjects are objects and objects are not called. Methods are called. The compiler will in fact call some specific methods of the metaobject which are not specified in the metaobject. It would be more precise to say that the metaobject is employed in the code in a line as

```cyr
:t = @text(<+ ... +>);
```

The metaobject may return a string of characters that is the Cyan code corresponding to the metaobject call. It does so in the call to `text`. It does not in the call to `checkStyle` (which does not generate code). Instead of returning a string, the metaobject method may return a modified AST of the prototype or the method (in case of `log`). Metaobject `log` would add code to the start of the method to log how many times it was called. This information would be available to other parts of the code. Again, a metaobject does not return anything. It is an object. What happens is that a method of the metaobject, not specified in the code, is called and it returns something.

User-Defined Literal Objects

Cyan supports user-defined literal objects. One can define a literal object delimited by `<?, and >` by a call to the pre-defined metaobject `literalObject`:

```cyr
@literalObject<<
  start: "<?,"
  parse: ParseList
>>
```

After `parse`: there should appear the name of a Java class that should have methods to parse the text that appear between the delimiters. In the source code that appears textually below the call to `literalObject`, one could write
null
method called will be `pay: Worker`. This may be terrible consequences. The compiler could warn that this change may have introduced a bug in the program. See more about this in Section 4.5.

Another example of use of the past is when there is a sequence of `if`'s that test for the prototype of a variable:

```plaintext
:v Person;
...
if ( v isa: Student ) [ ...
] else if ( v isa: Worker ) [ ...
]```

Here `Person` is an abstract prototype whose only sub-prototypes are `Student` and `Worker`. Then the cascaded `if` statements cover all cases. However, when another sub-prototype of `Person` is created, this is no longer the case. The compiler or another tool could warn this based on the information kept in the XML file that contains the source code.
Chapter 2

Packages and File organization

We will call “program unit” a prototype declaration or interface. A Cyan program is divided in files, program units, and packages that keep the following relationship:

(a) every file, with extension .cyan, declare exactly one public or one protected program unit (but not both) and any number of private program units. Keywords public, protected, and private may precede the program unit to indicate that it is public, protected, or private:

```cyn
... public object Person
    public :name String;
    ... // methods
end
```

If no qualifier is used before “object”, then it is considered public. A protected program unit is only visible in its package. A private program unit can only be used in the file in which it is declared. No private entities can appear in the public part of a public or protected entity. So the following code is illegal:

```cyn
... private object ListElement
    public :item Int
    public :next ListElement
end
```

```cyn
public object List
    private :head ListElement
    // oops ... private prototype in the public
    // interface of method getHead
    public getHead -> ListElement [ "head "];
    ... // other methods
end
```

(b) every file should begin with a package declaration as “package ast” in

```cyn
package ast

object Variable
```
public :name String;
public :type Type;
... // methods
end

All objects and interfaces declared in that file will belong to the package “ast”;

(c) a package is composed by program units spread in one or more source files. The name of a package can be composed by identifiers separated by “.”. All the source files of a package should be in the same directory. The source files of a package id1.id2. ... idn should be in a directory idn which is a sub-directory of id(n-1), and so on. There may be packages id1.id2 and id1.id3 that share a directory id1. Although a directory is shared, the packages are unrelated to each other.

d) a Cyan source file is described in XML and has the following structure:

```xml
<?xml version="1.0"?>
<cyanfile>
<cyansource>
package ast

object Variable
  public :name String;
  public :type Type;
  ... // methods
end
</cyansource>
<!-- here comes other elements -->
</cyanfile>
```

The root XML element is cyanfile. There is child of cyanfile called cyansource that contains the source code in Cyan of that file. After that comes other elements. What exactly there are is yet to be defined. Certainly there will be elements that keep the interfaces of all prototypes that every prototype of this file uses. An object interface is composed by the signatures of its public methods. The signature of a method is composed by its selectors, parameter types, and return value type. This information will be put in the XML file by the compiler. The information stored in the XML file can be used to catch errors at compile time that would otherwise go undetected or to improve current error messages. Based in this information, the compiler could check:

(a) if the textual order of declaration of multi-methods\(^1\) was changed;

(b) if the return value type of methods was changed (to replace a return value type T by its subtype S is ok. The opposite may introduce errors.);

(c) if methods were added to multi-methods;

(d) if the textual order of declaration of the instance variables was changed. This is important for metaobject @init when it is called without parameters (See page 68);

(e) if the type of a parameter of a generic prototype was changed.

\(^1\)Methods with the same name but different parameter types or number of parameters in each selector.
The compiler could also put in one of the XML elements the restrictions that a generic parameter type should obey. For example, a generic object

```cya
object TwoItems<:T>
    public fun set: (:a, :b T) [ self.a = a; self.b = b; ]
    public max -> T [ return (a > b) f: a f: b ]
    private :a, :b T
end
```

would keep, in the XML file, that generic parameter T should support the operator <.

To know one more Cyan feature that uses the XML file, see page 100 on metaobject `onChangeWarn`.

If the source file does not start with `<?xml`, then it is assumed that the text contains only source code in Cyan. Then it is optional to put or not the source code in a XML file.

A package is a collection of prototype declarations and interfaces. Every public Cyan prototype declared as `object ObjectName ... end` must be in a file called “ObjectName.cyan” (even if it is a XML file). Preceding the object declaration there must appear a package declaration of the form `package packageName` as in the example given above.

Program units defined in a package `packB` can be used in a source file of a package `packA` using the import declaration:

```cya
package packA
import packB

object Program
    public fun run [ ...
[...
] end
```

The public program units of package `packB` are visible in the whole source file. A program unit declared in this source file may have the same name as an imported program unit. The local one takes precedence.

More than one package may be imported; that is, the word `import` may be followed by a list of package names separated by comma. It is legal to import two packages that define two identifiers with the same name. However, to use one identifier (program unit) imported from two or more packages it is necessary to prefix it with the package name. See the example below.

```cya
package pA

import pB, pC, pD

object Main
    public fun doSomething [ :
p1 pB.Person; // Person is an object in both packages
    :
p2 pD.Person;
[...
] end
```
An object or interface can be used in a file without importing the package in which it was defined. But in this case the identifier should be prefixed by the package name:

```javascript
:var = ast.Variable;
:window gui.Window;
```

There is a package called `cyan.lang` which is imported automatically by every file. This package defines all the basic types, arrays, prototype `System`, block interfaces, tuples, unions, etc. See Chapter 8.
Chapter 3

Basic Elements

This chapter describes some basic facts on Cyan such as identifiers, number literals, strings, operators, and statements (assignment, loops, etc). First of all, the program execution starts in a method called `run` (without parameters or return value) or

```java
run: Array<String>
```
of a prototype specified at compile-time through the compiler or IDE option. Type `Array<String>` is an array of strings. The arguments to `run` are those passed to the program when it is called. In this text (all of it) we usually call `Program` the prototype in which the program execution starts. But the name can be anyone. The program that follows prints all arguments passed to it when it is called.

```java
package main

object Program
  public fun run: (:args Array<String>) [
    args foreach: [:elem String|
      Out println: elem
    ]
  ]
end
```

3.1 Identifiers

Identifiers should be composed by letters, numbers, and underscore and they should start with a letter or underscore. However, a single underscore is not considered a valid identifier. Upper and lower case letters are considered different.

`:one Int;
:one000 Long;
:___0 Float;
```

It is expected that the compiler issues a warning if two identifiers visible in the same scope differ only in the case of the letters as “one” and “One”.

3.2 Comments

Comments are parts of the text ignored by the compiler. Cyan supports two kinds of comments:
• anything between /* and */. Nested comments are allowed. That is, the comment below ends at line 3.

```plaintext
1 /* this is a /* nested
2    comment */
3    that ends here */
```

• anything after // till the end of the line.

A comment may appear anywhere (maybe this will change). A comment is replaced by the compiler by a single space.

```plaintext
:value = 1/* does value holds 10? */0;
```

This code is the same as :value = 1 0 and therefore it causes a compile-time error instead of being an assignment of 10 to value.

### 3.3 Assignments

An assignment is made with “=” as in

```plaintext
x = expr;
```

After this statement is executed, variable `x` refer to the object that resulted in the evaluation of `expr` at runtime. The compile-time type of `expr` should be a `subtype` of the compile-time type of `x`. See Section [4.16](#) for a definition of subtype.

A variable may be declared and assigned a value:

```plaintext
:x = expr;
```

The type of `x` will be the compile-time type of `expr`. If `expr` is `nil`, the type of `x` will be `Any`. Both the type of the variable and the expression can be supplied:

```plaintext
:x Int = 100;
```

Cyan supports a restricted form of multiple assignments. There may be any number of comma separated assignable expressions in the left-hand side of “=” if the right-hand side is a tuple (named or unnamed) with the compatible types. That is, it is legal to write

```plaintext
v1, v2, ..., vn = tuple
```

if `tuple` is a tuple with at least `n` fields and the type of field number `i` (starting with 1) is a subtype of the type of `vi`.

```plaintext
:x, :y Float;
:x, y = [. 1280, 720 .];
:tuple = [. 1920, 1080 .];
```

However, a variable cannot be declared in a multiple assignment:

```plaintext
:x, :y = [. 1280, 720 .]
```

The compiler would sign an error in this code.

The assignment “v1, v2, ..., vn = tuple” is equivalent to

```plaintext
// tuple may be an expression
:tmp = tuple;
:tuple = tmp fn;
...```

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v2 = tmp f2;
v1 = tmp f1;

A multiple assignment is an expression that returns the value of the first left-hand side variable, which is v1 in this example.

A method may simulate the return of several values using tuples.

```object Circle
    public fun getCenter -> Tuple<x, Float, y, Float> [
        return [. x, y .]
    ]
    ...
    private :x, :y Float // center of the circle
    private :radius Float
end
```

```plaintext
:x, :y Float;
x, y = Circle getCenter;
```

## 3.4 Basic Types

Cyan has one basic type, starting with an upper case letter, for each of the basic types of Java: Void, Byte, Short, Int, Long, Float, Double, Char, and Boolean.

Unless said otherwise, Cyan literals of the basic types are defined as those of Java. In particular, the numeric types have the same ranges as the corresponding Java types. Byte, Short, and Long literals should end with B or Byte, S or Short, and L or Long, respectively as in

```plaintext
:aByte = 7B;
:aShort = 29Short;
:aLong = 1234567L;
:bLong = 37Long;
:anInt = 223Int;
```

Int literals may optionally end with I or Int. All basic types but Void inherit from Any. Therefore there are not two separate hierarchies for basic and normal types. All types obey “reference” semantics. Conceptually, every object is allocated in the heap. However, objects of basic types such as 1, 3.1415, and true are allocated in the stack most of the time.

Integral literal numbers without a postfixed letter are considered as having type Int. Numbers with a dot such as 10.0 as considered as Float’s. Float literals can end with F or Float. Double literals should end with D or Double. There is no automatic conversion between types:

```plaintext
:age Int;
:byte Byte;
:height Float;
    // ok
age = 21;
    // compile-time error, 0 is Int
byte = 0;
```
// ok
byte = 0B;
// ok
height = 1.65;
// compile-time error
height = 1;
// ok
height = 1F;

Underscores can be used to separate long numbers as in
1_000_000
Two underscores cannot appear together as in
1__0
The first symbol cannot be an underscore: _1_000 would be considered an identifier by the compiler.

The Boolean type has two enumerated constants, false and true, with false < true. When false
is cast to an Int, the value returned is 0. true is cast to 1. Char literals are given between ' as in
'A'  '#'  '\n'

noObject is the only value of Void. It is not an object, although Void is. Messages sent to noObject
cause a runtime error. Methods that do not declare a return type, as

public fun set: (:newValue Int) [ ... ]
in fact return a value of type Void. Therefore this declaration is equivalent to

public fun set: (:newValue Int) -> Void [ ... ]

Any method that has Void as the return type always return noObject at the end of its execution.
noObject has identical semantics to null in Java or NULL in C++. It is not an object. The return
statement (explained later) is required in methods that return anything other than Void.

As soon as possible, the status of noObject will be changed or maybe it will be eliminated from the
language. It is not semantically-sound: its type is Void. But Void as an object is also from type Void:

public fun nothing -> Void [
  return Void
]

That would be type-correct because Void has type Void. But that is prohibited: a return statement
cannot be followed by an expression if the method in which it is has Void as the return type. On the
other side, methods returning Void return noObject which do not have any methods. But Void itself
supports all methods of Any. It is legal to write

Out println: (Void prototypeName);

A literal string should be given enclosed by " as in C/C++/Java: "Hi, this is a string", "um",
"ended by newline\\n". Cyan strings and literal characters support the same escape characters as Java.
A literal string may start with @ to disable any escape character inside the string:

:fileName = @"D:\User\Carol\My Texts\text01"

In this case “\t” do not mean the tab character. Of course, this kind of string cannot contain the
character ‘\’.

nil is an object assigned to every variable that does not receive a value in its declaration. It is a true
object that inherits from Any. Prototype nil redefines the isNil and notNil methods inherited from
Any to return true and false — it is the only prototype allowed to do so. Every other message sent to
nil causes the exception DoesNot UnderstandException to be thrown. nil is very similar to the object
of the same name of Smalltalk.
Types Byte, Short, Int, Long, Float, and Double support almost the same set of arithmetical and logical operators as the corresponding types of Java. We show just the interface of Int. Types Float and Double do not support methods &|, ~|, and !. All basic types are automatically included in every Cyan source code because they belong to package cyan.lang.

```plaintext
public final object Int

public fun + (:other Int) -> Int [ ... ]
public fun - (:other Int) -> Int [ ... ]
public fun * (:other Int) -> Int [ ... ]
public fun / (:other Int) -> Int [ ... ]
public fun % (:other Int) -> Int [ ... ]
public fun < (:other Int) -> Boolean [ ... ]
public fun <= (:other Int) -> Boolean [ ... ]
public fun > (:other Int) -> Boolean [ ... ]
public fun >= (:other Int) -> Boolean [ ... ]
public fun == (:other Int) -> Boolean [ ... ]
public fun != (:other Int) -> Boolean [ ... ]

// all unary operators are prefixed
public fun - -> Int [ ... ]
public fun + -> Int [ ... ]

// and bit to bit
public fun & (:other Int) -> Int [ ... ]

// or bit to bit
public fun | (:other Int) -> Int [ ... ]

// exclusive or bit to bit
public fun ^ (:other Int) -> Int [ ... ]

// binary not
public fun ~ -> Int [ ... ]

// left shift. The same as << in Java
public fun << (:other Int) -> Int [ ... ]

// right shift. The same as >> in Java
public fun >> (:other Int) -> Int [ ... ]

// right shift. The same as >>> in Java
public fun >>> (:other Int) -> Int [ ... ]

public fun asByte -> Byte [ ... ]
public fun asShort -> Short [ ... ]
public fun asLong -> Long [ ... ]
public fun asFloat -> Float [ ... ]
public fun asDouble -> Double [ ... ]
public fun asChar -> Char [ ... ]
public fun asBoolean -> Boolean [ ... ]
public fun asString -> String [ ... ]
public fun to: (:max Int) do: (:b Block) [ ... ]
public fun to: (:max Int) do: (:b Block<Int><Void>) [ ... ]
public fun repeat: (:b Block) [
    :i = 0;
    while ( i < self ) [
```

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b eval;
++i;
]
]

public fun repeat: (:b Block<Int><Void>) [  
    :i = 0;
    while ( i < self ) [  
        b eval: i;
        ++i;
    ]
]

public fun to: (:max Int)  
    inject: (:initialValue Int)  
    into: (:b Block<Int, Int><Int>) -> Int [ ...
]

public fun to: (:max Int)  
do: (:injectTo InjectObject<Int>) -> Int [ ...
]

public fun to: (:max Int)  
    inject: (:initialValue Int)  
    into: (:b Block<Int, Int><Int>) -> Int [  
    :i = self;
    :total = initialValue;
    while ( i <= max ) [  
        total = b eval: total, i;
        ++i  
    ];  
    return total
]

// injection method to be used with context object.
// the initial value is private to injectTo
public fun to: (:max Int) do: (:injectTo InjectObject<Int>) -> Int [  
    :i = self;
    while ( i <= max ) [  
        injectTo eval: i;
        ++i  
    ];  
    return injectTo result
]

public fun in: (:container Iterable<Int> ) -> Boolean [  
    container foreach: [  
    |:item Int|  
        if ( self == item )  
            return true;
]
public fun in: (:inter Interval<Int>) -> Boolean [
    return self >= inter first & self <= inter last
]

interface InjectObject<T>
    fun eval: T
    fun result -> T
end

interface Iterable<T>
    fun foreach: Block<T><Void>
end

Variables of types Byte, Char, Short, Int, and Long may be preceded by ++ or --. When v is a private instance variable or a local variable, the compiler will replace ++v by

  (v = v + 1)

Idem for --. When v is a public or protected instance variable, ++v is replaced by

  (v: (v + 1))

If v is public, ++v can only occur inside the prototype in which v is declared. If it is protected, ++v can only appear in sub-prototypes of the prototype in which it is declared.

A prototype may declare an operator [] and use it just like an array (see Section 4.9). A variable whose type support both “[] at:” and “[] at:put:” methods can be used with ++. Then ++v[expr] is replaced by

  // tmp1 and tmp2 are temporary variables
  :tmp1 = expr;
  :tmp2 = v[tmp1] + 1;
  v[tmp1] = tmp2;

Each basic prototype T but Float and Double has an in: method that accepts an object that implements Iterable<T> as parameter. This call method foreach: of this parameter comparing each element with self. It returns true if there is an element equal to self. It can be used as in

:ch Char;
ch = In readChar;
( ch in: [. 'a', 'e', 'i', 'o', 'u' .] ) ifTrue: [
    Out println: "#ch is a vowel"
];
:intArray Array<Int>;;
:intList List<Int>;;
:n Int = In readInt;
if ( n in: intArray || n in: intList ) [
    Out println: "#n is already in the lists"
]
The parameter to `in:` can be any object that implements `Iterable` of the correct type. In particular, all arrays and tuples whose elements are all of the same basic type implement this interface.

Each basic prototype `T` but `Float` and `Double` has an `in:` method that accepts an interval as parameter:

```plaintext
:ch Char;
ch = In readChar;
( ch in: 'a'..'z' ) ifTrue: [ 
   Out println: "#{ch} is a lower case letter"
];
:age = In readInt;
if ( age in: 0..2 ) [ Out println: "baby" ]
else if ( age in: 3..12 ) [ 
   Out println: "child"
]
else if ( age in: 13..19 ) [ 
   Out println: "teenager"
]
else [ 
   Out println: "adult"
]
```

Prototype `Boolean` has the logical operators `&&` (and), `||` (or), and `!` (not). Every method that starts with `!` is a prefixed unary method.

```plaintext
if ( ! ok ) [ Out println: "fail" ]
if ( age < 0 || age > 127 ) [ Out println: "out of limits" ]
if ( index < array size && array[index] == x ) 
   Out println: "found #{x}";
```

In the last statement, there is a problem: the argument to `&&` will be evaluated even if "index < array size" is `false`, causing the runtime error “array index out of bounds”. To prevent this error, the expression on the right of `&&` should be put in a block.

```plaintext
if ( ! ok ) [ Out println: "fail" ]
   // no need of a block here
if ( age < 0 || [ ~ age > 127 ] ) [ Out println: "out of limits" ]
if ( index < array size && [ ^array[index] == x ] )
   Out println: "found #{x}";
```

In the `Boolean` prototype, there are methods `&&` and `||` that take a block as parameter. These methods implement short-circuit evaluation.

```plaintext
public final object Boolean
public fun && (:other Boolean) -> Boolean [ ... ]
public fun || (:other Boolean) -> Boolean [ ... ]
public fun ! -> Boolean [ ... ]

   // short-circuit evaluation
public fun && (:other Block<Boolean>) -> Boolean [ ... ]
public fun || (:other Block<Boolean>) -> Boolean [ ... ]
```
Prototype Char has the usual methods expected for a character.

public final object Char

public fun < (:other Char) -> Boolean [ ... ]
public fun <= (:other Char) -> Boolean [ ... ]
public fun > (:other Char) -> Boolean [ ... ]
public fun >= (:other Char) -> Boolean [ ... ]
public fun == (:other Char) -> Boolean [ ... ]
public fun != (:other Char) -> Boolean [ ... ]
public fun asByte -> Byte [ ... ]
public fun asInt -> Int [ ... ]
public fun asLong -> Long [ ... ]
public fun asBoolean -> Boolean [ ... ]
public fun asString -> String [ ... ]
public fun to: (:max Char) do: (:b Block) [ ... ]
public fun to: (:max Char) do: (:b Block<Char><Void>) [ ... ]
public fun repeat: (:b Block) [ ... ]
public fun repeat: (:b Block<Char><Void>) [ ... ]
public fun ifTrue: (:trueBlock Block) [ ... ]
public fun ifFalse: (:falseBlock Block) [ ... ]
public fun ifTrue: (:trueBlock Block) ifFalse: (:falseBlock Block) [ ... ]
public fun ifFalse: (:falseBlock Block) ifTrue: (:trueBlock Block) [ ... ]
@checkTF public fun T: (:trueValue Any) F: (:falseValue Any) -> Any [ ... ]
@checkTF public fun F: (:falseValue Any) T: (:trueValue Any) -> Any [ ... ]
end

public fun in: (:container Iterable<Char> ) -> Boolean [ ... ]

container foreach: [
    |:item Char|
    if ( self == item )
    return true;
Figure 3.1: Precedence order from the lower (top) to the higher (bottom)

```java
public fun daysMonth: (:month String, :year Int) -> Int [  
  if ( month in: {# "jan", "mar", "may", "jul", "aug", "oct", "dec" #} ) [  
    return 31  
  ]  
  else if ( month in: [. "apr", "jun", "sep", "nov" .] ) [  
    return 30  
  ]  
  else if ( month == "fev" ) [  
    return (leapYear: year) T: 29 F: 28  
  ]  
  else [  
    return -1  
  ]
]
```

Other methods from this prototype will be defined in due time. Maybe the `String` class of Java will be used as the `String` prototype of Cyan.

### 3.5 Operator and Selector Precedence

Cyan has special precedence rules for methods whose names are the symbols given in Figure 3.1. The meaning of these methods is given in the declaration of the basic types that use them (see page 48). The precedence is applied to every message send that uses some of these symbols. So a message send

```java
x + 1 < y + 2
```

will be considered as if it was

```java
(x + 1) < (y + 2)
```

Then when we write

```java
if ( age < 0 || age > 127 ) [ Out println: "out of limits" ]  
if ( index < array size && array[index] == x )
```
Out println: "found #{x}";

the compiler interprets this as

```ruby
if ( (age < 0) || (age > 127) ) [ Out println: "out of limits" ]
if ( (index < array size) && (array[index] == x) )
Out println: "found #{x}";
```

In a message send, unary selectors have precedence over multiple selectors. Then

```ruby
obj a: array size
```

is the same as

```ruby
obj a: (array size)
```

Unary methods associate from left to right. Then

```ruby
:name = club members first name;
```

is the same as:

```ruby
:name = ((club members) first) name;
```

The method names of the last line of the Figure 3.1 are unary. All other methods are binary and left associative. That means a code

```ruby
ok = i >= 0 && i < size && v[i] == x;
```

is interpreted as

```ruby
(ok = i >= 0 && i < size) && v[i] == x;
```

This is true even when Boolean is not the type of the receiver.

The compiler does not check the type of the receiver in order to discover how many parameters each selector should use. When the compiler finds something like

```ruby
obj s1: 1 s2: 1, 2 s3: 1, 2, 3
```

it considers that the method name is `s1:s2:s3` and that `si` takes `i` parameters. This conclusion is taken without consulting the type of `obj`. Therefore, code

```ruby
// get: takes two parameters
:k = matrix get: (anArray at: 0), 1;
```

cannot be written

```ruby
:k = matrix get: anArray at: 0, 1;
```

This would mean that the method to be called is named `get:at:` and that `get:` receives one parameter, `anArray`, and `at:` receives two arguments, 0 and 1. To know the reason of this rule, see Chapter 6.

### 3.6 Loops, Ifs, and other Statements

Currently each statement or local variable declaration should end with a semicolon (";"). However we expect to make the semicolon optional as soon as possible.

Decision and loop statements are not really necessary in Cyan. As in Smalltalk, they can be implemented as message sends to Boolean objects and to block objects. There are four methods of prototype `Boolean` used as decision statements: `ifTrue:`, `ifFalse:`, `ifTrue:ifFalse:`, and `ifFalse:ifTrue:`.

```ruby
( n%2 == 0 ) ifTrue: [ s = "even" ];
( n%2 != 0 ) ifFalse: [ s = "even" ];
( n%2 == 0 ) ifTrue: [ s = "even" ] ifFalse: [ s = "odd" ];
( n%2 != 0 ) ifFalse: [ s = "even" ] ifTrue: [ s = "odd" ];
```
They are self explanatory. Besides that, there are methods in Boolean that return an expression or another according to the receiver:

```plaintext
s = ( n%2 == 0 ) t: "even" f: "odd";
s = ( n%2 != 0 ) f: "even" t: "odd";
```

If the expression is true, the expression that is parameter to `t:` is returned. Otherwise it is returned the parameter to `f:`. A metaobject (Chapter 5) `checkTF` checks whether the arguments of both selectors have the same type (both are strings in this case).

Block objects that return a Boolean value have a `whileTrue:` and a `whileFalse:` methods.

```plaintext
:i = 0;
[^ i < 5 ] whileTrue: [
   Out println: i;
   ++i
]
:i = 0;
[^ i >= 5 ] whileFalse: [
   Out println: i;
   ++i
]
```

Of course, `whileTrue` calls the block passed as parameter while the block that receives the message is true. `whileFalse` calls while the receiver is false.

The language supports the Elvis operator `[]`, nil-safe message sends, and nil-safe array access. The Elvis operator is implemented as a method `ifNil:` (see page 81), nil-safe message sends have all selectors prefixed with `?`, and nil-safe array access is made with `?[ and ]?`. See the examples.

```plaintext
:userName String;
   // getUserName is a method name
:gotUserName = UserDatabase getUserName;
:userName = gotUserName ifNil: "anonymous";
```

The last line is the same as

```plaintext
    userName = (gotUserName == nil) f: gotUserName t: "anonymous";
```

This is not exactly the Elvis operator of language Groovy. In Cyan both the receiver of message `ifNil:` and its parameters are evaluated.

nil-safe message send:

```plaintext
:v IndexedList<String>;
   // it may associate nil to v
:v = obj getPeopleList;
:v ?.at: 0 ?.put: "Gauss";
```

The last line is the same as

```plaintext
if ( v != nil ) [
   v at: 0 put: "Gauss";
]
```

There should not be any space between the `?.` and the selector. And all selectors of a message should be preceded by `?.` in a nil-safe message send.

nil-safe array access:

---

1For the time being, one cannot be subtype of another.
:clubMembers Array<Person>;
...
:firstMember = clubMembers?[0]?

The last line is the same as

    firstMember = (clubMembers != nil) t: clubMembers[0] f: nil;

The result of clubMembers?[0]? when clubMembers is nil is nil too.

We can use all features at the same time:

:clubMembers Array<Person>;
...

:firstMemberName String = (clubMembers?[0]? ?.name) ifNil: "no member";

The if and the while statements were added to the language to make programming easier. The syntax of these statements is shown in this example:

    if ( n%2 == 0 ) [  
        s = "even"
    ]
    else [ // the else part is optional
        s = "odd"
    ];
:i = 0;
while ( i < 5 ) [
    Out println: i;
    ++i
]

Cascaded if´s are possible:

    if ( age < 3 ) [  
        s = "baby"
    ]
    else if ( age <= 12 ) [  
        s = "child"
    ]
    else if ( age <= 19 ) [  
        s = "teenager"
    ]
    else [  
        s = "adult"
    ];

There are other kinds of loop statements, which are supplied as message sends:

:i = 0;
    // the block is called forever, it never stops
[  
    ++i;
    Out println: i
] loop;
:i = 0;
```plaintext
if ( v[i] = x ) [
    return i;
] ++i
] repeatUntil [^ i >= size];
// the block is called till i >= size

Prototype Int also defines some methods that act like loop statements:

// this code prints numbers 0 1 2
:i = 0;
3 repeat: [
    Out println: i;
    ++i
];
// this code prints numbers 0 1 2
3 repeat: [ |:i Int|
    Out println: i
];
:aBlock = [ |:i Int| Out println: i ];
// this code prints numbers 0 1 2
3 repeat: aBlock;

// prints 0 1 2
i = 0;
1 to: 3 do: [
    Out println: i;
    ++i
];
// prints 0 1 2
1 to: 3 do: [ |:j Int|
    Out println: j
];

Prototype Char also has equivalent repeat: and to:do: methods:

´a´ to: ´z´ do: [ |:ch Char|
    Out println: ch
];

Prototype Any, the super-prototype of every object, defines a grammar method (see Chapter 9) that can be used as a C-like switch statement:

:n = In readInt;
if ( n >= 0 && n <= 6 ) [
    n switch:
    case: 0 do: [
        Out println: "zero"
    ]
    case: 1 do: [
        Out println: "one"
    ]
    case: 2 do: [
        Out println: "two"
    ]
    case: 3 do: [
        Out println: "three"
    ]
    case: 4 do: [
        Out println: "four"
    ]
    case: 5 do: [
        Out println: "five"
    ]
    case: 6 do: [
        Out println: "six"
    ]
]
```

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case: 2, 3, 5 do: [
    Out println: "prime"
] else: [
    Out println: "four or six"
]

:command Int;
:strCmd String = In readString;
strCmd switch:
    case: "on" do: [ command = 1 ]
    case: "off" do: [ command = 2 ]
    case: "left" do: [ command = 3 ]
    case: "right" do: [ command = 4 ]
    case: "move" do: [ command = 5 ]
    else: [ command = 1 ]

A metaobject attached to this method checks whether the expressions after case: have the same type as the receiver. The block after do: is of type Block (no parameters or return value). This grammar method uses method == of the receiver to find the correct do: block to call. Therefore this “switch:” method works even with regular objects.

### 3.7 Arrays

Array is a generic prototype that cannot be inherited for sake of efficiency. It has methods for getting and setting elements:

```plaintext
object Array::<T> implements Iterable<T>
    // only the signatures are shown
    public fun init: (:sizeArray Int)
    public fun [] at: (:index Int) -> T
    public fun [] at: (:index Int) put: (:elem T)
    public fun [] at: (:interval Interval<Int>) -> Array<T>
    public fun [] at: (:interval Interval<Int>) put: (:elem Array<T>)
    public fun size -> Int
    public fun foreach: (:b Block<T><Void>)
    ...
end
```

Intervals can be arguments to at: which allows the slicing of arrays:

`:letters = # 'b', 'a', 'e', 'i', 'o', 'u', 'c', 'd' #;
:vowels = letters[1..5];
// print a e i o u
Out println: vowels;`
Chapter 4

Objects

A prototype may declare zero or more slots, which can be variables, called instance variables, methods, called instance methods, or constants. In Figure 4.1, there is one instance variable, name, and two methods, getName and setName. Keywords public, private, or protected should precede each slot declaration. A public slot can be accessed anywhere the prototype can. A private one can only be used inside the prototype declaration. Protected slots can be accessed in the prototype and its sub-prototypes (a concept similar to inheritance which will soon be explained).

A prototype declaration is a literal object that exists since the start of the program execution. There is no need to create a clone of it in order to use its slots.

Public or protected instance variables are allowed. In this case, the compiler creates public or protected get and set methods for a hidden variable that is only accessed, in the source code, by these methods. If the source code declares a public instance variable instvar of type T, the compiler eliminates this declaration and declares:

(a) a private instance variable _instvar (it is always underscore followed by the original name);
(b) methods

    public instvar -> T [ return _instvar ]
    public instvar: (: _newInstvar T) [ _instvar = _newInstVar ]

Methods instvar and instvar: are different. The compiler does not change the user source code. It only changes the abstract syntax tree it uses internally.

Information on the slots can be accessed through the Introspective Reflection Library (IRL, yet to be made). The IRL allows one to retrieve, for example, the slot names. The IRL will inform you that a prototype with a public instance variable instvar has a private instance variable "_instvar" and public methods instvar and instvar:. The same applies to protected variables, which are also accessed through methods, as the public variables. In the declaration of a public instance variable, to it can be assigned an expression expr. In this case, this expression is assigned to the private instance variable _instvar.

Inside the prototype, instvar should always be accessed through methods instvar and instvar: since there is no variable instvar and _instvar is inaccessible:

Prototype Client could have been declared as

package bank

object Client
    public :name String = ""
package bank
import inOut

object Client
  public fun getName -> String [
    "self.name"
  ]
  public fun setName: (:name String) [
    self.name = name
  ]
  public fun print [
    Out println: name
  ]
  private :name String = ""
end

The instance variable should be used as in:

Client name: "Anna";
Out println: (Client name);
// compilation error in the lines below
Client.name = "Maria";
Out println: Client.name;

In future versions of Cyan it may be possible to access name as in

Client.name = "Maria";

To allow that, it would be necessary a syntax for grouping the get and set methods associated to a public variable. Currently this syntax in unnecessary. To replace a public instance variable by methods it is only necessary to delete the variable declaration and replace it by methods. It is expected that the compiler helps the user in converting assignments like the above into

Client name: "Maria";

A method or prototype declared without a qualifier is considered public. An instance variable without a qualifier is considered private. Then, a declaration

package Bank

object Account
  fun set: :client Client [
    self.client = client
  ]
  fun print [
    Out println: (client getName)
  ]
The declaration of local variables is made with the following syntax:

`:name String;
:x1, :y1, :x2, :y2 Int;

The last line declares four variables of type Int.

Keyword `var` is reserved and may be used before the declaration of an instance variable or a local variable:

```plaintext
private var :client Client
var :sum Int
```

However, its use is optional.

The scope of a local variable is from where it was declared to the end of the block in which it was declared:

```plaintext
public fun p: (:x Int) [
   :iLiveHere String;
   if ( x > 0 ) [
      :iLiveInsideThenPart Int;
      doSomething: [
         :iLiveOnlyInThisBlock String;
         ...
      ]
   ]
]
```

Then `iLiveHere` is accessible from line 2 to line 11 (before the `]`). Variable `iLiveInsideThenPart` is live from line 4 to 10 (before the `]`). The scope of `iLiveOnlyInThisBlock` is the block that in between lines 6 and 8 (after the declaration and before the `]`).

The type of a variable should be a prototype or an interface (explained later). In the declaration

```plaintext
:name String;
```

prototype “String” plays the rôle of a type. Then a prototype name can play two rôles: objects and types. If it appear in an expression, it is an object, as “String” in:

```plaintext
anObj = String;
```
If it appears as the type of a variable or return value type of a method, it is a type. Here “variable” means local variable, parameter, or instance variable.

A local variable or an instance variable can be declared and assigned a value:

```plaintext
private :n Int = 0;
```

Both the type and the assigned value can be omitted, but not at the same time. If the type is omitted, it is deduced from the expression at compile-time. If the expression is omitted, a default value for each type is assigned to the variable. Therefore a variable always receive a value in its declarations. We call this “definition of a variable” (instead of just “declaration”). When the type is omitted, the syntax

```plaintext
:variableName = expr
```

should be used to define the variable as in:

```plaintext
private :n = 0;
```

Variable `variableName` cannot be used inside `expr`. It it could, the compiler would not be able to deduce the type of `expr` in some situations such as

```plaintext
:n = n;
```

In an assignment “`:n = expr`”, the type of the expression is deduced by the compiler using information collected in the previous lines of code. The Hindley-Milner inference algorithm is not used. In particular, the type of parameters and return value of methods are always demanded unless you are using some kind of dynamic typing in Cyan (see Chapter 6 for details).

The default value assigned to a variable depends on its type and is given by the table:

| type   | default value |
|--------|---------------|
| Byte   | 0Byte         |
| Short  | 0Short        |
| Int    | 0Int          |
| Long   | 0Long         |
| Float  | 0Float        |
| Double | 0Double       |
| Char   | '\0'         |
| Boolean| false         |
| String | ""            |
| others | nil           |

`Void` does not appear in this table because a variable cannot be declared as having this type. Any type other than the basic types or `String` has `nil` as the default value. All prototypes, including the basic types, are objects in Cyan. Then `Int` is an object which happens to be an ... integer! And which integer is `Int`? It is the default value of type `Int`. So the code below will print 0 at the output:

```plaintext
Out println: Int;
```

However, it is clearer to have a method that returns the default value. To every prototype `P` that is not a basic type or `String` the compiler adds a method

```plaintext
public fun defaultValue -> P [ ^nil ]
```

if the user does not define this method herself. For basic types, the compiler returns the value of the above table.

A method is declared with keyword `fun` followed by the method selectors and parameters, as shown in Figure 4.1. Following Smalltalk, there are two kinds of methods in Cyan: unary and keyword methods.

A unary method does not take any parameters and may return a value. Its name may be an identifier followed optionally by a “:” (which is not usual and is not allowed in Smalltalk). For example, `print` in
Figure 4.1 is a unary method.

When a method takes parameters its name should be followed by “::” (without spaces between the identifier and this symbol). For example,

public fun set:: (:client Client) [ ... ]

An optional return value type can be given after symbol `->` that may appear after the parameters. The return value should be given by the `return` command or by an expression after “^” (which should be in the outer scope of the method — that will be seen later). Using `Void` as the return value type is the same as to omit symbol `->`.

Objects are used through methods and only through methods. A method is called when a message is sent to an object. A message has the same shape as a method declaration but with the parameters replaced by real arguments. Then method `setName::` of the example of Figure 4.1 is called by

Client setName:: "John";

This statement causes method `setName::` of `Client` to be called at runtime.

There are two kinds of literal strings in Cyan: one is equal to those of C/C++/Java, "Hello world", "n = 0\n", etc. This form allows one to put escape characters in the string. The other kind of literal string is using `@` in the start of the string. This form disables any escape characters:

:fileName = "@c:\texts\readyToPrint\nightPoem.doc"

This means that the string is really

c:\texts\readyToPrint\nightPoem.doc

Object `CySymbol` inherits from `String` and it is the prototype of all literal Cyan symbols. There are two kinds of literal symbols. The first one is `#` followed, without spaces, by letters, digits, and any number of `:` s, as in

#af #age #age:
#123 #_0 #field001
#foreach:do:

The second kind of literal symbol starts with `#"` and ends with `"` and obey the same restrictions as regular literal strings:

"Hello world - spaces are allowed"
"valid: & \n this was a escape character"
"1 + 2"

Method `eq::` of `CySymbol` returns true if the argument and `self` have the same contents. Strings test whether the object is the same:

:s = "I am s";
:p = s;
assert: ( #name eq:: #name );
assert: ! ("name" eq:: "name") ;

// strings and symbols are of different prototypes
assert: ( #name neq:: "name" ) ;

// s and p refer to the same object
assert: (s == p) & (s eq:: p);

// s is not equal to "I am s" because they are different objects
// although they have the same contents
assert: !(s == "I am s");

Both `String` and `CySymbol` are final prototypes.
4.1 Constants

A constant object can be defined inside an object using keyword `const`:

```object Date
    public const :daysWeek = 7
    public const :daysMonth = {# 31, 28, 30, 31, 30, 31, 31, 30, 31, 30, 31 #}
    public :day, :month, :year Int
end```

The constant can be public, private, or protected and its type can be anyone. It should be initialized at the declaration. The expression that initializes a constant is evaluated right before the prototype is created, before the program execution. The constants are created in the textual order in which they are declared:

```object MyConstants
    public const :first = A new
    // second is created after first
    public const :second = (B new: 100) add: 5
end```

4.2 self

Inside a method of a prototype, pseudo-variable `self` can be used to refer to the object that received the message that caused the execution of the method. This is the same concept as `self` of Smalltalk and `this` of C++/Java. An instance variable `age` can be accessed in a method of a prototype by its name or by the name preceded by "self." as in

```public fun getAge -> Int [
    ^ self.age
]
```

Then we could have used just "age" in place of "self.age".

4.3 clone Methods

A copy of an object is made with the `clone` method. Every prototype `P` has a method

```public fun clone -> P```

that returns a shallow copy of the current object. In the shallow copy of the original to the cloned object, every instance variable of the original object is assigned to the corresponding variable of the cloned object.

In the message send

```Client setName: "John";```

method `setName` of `Client` is called. Inside this method, any references to `self` is a reference to the object that received the message, `Client`. In the last statement of

```:c Client;
c = Client clone;
c setName: "Peter";```
method `setName` declared in `Client` is called because `c` refer to a `Client` object (a copy of the original `Client` object, the prototype). Now the reference to `self` inside `setName` refers to the object referenced to by `c`, which is different from `Client`.

The `clone` method of an object can be redefined to provide a more meaningful clone operation. For example, this method can be redefined to return `self` in an `Earth` prototype (since there is just one earth) or to make a deep copy of the `self` object.

In language Omega [1], the pseudo-type `Same` means the type of `self`, which may vary at runtime. Method `clone` declared in the `Object` prototype returns a value of type `Same`. That means that in object `Object`, the value returned is of type `Object` and that in a prototype `P` the return value type of `clone` is `P`. In Cyan the compiler adds a new `clone` method for every prototype `P`. This is necessary because there is nothing similar to `Same` in the language.

### 4.4 Shared Variables

A prototype may declare a variable as `shared`, as in

```object
object Date
  public :day, :month, :year Int
  public shared :today Date
end
```

Variable `today` is shared among all `Date` objects. The `clone` message does not duplicate shared variables. By that reason, we do not call shared variables “instance” variables.

### 4.5 new, init, and initOnce Methods

It is possible to declare two or more methods with the same name if they have parameters with different types. This concept, called overloading, will soon be explained. A prototype may declare one or more methods named `init` or `init:`. All of them have special meaning: they are used for initializing the object. For each method named `init` the compiler adds to the prototype a method named `new` with the same selectors and parameter types. Each `new` method creates an object without initializing any of its slots and calls the corresponding `init` method. If the prototype does not define any `init` method, the compiler supplies an empty one that does not take parameters. `init` methods should not have a return value type different from `Void`. All of them should be public (this may change in the future).

It is legal to declare methods with the name `new` or `new:`. However, these methods should have the prototype as the return type:

```object
object Test
  public fun new -> Test [ return Test ]
  public fun new: (:newValue Int) -> Test [
    :t Test = new;
    t value: newValue;
    return t
  ]
  public :value Int
    // this is illegal: return type is not Test
    public fun new: (:newValue Float) -> Int [
      return Int cast: newValue
    ]
```

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It is illegal to declare an init method with the same signature as a user-defined new method:

```cay\nobject Test
  public fun new: (:k Int) -> Test [ ... ]
    // legal
  public fun init: (:s String) [ ... ]
    // illegal for there is a new
    // method with the same parameters
  public fun init: (:n Int) [ ... ]
end
```

init methods can only be called by init methods of the prototype in which they were declared or in init methods of direct sub-prototypes of the prototype (the concept of sub-prototype, inheritance, will soon be explained). To explain that, suppose a prototype A is inherited by prototype B that is inherited by C. Then a init method of C cannot call a init method of A, which is not a direct super-prototype of C. But a init method of B may call a init method of A.

Methods new and new: are only accessible through prototype objects. That means an object returned by new or new: cannot be used to create new objects of that prototype using “new:” or “new”:

```cay\nobject Test
  public fun new: (:k Int) -> Test [ ... ]
    // legal
  public fun init: (:s String) [ ... ]
end
```

```cay\nobject Program
  public fun run [
    :t = Test clone;
    :u Test;
    // Ok !
    u = t clone;
    // compile-time error
    u = t new: 100;
    // compile-time error
    u = t init: "Hi";
    // ok
    :any = "just a test";
    u = Test new: any;
  ]
end
```

The last two lines of method run exemplify the use of dynamic dispatch with new: methods. Prototype Test has two new: methods, one of them is user-defined and the other is created by the compiler from the init: method. Message send “Test new: any” will cause a method search at runtime for an adequate new: method. Method created from init: will be chosen. The important thing here is that the choice of the method to be called is made at runtime. This is the regular Cyan mechanism for method dispatching,

---

1Signature will be defined later. For now, assume that is composed by the method name, parameter types, and return value types.
which is not that nice when applied to `new`: constructors (it is slow). But it is probably worse to create a search mechanism specific to constructors.

Every prototype `A` has a private method called `primitiveNew` that creates a new copy of it, just like the unary `new`:

```kotlin
private fun primitiveNew -> A
```

Unlike `new`, no initialization is made on the object. This method is added by the compiler and it cannot be redefined by the user.

Since `primitiveNew` is private, it can only be called by a message send to `self`. This method can be used, for example, to count how many objects were created:

```kotlin
public object University
    public fun new -> University [
        // an easy way of creating an University: in code
        ++universityCounter;
        return primitiveNew
    ]
    ...
    shared :universityCounter = 0;
end
```

A prototype may declare a single method called `initOnce` without parameters or return value that will be called once in the beginning of the program execution. Or maybe this method will be called when the prototype is loaded into memory (this is yet to be defined). Method `initOnce` should be used to initialize shared variables or even the instance variables of the prototype. This method should be private. Therefore it cannot be called outside the object. It will rarely be called inside the prototype since it is automatically called once.

```kotlin
public object Lexer
    ...
    private fun initOnce [
        keywordsTable add: "public";
        keywordsTable add: "private";
        keywordsTable add: "object";
        ...
    ]
    private shared :keywordsTable Set<String>
end
```

Metaobject `@init` automatically creates two methods: one that returns nothing and initializes instance variables and a `new` method. Consider a prototype `Proto` that declares instance variables `p1`, `p2`, ..., `pn` of types `T1`, `T2`, ..., `Tn`. Then a metaobject call

`@init(p1, p2, ..., pn)`

can be put anywhere a slot declaration may appear inside the `Proto` declaration. When the compiler finds this metaobject call, it will add the two following methods to the prototype, if they were not declared by the user.

```kotlin
public fun v1: (:p1 T1) v2: (:p2 T2) ... vn: (:pn Tn) [
    v1 = p1;
    v2 = p2;
    ...
    vn = pn;
```
If \( vi \) is a public or protected instance variable, \( vi = pi \) is replaced by \( vi: pi \) as expected.

    public fun new: (:p1 T1), (:p2 T2), ... (:pn Tn) -> Proto [
      :p Proto = self primitiveNew;
      // initialize variable vi with pi
      ...
      return p;
    ]

So, a prototype

    object University
      @init(name, location)
      public :name String
      public :age Int
    end

can be used as

    :p = Person new;
    p name: "Carol" age: 1;
    :peter = Person new: "Peter", 3;
    p age: 1 name: "Carol; // compile time error

One can use just @init, without parameters, to create two methods above for all of the instance variables of a prototype. The order of the variables in both method is the textually declared order in the prototype. Of course, if a new instance variable is added to the prototype or the declaration order is changed an error will be introduced in the code. The compiler should warn the user that the changes made are dangerous. The information that the previous version of the prototype has a different order or a different number of instance variables is available in the XML file which contains the source code.

There is an abbreviation for calling methods called new or new: of a prototype. Expressions

    P new
    P new: a
    P new: a, b, c

can be replaced by

    P()
    P(a)
    P(a, b, c)

Using prototypes Test and Person we can write

    :t1 = Test(0);
    :t2 Test = Test("Hello");
    :p Person = Person("Mary", 1);
    :q = Person("Francisco", 5);

However, in this text we will usually employ method new or new: for object creation.

Using the short form for object creation, we can easily create a net of objects. In this example, BinTree inherits from Tree (Section 4.11).
object Tree
end

object BinTree extends Tree
  @init(left, value, right)
  public :left, :right Tree
  public :value Int
end

object No extends Tree
  @init(value)
  public :value Int
end

... 

tree = BinTree( No(-1), 0, BinTree(No(1), 2, No(3)) );

### 4.6 Order of Initialization

A prototype may have assignments of expressions to instance variables, shared variables, constants, and methods. Besides that, the `initOnce` method is called once to initialize instance or shared variables and expressions is compile-time metaobjects should be evaluated.

When a prototype is loaded into memory (or when it is created at the beginning of the program execution), the runtime system evaluates all parameters to metaobjects associated to the prototype, constants, instance variables, methods, and statements of the method bodies (in this order). All of the same type are evaluated before the evaluation of the next type starts. Inside metaobjects of the same category, say methods, the textual order is used. In a metaobject, the parameters are evaluated from left to right. In this example, the names give the evaluation order.

```plaintext
@feature( #one, "t" + "wo") @feature( #three, "fo" + "ur" )
object MetaTest
  @annot( #five ) const :five = 5
  @xml( #six ) private :six = 6
  @order<< [ seven:"seven", eight: "eight" ] >>
  @another(++ #nine, "ten", ++)
  public fun test [ 
    @log( #eleven ) Out println: "just a test"
  ]
```

After evaluating the metaobjects, the runtime system does the following for every assignment `id = expr` that is outside the body of the prototype’s methods: it evaluates `expr` and assigns it to `id` for every constant, shared variable, and instance variable. After that the same is made for methods. Inside each one of these groups, the textual order of declaration is followed. After doing these initializations, `initOnce` is called.

object Test
  public const :one = 1
  public const :two = one + 1
  private shared :three = two + 1
  private shared :four = three + 1
private :five = four + 1
private :six = five + 1
public fun seven -> Int = [ `six + 1 ]
public fun eight -> Int = RetEight
private :nine Int
private :ten Int
private fun initOnce [
    nine = 9;
    ten = 10;
]
end

This example shows the order of initialization: it is the order given by the variable names. Then six is initialized before two, for example. RetEight is a prototype that can be assigned to a method. It should implement UBlock<Int><Void>.

Every time a new object of the prototype is created, with new, new:, or clone, the expressions assigned to instance variables are evaluated and assigned again.

4.7 Keyword Methods and Selectors

The example below shows the declaration of a method. The method body is given between [ and ].

    public fun withdraw: (:amount Int) -> Boolean [ // start of method body
    (total - amount >= 0) ifTrue: [
        total = total - amount;
        return true
    ]
    ifFalse: [
        return false
    ]
] // end of method body

A block is a sequence of statements delimited by [ and ]. In the code above, there are three blocks: the method body, one after ifTrue:; and another after ifFalse:. Blocks are full closures and were inspired in Smalltalk blocks. However, the Cyan blocks are statically typed. The syntax for declaring the body of a method between [ and ] came from language Omega. Based on this syntax we thought in considering methods as objects (to be seen later).

Command return returns the method value and, unlike Smalltalk, its use is demanded. The execution of the block is ended by the return command. Note that the method itself is a block which has inside other blocks. It is legal to use nested blocks. Symbol ` returns the value of a block. However, it does not necessarily cause the method in which the block is to finish its execution. See page 154 for a more detailed explanation.

Method withdraw takes an argument amount of type Int and returns a boolean value (of type Boolean). It uses an instance variable total and sends message

    ifTrue: [ .. ] ifFalse: [ ... ]

to the boolean value total - amount >= 0. The message has two block arguments,

    [ total = total - amount; return true ]

and

    [ return false ]
A message like this is called a **keyword message** and is similar to Smalltalk keyword messages. As another example, an object `Rectangle` can be initialized by

```plaintext
Rectangle width: 100 height: 50
```

This object should have been defined as

```plaintext
object Rectangle
    public fun width: :w Int height: :h Int [
        self.w = w;
        self.h = h;
    ]
    public fun set: :x, :y Int [ self.x = x; self.y = y; ]
    public fun getX -> Int [ ^ x ]
    public fun getY -> Int [ ^ y ]
    private :w, :h Int // width and height
    private :x, :y Int // position of the lower-left corner
...
end
```

Each identifier followed by a “:” is called a **selector**. So `width:` and `height:` are the selectors of the first method of `Rectangle`. Sometimes we will use “method with multiple selectors” instead of “keyword method”.

The signature of a method is composed by its selectors, parameter types, and return value type. Then the signature of method “width:height:” is

```plaintext
width: Int height: Int
```

The signature of `getX` is

```plaintext
getX -> Int
```

It is important to note that there should be no space before “:” in a selector. Then the following code is illegal:

```plaintext
(i > 0) ifTrue : [ r = 1 ] ifFalse : [ r = 0 ]
```

And so are the declarations

```plaintext
public fun width : :w Int height : :h Int [
public fun width ::w Int height ::h Int [
```

To make the declaration of a keyword method clear, parenthesis can be used to delimit the parameters that appear after a selector:

```plaintext
object Rectangle
    public fun width: (:w Int) height: (:h Int) [
        self.w = w;
        self.h = h;
    ]
    public fun set: (:x, :y Int) [
        self.x = x; self.y = y;
    ]
...
end
```

Parameters are read-only. They cannot appear in the right-hand side of an assignment.
4.8 On Names and Scope

Methods and instance variables of an object should have different names. A local variable declared in a method should have a name different from all variables of that method. So, the declaration of the following method is illegal.

```plaintext
public fun doAnything :x Int, :y Int [  
  :newY = -y; // equivalent to ":newY Int = -y;"  
  (x < 0) ifTrue: [  
    :newX Int = -x;  
    (y < 0) ifTrue: [  
      :newY Int = -y; // error: redeclaration of newY  
      rotate newX, newY;  
    ]  
  ]
]
```

However, instance variables and shared variables can have names equal to local variables (which includes parameters):

```plaintext
public fun setName: (:name String) [  
  self.name = name
]
```

An object can declare methods “value” and “value:” as in the following example:

```plaintext
object Store  
private :_value Int = 0  
public fun value -> Int [ ^ _value ]  
public fun value: :newValue Int [  
  self._value = newValue
]
end

object Program  
public fun run [  
  :s = Store clone;  
  :a Int;  
  a = In readInt;  
  s value: a;  
  Out println: (s value);
]
end
```

 Usually we will not use get and set methods. Instead, we will use the names of the attributes as the method names as in

```plaintext
:fish Fish = Fish new;  
fish name: "Cardinal tetra";  
fish lifespan: 3;  
Out println: "name: ", (fish name), " lives up to: ", (fish lifespan);
```
Fish could have been declared as

```csharp
object Fish
    private :_name String;
    private :_lifespan Int;
    public fun name -> String [ ^_name ]
        // parameter with the same name as instance variable
    public fun name: _name String [ self._name = _name ]
    public fun lifespan -> String [ ^_lifespan ]
    public fun lifespan: :_lifespan Int [ self._lifespan = _lifespan ]
end
```

4.9 Operators as Method Names

Methods can have names composed by symbol sequences such as **#, !-=, &&&,** or **+-^**. These user-defined methods are sometimes called “operators” and are always binary unless they start with !. In this case, they are considered unary and used before the receiver:

```csharp
if ( ! ok ) [ a = !++ b ]
```

Methods starting with !! are reserved and cannot be user-defined.

Binary operators have the precedence of non-ary message sends and unary operators have the precedence of unary message sends. However, if the operator have the symbol sequence of a arithmetical or logical operator, the precedence of Figure 3.1 is followed. That is, a message send

```csharp
n = a + k <= 5 && b*c + f > 0 && ! obj
```

is equivalent to

```csharp
n = (((a+k) <= 5) && (((b*c) + f) > 0)) && (! obj)
```

guardless of the types of the variables that appear in the expression.

Not every combination of symbols is a valid user-defined operator. Some symbol sequences may appear in Cyan programs that do not use any user-defined operators. These sequences are prohibited. For example, sequences ![| and (: cannot be used as operators because they appear in declaration of block parameters and method parameters:

```csharp
object Test
    public fun test: (:n Int) -> Block<Int><Int> [ ]
end
```

Note that the definition of user-defined operator should be refined. As it is, we cannot change the grammar in any way because the changes may crash with user-defined operators of legacy code. There is a solution for this problem that will be detailed in due time.

The symbols that may be part of a user-defined operator are:

```csharp
! ? @ # $ =
% & * + / <
- ^ ~ . : >
| \ ( ) [ ]
{ }
```

It is possible to define operator [] for indexing:
object Table
  public fun [] at: (:index Int) -> String [ return anArray[index] ]
  public fun [] at: (:index Int) put: (:value String) [ anArray[index] = value ]
  private :anArray Array<String>
end

:t = Table new;
t[0] = "One";
t[1] = "Two";
  // prints "One Two"
Out println: t[0], " ", t[1];

After [] they may appear only three signatures:
  at: T -> U
  at: T put: W
  at: T put: W -> V

Only one of the last two signatures may be used. Usually, U = W. But these types can be different from each other. It is legal to declared only one of these methods.

4.10 Method Overloading

There may be methods with the same selectors but with different number of parameters and parameter types (method overloading). For example, one can declare

object MyPanel
  public fun draw: (:f Square) [ ... ]
  public fun draw: (:f Triangle) [ ... ]
  public fun draw: (:f Circle) [ ... ]
  public fun draw: (:f Shape) [ ... ]
  private :name String
end

There are four draw methods that are considered different by the compiler. In a message send
  MyPanel draw: fig
the runtime system searches for a draw method in prototype MyPanel in the textual order in which the methods were declared. It first checks whether fig references an object which is a subtype of Square (See Section 4.16 for a definition of subtype). If it is, this method is called. If it is not, the searches continues in the second method,
  draw: (:f Triangle)
and so on. If an adequate method is not found in this prototype, the search would continue in the super-prototype. In this case, that will never happens: the compiler will assure that a method will be found at runtime. After all, the language is statically-typed.

Method overloading is also possible when there is more than one selector:
```plaintext
object FullIndexable
    public fun init: (:size Int) [ v = Array<String> new: size ]
    public fun at: (:i Int) -> String [ ^v[i] ]
    public fun at: (:s CySymbol) -> String [ ^v[ Int cast: s ] ]
    public fun at: (:s String) -> String [ ^v[ Int cast: s ] ]

    public fun at: (:i Int) put: (:value String) -> String [
        ^v[i] = value
    ]
    public fun at: (:s CySymbol) put: (:value String) -> String [
        ^v[ Int cast: s ] = value
    ]
    public fun at: (:s String) put: (:value String) -> String [
        ^v[ Int cast: s ] = value
    ]
    private :v Array<String>
end

This object could be used as in
: f = FullIndexable new: 10;
f at: 0 put: "zero";
f at: #1 put: "one";
f at: "2" put: "two";
Out println: (f at: "0"); // prints "zero"
Out println: (f at: 1); // prints "one"
Out println: (f at: #2); // prints "two"

The name of a method is the concatenation of all of its selectors. So method
public fun at: (:i Int) put: (:value String) -> String
has name "at:put:". Methods of the same prototype with the same name should have the same return
value type. Therefore the compiler would sign an error in the code

object Point
    public fun dist: (:nx, :ny Int) -> Int [ ...
    public fun dist: (:nx, :ny Float) -> Float [ // compilation error here ...
    ...
    private :x, :y Int
end

One important restriction of overloaded methods is that, in a prototype, all methods with the same
name should appear in sequence. Then the only element allowed between two declarations of methods
with the same name is another method with this same name.

object FullIndexable
    public fun at: (:i Int) -> String [ ^v[i] ]
    // init should not be here!
    public fun init: (:size Int) [ v = Array<String> new: size ]
    // compilation error
    public fun at: (:s CySymbol) -> String [ ^v[ Int cast: s ] ]
```

4.11 Inheritance

A prototype may extends another one using the syntax:

```
object Student extends Person ... end
```

This is called inheritance. Student inherits all methods and variables defined in Person. Student is called a sub-object or sub-prototype. Person is the super-object or super-prototype. Every instance variable of the sub-object should have a name different from the names of the public methods of the super-object (including the inherited ones) and different from the names of the methods and other instance variables of the sub-object. Since the name of a non-unary method includes the ":", there may be instance variable iv and method iv:.

A method of the sub-object may use the same selectors as a method of the super-object (their names may be equal). There is no restriction on the parameter types used in the sub-object method. However, the return value type of the sub-object method should be a subtype of the return value type of the super-object method. That is, Cyan supports co-variant return value type. This does not cause any runtime type errors, which is justified using the following example.

```
:v Super = anObject;
:x A;
x = v selector: 0;
```

The compiler checks whether the return value of method selector: of Super (which may be inherited from super-objects) is a subtype of the declared type of x, A. The code is only run if this is true. Then at runtime v may refer to a sub-object of Super referenced by anObject. This sub-object may declare a selector: method whose return value type is C, a subtype of the return value type B of method selector: of Super. That will not cause a runtime type error because subtyping is transitive: C is subtype of B which is a subtype of A. Therefore, C is also a subtype of A. At runtime there will be an assignment of an object of C to a variable of type A, which is type-correct.

The method of the sub-object that overrides the super-object method should be declared with the word override following the qualifier (public, protected, or private). See the examples.

```
object Animal
  public fun eat: (:food Food) [ Out println: "eating food" ]
end

object Cow extends Animal
  public override fun eat: (:food Grass) [ Out println: "eating grass" ]
end

object Person
  public fun print [  
    Out println: "name: ", name, " (", age, ")"
  ]
  public :name String
  public :age Int
end
```
There is a keyword called `super` used to call methods of the super-object. In the above example, method `print` of `Student` calls method `print` of prototype `Person` and then proceeds to print its own data.

Methods `init`, `init:`, `new`, new:; and `initOnce` are never inherited. However, `init` or `init:` methods of a sub-object may call `init` or `init:` methods of the super-object using `super`:

```
object Person
    public fun init: (:name String, :age Int) [  
        self.name = name;  
        self.age = age;  
    ]  
    public fun print [  
        Out println: "name: ", name, " (", age, ")"  
    ]  
    public :name String  
    public :age Int  
end
```

```
object Student extends Person
    public fun init: (:name String, :age Int, :school String) [  
        super init: name, age;  
        self.school = school  
    ]  
    public override fun print [  
        super print;  
        Out println: " School: ", school  
    ]  
    public fun nonsense [  
        // compile-time error in this line  
        // new: cannot be called  
        :aPerson = super new: "noname", 0;  
        // ok, clone is inherited  
        :johnDoe = super clone;  
    ]  
    public :school String  
end
```

Keyword `override` is not necessary in the declaration of method `init:` of `Student` because `init:` of `Person` is not inherited. The compiler adds to prototype `Person` a method

```
    new: (:name String, :age Int) -> Person
```

and to `Student`

```
    new: (:name String, :age Int, :school String) -> Student
```
Since methods \texttt{clone} and \texttt{new} are not inherited, there will be compile-time errors in method \texttt{nonsense}.

A prototype may be declared as “final”, which means that it cannot be inherited:

\begin{verbatim}
public final object String
...
end
\end{verbatim}

There would be a compile-time error if some prototype inherits \texttt{String}. The prototypes \texttt{Byte}, \texttt{Short}, \texttt{Int}, \texttt{Long}, \texttt{Float}, \texttt{Double}, \texttt{Char}, \texttt{Boolean}, \texttt{Void}, and \texttt{String} are all final.

A method declared as “final” cannot be redefined in sub-prototypes:

\begin{verbatim}
public object Car
  public final fun name: (:newName String) [ _name = newName ]
  public final fun name -> String [ ^_name ]
  private :_name String
...
end
\end{verbatim}

Final methods should be declared in non-final prototypes (why?). Final methods allow some optimizations. The message send of the code below is in fact a call to method \texttt{name} of \texttt{Car} since this method cannot be overridden in sub-prototypes. Therefore this is a static call, much faster than a regular call.

\begin{verbatim}
:myCar Car;
...
s = myCar name;
\end{verbatim}

Public instance variables can be declared final. That means the get and set methods associated to this variable are final.

\section*{4.12 Multi-Methods}

The mechanism of method overloading of Cyan implements a restricted form of multi-methods. In most languages, the receiver of a message determines the method to be called at runtime when the message is sent. In CLOS \cite{18}, all parameters of the message are taken into consideration (which includes what would be the “receiver”). This is called multiple dispatch and the methods are called “multi-methods”.

Cyan implements a restricted version of multi-methods: the method to be called is chosen based on the receiver and also on the runtime type of the parameters. To make the mechanism clearer, study the example below. Assume that \texttt{Grass}, \texttt{FishMeat}, and \texttt{Plant} are prototypes that inherit from prototype \texttt{Food}.

package main
...

private object Animal
  public fun eat: (:food Food) [ Out println: "eating food" ]
end

private object Cow extends Animal
  public override fun eat: (:food Grass) [ Out println: "eating grass" ]
end
private object Fish extends Animal
    public override fun eat: (:food FishMeat) [ Out println: "eating fish meat" ]
    public override fun eat: (:food Plant) [ Out println: "eating plants" ]
end

public object Program
public fun run [ :animal Animal; :food Food;
animal = Cow;
animal eat: Grass; // prints "eating grass"
animal eat: Food; // prints "eating food"
    // the next two message sends prints the same as above
    // the static type of the parameter does not matter
food = Grass;
animal eat: food; // prints "eating grass"
food = Food;
animal eat: food; // prints "eating food"

animal = Fish;
animal eat: FishMeat; // prints "eating fish meat"
animal eat: Plant; // prints "eating plants"
animal eat: Food; // prints "eating food"
    // the next two message sends prints the same as above
    // the static type of the parameter does not matter
food = FishMeat;
animal eat: food; // prints "eating fish meat"
food = Plant;
animal eat: food; // prints "eating plants"
food = Food;
animal eat: food; // prints "eating food"
]
end

4.13 Any, the Super-prototype of Everybody

Prototypes that are declared without explicitly extending a super-prototype in fact extend an object called Any. Therefore Any is the super-object of every other object. It defines some methods common to all objects such as asString, which converts the object data to a format adequate to printing. For example,

    Rectangle width: 100 height: 50
    Rectangle set 0, 0;
    Out println: (Rectangle asString);

would print something like

object Rectangle
    :w Int = 100
The methods declared in Any are given below. Some method bodies are elided.

@checkIfNil
public final fun ifNil: Any -> Any
public final fun isNil -> Boolean
public final fun notNil -> Boolean [ ~ !isNil ]
public final fun eq: (:other Any) -> Boolean
public final fun neq: (:other Any) -> Boolean [ ~ ! eq: other ]
@prototypeCallOnly
public final fun cast: Any -> Any
public final fun prototype -> Any
public final fun prototypeName -> String
public final fun parent -> Any
public final fun isInterface -> Boolean
@checkIsA
public final fun isA: (:proto Any) -> Boolean
@checkThrow
public final fun throw: (:e CyException)

public fun hashCode -> Int
public fun clone -> Any
@prototypeCallOnly
public fun asString -> String
public fun == (:other Any) -> Boolean
public fun assert: (:expr Boolean)
public fun print [ Out println: (self asString) ]
public fun defaultValue -> Any [ ^nil ]
@checkAttachMixin
public fun attachMixin: (:mixProto Any)
public fun popMixin -> Boolean
public fun in: (:container IHas<P>) -> Boolean [ return container has: self ]
public fun evalSelfContext: (:b ContextObject<P>) [ :block Block = b newObject: self;
   block eval;
]

public fun featureList -> Array<Tuple<key, String, value, Any>>
public fun addFeature: key: (:aKey String)
   value: (:aValue Any)

public fun annotList -> Array<Any>

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public fun addAnnot: (:annot Any)

public fun (selector: String (param: (Any)+)? )+ :t -> Any
public fun (invokeMethod: selector: String (param: (Any)+)? )+ :t -> Any

@checkAddMethod
public fun (addMethod: 
    (selector: String (param: (Any)+)? )+
    (returnType: Any)?
    body: ContextObject) :t

public fun doesNotUnderstand: (:methodName CySymbol, :args Array<Any>)

@checkSwitch public fun ( switch: 
    (case: (Any)+ do: Block)+
    (else: Block)?
) :t UTuple<Any, Array<UTuple<Array<Any>, Block>>, UUnion<Block>> [ // method body ]

Method ifNil returns self if self is not nil and its parameter otherwise:

username = name ifNil: "anonymous";
connect: username with: password;

Although ifNil: takes and returns an Any object, the compiler demands that, in a message send, the parameter have the same type as the receiver. It considers that the return value has the receiver type also. This can be implemented through metaobjects: in a message send, when the selector is ifNil a metaobject checkIfNil associated to this method is used. That is, a specific method of this metaobject is called to check if the parameter is of the same type as the receiver. This metaobject method also asserts that the return value is considered as having the same type as the receiver.

Method isNil returns true is the receiver is nil, false otherwise. notNil returns the negation of isNil. Method eq: returns true if self and the parameter reference the same object, false otherwise.

For every user-declared prototype P the compiler adds a method “cast: Any -> P” A metaobject attached to this method issues an error if the receiver of a message cast: is not a prototype.

:a A;
:p Proto;
p = A cast: Person;
p = a cast: Person; // compile-time error

A prototype may redefine method cast: to take more appropriate actions:

object PolarPoint
    public cast: (:other Any) -> PolarPoint [ 
        if ( other is a regular point ) [ 
            convert other to a polar point p
            return p
        ]
        else [ 
            // test whether other prototype is PolarPoint or
            // a sub-prototype of PolarPoint. If it is,
The `cast:` method of the basic types do the usual conversion between these types (the same conversion Java does). The `cast:` method of a prototype P tests whether its parameter prototype inherits from P or if it is P itself. In these cases, the parameter itself is returned. Otherwise an exception `CastException` is thrown.

Method “`prototype`” returns the prototype that was used to create the object or the prototype itself (if it is the receiver):

```plaintext
:p Person = Person clone;
:w = Worker new;
assert: Person prototype == Person &&
    p prototype == Person &&
    w prototype == Worker &&
    w prototype != Person;
```

To every user-declared prototype P the compiler adds method

```plaintext
   public final fun prototype -> P [ return P ]
```

This method cannot be redefined. Note that the return type of this method is a sub-prototype of the return type of the method of `Any`. This is legal: the return type of a method can be subtype of the type of the method of the same name defined in the super-prototype. `prototypeName` returns the name of the original prototype. It would be “Person” for prototype `Person` and “`Hashtable<String, Int>`” for an instantiation of generic object `Hashtable`.

Method `parent` returns the parent prototype of the receiver. If the receiver is not a prototype, it returns the parent of the receiver’s prototype:

```plaintext
:p Person = Person name: "fulano";
assert: (p parent == Person parent);
```

Method `isInterface` returns `true` if the receiver is an interface. It cannot be redefined.

Method `isA` returns true if the prototype of `self` is the same as `proto` or a descendent of it. Parameter `proto` should be a prototype, which is checked by a metaobject `checkIsA`. Assuming that `Circle` inherits from `Elipse` that inherits from `Any`, we have

```plaintext
:e Elipse = Elipse;
:c Circle = Circle x: 100 y: 200 radius: 30;
assert: (c isA: Elipse && c isA: Circle);
assert: (c isA: Any && Circle isA: Any && Circle isA: Circle);
/* if uncommented the statement that follows would
 cause a compile-time error */
assert: (c isA: e);
```

Method `throw:` throws the exception that is the parameter. See more on Chapter 12.

`hashCode` returns an integer that is the hash code of the receiver object (this needs to be better defined).

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clone returns a cloned copy of self. It is used shallow copy. Method asString returns a string with the content of self. It can and should be override to give a more faithful representation of the object. Method == returns the same as eq: by default. But it can and should be user-defined.

Method assert: takes a boolean expression as parameter and throws exception AssertException if expr is false. Method print prints information on the receives using methods print: and println: of prototype Out. Method defaultValue returns the default value for the prototype — see page 62. It is nil for all prototypes and special values for the basic types (for example, 0 for Int).

Method attachMixin attaches a mixin object to the current object. For each user-defined prototype P, the compiler adds a method

```plaintext
public fun attachMixin: (:mixProto Any) [ ... ]
```
to P. Metaobject checkAttachMixin checks whether mixProto is a mixin object that can be attached to objects of P and its sub-prototypes. This method is described in page 94. popMixin removes the last mixin object dynamically attached to the receiver. It returns true if there was a mixin attached to the object and false otherwise.

To each prototype P the compiler adds a method

```plaintext
public fun in: (:container IHas<P>) -> Boolean [
  return container has: self
]
```

```plaintext
... interface IHas<T>
  fun has: T
end
```

This method is to be used with containers (arrays, sets, lists, stacks, and so on) to make the operation "does x belongs to container C" more natural. Instead of writing

```plaintext
if ( list has: x ||
    {% # 'a', 'e', 'i', 'o', 'u' #} has: letter ) [
... ]
```

we can write

```plaintext
if ( x in: list ||
    letter in: {% # 'a', 'e', 'i', 'o', 'u' #} ) [
... ]
```

To each prototype P the compiler also adds a method that just execute its context block parameter in the context of self.

```plaintext
public fun evalSelfContext: (:b ContextObject<P>) [
  :block Block = b newObject: self;
  block eval;
]
```

This method helps the building of Domain Specific Languages. See Section 9.8 for more details.

Section 5.1 explains in detail the Any methods that deal with features and annotations. Here we just comment briefly these methods.
Method `featureList` returns an array with all features of the prototype. Method `addFeature` adds a feature to the object at runtime. The key and value are given as parameters. Annotations are a special case of features. An attachment

```java
@annot( #root )
```

is the same as

```java
@feature("annot", #root)
```

Method `annotList` returns a list of annotation objects attached to the prototype. Method `addAnnot` adds an annotation dynamically.

Method

```java
(selector: String (param: (Any)+)? )+ -> Any
```

is a grammar method (described in Chapter 9) used to call a method by its name. For example, suppose an object `Map` has a method

```java
key: String value: Int
```

This method can be called using the grammar method `selector: ...` in the following way:

```java
Map selector: "key:" param: "One"
selector: "value:" param: 1;
```

This grammar method checks whether the object has the method at runtime (of course!). Then this example is equivalent to

```java
Map ?key: "One" ?value: 1;
```

Note that there may be one or more parts “selector: ...”. Selector “param:” is optional. At least one parameter should follow selector “param:” if it is present. The value returned by this method is the object returned by the called method or `noObject` is the return type is `Void`.

Conceptually, a message send to object `obj` causes the execution of method

```java
public fun (invokeMethod: selector: String (param: (Any)+)? )+ :t -> Any
```

of `obj`. That means the regular search for methods is used when searching for this method (in the prototype of `obj`, the super-prototype of the prototype, and so on).

Method `invokeMethod: ...` is then responsible for calling the method associated to the message. For example, suppose `Worker` inherits from `Person` and both define a `print` method.

```java
:w Worker;
w = company getOldestWorker;
w print;
```

In the last message send, first method `invokeMethod: ...` of `Any` is called (assume that this method is not overridden in sub-prototypes). Then `invokeMethod: ...` of `Any` does a search for an appropriate method starting in `Worker`. Since a `print` method is found there, it is called.

Then, conceptually, usually Cyan does two searches for each method call:

(a) one for finding an `invokeMethod: ...` method;

(b) the other, inside this method of `Any`, to find the appropriate method. It is this call that is made in almost all object-oriented languages.

There are two occasions in which things happens a little different from described above:

(a) when `invokeMethod: ...` calls itself, as in

```java
:any = Any;
any invokeMethod: selector: "invokeMethod:"
```
There is an infinity loop;

(b) when `invokeMethod: ...` is redefined in a prototype. In this case, the redefined method is responsible for calling the appropriate method.

Of course, we used the name `invokeMethod: ...` because of Groovy.

Method

```java
public fun (addMethod:
    (selector: String ( param: (Any)+ )? )+
    (returnType: Any)?
    body: ContextObject)
```

adds a method dynamically to an object. It is explained in page 178 of Section 10.11.

Method `doesNotUnderstand:` is called whenever a message is sent to the object and it does not have an appropriate method for that message. The message name (as a symbol) and the arguments are passed as arguments to `doesNotUnderstand:`. This method ends the program with an error message. The name of a message is the concatenation of its selectors. The name of message `at:put:with:` is “at:put:with:.”

Since Cyan is statically typed, regular message sends will never cause the runtime error “method not found”. But that can occur with dynamic message sends such as `s ?push: 10;`
or

```java
    s selector: #push param: 10
```

Method `switch: ...` implements the “switch” statement and is discussed elsewhere (Section 3.6).

There are several missing methods in `Any` related to reflective introspection. For example, there is no method that lists the object methods or constants or that returns the features of a given method. These reflective introspection methods will be added to `Any` during the design of the Metaobject-Protocol for Cyan.

### 4.14 Abstract Prototypes

Abstract prototypes in Cyan are the counterpart of abstract classes of class-based object-oriented languages. It is a compile-time error to send a message to an abstract prototype, which includes messages `new` and `new:`. Since these methods can only be called through a prototype, no objects will ever be created from an abstract prototype. However, an object may refer to an abstract prototype and it may call method `clone`. But it will return `nil`. `init` and `init:` methods may be declared — they may be called by sub-prototypes.

The syntax for declaring an abstract object is

```java
public abstract object Shape
    public fun init: (:newColor Int) [ color: newColor ]
    public abstract fun draw
    public fun color -> Int [ ^ shapeColor ]
    public fun color: (:newColor Int) [ shapeColor = newColor ]
    private :shapeColor Int
end
```
An abstract method is declared by putting keyword “abstract” before “fun” and it can only be declared in an abstract object, which may also have non-abstract methods. A sub-prototype of an abstract object may be declared abstract or not. However, if it does not define the inherited abstract methods, it must be declared as abstract.

Objects are concrete things. It seems weird to call a concrete thing “abstract”. However, this is not worse than to call an abstract thing “abstract”. Classes are abstraction of objects and there are “abstract classes”, an abstraction of an abstraction.

Since all prototypes are concrete things in Cyan, the compiler adds a body to every abstract method to thrown an exception `ExceptionCannotCallAbstractMethod`:

```kotlin
public fun draw [
    throw: ExceptionCannotCallAbstractMethod("Shape::draw")
]
```

Note that

```kotlin
Shape draw
```

causes a compile-time error. And

```kotlin
:s Shape = Shape;
s draw;
```

causes a runtime error. The method `draw` added to the compiler is called. It is legal to assign an abstract object to a variable. To prohibit that would say that not all “objects” are really objects in Cyan. We could not pass `Shape` as parameter, for example. That would be bad.

Keyword “override” is optional when used with the “abstract” keyword:

```kotlin
public abstract object Shape
    public abstract fun draw
...
end

abstract object Polygon extends Shape
    public abstract fun draw
end
```

We could have used

```kotlin
public override abstract fun draw
```

### 4.15 Interfaces

Cyan supports `interfaces`, a concept similar to Java interfaces. The declaration of an interface lists zero or more method signatures as in

```kotlin
interface Printable
    fun print
end
```

The `public` keyword is not necessary since all signatures are public. `fun` is not necessary but it is demanded for sake of clarity (should it be eliminated too?).

An interface has two uses:
(a) it can be used as the type of variables, parameters, and return values;

(b) a prototype can implement an interface. In this case, the prototype should implement the methods described by the signature of the interface. A prototype can implement any number of interfaces. Name collision in interface implementation is not a problem.

Interfaces are similar to the concept of the same name of Java.
As an example, one can write

```
interface Printable
    fun printObj
end

object Person
    public :name String
    public :age Int
end

object Worker extends Person implements Printable
    private :company String
    public fun printObj [
        Out println: "name: " + name + " company: " company
    ]
    ... // elided
end
```

Here prototype Worker should implement method printObj. Otherwise the compiler would sign an error. Interface Printable can be used as the type of a variable, parameter, and return value:

```
:p Printable;
p = Worker clone;
p print;
```

An interface may extend any number of interfaces:

```
interface ColorPrintable extends Printable, Savable
    fun setColor: (:newColor Int)
    fun colorPrint
end
```

An interface is a prototype that may inherit from any number of other interfaces. Therefore Cyan supports a limited form of multiple inheritance. An interface that does not explicitly inherits from any other in fact inherits from prototype AnyInterface (which inherits from Any).

```
object AnyInterface
end
```

The method signatures declared in an interfaces are transformed into public methods. These methods throw exception ExceptionCannotCallInterfaceMethod:

```
// interface ColorPrintable as a prototype
object ColorPrintable extends Printable, Savable
    public fun setColor: (:newColor Int) [
        throw: ExceptionCannotCallInterfaceMethod("ColorPrintable::setColor");
    ]
```
 Interfaces are then objects with full rights: they be assigned to variables, passed as parameters, and receive messages.

Although interfaces are objects, the compiler puts some restrictions on their use.

(a) An interface can only extend another interface. It is illegal for an interface to extend a non-interface prototype.

(b) Interfaces do not have any \texttt{new} or \texttt{new:} methods. No object will never be created from them. But the interface itself may receive messages.

(c) A regular prototype cannot inherit from an interface.

(d) If the type of an expression is an interface I, then the compiler checks whether the messages sent to it match those method signatures declared in the interface, super-interfaces, and \texttt{Any} (See Section 4.13).

Besides that, method \texttt{isInterface} inherited from \texttt{Any} returns \texttt{true} when the receiver is an interface. The examples that follow should clarify these observations.

```plaintext
// ok :inter Printable = Printable;
// ok, asString is inherited from Any
Out println: (inter asString);
// ok, Printable is a regular object
Out println: (Printable asString);
:any Any = Printable;
// ok
Out println: (any asString);
// it is ok to pass an interface as parameter
assert: (any isA: Printable);
assert: (any isInterface && Printable isInterface &&
    inter isInterface);
```

### 4.16 Types and Subtypes

A type is a \texttt{prototype} (when used as the type of a variable or return value) or an interface. Subtypes are defined inductively. $S$ is subtype of $T$ if:

(a) $S$ extends $T$ (in this case $S$ and $T$ are both prototypes or both interfaces);

(b) $S$ implements $T$ (in this case $S$ is a prototype and $T$ is an interface);

(c) $S$ is a subtype of a type $U$ and $U$ is a subtype of $T$.

Then, in the fake example below, $I$ is supertype of every other type, $J$ is supertype of $I$, $J$ and $D$ are supertypes of $E$, and $B$ is supertype of $C$, $D$, and $E$. 

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interface I end
interface J extends I end
object A implements I end
object B extends A end
object C extends B end
object D extends C implements J end
object E extends D end

Considering that the static type or compile-time type of \( s \) is \( S \) and the static type of \( t \) is \( T \), the assignment “\( t = s \)” is legal if \( S \) is a subtype of \( T \). Using the previous example, the following declarations and assignments are legal:

\[
i \ I;
\ : j \ J;
\ : a \ A;
\ : b \ B;
\ : d \ D;
\ : e \ E;
\]
\[
i = j; \ i = a; \ a = e; \ i = a;
\]
\[
j = d; \ b = d; \ j = e;
\]

There is a predefined function \texttt{type} evaluated at compile-time that return the type of an variable, constant, or literal object. In the example

\[
\ x\ \ Int;
\ : y\ \ type(x);
\]
\( \ x \) and \( \ y \) have both the \texttt{Int} type.

### 4.17 Mixin Inheritance

An object can inherit from a single object but it can be mixed with any number of other objects through the keyword \texttt{mixin}. This is called \textit{mixin inheritance} and it does not have the problems associated to multiple inheritance.

\[
\texttt{object B extends A mixin M1, M2, ... Mn}
\]
\hspace{1cm} // method and variable declarations go here
end

M1, M2, ... Mn are mixin objects. A mixin object M is declared as

\[
\texttt{mixin(S) object M extends N}
\]
\hspace{1cm} // method and variable declarations of the mixin
end

Mixin M extends mixin N. This inheritance is optional, of course. Mixin N should be declared as

\[
\texttt{mixin(R) object N extends P}
\]
\hspace{1cm} // method and variable declarations of the mixin
end

Here \( R \) should be a subtype of \( S \). The difference of a mixin from a normal object declaration is that a mixin object does not extends \texttt{Any}, the root of the object hierarchy, even if it does not extends explicitly any other object.
Mixin \( M \) may be inherited by prototype \( S \), specified using “mixin(\( S \))”, or by sub-prototypes of \( S \), or to prototypes implementing interface \( S \). Methods of the mixin object \( M \) may call methods of \( S \) using super.

Object or interface \( S \) may not appear in the declaration of a mixin object.

```ruby
mixin object PrintMe
    public fun whoIam [
        Out printn: "I am #{super prototypeName}"
    ]
end
```

In this case the mixin methods may call, through self or super, methods of prototype Any.

```ruby
mixin object Empty
end
```

Since mixin Empty does not inherit from any other mixin, it does not have any methods or instance variables. This mixin could have been declared as

```ruby
mixin(Any) object Empty
end
```

Currently a mixin object cannot be the type of a variable, parameter, or return value. Maybe this restriction will be lifted in the future. If \( M \) defines a method already defined in object \( S \) (assuming that \( S \) is not an interface), then the method declaration should be preceded by override, as is demanded when a sub-object override a super-object method.

The compiler creates some internal classes when it encounters an object that inherits from one or more mixin objects. Suppose object \( B \) extends object \( A \) and inherits from mixin objects \( M_1, M_2, ..., M_n \) (as in one of the previous examples). The compiler creates an object \( B' \) with the body of \( B \). \( B' \) defines a method with an empty body for each method declared in the mixin objects \( M_1, ..., M_n \). Then the compiler makes \( B' \) inherit from \( A \). After this, it creates prototypes \( M_1', M_2', ..., M_n' \) in such a way that

(a) each \( M_i \) has the same body as \( M_i' \);
(b) \( M_1' \) inherits from \( B' \) and \( M(i+1) \) inherits from \( M_i \);
(c) \( M_n' \) is renamed to \( B \).

Note that:

(a) there is never a collision between methods of several mixins inherited from an object;
(b) the object that inherits from one or several mixins is placed above them in the hierarchy — the opposite of inheritance.

A prototype may call methods of its mixins:

```ruby
mixin(Person) object Comparison
    public fun older: (:other Person) [
        return super age > other age
    ]
end
```

```ruby
object Person mixin Comparison
...
    public fun compare: (:other Person) [
```
// calling method older: of mixin Comparison

if ( older: other ) [  
  Out println: "#{other name} is older than #{name}"
]
]

public :age Int
public :name String
end

It is legal to send message other: to self since the compiler adds a method

    public fun older: (:other Person) [ ]

    to protototype Person. In Person objects, the method called by “older: other” will be older: of Comparison.

    A mixin object may declare instance variables. However a mixin object that declares instance variables cannot be inherited twice in a prototype declaration:

    mixin object WithName
        public fun print [ ... ]
        public :name String
    end

mixin object WithNameColor extends WithName
    public fun print [ ... ]
    public :color Int
end

mixin object WithNameFont extends WithName
    public fun print [ ... ]
    public :font String
end

mixin object PersonName mixin WithNameFont, WithNameColor
    public fun print [  
      Out println: "Person: ";
      super print
    ]
end

Here WithName is inherited by PersonName by two different paths:

    WithName -> WithNameColor -> PersonName
    WithName -> WithNameFont -> PersonName

Hence objects of PersonName should have two instances of instance variable name. Each one should be accessed by one of the inheritance paths. Confusing and that is the reason this is not allowed. This is the same problem of diamond inheritance in languages that support multiple inheritance.

    As said above, Cyan does not allow a mixin object that declares instance variables to be inherited by two different paths. Then the introduction of an instance variable to a mixin object may break a working code. In the above example, the introduction of name to WithName after the whole hierarchy was built would cause a compile-time error in prototype PersonName. That is bad. The alternative would be to
prohibit instance variables in mixin objects. We believe that would be much worse than to prohibit the double inheritance of a mixin object that declares instance variables.

Let us show an example of use of mixin objects.

```java
mixin(Window) object Border
    public fun draw [ /* draw the window */
        drawBorder;
        super.draw
    ]
    public fun drawBorder [ // draw a border of color "color"
        ...
    ]
    public fun setBorderColor :color Int [ self.color = color ]
    private :color Int;
    ...
end

object Window mixin Border
    public fun draw [ /* method body */ ]
    ...
end
```

Object `Window` can inherit from mixin `Border` because the mixin object is declared as `mixin(Window)` and therefore `Window` and its sub-objects can inherit from it. Methods of `Window` can be called inside mixin `Border` using `super`.

The compiler creates the following hierarchy:

```
Any
    Window' (with the body of Window)
    Window (with the body of Border)
```

See Figure 1.3. When message `draw` if sent to `Window`, method `draw` of the mixin `Border` is called. This method calls method `drawBorder` of the mixin to draw a border (in fact, the message is sent to `self` and in this particular example method `drawBorder` of `Border` is called). After that, method `draw` of `super` is called. In this case, `super` refer to object `Window'` which has the body of the original `Window` object. Then a window is drawn.

As another example, suppose we would like to add methods `foreach` to objects that implement interface `Indexable`:

```java
interface Indexable<:T>
    // get element "index" of the collection
    fun get: (:index Int) -> T
    // set element "index" of the collection to "value"
    fun set: (:index Int) value: (:aValue T)
    // size of the collection
    fun size -> Int
end
```

The mixin object defined below allows that:
mixin(Indexable<T>) object Foreach<T>
    public fun foreach: :b Block<T><Void> [ 
        i = 0;
        [~ i < size ] whileTrue: [ 
            b eval: (get i)
        ]
    ]
end

Note that there may be generic mixin objects (see more on generic objects in Chapter[7]). The syntax is not the ideal and may be modified at due time.

Suppose object PersonList implements interface Indexable<Person>:

object PersonList implements Indexable<Person> mixin Foreach<Person>
    public fun get: (:index Int) -> Person [ ... ]
    public fun set: (:index Int) :value (:person Person) [ ... ]
    public fun size -> Int [ ... ]
    // other methods
end

Now method foreach inherited from Foreach can be used with PersonList objects:

PersonList foreach: [ |:elem Person| Out println: elem ]

Method foreach: sends messages size and get to self, which is PersonList in this message send. Then the methods size and get called will be those of PersonList. self can be replaced by super in this case. Be it self or super, the compiler does not issue an error message because methods size and get are defined in Indexable<Person>, the prototype that appears in the declaration of Foreach<T>.

Another example would be to add a method select that selects, from a collection, all the elements that satisfy a given condition.

interface ForeachInterface<T>
    fun foreach: Block<T>
end

mixin(ForeachInterface<T>) object SelectMixin<T>
    public fun select: :condition Block<T> -> Collection<T> [ 
        c = Collection<T> new;
        foreach: [ |:elem T| 
            if ( condition eval: elem ) [ 
                c add: elem
            ]
        ]
        return c
    ]
end

object List<T> mixin SelectMixin<T>
    ...
end

...
:list = List<Person> new;
list add: peter, john, anne, livia, carolina;
:babyList = list select: [ |:p Person| ^ (p age) < 3 ];

Here babyList would have all people that are less than three years old. Note that object Collection in mixin object SelectMixin could have been a parameter to the mixin:

mixin(ForeachInterface<T>) object SelectMixin<:T, :CollectTo>
  public fun select: :condition Block<T> -> CollectTo<T> [
    :c = CollectTo<T> new;
    foreach: [ |:elem T|
      if ( condition eval: elem ) [
        c add: elem
      ]
    ]
    return c
  ]
end

The same idea can be used to create a mixin that iterates over a collection and applies a function to all elements, collecting the result into a list.

4.18 Runtime Metaobjects or Dynamic Mixins

Mixin prototypes can also be dynamically attached to objects. Returning to the Window-Border example, assume Window does not inherit from Border. This mixin can be attached to Window at runtime by the statement:

Window attachMixin: Border;

Effectively, this makes Border a metaobject with almost the same semantics as shells of the Green language [12]. Any messages sent to Window will now be searched first in Border and then in Window. When Window is cloned or a new object is created from it using new, a new Border object is created too.

As another example, suppose you want to redirect the print method of object Person so it would call the original method and also prints the data to a printer. This can be made with the following mixin:

mixin(Any) object PrintToPrinter
  public override fun print [ super print;
    // print to a printer
    Printer print: (self asString)
  ]
end

"self asString" returns the attached object as a string, which is printed in the printer by method print:. This mixin can be added to any object adding a print method to it:

object Person
  public :name String
  public :age String
  public override fun asString -> String [
    ~"name: #name age: #age"
... 
:p = Person new;
p name: "Carol";
p age: 1;
p attachMixin: PrintToPrinter;
    // prints both in the standart output and in the printer
p print;
Person name: "fulano";
Person age: 127;
    // print only in the standard output
Person print;

Note that attachMixin is a special method of prototype Any: it is added by the compiler and it can only be called by sending messages to the prototype. These dynamic mixins are runtime metaobjects. Probably they can only be efficiently implemented by changing the Java Virtual Machine (but I am not so sure). Maybe efficient implementation is possible if the metaobjects (dynamic mixins) that can be attached to an object are clearly identified:

```
object(PrintToPrinter) Person
    public :name String
    public :age String
    public override fun asString -> String [
        ^"name: #name age: #age"
    ]
end
```

Then only PrintToPrinter metaobjects can be dynamically attached to Person objects.

The last dynamic mixin attached to an object is removed by method popMixin defined in prototype Any. It returns true if there was a mixin attached to the object and false otherwise. Therefore we can remove all dynamic mixin of an object obj using the code below.

```
while ( obj popMixin ) []
```

The above definition of runtime mixin objects is similar to the definition of runtime metaobjects of Green [12]. The semantics of both are almost equal, except that Green metaobjects may declare a interceptAll method that is not supported by mixin objects (yet).
Chapter 5

Metaobjects

A metaobject is an object that can change the behavior of a program, add information to it, or it can just inspect the source code, using the collected information in the source code itself. Metaobjects may appear in several places in a Cyan program. A metaobject is attached to a prototype, method, interface, and so on using @ as in

@checkStyle object Person
  public fun print [ Out println: "name: ", name, " (", age, ")"
 ]
  public :name String
  public :age Int
end

checkStyle is a metaobject written in Java. The compiler loads a Java class checkStyle from the disk and creates an object from it. Then it calls some methods of this object passing some information on the object Person as parameter. For example, it could call method change of the checkStyle object passing the whole abstract syntax tree (AST) of Person as parameter. Then method change of checkStyle could change the AST or issue errors or warnings based on it. The intended meaning of checkStyle is to check whether the identifiers of the prototype follow Cyan conventions: method names and variables should start with an lower case letter and prototype and interfaces names should start with an upper case letter. In this metaobject, the AST is not changed at all.

The interactions of metaobjects with the Cyan compiler should be defined by a Meta-Object Protocol (MOP). The MOP would define how and which parts of the compiler are available to the metaobjects, which can be written by common users. The MOP has not yet being designed. It will be in a few years.

5.1 Pre-defined Metaobjects

There is a set of metaobjects that are automatically available in every Cyan source code: import, prototypeCallOnly, javacode, annot, feature, text, dynOnce, dynAlways (page 109), doc, and init (see page 67). By putting @import(p1, p2, ..., pn) as the first non-blank characters of a file (even before any comments), the compiler will import the Java packages p1, ..., pn that define metaobjects, which are Java classes that inherit from a CyanMetaobject class. Whenever the compiler finds @meta in the source code, it will load into memory a class Meta from one of these packages.

Metaobject prototypeCallOnly should be followed by a public method declaration. It checks whether the method is only called through the prototype. A call to the method using a variable is forbidden:
object Person
    public :name String
        @prototypeCallOnly public fun create -> Person [ ^ Person new ]
    end
...
:p Person;
p = Person create; // ok
p = p create; // compile-time error

All new methods are implicitly declared by the compiler with a metaobject prototypeCallOnly. Even if the user declares a new method the compiler attaches to it this metaobject.

The pre-defined metaobject annot attaches to an instance variable, shared variable, method, constant, prototype, or interface a feature given by its parameter, which may be any object. This feature can be retrieved at runtime by method
    annotList -> Array<Any>
inherited by any object from Any.

As an example of its use, consider an annotation of object Person:

@annot( #Author ) object Person
    public fun print [
        Out println: "name: ", name, " (", age, ")"
    ]
    @annot( #Authorname ) public :name String
    public :age Int
end

There could exist a prototype XML to create XML files. Method write: of XML takes an object writeThis as parameter and writes it to a file filename as XML code using the annotations as XML tags:
    write: (:writeThis Any) tofilename: (:filename String)
The annotated instance and shared variables are written in the XML file. The root element is the annotation of the prototype. Therefore the code

Person name: "Carol";
Person age: 1;
XML write: Person tofile: "Person.xml";

produces a file "Person.xml" with the contents:

<?xml version="1.0"?>
<Author>
    <Authorname>
        Carol
    </Authorname>
</Author>

To see one more example of use of annotations, see page 117 of Chapter 8 on tuples and unions. text is another pre-defined metaobject. It allows one to put any text between the two sets of symbols. This text is passed by the compiler to a method of this metaobject which returns to the compiler an object of the AST representing an array of characters. So we can use it as in

:xmlCode Array<Char>;
xmlCode = @text<<**
xmlCode has the text of the XML code as an array of Char’s.

Metaobject strtext works exactly as text but it produces a String. In either one, #{expr} is replaced by the value of expr at runtime:

Person name: "Peter" salary: 10000.0;
:text String;

\[\text{text} = @\text{strtext}(+
\text{The name is } \#{\text{Person name}} \text{ and the salary is } \#{\text{Person salary}}\n+);
\]

\(/\text{ prints "The name is Peter and the salary is 10000.00"}\\
\text{Out println: text;}

Every prototype has a list of features. A feature is simple a key-value pair in which the key is a string and value can be any object. Different objects of a prototype share the feature list. features may be associated to a prototype through metaobject feature or using method addFeature: key: value:

At compile-time, a feature is associated to a prototype by the pre-defined metaobject feature:

\[\text{@feature("compiler", \#nowarning) @feature<"author", "José" >}\]

\text{object Test extends Any\\
\text{public fun run [\\
\text{featureList foreach: [ |:elem Tuple<key, String, value, Any>|\\
\text{Out println: "key is } \#{\text{elem key}}, value is } \#{\text{elem value}}\"\\
\text{]}\\
\text{]}\\
\text{end}}\]

features are used to associate information to objects, methods, constants, interfaces, etc. This information can be used by tools to do whatever is necessary. The example given in page[97] uses annotations (a kind of features) to produce a XML file from a tree of objects. Annotations are used in grammar methods to automatically produce an AST from a grammar message send.

The first parameter to metaobject feature should be a literal string or Cyan symbol. The second one is any expression which is evaluated at runtime according to the order specified in Section[4.6] features can be used to set compiler options. In the example above, the compiler is instructed to give no warnings in the compilation of Test. Maybe it would warn that Any is already automatically inherited.

Method featureList is inherited from Any by any prototype. It returns an array with all features of the prototype. This array has type

\text{Array<Tuple<key, String, value, Any>>>}

That is, the elements are tuples with fields key and value. In the above example, method run scans the array returned by featureList and prints information on each feature. Since elem has type

\text{Tuple<key, String, value, Any>}

does not have the type of the prototype. Method run will print

\footnote{This method is somehow a “shared” method because it only accesses hidden shared variables of the prototype.}
key is compiler, value is nowarning
key is author, value is José

Possibly the compiler will add some features to each prototype such as the compiler name, version, compiler options, date, author of the code, and so on.

Method `addFeature` is inherited from `Any` by every prototype. It adds a feature to the object at runtime. The key and value are given as parameters. Currently a feature may not be removed from a prototype (is there any examples in which this is necessary?). The signature of this method is

```java
public fun addFeature: key: (:aKey String)
    value: (:aValue Any)
```

Annotations are a special case of features. A call

```java
@annot( #first )
```

is the same as

```java
@feature("annot", #first)
```

Method `annotList` is inherited from `Any` by any prototype. It returns a list of annotation objects attached to the prototype.

```java
@annot( #first ) @annot("second") object Test
    public fun run [
        annotList foreach: [
            |:annot String|
            Out print: annot + " "
        ]
    ]
end
```

When `run` is called, it prints

`first second`

Method `addAnnot: (:annot Any)` inherited from `Any` adds an annotation dynamically to the prototype of the receiver.

Since methods are objects (see Section 10.8), one can discover the annotations of methods too:

```java
object Test
    @annot( #f1 ) @annot( #firstMethod ) public fun test [ ]
    public fun run [
        // Test.{test}. is the method test of Test
        (Test.{test}).annotList foreach: [
            |:annot String|
            Out print: annot + " "
        ]
    ]
end
```

doc is a pre-defined metaobject used to document any kind of identifier such as prototypes, constants, interfaces, and methods.

```java
@doc<<
This is a syntactic analyzer.
It should be called as
Parser parse: "to be compiled"
```
This call is equivalent to "@feature("doc", doctext)" in which doctext is the text that appears between << and >> in this example.

There is a pre-defined metaobject javacode that inserts Java code in Cyan programs:

```csharp
object Out
    public fun println: (:s String) [ 
        @javacode(**
            System.out.println(s);
        **) 
    ]

end
```

As soon as possible this metaobject will be eliminated.

Metaobject `onChangeWarn` may be attached to a prototype (including interfaces), a method declaration, or an instance variable declaration. This metaobject adds information to the XML file describing the current source code. This information will be used in future compilations of the source code even if the metaobject call is removed from the code. Using `onChangeWarn` one can ask the compiler to issue a warning whenever the signature of a method was changed, even after the programmer deleted the call to `onChangeWarn`:

```csharp
object Test
    @onChangeWarn( #signature,
        "This signature should not be changed." +
        " Keep it as 'public fun test'"
    )
    public fun test [ ... ]
end
```

If the signature was changed to

```csharp
object Test
    public fun test: (:n Int) [ ... ]
end
```

the compiler would issue the warning given in the second parameter of the call to `onChangeWarn`. All methods of the same name are grouped in the same set — they all can be considered as the same multi-method. By change in the signature we mean any changes in this set, which may be addition of method, deletion of method, changes in the parameter type of any method, changes in the return value type of all methods.

`onChangeWarn` takes two parameters. The first specifies the change, which may be:

(a) `#signature` for changes in the method signature;

(b) `#name` for changes in the name (used for prototypes);

(c) `#type` for changes in the return type of a method, type of a variable;

(d) `#qualifier` for changes in the visibility qualifier (public, protected, private);
The second parameter gives the message that should be issued if the change specified in the first one was made. It should be a string. Other metaobjects that makes the linking past-future will be added to Cyan. Await.

There are other metaobjects used in the Cyan library. For example, there is checkAddMethod that checks whether the parameters to the grammar method addMethod: ... of Any are correct. And there are metaobjects for defining literal objects in the language — see Section 13.

5.2 Syntax and Semantics

A metaobject may take an arbitrary text as parameter put between two sets of symbols. The first set of symbols should be put, without spaces, after the metaobject name. The second set of symbols should be the mirror of the first. Then valid metaobject calls are:

```plaintext
1 @annot( #Author )
2 @annot<& #Author &>
3 @annot[#Author]
4 @name
5 @name([+Ok, this ...end+])
6 @name([+ Ok, this
7      ... end +])
8 @text<<< this is
9    a text which ends with << < <<, but
10       without spaces
11      >>>
12 @text{ another text
13       this is the end: }
```

The valid symbols are:

```
!@$%&*()-+={}
```

Note that symbols ", ; : # ' ` " cannot be used. A metaobject may be called using any set of symbols. In lines 1, 2, and 3, annot is called with the same parameter in three different ways.

Depending on the methods defined by the metaobject, the compiler passes to a method of the metaobject:

(a) the text between the two sets of symbols;
(b) the AST of the text between the two sets of symbols, which should be an expression;
(c) the object, evaluated at compile-time, resulting from the text between the two sets of symbols.

The call of line 1 could be in the last case. Here “#Author” can be evaluated at compile-time resulting in a string that is passed as argument to a method of metaobject annot.

Options can be passed to the metaobject between ( and ). After the ), there should appear another set of symbols starting the text:

```plaintext
@meta(options)<<+ ... +>>
```

There should not be any spaces between ) and <<+. Of course, any valid delimiter may replace <<+ or +>>.

Metaobject text has an option trim_spaces to trim the spaces that appear before the column of @ in @text. As an example, variables t1 and t2 have the same content.
5.3 Metaobject Examples

Compile-time metaobjects have thousands of applications. We describe next some metaobjects without giving any hint on how they will be implemented (there is no MOP yet).

A metaobject singleton may be used to implement the design pattern singleton \[8\].

```cay
// CTMO on an object
@singleton object Earth
  public fun mass -> Float [ ^earthMass ]
  private Float earthMass = 6e+24;
  ...
end
```

The metaobject redefines method clone and new.

```cay
  public fun clone -> Earth [ ^Earth ]
  public fun new -> Earth [ ^Earth ]
```

It also checks whether there is any other init, clone, or new method declared in the prototype body. If there is, it signs an error.

Metaobject profilePrototype inserts code before every method of the prototype to count how many times every method was called. The results are added to a file. At the end of the program, the runtime statistics of calls may be printed.

Metaobject beforeCode should be attached to a method. It inserts some code to be executed before the execution of the method code. For example, it could initiate a transaction in a data base or lock some data in a concurrent program.

5.4 Codegs

There is a special kind of compile-time metaobject called Codeg (code + egg) that makes the integration between the compiler and the IDE used with Cyan. Each codeg works like a plug-in to the IDE but with the added power of being a metaobject of the language. There are many technical details of the workings of a codeg. Few of them will be given here. For more information, read the report \[20\] (in Portuguese).

Codegs have been fully implemented using the IDE Eclipse \[7\] by adding a plug-in to it. Therefore currently codegs work only in Eclipse. After installing the Codeg plug-in and defining a project as being a “Cyan project”, source files ending with “.cyan” will receive special treatment. Let us shown an example
using codeg “color”\(^2\). When the user type
\[
\texttt{@@color(red)}
\]
the Eclipse editor loads a Java class to memory that treats the codeg “color”. This text will be shown in a color different from the rest of the code (the color will be blue regardless of the codeg). By putting the mouse pointer above \texttt{@@color(red)}, a standard menu will appear which allows the editing of this codeg call.\(^3\) This menu is standard just by convention — the codeg designer is free to choose another one if she so wishes.

By clicking in an “edit” button in the menu, another window will appear with a disk of colors. A color may now be chosen with the mouse. After that, the user should click in the “Ok” button. All codeg windows will disappear and the source code editing may continue. Now when the mouse pointer is over the text “@@color(red)” the standard menu will appear with an edit button and a bar showing the chosen color (it is expected that “red” was chosen).

This is what happened at editing time. When the compiler finds the codeg call “@@color(red)” it will load the codeg class (written in Java), create an object from it, and calls method \texttt{getCode} of this object. This method takes a parameter of class \texttt{CodeGenerationContext} that gives information on the compilation itself. In future versions of the compiler, the AST of the current source code will be available from the \texttt{CodeGenerationContext} object. Currently this class only provides two methods: \texttt{getLanguage} and \texttt{getCodegsList}. The first method returns the target language of the codeg, which may be Java or Cyan. In due time, there will be only the options AST and Cyan. Method \texttt{getCodegsList} returns a list of codegs of the same source code. This allows communications among the codegs of the same file.

Method \texttt{getCode} returns an object of class \texttt{CodeGeneration}. This class has three methods that return the generated code:

\begin{verbatim}
String getLocalCode()
String[] getImports()
String getGlobalCode()
\end{verbatim}

The string returned by \texttt{getLocalCode} replaces the codeg call, “@@color(red)”. It should be compiled by the compiler and may contain errors although it is expected that it does not. This code may need packages that were not imported by the source file in which the codeg call is. The packages used in the code returned by \texttt{getLocalCode} should be returned by method \texttt{getImports}. Finally, \texttt{getGlobalCode} returns code that should be added just after the import section of the source code in which this code is. So, suppose we have a code like

```java
package main

object Program
    public fun run [
        Out println: @@color(red)
    ]
]
```

Consider that method \texttt{getCode} of codeg color (which is a Java class called \texttt{ColorCodeg}) returns an object of \texttt{CodeGeneration} whose methods return the following:

\begin{verbatim}
String getLocalCode() returns "RGBColor new: 255, 0, 0"
String[] getImports() returns "RGB"
String getGlobalCode() returns "/* global code */"
\end{verbatim}

\(^2\)For didactic reasons, the codeg described here may differ from the real implementation.

\(^3\)Since codegs are metaobjects, this is a metaobject call.
Then the compiler will add these strings to the source code in such a way that the program above will become

```groovy
package main
import RGB

/*@ global code */

object Program
  public fun run [
    Out println: (RGBColor new: 255, 0, 0)
  ]
]

It is expected that prototype RGBColor is in package RGB.

Method `getCodegsList` is used for communication among the codegs of the same source file. Codegs `world` and `actor` use this method. They implement a very small programming learning environment that resembles Greenfoot [15].

```groovy
package main
object Program
  public fun run [
    @@world(myWorld)
    @@actor(ladybug)
    @@actor(butterfly)
  ]
]
```

The `world` codeg call generates code that creates a windows in which all actions will happen. At editing time, the user may choose the size of the window and its background color.

Codeg `actor` defines an actor that will be added to the world at runtime. At editing time, the user may choose a color for the actor [4] and the code the actor should obey. This code is given in a small language called Locyan defined in the report [13] (in Portuguese). It is a Logo-based language [16].

It is an error to define two codegs “actor” with the same name:

```groovy
@@actor(ladybug)
@@actor(ladybug)
```

But how the actor codeg may detect this? Using `getCodegsList`. A codeg actor call scans the list of codegs returned by this method searching for a codeg with the same name as the current one. If it founds one, it issues an error.

Codeg `world` is responsible for creating the actor objects and putting them in motion. This motion is specified by the Locyan code associated to each actor. Therefore the world codeg calls `getCodegsList` to retrieve the codegs of the same source code. It uses this information in order to generate code.

Several other codegs have been implemented:

(a) `color`, `world`, and `actor`, already described;
(b) `matrix`, which allows a two dimensional matrix to be edited like a spreadsheet;
(c) `image`, that encapsulates the path of an image in the file system. A future improvement would be to keep the image itself in the codeg;

[4] It would be good to allow the user to choose a picture instead of just a color — this will be allowed some day.
(d) **file**, that encapsulates the path of a file and options for reading or writing. The generated code is the creation of an object representing a file with the options chosen;

(e) **text**, which pops up a text editor and returns the edited text either as a **String** or an array of **Char**’s. A generalization of this would allow code in HTML or XML inside Cyan code.

Nowadays when the mouse pointer is on a codeg call such as “@@color(red)” the codeg plugin of the IDE shows a menu. This menu includes a bar with the color in this case. Or the image in the image codeg. Future versions of the plugin may replace the codeg call with an image. Then

```cpp
:color RGBColor = @@color(black);
```

would be shown as

```cpp
:color RGBColor = 
```

in the editor. In the codeg image, the real image would be shown.

The metaobject protocol of codegs is minimal. That needs to be changed. It is necessary to add to the protocol:

(a) better mechanisms for communication among codegs of the same source file;

(b) communication of codegs of different source files. Then code generated in one source file may depend on options of another source file. This will probably be used in the implementation of Design Patterns that need more than one prototype;

(c) access to compiler data such as the local variables, prototype name, source file name, compiler options, etc. For short, the whole AST and other compiler information should be available to the codegs;

(d) methods that return the code generated by the codeg in form of the AST.

There are endless uses for codegs. We can cite some codegs that we would like to implement. Most of them depend on features that are not available nowadays.

(a) An interactive console for Cyan similar to those of scripting languages. The user could just type

```cpp
@@console()
```

in any Cyan source file and experiment with the language.

(b) **Codeg test** for testing. This codeg could show a spreadsheet with expressions that are evaluated at compile time:

| code                     | checks               |
|--------------------------|----------------------|
| :set = IntSet new;       | set size == 2        |
| set add: 0;              |                      |
| set add: 1               | name == "UFSCar"     |

In this figure, “name” is used without qualification. It could be a local variable or an instance variable or method of the prototype in which the codeg is declared.

The codeg would load the last compiled prototypes cited in the spreadsheet. Then it would create, compile, and run the code of the cells, checking the results. Errors could be shown in red. More than that: all **test** codegs could communicate with a **programTest** codeg that would shown all the places with errors. The **test** codeg could offer tools for make it easy to do test the program.
(c) Codegs that implement design patterns. The programmer gives the information and the codegs generate the code. There should be an option for replacing the codeg call with the generated code.

(d) PerfectHashtable that generates a perfect hash table given a list of fixed keys.

(e) codegs to help to build grammar methods — Chapter 9.

(f) FSM which allows one to define graphically a finite state machine. The generated code would be an object of prototype FSM.

(g) TuringMachine. As the name says, the user could define graphically a Turing machine (much like the FSM).

The problem with codegs is that they link tightly the source code and the IDE. Changing the IDE means losing the codegs if the new IDE does not support exactly the same set of codegs the old one supports. Although this can bring some problems, it is not so bad for two reasons:

(a) the compiler will continue to work as expected because it uses the data collected in the old IDE. Although this data cannot be changed by a Codeg in the new IDE, the code will continue to compile;

(b) it is easy to add to the compiler an option that makes it replace every codeg call by the code produced by that codeg call. This will eliminate all codegs from a source code. And with them the dependency from the old IDE.

Textual programming has dominated programming languages for a long time. By textual programming we mean that all source code is typed in a text editor as is made in C/C++/Ruby/Java/C#/Lisp/Prolog/etc. There has been several attempts to change that such as the integrated environment of Smalltalk and visual programming languages. It is difficult to imagine software development within one hundred years based on full textual representation of programs like most of the code made today. There should be some visual representation. Codegs are another attempt to achieve that.
Chapter 6

Dynamic Typing

A dynamically-typed language does not demand that the source code declares the type of variables, parameters, or methods (the return value type). This allows fast coding, sometimes up to ten times faster than the same code made in a statically-typed language. All type checking is made at runtime, which brings some problems: the program is slower to run and it may have hidden type errors. When a type error occur, usually the program is terminated. Statically-typed languages produce faster programs and all type errors are caught at compile time. However, program development is slower.

The ideal situation is to combine both approaches: to develop the program using dynamic typing and, after the development ends, convert it to static typing. Cyan offers three mechanism that help to achieve this objective.

The first one is dynamic message sends. A message send whose selectors are preceded by # is not checked at compile-time. That is, the compiler does not check whether the static type of the expression receiving that message declares a method with those selectors. For example, in the code below, the compiler does not check whether prototype Person defines a method with selectors name: and age: that accepts as parameters a String and an Int.

```cyn
:p Person;
...
p ?name: "Peter" ?age: 31
```

This kind of message send is called #message send.

This non-checked message send is useful when the exact type of the receiver is not known:

```cyn
public fun openArray: (:anArray Array<Any>) [   anArray foreach: [ I:elem Any]      elem ?open  ]
]
```

The array could have objects of any type. At runtime, a message open is sent to all of them. If all objects of the array implemented an IOpen interface then we could declare parameter anArray with type Array<IOpen>. However, this may not be the case and some kind of dynamic message send would be necessary to call method open of all objects.

If every message selector (such as open in the above examples) is preceded by a # we have transformed Cyan into a dynamically-typed language. If just some of the selectors are preceded by #, then the program will use a mixture of dynamic and static type checking.

---

With a method open.
A call  
    obj ?set: 11;
is roughly equivalent to  
    obj selector: "set:" param: 11;
in which selector:param: is a method inherited from Any by every Cyan object. It invokes the method corresponding to the given selector using the parameters after param:. Therefore #message sends are a syntax sugar for a call to the selector:param: method with one important difference: the compiler does not do any further type checking with the return type of the method. That is, any use of the return value is considered correct.

:stack = Stack<Int>  
  // no compile-time error here  
stack push: (obj ?get);  
  // no compile-time error here  
if ( obj ?value ) [  
  stack push: 0  
];

The compiler just checks, in “stack push: (obj ?get)” that Stack<Int> has a method push: that accepts one parameter. When the return value of a dynamic message is assigned to a variable declared without a type, the compiler considers that the type of the variable is Any.

:n = obj ?value;  
assert: (n prototypeName) == "Any";

Several statically-typed languages such as Java allows one to call a method using its name (as a string) and arguments. Cyan just supplies an easy syntax for doing the same thing. Section 4.13 describes the selector:param: method which is in fact a grammar method. Grammar methods are described in Chapter 9.

Dynamic checking with ? plus the reflective facilities of Cyan can be used to create objects with dynamic fields. Object DTuple of the language library allows one to add fields dynamically:

:t = DTuple new;  
t ?name: "Carolina";  
  // prints "Carolina"  
Out println: (t ?name);  
  // if uncommented the line below would produce a runtime error  
  //Out println: (t ?age);  
t ?age: 1;  
  // prints 1  
Out println: (t ?age);

Here fields name and age were dynamically added to object t. Whenever a message is sent to an object and it does not have the appropriate method, method doesNotUnderstand is called. The original message with the parameters are passed to this method. Every object has a doesNotUnderstand method inherited from Any. In DTuple, this method is overridden in such a way that, when a DTuple object receives a message ?id: expr without having a ?id: method, doesNotUnderstand creates:

(a) two methods, id: T and id -> T, in which T is the dynamic type of expr;

(b) a field _id of type T in the DTuple object. Prototype DTuple inherits from a mixin that defines a hash table used to store the added fields.
Then message \texttt{?id: expr} is sent to the object (now it does have a \texttt{?id:} method and no runtime error occurs).

Future versions of Cyan may support the \texttt{'} operator which would “link the runtime value of a \texttt{String} variable to a compile-time meaning of this value”. Sometime like that:

\begin{verbatim}
:selector String;
selector = (In readInt > 0) t: "prototypeName" : "asString";
   // a runtime test is inserted to check if the result
   // is really a String
:result String = 0 'selector;
Out println: result;
\end{verbatim}

Here \texttt{0 'selector} is the sending of the message given by the runtime value of \texttt{selector} to object \texttt{0}. If \texttt{selector} is "\texttt{prototypeName}"}, the result will be "\texttt{Int}". If \texttt{selector} is "\texttt{asString}"}, the result will be "\texttt{0}". The \texttt{'} operator could also be used to retrieve the value of a variable whose name is the runtime value of another variable:

\begin{verbatim}
:name String;
:age = 21;
:limit = 18;
name = (In readInt > 0) t: "age" : "limit";
Out println: 'name;
\end{verbatim}

If the value read from the keyboard was greater than \texttt{0}, it will be printed \texttt{21}, the value of \texttt{age}. Otherwise it will be printed \texttt{18}, the value of \texttt{limit}. Language Groovy has this mechanism for message sends:

\begin{verbatim}
animal.%$action"()
\end{verbatim}

The method of \texttt{animal} called will be that of variable \texttt{action}, which should refer to a \texttt{String}.

The second and third mechanisms that allow dynamic typing in Cyan are the metaobjects \texttt{dynOnce} and \texttt{dynAlways}. These are pre-defined metaobjects — it is not necessary to import anything in order to use them.

Metaobject \texttt{@dynOnce} makes types optional in declarations of variables and methods of the prototype it is attached to. For example, the instance variables and parameters of prototype \texttt{Person} are declared without a type:

\begin{verbatim}
@dynOnce object Person
   public fun init: (:newName, :newAge) [
      name = newName;
      setAge: newAge
   ]
   public fun print [
      Out println: "name: ", name, " (", age, ")"
   ]
   public fun setAge: ( :newAge ) [
      if ( newAge >= 0 and newAge <= MaxAge ) [
         age = newAge
      ]
   ]
private :name
private :age
private const :MaxAge = 126
\end{verbatim}
The compiler will not issue no error or warning. After the program runs for the first time, it may be the case that an object of prototype `Person` is used — maybe `Person` itself receives messages or maybe an object created from `Person` using `clone` or `new` receives messages. In any case, metaobject `dynOnce` inserts statements in the generated `Person` code to collect information on the types of variables and return value types of methods. At the end of the first execution of the program, code inserted by the metaobject `dynOnce` can insert in the source code the type of some or all of the variable and method declarations. As an example, suppose object `Person` is used in the following code and only in this code:

```kotlin
Person name: "Maria";
Person setAge: 12;
Person print;
```

Code inserted by the metaobject detects in the first run of the program that instance variable `name` has type `String` and `age` has type `Int`. Then at the end of the execution another code inserted by the metaobject `dynOnce` changes the source code transforming it into

```kotlin
object Person
    public fun init: (:newName String, :newAge Int) [
        name = newName;
        setAge: newAge
    ]
    public fun print [        Out println: "name: ", name, " (", age, ")"
    ]
    public fun setAge: ( :newAge Int ) [
        if ( newAge >= 0 and newAge <= MaxAge ) [
            age = newAge
        ]
    ]
    private :name String
    private :age Int
    private const :MaxAge = 126
end
```

If it was possible to discover the types of all variables and methods declared without types, the `dynOnce` metaobject call is removed, as in this example. But it may happens that part of the code is not exercised in a single run (or maybe in several or any execution of the program). In this case, a variable that did not receive a value at runtime do not receive a type. And the metaobject call `@dynOnce` is kept in the source code.

There are some questions relating to `dynOnce` that need to be cleared. The most important question is that the implementation of methods with typeless parameters and return value (untype methods) is different from the implementation of typed methods. Consequently, message sends to typed methods is different to message sends to untyped methods. Then how do we generate code for the statement

```kotlin
p print
```

knowing that `p` was declared as having type `Person`? The problem is that a subclass `Worker` of `Person` may not use `dynOnce` — it may be typed. And it may override method `print`, which means `p print` may call `print` of `Person` (call to an untyped method) or `print` of `Worker` (call to a typed method). The two calls should be different. A solution is:
1. to allow a prototype without `dynOnce` to inherit from a prototype with `dynOnce` but not vice-versa. Then there should be a special `Any` prototype for dynamic typing and there should be conversions between these two `Any` prototypes;

2. in a message send such as “p print”, the compiler generates a test to discover whether p refers to an object with or without `dynOnce`. Then two different call would be made according to the answer. At compile time, the type of p, `Person` was declared with `dynOnce`. Using this information, all message sends whose receiver has type `Person` would have the test we just explained. But if the receiver has a type which was not declared with `dynOnce` the generated code for the message send would be the regular one — it will be assumed that the message receiver can only refer to objects that were declared (or its prototype) without `dynOnce`.

The third mechanism that allows dynamic typing in Cyan is `dynAlways`. A prototype declaration preceded by `@dynAlways` should not use types for variables and methods. All declarations of variables (including parameters, instance variables, and shared variables) and method return values should not mention the type, as in dynamically-typed languages. This metaobject would generate code for message sends appropriately. This metaobject has problems similar to `dynOnce` (which are explained above).

It is important to note that we have not defined exactly neither how `dynOnce` and `dynAlways` will act nor how they will be implemented. This is certainly a research topic.

During the design of Cyan, several decisions were taken to make the language support optional typing:

(a) types are not used in order to decide how many parameters are needed in a message send. For example, even if method `get:` of `MyArray` takes one parameter and `put:` of `Hashtable` takes two parameters, we cannot write

\[ n = Hashtable \text{ put: } MyArray \text{ get: } i, j \]

The compiler could easily check that the intended meaning is

\[ n = Hashtable \text{ put: } (MyArray \text{ get: } i), j \]

by checking the prototypes `Hashtable` and `MyArray` (or, if these were variables, their declared types). `get:` should have one parameter and `put:` should have two parameters. However, if the code above were in a prototype declared with `dynAlways` or `dynOnce`, this would not be possible. The type information would not be available at compile time. Therefore Cyan consider that a message send includes all the selectors that follow it and that are not in an expression within parentheses. To correct the above code we should write:

\[ n = Hashtable \text{ put: } (MyArray \text{ get: } i), j \]

(b) when a method is overloaded, the static or compile-time type of the real arguments are not taken into consideration to chose which method will be called at runtime. In the `Animal`, `Cow`, and `Fish` example of page 78, the same methods are called regardless of the static type of the parameter to `eat:`. Therefore when metaobjects `dynOnce` or `dynAlways` are removed from a prototype (after giving the types of the variables and methods), the semantics of the message sends is not changed.

There is one more reason to delay the search to runtime: the exception system. Most exception handling systems of object-oriented languages are similar to the Java/C++ system. There are catch clauses after a try block that are searched for after an exception is thrown in the block. The catch clauses are searched in the declared textual order. In Cyan, these catch clauses are encapsulated in `eval` methods which are searched in the textual order too. The `eval` methods have parameters which correspond to the parameters of the catch clauses in Java/C++. The `eval` methods are therefore
overloaded. The search for an `eval` method after an exception is made in the textually declared order of these methods, as would be made in any message send whose correspondent method is overload. This matches the search for a catch clause of a try block in Java/C++, which appear to be the best possible way of dealing with an thrown exception. And this search algorithm is exactly the algorithm employed in every message send in Cyan;

(c) The Cyan syntax was designed in order to be clear and unambiguous even without types. For example, before a variable declaration it is necessary to use "::", which asserts that a list of variables follow, with or without a type. The declaration of `Int` variables in Cyan is

```plaintext
:a, :b, :c Int;
```

In a prototype declared with `dynOnce` or `dynAlways`, this same declaration would be

```plaintext
:a, :b, :c;
```

A method declaration would be

```plaintext
public fun sqr :x Int -> Int [ ^ x*x ]
```

in a regular prototype and

```plaintext
public fun sqr :x [ ^ x*x ]
```

in a prototype declared with `dynOnce` or `dynAlways`. 
Chapter 7

Generic Prototypes

Generic prototypes in Cyan play the same rôle as generic classes and template classes of other object-oriented languages. Unlike other modern languages, Cyan takes a loose approach to generics. In many languages, the compiler guarantees that a generic class is type correct if the real parameter is subtype of a certain class specified in the generic class declaration. For example, a generic class `Hashtable` takes a type argument `T` which should be subtype of `Hashable`, an interface with a single method `hashCode -> Int` (using Cyan syntax). Then whenever one uses `Hashtable<A>` and `A` is subtype of `Hashable`, it is guaranteed that `Hashtable<A>` is type correct — the compiler does not need to check the source code of `Hashtable` to assert that. In Cyan, `Hashtable` has to be compiled with real argument `A` in order to assure the type correctness of the code (although the parameter of `Hashtable` may be associated to `Hashable`, this does not guarantee that the code is correct). This has pros and cons. The pro part is that there is much more freedom in Cyan to create generic objects. The con part is that any changes in the code of a generic prototype can cause compile-time errors elsewhere. Cyan does not supports the conventional approach for two reasons: a) there would not be any novelty in it (no articles about it would be accepted for publishing) and b) the freedom given by the definition of Cyan generics makes them highly useful — see the examples given here, in Section 12.5, and in Section 8.

As said in Chapter 2, the source code of a Cyan source can be a XML file. In this file some information on the source can be kept. One of them is the restrictions a generic prototype should obey. So the XML file can keep that the generic parameter `T` of `Hashtable` should have a `hashCode -> Int` method. In this way the compiler will be able to catch type errors in the instantiations of generic objects, such as to use an object `Person` that does not have a `hashCode` method as parameter to `Hashtable`. This error would be caught without consulting the source code of `Hashtable`.

There are several ways of declaring a generic prototype in Cyan. One of them demands that parameters have an associated type just like the parameter to `Hashtable` is associated to `Hashable`. The prototype `A` associated `Pi` to type `Ti`.

```cayn
object A< :P1 T1, :P2 T2, ... :Pn Tn >
    ...
end
```

To use `A` one has to supply the real arguments, which should be types:

```cayn
:x A<R1, R2, ... Rn>;
```

Type `Ri` replaces the formal parameter `Pi` for `1 ≤ i ≤ n`. Type `Ri` should be subtype of `Ti`. The compiler creates a new object in which the formal parameters are replaced by the real ones. Only after that the new object is compiled. Therefore there is no reuse of compiled code as in Java. When compiling generic object `A` (without any real parameters), the compiler checks whether the messages sent to variables of type `Pi` are type correct (assuming these variables have type `Ti`). Note that even if `Ri` is subtype of `Ti`
for all arguments, there could be an error in the compilation of $A<R_1, R_2, \ldots R_n>$. 

The restriction $T_i$ is optional. If absent, the corresponding formal parameter can be anyone, as in

```plaintext
object Stack< :T >

... public fun print [
    array foreach [ |:elem T|
        elem print // message print is sent to an object of type T
    ]
]
end
```

When compiling this generic object the compiler does not do any type checking regarding variables of type $T$.

One can give more than one definition of a generic type. The definitions can have different number of parameters and some of them can specify the real arguments in the declarations. For example, one could write

```plaintext
public object Set<Int>
    public fun add: (:elem Int) [ ... ]
    public fun has: (:elem Int) -> Boolean [ ... ]
        // other methods and instance variables
end
```
in a source file called `Set(Int).cyan` and

```plaintext
public object Set<:T>
    public fun add: (:elem T) [ ... ]
    public fun has: (:elem T) -> Boolean [ ... ]
        // other methods and instance variables
end
```
in a source file called `Set(1).cyan`. In general, the declaration of a generic `Set` prototype with $n$ parameters should be in a file “`Set(n).cyan`”.

Blocks may have more than one set of parameters between parentheses:

```plaintext
@restricted abstract object AnyBlock<:T1, :T2, :T3>:R>
    public abstract fun eval: (T1, T2, T3) -> R
end
```

There are two sets of parameters: “`:T1, :T2, :T3:>” and “`:R>””. This object should be in a file “`AnyBlock(3)(1)`”. When a real argument is specified in the declaration of a generic prototype, there should not appear any formal parameter in this declaration.

```plaintext
object MyHashTable<String, :T>
    public fun put: (:key String, :value T) [ ... ]
... end
```

The compiler would sign an error in formal parameter $:T$ because the first parameter, `String`, is a real prototype.
When the compiler finds `Set<X>` in the source code, it searches for a source file “`Set(X).cyang`”. If this is not found, it searches for a source file `Set(1).cyang` (that declares the generic prototype with formal parameters). Note that exact match is used here. To explain that, suppose there are files `Set(Any).cyang` and `Set(1).cyang` with prototypes `Set<Any>` and `Set:<T>`. If `Set<Int>` appear in the source code, the compiler will use `Set:<T>` to instantiate `Set<Int>` even though Int inherits from Any.

There may exist a non-generic prototype `Set` and generic prototypes `Set:<T>`, `Set:<T, :U>`, and so on. The compiler knows how to differentiate them. The interfaces of the `Set` prototypes need not to be related. One of them, for example, can declare a method that the other do not support.

All prototypes called `Set` should be in the same package. This restriction may be lifted in the future.

A generic object should be used with “<” put right after the generic object name, as in the examples above. If there is a space between the object name and “<”, the compiler will consider “<” as the operator “less than”. Therefore, assuming the existence of a generic object `A` that takes one parameter,

```
x m: A<Int>
```

means that object `A<Int>` is being passed as parameter to method `m` and

```
x m: A < Int 
```

causes a type error detected at compile-time: it is illegal to compare a generic object `A` with type `Int` using “<”.

Cyan does not support generic methods. However, it is very probably it will do in the future. We then give a first definition of this construct and show the characteristics it should have in the language.

A generic method is declared by putting the generic parameters after keyword `fun` as in

```object MySet
   public fun:<T> add: (:elem T) -> T [ ... ]
   ...
end```

When the compiler finds a message send using `add:` of `MySet`, as in

```
 p = MySet add: Person
```

it considers that the return value of `add:` has type equal to the type of the parameter, which is `Person`. Then it checks whether `p` can receive a `Person` in an assignment.

The difference between using a generic method `add:` and declaring a method

```public fun add: (:elem Any) -> Any
```

is that the compiler checks the relationships between the parameter and the return value. As another example, a generic method

```public fun:<T>  relate: (:first T, :second T)
```

demands that the arguments to the method be of the same compile-time type.

After the generic parameter there may be a type:

```public fun:<T Printable> add: (:elem T) -> T [ ... ]
```

Then the real arguments to `add:` should have a static type that is subtype of `Printable`.

Again, it is important to say that generic methods are not adequately defined. The paragraphs above just give an idea of what they can be.
Chapter 8

Important Library Objects

This Chapter describes some important library objects of the Cyan basic library. All the objects described here are automatically imported by any Cyan program. They are in a package called cyan.lang.

8.1 System

Prototype System has methods related to the runtime execution of the program. It is equivalent to the System class of Java. Its methods are given below. Others will be added in due time.

```
// ends the program
public fun exit

// ends the program with a return value
public fun exit: (:errorCode Int)

// runs the garbage collector
public fun gc

// current time in milliseconds
public fun currentTime -> Long

// prints the stack of called methods in the standard output
public fun printMethodStack
```

8.2 Input and Output

Prototype In and Out are used for doing input and output in the standard devices, usually the keyboard and the monitor.

```
public object In

public fun readInt -> Int
public fun readFloat -> Float
public fun readDouble -> Double
public fun readChar -> Char
  // read a string till a white space
public fun readString -> String
public fun readLine -> String
...
```

end
public object Out
    public fun println: (:any Any)*
end

8.3 Tuples

A tuple is an object with methods for getting and setting a set of values of possibly different types. It is a concept similar to records of Pascal or structs of C. A literal tuple is defined in Cyan between “[.” and “.]” as in the example:

:t = [. name: "Lívia", age: 4, hairColor: "Blond" .];
Out println: "name: #{t name} age: #{t age} hair color: #{t hairColor}"

This literal object has type Tuple<name, String, age, Int, hairColor, String>, described below. There should be no space between the field name such as “name” and the symbol “:”.

A literal tuple may also have unnamed fields which are further referred as f1, f2, etc:

:t = [."Lívia", 4, "Blond" .];
Out println: "name: #{t f1} age: #{t f2} hair color: #{t f3}";

The type of this literal tuple is Tuple<String, Int, String>.

Object Tuple is a generic object with an even number of parameters. For each two parameters, one describe the field name and the other its type. We will show only the Tuple object with four parameters:

object Tuple<:F1, :T1, :F2, :T2>
    public fun F1: (:newF1 T1) F2: (:newF2 T2) -> Tuple<F1, T1, F2, T2> [ // create a new object
        :t = self clone;
        t F1: newF1;
        t F2: newF2;
        return t
    ]
    @annot( #f1 ) public :F1 T1
    @annot( #f2 ) public :F2 T2
    ...
end

Metaobject @annot attaches to an instance variable, shared variable, method, prototype, or interface a feature given by its parameter. This feature can be retrieved at runtime by a method of the introspective library.

After compiling the above prototype, the compiler creates the following instance variables and methods:

@annot( #f1 ) private :_F1 T1
@annot( #f2 ) private :_F2 T2
@annot( #f1 ) public fun F1 -> T1 [ _F1 ]
@annot( #f1 ) public fun F1: (:newF1 T1) [ _F1 = newF1 ]
@annot( #f2 ) public fun F2 -> T2 [ _F2 ]
@annot( #f2 ) public fun F2: (:newF2 T2) [ _F2 = newF2 ]

So we can use this object as in
:t Tuple<name, String, age, Int>; 
t name: "Carolina" age: 1; 
Out println: (t name); 
t name: "Lívia"; 
t age: 4; 
Out println: "name: #{t name} age: #{t age}";

Every object Tuple has a method
copyTo: Any
that copies the tuple fields into fields of the same name of the parameter. For example, consider a book object:

object Book
public :name String
public :authorList Array<String>
public :publisher String
public :year String
public fun print [
    Out println: (authorList[0] + " et al. "
    Out println: name + ". Published by " + publisher + ". " + year;
]
end

... // in some other object ...
:b = Book new;
:t = [. name: "Philosophiae Naturalis Principia Mathematica",
    authorList: {# "Isaac Newton" #},
    publisher: "Royal Society",
    year: 1687
.];
t copyTo: b;

The last line copies the fields of the tuple into the object fields. That is, “name” of t is copied to “name” of b and so on. The Book object may have more fields than the tuple. But if it has less fields, an exception CopyFailureException is thrown. Note that copyTo: can be used to copy tuples to tuples:

:t = Tuple<name, String, age, Int>;
:maria = [. name: "Maria", age: 4, hairColor: "Blond" .];
maria copyTo: t;

Method copyTo: uses reflection in order to copy fields. Since public instance variables are not allowed in Cyan, copyTo: uses the corresponding getters and setters to copy the values.

Method copyTo: creates new objects if any of the tuple fields is another tuple.

object Manager
public :person Person
public :company String
end

object Person
public :name String

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public :age Int
end

Manager should have a reference to another object, Person. When copying a tuple corresponding to a manager, an object of Person should be created.

:manager = Manager new;
:john = [. person: [. name: "John", age: 28 .], company: "Cycorp" .];
john copyTo: manager;

Here copyTo: copies field company to object referenced by manager and creates an object of Person making manager.person refer to it. After that copyTo: is called with the tuple

  [. name: "John", age: 28 .]
and this new Person object. It is as if we had

:manager = Manager new;
:john = [. person: [. name: "John", age: 28 .], company: "Cycorp" .];
manager.person = Person new;
manager.person.name = "John";
manager.person.age = 28;
manager.company = "Cycorp";

Object UTuple is a generic object that takes any number of type parameters (up to 16). It is an unnamed tuple whose elements are accessed by names fi. Then UTuple<T1, T2> is almost exactly the same as

Tuple<f1, T1, f2, T2>.

In fact, this object is defined as

object UTuple<:T1, :T2> extends Tuple<f1, T1, f2, T2>
end

An example of use of this object is

:t UTuple<String, Int>;
t f1: "Ade" f2: 23;
Out println: (t f1);
t f1: "Melissa";
t f2: 29;
Out println: "name: #{t f1} age: #{t f2}";

Object UTuple has a method copyTo: that copies the information of the tuple into a more meaningful object. We will shown how it works using the book example. We want to copy a tuple of type

UTuple<String, Array<String>, String, Int>
into an object of Book. However, copyTo: has to know to which instance variable of Book it should copy f1 of the tuple. This method cannot choose one instance variable based on the types — there are two of them whose type is String. We should use annotations for that:

object Book
  @annot( #f1 ) public :name String
  @annot( #f2 ) public :authorList Array<String>
  @annot( #f3 ) public :publisher String

1In fact, it calls “manager person: (Person new)”. 119
Now the following code will work as expected.

:t UTuple<String, Array<String>, String, Int>;  
:b = Book new;  
t = ["Philosophiae Naturalis Principia Mathematica",  
     
     #"Isaac Newton" #,  
     "Royal Society",  
     1687  
     .];  
t copyTo: b;  
b print;

As with method copyTo: of Tuple, tuples inside tuples are copied recursively. The Manager example with UTuples is

object Manager  
@annot( #f1 ) public :person Person  
@annot( #f2 ) public :company String  
end

object Person  
@annot( #f1 ) public :name String  
@annot( #f2 ) public :age Int  
end
...

:manager = Manager new;  
:john = [. [. "John", 28 .], "Cycorp" .];  
john copyTo: manager;  
  // john has the same values as in the example  
  // with Tuple

Method copyTo: can be used in grammar methods to store the single method argument into a meaningful object:

object BuildBook  
public fun (bookname: String (author: String)* publisher: String year: Int)  
  :t UTuple< String, Array<String>, String, Int>  
  -> Book [  
    :book = Book new;  
    t copyTo: book;  
    return book  
  ]

This method accepts as arguments all the important book information: name, authors, publisher, and publication year:
Tuples whose all types are from the same basic type have a method `foreach` for iterating over the elements:

```java
object UTuple<Int, Int, Int> extends Tuple<f1, Int, f2, Int, f3, Int>
    implements Iterable<Int>

    public fun f1: (:newF1 Int) f2: (:newF2 Int) f3: (:newF3 Int)
        -> Tuple<f1, Int, f2, Int, f3, Int> [ // create a new object
            t = self clone;
            t f1: newF1;
            t f2: newF2;
            t f3: newF3;
            return t
        ]

    public fun foreach: (:b Block<Int><Void>) [ // create a new object
        b eval: f1;
        b eval: f2;
        b eval: f3
    ]

    @annot( #f1 ) public :f1 Int
    @annot( #f2 ) public :f2 Int
    @annot( #f3 ) public :f3 Int
end
```

This tuple prototype can be used as a set of elements:

```java
:s String = "";
:age Int = In readInt;
if ( age in: [. 0, 1, 2 .] ) [ // create a new object
    s = "baby"
] else if ( age in: [. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 .] ) [ // create a new object
    s = "child"
] else if ( age in: [. 13, 14, 15, 16, 17, 18, 19 .] ) [ // create a new object
    s = "teenager"
] else [ // create a new object
    s = "adult"
]
```

An empty tuple is illegal:
8.4 Dynamic Tuples

Object DTuple is a dynamic tuple. When an object of DTuple is created, it has no fields. When a dynamic message “#attr: value” is sent to the object, a field whose type is the same as value is created. The value of this field can be retrieved by sending the message “#attr” to the object. See the example:

:t = DTuple new;
:t ?name: "Carolina";
   // prints "Carolina"
Out println: (t ?name);
   // if uncommented the line below would produce a runtime error
//Out println: (t age);
:t ?age: 1;
   // prints 1
Out println: (t ?age);

Object DTuple is the object

object DTuple mixin AddFieldDynamicallyMixin
end

Mixin AddFieldDynamicallyMixin redefines method doesNotUnderstand in such a way that a field is added dynamically to objects of DTuple. When a non-existing method f: value is called on the object, doesNotUnderstand of AddMethodDynamicallyMixin adds to the receiver a field _f and methods f: T and f -> T. The methods set and get the field. T is the type of value.

Object DTuple has methods checkTypeOn and checkTypeOff that turn on and off (default) the type checking with dynamic fields:

:t = DTuple new;
:t ?name: "Carolina";
:t ?name: 100; // ok, default off
:t ?name: "Carolina"; // ok, default off
:t checkTypeOn;
   // runtime type error here. name: should receive
   // a string as argument
:t ?name: 100;

Mixin AddFieldDynamicallyMixin has a method remove: that allows one to the remove a field from a prototype:

:t = DTuple new;
:t ?name: "Carolina";
:t remove: ?name;
   // runtime error in "(t name)"
Out println: (t ?name);

The mixin object AddFieldDynamicallyMixin is defined as
mixin(Any) object AddFieldDynamicallyMixin

    public fun doesNotUnderstand: (:methodName CySymbol, :args Array<Any>) [  
        if ( methodName indexOf ':' == (methodName size) - 1 ) [  
            if ( args size != 1 ) [  
                super doesNotUnderstand: methodName, args  
            ] else [  
                // add field to table addedFieldsTable and add  
                // methods for getting and setting the field  
                ...  
            ]  
        ]  
    ]

    public fun remove: (:what CySymbol) [  
        addedFieldsTable remove: what  
    ]

    private :addedFieldsTable Hashtable<CySymbol, Any>
end

8.5 Unions

Generic object Union represents a single field taken among many possible fields specified in its declaration. It is similar to unions of the language C.

:u Union<wattsHour, Float, calorie, Float, joule, Float>;
u wattsHour: 120;
Out println: (w wattsHour);
    // runtime error if the line below is uncommented
    //Out println: (w joule);
w joule: 777;
Out println: (w joule);

There would be an error in the first call “w joule” because the object u currently keeps field wattsHour.

    Method contains: of Union returns true if the union really contains a value of field passed as parameter as a Cyan symbol. If the field name is f, the Cyan symbol is #f. To prevent runtime errors, before retrieving the value of a field one can check whether the union is currently keeping a value of that field:

:u Union<wattsHour, Float, calorie, Float, joule, Float>;
u wattsHour: 120;
    // unnecessary since u contains a wattsHour field
if ( u contains: #wattsHour ) [  
    Out println: (w wattsHour);
]
    // returns false
if ( u contains: #joule ) [  
    Out println: (w joule);
]
w joule: 777;
Out println: (w joule);

Object Union with two parameters is declared as

```
object Union<:F1, :T1, :F2, :T2>
  private :field Any
  public :whichOne CySymbol
  public fun init [ whichOne = nil ]
  public fun contains: (:whichField CySymbol) -> Boolean [ return whichField ==
    whichOn ]
  public fun F1: (:value T1) [ whichOne = #F1; field = value ]
  public fun F1 -> T1 [ if ( whichOne != #F1 ) [ throw: StrException("Illegal use of Union") ]
    // method cast casts "field" to type T1
    // In C++/Java, it would be "return (T1 ) field"
    ^ T1 cast: field ]
  public fun F2: (:value T2) [ whichOne = #F2; field = value ]
  public fun F2 -> T2 [ if ( whichOne != #F2 ) [ throw: StrException("Illegal use of Union") ]
    // method cast casts "field" to type T2
    // In C++/Java, it would be "return (T2 ) field"
    ^ T2 cast: field ]
end
```

See the description of StrException in page [220](#).

Generic object UUnion is an unnamed union. That is, the fields have names fn. Object UUnion of two parameters is declared as

```
object UUnion<:T1, :T2> extends Union<f1, T1, f2, T2>
end
```

There is no syntax for a literal union object. This should not be necessary.

Unions and switch’s can be combined

```
public fun print: ( :u Union<wattsHour, Float,
  calorie, Float,
  joule, Float> ) [ (u whichOne) switch:
  case: #wattsHour do: [ Out println: "#{u wattsHour} Watts"
  ]
  case: #calorie do: [ Out println: "#{u calorie} Calories"
  ]
  case: #joule do: [ Out println: "#{u joule} Joules"
  ]
]
```


8.6 Intervals

There is a generic interval prototype which can hold values of Byte, Short, Int, Long, Char, and Boolean. A literal interval is given as a..b in which a < b. Assume that false < true.

```plaintext
:I Interval<Int>;
I = 3..5;
// this code prints numbers 0 1 2
0..2 foreach: [:i Int|
  Out println: i |
];
// this code prints numbers 3 4 5
I repeat: [:i Int|
  Out println: i |
];
// prints the alphabet
A..Z foreach: [:ch Char|
  Out println: ch |
];
```

Operator “..” has smaller precedence than the arithmetical operators and greater precedence than the logical and comparison operators. So, the lines

```plaintext
i+1 .. size - 1 repeat: [ ... ]
if ( 1..n == anInterval ) [ ... ]
```

are equivalent to

```plaintext
(i+1) .. (size - 1) repeat: [ ... ]
if ( (1..n) == anInterval ) [ ... ]
```

Prototype `Interval` is defined as follows. There is one instantiation for every one of the types Byte, Short, Int, Long, Char, and Boolean. And there is no definition for a generic type T.

```plaintext
public object Interval<Int> implements Iterable<Int>
```

```plaintext
  public fun init: (:start, :theend Int) [
    if ( start > theend )
      throw: StrException("end < start in interval");
    self.start = start;
    self.theend = theend
  ]

  public fun foreach: (:b Block<Int><Void>) [
    :i = start;
    while ( i <= theend ) [
      b eval: i;
      ++i
    ]
  ]
```


// Smalltalk-like injection
public fun inject: (:initialValue Int)
    into: (:b Block<Int, Int><Int>) -> Int [<br>
    :i = start;<br>
    :total = initialValue;<br>
    while ( i <= theend) [<br>
        total = b eval: total, i;<br>
        ++i<br>];<br>
    return total<br>]<br>
// injection method to be used with context object.<br>// the initial value is private to injectTo
public fun to: (:max Int)
do: (:injectTo InjectObject<Int>) -> Int [<br>
    :i = start;<br>
    while ( i <= theend) [<br>
        injectTo eval: i;<br>
        ++i<br>];<br>
    return injectTo result<br>]<br>
public fun first -> Int [ ^start ]
public fun last -> Int [ ^theend ]

// other methods elided
private :start, :theend Int<br>
end<br>

// this is declared in cyan.lang<br>interface Iterable<:T> <br>    fun foreach: Block<T><Void> <br>end<br>

public object Interval<Char> <br>...<br>end<br>
// other instantiations of Interval<br>
interface InjectObject<:T> extends Block <br>    fun eval: T <br>    fun result -> T <br>end<br>

Intervals can be used with method in: of the basic types:
s String = "";
age Int = In readInt;
if ( age in: 0..2 ) [
    s = "baby"
]
else if ( age in: 3..12 ) [
    s = "child"
]
else if ( age in: 13..19 ) [
    s = "teenager"
]
else [
    s = "adult"
]
Chapter 9

Grammar Methods

Cyan supports an innovative way of declaring methods and sending messages: grammar methods and grammar message sends. A grammar method is a method of the form

```plaintext
fun (rexp) :v T [ ... ]
```

in which `rexp` is given as a regular expression that uses selectors, parameter types, and regular expression operators. There is only one parameter put after the regular expression.

Let us introduce this concept in the simplest form: methods that accept a variable number of real arguments. A method `add:` that accepts any number of real arguments that are subtypes of type `T` should be declared as

```plaintext
public fun (add: (T)*) :v Array<T> [ ... ]
```

After `fun` the method keywords should be declared between parentheses. Assuming this method is in an object `MyCollection`, it can be called as in

```plaintext
MyCollection add: t1;
MyCollection add: t1, t2, t3;
MyCollection add: t2, t1;
```

The `*` means one or more real arguments of type `T` or its subtypes. We could have used `*` instead to mean “zero or more real arguments”. In this case, the call “MyCollection add: ;” would be legal. In the call site, all real arguments are packed in an array of type `T` and then it is made a search for an appropriate method `add:`. The formal parameter `v` of `add:` will refer to the array object with the real arguments. The one formal parameter is declared after the parenthesis that closes the declaration of the method signature, which is a regular expression.

The compiler groups all real arguments into one array that is then passed as parameter to the method. It is as if we had

```plaintext
MyCollection add: {# t1, t2, t3 #}
```

in message send

```plaintext
MyCollection add: t1, t2, t3;
```

As another example, a method `add:` that accepts a variable number of integers as real parameters is declared as

```plaintext
object IntSet
    public fun (add: (Int)*) :v Array<Int> [
        v foreach: [ |:elem Int|
            addElement: elem
        ]
    ]
```
public fun addElement: :elem Int [
    ...
] end

What if instead of saying
    IntSet add: 2, 3, 5, 7, 11;
we would like
    IntSet add: 2 add: 3 add: 5 add: 7 add: 11;
? No problem. Just declare the method as

object IntSet
    public fun (add: Int)+ :v Array<Int> [
        v foreach: [ |:elem Int|
            addElement: elem
        ]
    ]

public fun addElement: :elem Int [
    ...
] end

Here we should use + because we cannot have zero “add: value” elements. Again, in a message send
    IntSet add: 2, 3, 5, 7, 11
the compiler would group all arguments into one array:
    IntSet add: {# 2, 3, 5, 7, 11 #}

More than one keyword may be repeated as in

object StringHashtable
    public fun (key: String value: String)+
        :v Array<Tuple<key, String, value, String>> [ 
            v foreach: [ |:pair Tuple<key, String, value, String> |
                addKey: (pair key) withValue: (pair value)
            ]
        ]

public fun addKey: (:k String) withValue: (:v String) [
    ...
] end

Part “key: String, value: String” is represented by Tuple<key, String, value, String> — see Chapter 8 for the description of object Tuple. Since there is a plus sign after this part, the whole method takes a parameter of type

Array<Tuple<key, String, value, String>>
9.1 Matching Message Sends with Methods

The grammar method of `StringHashtable` defined in the last section can be called by supplying a sequence of `key:value:` pairs:

```cay
:ht StringHashtable;
ht = StringHashtable new;
ht key: "John" value: "Professor"
   key: "Mary" value: "manager"
   key: "Peter" value: "designer";
```

The last message send would be transformed by the compiler into something like

```cay
ht key:value: {#
   [. "John", "Professor" .],
   [. "Mary", "manager" .],
   [. "Peter", "designer" .]
#};
```

This is not valid Cyan syntax: although the object passed as parameter is legal, the selector `key:value:` is illegal.

When the compiler reaches the last message send of this example, it makes a search in the declared type of `ht`, `StringHashtable`, for a method that matches the message pattern. This matching is made between the message send and an automaton built with the grammar method. It is always possible to create an automaton from a grammar method since the last one is given by a regular expression. To every regular expression there is an automaton that recognizes the same language.

The compiler may implement the checking of a message send, the search for a method that correspond to it, in the following way:

(a) every prototype has an automaton for method search. There is just one automaton for every prototype;

(b) the automaton of a prototype has many final states. At least one for every method, including the inherited ones. And a state without outgoing arrows (transitions) meaning “there is no method for this message”;

(c) when the compiler finds a message send

```
"expr s1: p11, p12, ... sk: pk1, pk2, ... pkm"
```

it gives this message as input to the automaton of the prototype or interface `T`, which is the static type of `expr`. If a final state is reached, there is a method in `T` that correspond to this message send. Each final state is associated to a method (including the inherited ones). The no final state is reached, there is no method for this message and the compiler signs an error.

A regular expression is transformed into a non-deterministic automaton which adds ambiguity to message sends in Cyan. For example, consider a method declared as

```cay
object A
   public fun ( (a: Int)* (a: Int)* )
      :t UTuple<Array<Int>, Array<Int>> [ ... ]
end
```

A message send

```
A a: 0 a: 1
```

can be interpreted in several different ways:
(a) a: 0 a: 1 refer to the first selector of the method. No argument is passed to the second selector. Then “t f1” is an array with two integers, 0 and 1 and “t f2” is an array with zero elements.

(b) “t f1” has one element and “t f2” has one too;

(c) “t f1” has zero elements and “t f2” has two integers.

To eliminate ambiguity, Cyan demands that every part of the regular expression of the method matches as much of the message as possible. Therefore the first way shown above will be the chosen by the compiler. Array “t f2” will always have zero elements.

This requirement of “match as much as possible” can be explained using regular expressions. A regular expression $a*a$ matches a sequence of $a$’s followed by an “a”. However, a string $aaaaa$ will be matched by the first part of the regular expression, $a*$, without using the last “a” (this is true if we demand “match as much of the input as possible”). Therefore it will not match the regular expression $a*a$ because the last “a” will not match any symbol of the input. Conclusion: you should not use a symbol like a that is matched by the previous part of the regular expression.

This requirement of “match as much as possible” is necessary to remove ambiguity and to make things work as expected. For example, a regular expression “a*b” (without the quotes) should match the string $aab$

However, this regular expression is transformed into a non-deterministic automaton which can try to recognize its input in several different ways. One of them is to match the first “a” of the input string with the part $a*$ of the regular expression, leaving the rest of the string, “ab” to be matched with the rest of the regular expression, “b”. There will be no match and the match fails, demanding a backtracking that would not be necessary if we had used the requirement “match as much of the input string as possible”.

For the time being, it is not possible to override grammar methods in sub-objects. That is, if a grammar method of a superobject accepts a message $M$ (considered as input to the automaton corresponding to the method), then no sub-object method can accept $M$. Then the following code is illegal:

```plaintext
object MyHash extends StringHashtable
    public fun key: (:k String) value: (:v String) [
        ...
    ]
end
```

A message send

```plaintext
MyHash key: "University" value: "UFSCar"
```
matches the method defined in `MyHash` and the grammar method of `StringHashtable`.

9.2 The Type of the Parameter

When the compiler finds the message send that is the last statement of

```plaintext
:ht StringHashtable;
ht = StringHashtable new;
ht key: "John" value: "Professor"
    key: "Mary" value: "manager"
    key: "Joseph" value: "designer";
```
it creates a single object of type

```
Array<Tuple<key, String, value, String>>
```
because this is the type of the parameter of the method that matches the pattern of this message send. It knows that three tuple objects should be added to the array and that every tuple should be initialized with the objects following `key:` and `value:`.

Using tuples and arrays to compose the type of the parameter of a grammar method is not generally meaningful. We can use more appropriate objects for that. As an example, the type of the `key:value:` method of `StringHashtable` can be changed to

```
object StringHashtable
  public fun (key: String value: String)+ :v Array<KeyValue> [
    v foreach: [ |:pair KeyValue |
      addKey: (pair key) withValue: (pair value)
    ]
  ]
  public fun addKey: (:k String) withValue: (:v String) [
    ...
  ]
  ...
end
```

Here `KeyValue` is declared as

```
object KeyValue
  @annot( #f1 ) public :key String
  @annot( #f2 ) public :value String
end
```

The compiler creates and adds to this object the following methods:

```
@annot( #f1 ) public key: (:newKey String) [ _key = newKey ]
@annot( #f1 ) public key -> String [ ^ _key ]
@annot( #f2 ) public value: (:newValue String) [ _value = newValue ]
@annot( #f2 ) public value -> String [ ^ _value ]
```

In a message send like

```
StringHashtable
  key: "John" value: "Professor"
  key: "Mary" value: "manager"
  key: "Joseph" value: "designer";
```

the compiler knows how to pack each group “`key:` string `value:` string” because of the annotations #f1 and #f2 in object `KeyValue`.

It is possible to declare a grammar method without given explicitly the type of the sole parameter:

```
object StringHashtable
  public fun (key: String value: String)+ :v [
    v foreach: [ |:pair UTuple<String, String> |
      addKey: (pair f1) withValue: (pair f2)
    ]
  ]
  public fun addKey: (:k String) withValue: (:v String) [
```

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In this case, the compiler will deduce a type for the parameter. It will always use either an array or an unnamed tuple. The type of \( v \) will be

\[
\text{Array< UTuple<String, String> >}
\]

The Cyan compiler will initially only support this form of declaration. See Chapter 8 for the description of object UTuple.

It is possible to declare a selector in a method without any parameters:

object MyFile
    public fun open: (:name String) read: [ ... ]
    public fun open: (:name String) write: [ ... ]

end

Here both methods start with \texttt{open:} but they are easily differentiated by the second keyword, which does not take any parameters. This object can be used in the following way:

:in = MyFile new;
:out = MyFile new;
in open: "address.txt" read: ;
out open: "newAddress.txt" write: ;
...

9.3 Unions and Optional Selectors

Generic object \texttt{UUnion} represents one or more values of different types (similar to language-C unions). A variable declared as

\[
\text{:u UUnion<T1, T2, ..., Tn>}
\]

holds a single value which can be of type \( T1 \), \( T2 \), and so on. This \texttt{UUnion} has public methods \( \text{fi -> Ti} \) for \( i \) from 1 to \( n \). To discover if \( u \) holds a field of type \( Ti \) you can use the test

\[
\text{u contains: #fi}
\]

Generic object \texttt{Union} allows one to give more meaningful names to the fields. Then \texttt{Union<age, Int>} has one field called \texttt{age} of type \texttt{Int}.

Unions are used to compose the type of the parameter of grammar methods that use the regular operator \( "|" \). The signature \( \text{"A \mid B"} \) means \( A \) or \( B \) (one of them but not both).

object EnergyStore
    public fun (add: (wattsHour: Float \mid calorie: Float \mid joule: Float))
        :t Tuple< add, Any, energy, Union<wattsHour, Float, calorie, Float, joule, Float> > [

        :u = t energy;
        if ( u contains: #wattsHour ) [
            amount = amount + (u wattsHour)*3600
        ]
        else if ( u contains: #calorie )[

}
amount = amount + (u calorie)*4.1868
]
else [
    amount = amount + (u joule);
]
]

// keeps the amount of energy in joules
:amount Float;
...
end

Any is the type associated to selectors without parameters such as add: of this example. Hence “Tuple<add, Any, ...>”. We can use this prototype as

EnergyStore add: wattsHour: 100.0;
EnergyStore add: calorie: 12000.0;
EnergyStore add: joule: 3200.67;

The optional selectors may be repeated as indicated by the “+” in the method declaration:

object EnergyStore
    public fun ( add: (wattsHour: Float | calorie: Float | joule: Float)+ )
        :t Tuple< add, Any, energyArray, Array<Union<wattsHour, Float, calorie, Float, joule, Float>>> > [

        :v = t energyArray;
        v foreach: [ | :u Union<wattsHour, Float, calorie, Float, joule, Float>>> |
            if ( u contains: #wattsHour ) [
                amount = amount + (u wattsHour)*3600
            ]
            else if ( u contains: #calorie ) [
                amount = amount + (u calorie)*4.1868
            ]
            else [
                amount = amount + (u joule);
            ]
        ]

        // keeps the amount of energy in joules
        :amount Float;
        ...
end

Now we can write things like

EnergyStore add:
    wattsHour: 100.0
    calorie: 12000.0
    wattsHour: 355.0
    joule: 3200.67
    calorie: 8777.0;
This is a single method call.

As another example, we can rewrite the `MyFile` object as

```object MyFile
    public fun ( open: (:name String) (read: | write:) )
        :t Tuple<open, Any, name, String, access, Union<read, Any, write, Any>> [

            :u = t access;
            if ( u contains: #read ) [
                // open the file for reading
            ]
            else [
                // open the file for writing
                ...
            ]
        ]
    ...
end
```

Optional parts should be enclosed by parentheses and followed by “?” as in

```object Person
    public fun ( name: String
        (age: Int)? )
        :t Tuple<name, String, age, Union<age, Int>> [
            _name = t name;
            if ( (t age) contains: #age ) [
                _age = (t age) age
            ]
            else [
                _age = -1
            ]
        ]
    ...
    :_name String
    :_age Int
end
```

```...:p = Person new;
p name: "Peter" age: 14;
:c = Person new;
    // ok, no age
    c name: "Carolina";
...```

Here it was necessary to use “age” as the name of the second field of the tuple and also as the name of the union. The name of the tuple field should be `age` and it seems that is no better name for the union field than `age` too.

In a grammar method, it is possible to use more than one type between parentheses separated by “|”: 135
object Printer
  public fun (print: (Int | String)*) :v Array<UUnion<Int, String>> [
    v foreach: [ | :elem UUnion<Int, String> |
      if ( elem contains: #f1 ) [ 
        printInt: (elem f1)
      ]
      else if ( elem contains: #f2 ) [ 
        printString: (elem f2)
      ];
    ]
  ]
  // definitions of printInt and printString
  ...
end

This method could be used as in
  Printer print: 1, 2, "one", 3, "two", "three", "four", 5;

There is an ambiguity if, when putting alternative types, one of them inherits from the other. For example, suppose Manager inherits from Worker and there is an object with a method that can accept both a manager and a worker.

object Club
  public fun (addMember: (Manager | Worker)*) :v Array<UUnion<Manager, Worker>> [ 
    ...
  ]
  ...
end

A code
  Club addMember: Manager;

is ambiguous because Manager can be given as the first or second field of UUnion<Manager, Worker>. To eliminate this ambiguity, Cyan will use the first field that is a supertype of the runtime type of the object that is parameter.

More clearly, suppose an object whose runtime type is S is passed as parameter to a method
  public fun (m: T1 | T2 | ... | Tn) :u UUnion<T1, T2, ..., Tn> [ ... ]
The runtime system (RTS) will test whether S is a subtype of T1, T2, and so on, in this order. If S is sub-
type of Ti and it is not a subtype of Tj for j < i, the RTS creates an object of UUnion<T1, T2, ..., Tn> packing the parameter as field i.

There is also an ambiguity in methods with alternative selectors such as

object Company
  public fun (addMember: Manager | addMember: Worker)+ :v Array<UUnion<Manager, Worker>> [ 
    ...
  ]
  ...
end
The treatment is exactly the same as with alternative types. The first adequate selector/type combination is used.

9.4 Refining the Definition of Grammar Methods

A grammar method should have a single parameter and it is not necessary to give its type. In the last case, the compiler will associate a type to this parameter to you. To discover this type, the compiler associates a type for each part of the method declaration. The composition of these types gives the type of the single grammar method parameter.

The following table gives the association of rules with types. \( T_1, T_2, ..., T_n \) are types and \( R \) In this table, \( R \) is part of the signature of the grammar method. For example, \( R \) can be

```
add:
  add: Int
  at: Int put: String
  add: Int | sub: Int
  (add: Int)*
```

Whenever there is a list of \( R \)'s, assume that the types associated to them are \( T_1, T_2, \) and so on. For example, in a list \( R R R \), assume that the types associated to the three \( R \)'s are \( T_1, T_2, \) and \( T_3 \), respectively.
We used `type(S)` for the type associated, by this same table, to the grammar element `S`.

| rule | type |
|------|------|
| T1   | T1   |
| R R ... R | UTuple<T1, T2, ..., Tn> |
| Id "::"    | Any |
| Id ":::" T | T, which must be a type |
| Id :: "+"  | Array<T> |
| Id :: "+"  | Array<T> |
| "(" R ")"  | type(R) |
| "(" R ")+" | Array<type(R)> |
| "(" R "+"  | Array<type(R)> |
| "(" R ")"?  | UUnion<type(R)> |
| T1 "|" T2 "|" ... "|" Tn  | UUnion<T1, T2, ..., Tn> |
| R "|" R "|" ... "|" R  | UUnion<T1, T2, ..., Tn> |

Let us see some examples of associations of signatures of grammar methods with types:

| Int  | Int  |
|------|------|
| add:  | Int  |
| add:  | Int, String |
| add:  | (Int)* |
| add:  | (Int)+ |
| (add: Int)* | Array<Int> |
| (add: Int)+ | Array<Int> |
| (add: Int | String) | UUnion<Int, String> |
| (add: (Int | String)+) | Array<UUnion<Int, String>> |
| (add: Int | add: String) | UUnion<Int, String> |
| key:  | Float  |
| value: | Float  |
| nameList: (String)* (size: Int)? | UTuple<Array<String>, UUnion<Int>> |
| coke: | Any |
| coke: | guarana: |
| (coke: | guarana:)* | Array<UUnion<Any, Any>> |
| (coke: | guarana:)+ | Array<UUnion<Any, Any>> |
| ((coke: | guarana:)+)? | UUnion<Array<UUnion<Any, Any>> |
| ((coke: | guarana:)+)?+ | Array<UUnion<UUnion<Any, Any>> |
| amount: (gas: Float | alcohol: Float) | UTuple<Any, UUnion<Float, Float>> |

By the above grammar, it is possible to have a method

```java
public fun (format: (:form String) print: (:s String)) :t UTuple<String, String> [ ...
```

which starts with "(" (after keyword `fun`) but which does not use any regular expression operator. This is legal. As usual, all the parameter are grouped into a one, a tuple, declared as the single parameter.

Conceptually, every Cyan method takes a single parameter whose type is given by the associations of
the above table. For example a method

```java
public fun at: (:x, :y Int) print: (:s String) [ ... ]
```

conceptually takes a single parameter of type `UTuple<UTuple<Int, Int>, String>`.

The method name of a grammar method is obtained by removing the spaces, parameter declaration, and types from the method. Then, the method names of

```java
public fun ( add: (wattsHour: Float | calorie: Float | joule: Float)+ )
: t Tuple< add, Any, energyArray, Array<Union<wattsHour, Float, calorie, Float, joule, Float>>> >
```

```java
public fun ( name: String (age: Int)? )
: t Tuple<name, String, age, Union<age, Int>> [are
```

```java
(add:(wattsHour:|calorie:|joule:)+)
(name:(age:)?)
```

9.5 Context-Free Languages

Although regular expressions are used to define grammar methods, any context-free language can be incorporated into a grammar method with the help of parentheses. Let us see an example. The grammar below uses `{ and }` to means repetition of zero ou more times and anything between quotes is a terminal. Then `EList` derives zero or more `E`'s.

```plaintext
L ::= "(" EList ")"
EList ::= { E }
E ::= L | N
N ::= a integer number
```

This represents a Lisp-like list of integers:

```plaintext
(()) (0 1) ((0 1) (2))
```

This grammar is not regular and cannot be converted into a regular grammar. There is no regular expression whose associated language is the same as the language generated by this grammar. The problem here is that `L` is defined in terms of `EList`, which is defined in terms of `E`, which is defined in terms of `L` and `N`. Therefore, `L` is defined in terms of itself. There is no way of removing this self reference: no grammar method will be able to represent this grammar. However, assuming prototype `List` keeps a list of integers, this grammar is representable through a grammar method. It is only necessary that some methods return a `List` object.

```plaintext
object List
  public :value Int
  public :next List
end
```

```plaintext
object GenList
  public fun (L: (List | Int)* ) : t Array<Union<List, Int>> -> List [ // here parameter t is converted into a list object
...
```
We will just have to use parentheses to delimit the construction of a list in terms of another list. Here the arguments that follow L: should be integers or objects of List (produced by any means, including by the return value of another call to this method). Therefore lists \((1, 2, 3)\) and 

\((1, (2, 3), 4)\)

are produced by

:a = GenList L: 1, 2, 3;
:b = GenList L: 1, (GenList L: 2, 3), 4;

Init or new methods cannot be grammar methods — that could change, since there is no technical reason they should not. The prohibition if because the introduction of this feature would make the language more complex. If at least init or new methods could accept a variable number of parameters, we could have a code like

:b = List(1, List(2, 3), 3)

to create the list \((1, (2, 3), 4)\). That would be much better than the previous example.

It is expected that there will be a prototype CyanCode capable of generating the whole of Cyan grammar. The grammar methods of CyanCode would return objects of the Abstract Syntax Tree of Cyan. These objects could be used in the reflection library (metaobjects of compile and runtime). In this way, meta-programming would be rather independent from a particular AST. That is, the AST would exist but the meta-programmer would not manipulate it directly.

We will show one more example on how to implement context-free grammar (CFG) that is not regular (RG) using grammar methods. A CFG that is not regular defines some non-terminal (also called “variable”) in terms of itself. This necessarily happens. If it does not, there is a regular expression that produces the same language as the CFG.

The non-terminal defined in terms of itself should be associated to one grammar method that returns an object representing that non-terminal. For example, if the non-terminal is \(S\) and there is a prototype SObj that represents the non-terminal \(S\), then the grammar method for \(S\) should return an object of SObj (which is the prototype of the Abstract Syntax Tree that keeps the data associated to \(S\)). Now any references to \(S\) in the grammar method should be replaced by a parameter of type SObj. Let us study the example below.

Suppose \(S\) is defined in terms of \(A\) which is defined in terms of \(S\):

\[
S ::= N A | C B \\
A ::= N S | C \\
B ::= N A | C \\
N ::= \text{a number} \\
C ::= \text{a char}
\]

It is always possible to change the grammar (preserving the language it generates) in such a way that \(S\) is defined in terms of \(S\) and \(A\) in terms of \(S\):

\[
S ::= N N S | N C | C \\
A ::= N S | C \\
B ::= N A | C \\
N ::= \text{a number} \\
C ::= \text{a char}
\]
Then we proceed as before to implement this grammar, using first:, second:, and third: to differentiate the grammar rules used in a message send. In \( A ::= X \mid Y \), the associated grammar method is 

\[
\text{public fun } (A: (\text{first: } X \mid \text{second: } Y)) : t [ ~ ]
\]

in which the grammar rule, \( A ::= \), is used as a selector.

The implementation of the grammar above follows.

```csharp
object S ... end
object GenS
    public fun ( S: (first: Int, Int, S \mid second: Int, Char \mid third: Char) ) : t -> S [ ... ]
    public fun ( A: (first: Int, S \mid Char) ) : t -> A [ ... ]
    public fun ( B: (first: Int, A \mid second: Char) ) : t -> B [ ... ]
end
```

A string

\[0 \ 1 \ 2 \ 'A'\]

can be derived from the grammar through the derivations

\[S \Rightarrow N \ N \ S \Rightarrow N \ N \ N \ C \Rightarrow 0 \ 1 \ 2 \ 'A'\]

The string \[0 \ 1 \ 2 \ 'A'\] can be given as input to \textit{GenS} through the message sends

\textit{GenS S: first: }0, 1, (GenS S: second: 2, 'A');

It is very important to note that there is an interplay between grammar terminals and Cyan literals. Here \( N \) means “any number” in the grammar. In the grammar method, we use \textit{Int} in place of \( N \), which matches a literal number of Cyan such as 0, 1, and 2. The same happens with \textit{Char} and \textit{C}. Therefore we assumed that integers in Cyan are the same thing as integers in this grammar.

### 9.6 Default Parameter Value

Grammar methods can be used to implement default values for parameters. One should use

\[
\text{selector: } T = \text{defaultValue}
\]

for a parameter of type \( T \) following \texttt{selector: } that has a default value \texttt{defaultValue}. A grammar method with at least one parameter with default value cannot use the regular operators + and *.

```csharp
object Window
    public fun (create: x1: Int
        y1: Int
        (width: Int = 300)?
        (height: Int = 100)?
        (color: Int = CyanColor)?
    ) : t [ ...
        ...
        public const : Cyan = 00ffffHex
end
```

When the calling code do not supply the width, height, or color, the compiler initialize the parameter \( t \) with the values given in the declaration:
// this call is the same as
// Window create: x1: 0 y1: 0 width: 300 height: 150 color: CyanColor;
:w = Window create: x1: 0 y1: 0 height: 150;
// this call is the same as
// Window create: x1: 0 y1: 0 width: 300 height: 100 color: 0000ffHex;
:p = Window create: x1: 100 y1: 200 color: 0000ffHex;

Currently, there is one limitation in the use of default parameters: inside the optional part in the declaration of the grammar method, there should be only one parameter and one selector. Therefore it is illegal to declare

object Window

  public fun (create: x1: (:aX1 Int)
    y1: (:aY1 Int)
    // error: two selectors
    (width: Int = 300 height: Int = 100)?
    // error: three parameters
    (rgbcolor: Int = 0, Int = 255, Int 255)?
      ) :t [

    ...;
    ...
  ]

end

Note that one can declare default parameters using “or” as in

object EnergySpending

  public fun (add: (wattsHour: Float (hours: Int = 1)? ) |
    (calorie: Float (amount: Int = 1)? ) |
    (joule: Float (amount: Int = 1)? )
      ) :t [

    ...;
    ...
  ]

end

A future improvement (or not ...) of the language would be to allow named parameters in grammar methods that do not use “|”, “*”, or “+” in their definitions and that have default values for parameters inside optional expressions (with “?”). So it would be legal to declare

object Window

  public fun (create: x1: (:aX1 Int)
    y1: (:aY1 Int)
    (width: :aWidth Int = 300)?
    (height: :aHeight Int = 100)?
    (color: :aColor Int = Cyan)?
      ) [

    x1 = aX1;
    y1 = aY1;
    width = aWidth;
This would make it easy to access the parameters with default values.

9.7 Domain Specific Languages

Grammar methods make it easy to implement domain specific languages (DSL). A small DSL can be implemented in Cyan in a fraction of the time it would take in other languages. The reasons for this efficiency are:

(a) the lexical analysis of the DSL is implemented using grammar methods is the same as that of Cyan;

(b) the syntactical analysis of the DSL is given by a regular expression, the signature of the grammar method, and that is easy to create;

(c) the program of the DSL is a grammar message send. The Abstract Syntax Tree (AST) of such a program is automatically built by the compiler. The tree is composed by tuples, unions, arrays, and prototypes that appear in the definition of the grammar method. The single method parameter refer to the top-level object of the tree;

(d) code generation for the DSL is made by interpreting the AST referenced by the single grammar method parameter. Code generation using AST’s is usually nicely organized with code for different structures or commands being generated by clearly separated parts of the compiler;

(e) it is relatively easy to replace the type of the single parameter of a grammar method by a very meaningful type of the AST. So, instead of using

   \[\text{Array<UTuple<Int, Int>>>}\]

one could use

   \[\text{Graph}\]

in which \text{Graph} is a prototype with appropriate methods.

To further exemplify grammar methods, we will give more examples of them.

object Edge
   \@annot( #f1 ) public :from Int
   \@annot( #f2 ) public :to Int
end

object Graph
   \@annot( #f1 ) public :numVertices Int
   \@annot( #f2 ) public :edgeArray Array<Edge>
end
object MakeGraph
    public fun ( numVertices: Int (edge: Int, Int)* ) :t Graph -> Graph |
        ^t
    ]
end
A call
:g = MakeGraph numVertices: 5
    edge: 1, 4
    edge: 3, 1
    edge: 1, 2
    edge: 2, 4;
would produce and return an object of type Graph properly initialized. Note that the grammar method of MakeGraph just return the method argument. This is a simple trick to produce an AST from a message send.

A small language with an if, list of commands (cl), assignment, while, and print statements is implemented by the following grammar methods:

object GP
    public fun (if: Expr then: Stat (else: Stat)? | cl: (Stat)* | assign: String, (Expr | String | Int) | while: (Expr | String | Int) do: Stat | print: (Expr | String | Int)
    ) :t -> Stat |
        // code to convert t into an AST object
    ]
    public fun (add: (Expr | String | Int), (Expr | String | Int) | mult: (Expr | String | Int), (Expr | String | Int)|
        lessThan: (Expr | String | Int), (Expr | String | Int)) :t -> Expr |
        // code to convert t into an AST object
    ]
end
It is assumed that variables in this language are automatically declared when used. Program
i = 0;
soma = 0;
while ( i < 10 ) {
    soma = soma + i;
    i = i + 1;
};
print soma
is represented by the following message send:
:program = GP cl:
    (GP assign: "i", 1),
    (GP assign: "soma", 0),
    (GP assign: "soma", 0),
(GP while: (GP lessThan: "i", 10)
  do: (GP cl: (GP assign: "soma", (GP add: "soma", "i") ),
  (GP assign: "i", (GP add: "i", 1 ))))));

program run: Hashtable();

The last message send would call a method to execute the program. Assume there is an abstract prototype Stat with sub-prototypes IfStat, StatList, AssigStat, and WhileStat. Each one of them has a run method that takes a hashtable as parameter. This hashtable holds the variables names and values. As an example, prototype IfStat would be as follows.

object IfStat extends Stat
  public fun run: (:h Hashtable) [  
    // if variable is not in the table
    // it is inserted there
    h key: variable value: (expr run: h)
  ]
  @annot( #f1 ) public :variable String
  @annot( #f2 ) public :expr Expr
end

Of course, the methods of prototype GP could just return the parameter as the Graph prototype if Stat, Expr, and other prototypes of the AST are properly annotated.

The possibilities of defining DSL’s with grammar methods are endless. For example, one can define a grammar method for creating XML files:

:xmlText String = XMLBuilder root: "booklist"
  elem: "book" contain: (XMLElem elem: "author" contain: "Isaac Newton"),
  (XMLElem elem: "title" contain: "Philosophiae Naturalis Principia Mathematica"),
  (XMLElem elem: "year" contain: "1687")
  elem: "book" contain: (XMLElem elem: "author" contain: "Johann Carl Friedrich Gauss"),
  (XMLElem elem: "title" contain: "Disquisitiones Arithmeticae"),
  (XMLElem elem: "year" contain: "1801");

This method call would return the string

<booklist>
  <book>
    <author> Isaac Newton </author>
    <title> Philosophiae Naturalis Principia Mathematica </title>
    <year> 1687 </year>
  </book>
  <book>
    <author> Johann Carl Friedrich Gauss </author>
    <title> Disquisitiones Arithmeticae </title>
    <year> 1801 </year>
  </book>
</booklist>

SQL queries could also easily be given as calls to grammar methods. Any syntax error would be discovered at compile-time. Horita [14] has designed a set of grammar methods for building graphical
user interfaces. There are methods for building menus, buttons, etc. It is much easier to use grammar methods for GUI than to compose them by explicitly creating objects and calling methods. A similar approach for building user interfaces is taken by the SwingBuilder of language Groovy (page 132 of [5]). Groovy builders are commented in Section 9.8.

Flower [6] gives an example of a DSL used to control a camera which is in fact a window of visibility over a larger image. As an example, we can have a 1600x900 image but only 200x100 pixels can be seen at a time (this is the camera size). Initially the “camera” shows part of the image and a program in the DSL moves the camera around the larger image, showing other parts of it. The DSL grammar is

```plaintext
<Program> ::= <CameraSize> <CameraPosition> <CommandList>
<CameraSize> ::= "set" "camera" "size" ":" <number> "by" <number> "pixels" "."
<CameraPosition> ::= "set" "camera" "position" ":" <number> "," <number> "."
<CommandList> ::= <Command>+
<Command> ::= "move" <number> "pixels" <Direction> "."
<Direction> ::= "up" | "down" | "left" | "right"
```

`CameraSize` is the size of the window visibility of the camera. `CameraPosition` is the initial position of the camera in the larger image (lower left point of the window). `CommandList` is a sequence of commands that moves the camera around the larger image. The site [6] shows an animation of this.

A grammar method implementing the above grammar is very easy to do:

```plaintext
object Camera
    public fun (sizeHoriz: Int sizeVert: Int
        positionX: Int positionY: Int
        (move: Int (up: | down: | left: | right:) )+ ) :t [
        // here comes the commands to actually change the camera position
    ]
end
```

This method could be used as

```plaintext
Camera sizeHoriz: 1600 sizeVert: 900
    positionX: 0 positionY: 0
    move: 100 up:
    move: 200 right:
    move: 500 up:
    move: 150 left:
    move: 200 down;
```

It takes seconds, not minutes, to codify the signature of this grammar method given the grammar of the DSL. Other easy-to-do examples are a Turing machine and a Finite State Machine.

A future work is to design a library of grammar methods for parallel programming that would implement some common parallel patterns. We could have calls like:

```plaintext
Process par: [ Out println: 0 ], [ Out println: 1 ]
    seq: [ Out println: 2 ], [ Out println: 3 ]
    par: Graphics.{convert}., Printer.{print}.
```

Blocks after `par` would be executed in any parallel. Blocks after `seq` would be executed in the order they appear in the message send. Then 1 may appear before 0 in the output. But 2 will always come before 3. Remember methods are u-blocks.
9.8 Groovy Builders

The excellent language Groovy supports a feature called “builders” that makes it easy to construct domain specific languages or tree-like structures. It would be very nice if Cyan had something similar. We tried to add an equivalent feature without introducing new language constructs. That was not possible. However, it is possible to define builders using dynamically typed message sends. To generate a HTML page, one can write in Groovy:

```groovy
def html = new groovy.xml.MarkupBuilder()
   html.html {
      head {
         title "Groovy Builders"
      }
      body {
         h1 "Groovy Builders are cool!"
      }
   }
```

In Cyan, one could design a `MarkupBuilder` prototype that plays a rôle similar to the Groovy class:

```cyber
:b = MarkupBuilder new;
b html: [b head: [b title: "Groovy Builders"];
b body: [b h1: "Groovy Builders are cool!"
]
];
```

However, it is undeniable that the Groovy code is more elegant. The Cyan code does not look like a tree-like structure as the Groovy code because it is necessary to send messages to the `b` variable.

`Context blocks` (Section 10.11) can be used to make Cyan more Groovy-like:

```cyber
:b = MarkupBuilder new;
b html: (:self MarkupBuilder)[
   head: (:self HeadBuilder)[
      title: "Groovy Builders"
   ];
b body: (:self BodyBuilder)[
      h1: "Groovy Builders are cool!"
   ]
];
```

Prototype `MarkupBuilder` defines methods `html`, `head`, and `body`. Method `html` calls the context block after initializing `self` to its own `self` (which is `b`). Then the call to `head:` is in fact “`b head: ...`” (idem for `body:`). Method `head:` of `MarkupBuilder` accepts a context block as parameter and sets the `self` of this context block to an object of prototype `HeadBuilder`. This prototype defines a method `title:`. Idem for `h1:` of `BodyBuilder`. An alternative implementation would use prototype `MarkupBuilder` in place of `HeadBuilder` and `BodyBuilder`. In this case, the code above would be almost equal to the Groovy code:
This Groovy-like Builder implementation in Cyan has the advantage of being compile-time checked. Any mistakes in the tree building would be caught by the compiler:

```
:b = MarkupBuilder new;
b html: (:self MarkupBuilder)[
    head: [
        title: "Groovy Builders"
    ];
    body: [
        h1: "Groovy Builders are cool!"
    ];
];
```

A new syntax could be defined to make Cyan more Groovy-like. This new syntax would define a context block without specifying the type of self:

```
() [ |signature| body ]
```

That would mean the same as

```
(:self Any) [ |signature| body ]
```

With this would-to-be syntax and non-checked dynamic calls, the example would be written as:

```
:b = MarkupBuilder;
b html: ()[
    ?head: ()[
        ?title: "Groovy Builders"
    ];
    ?body: ()[
        ?h1: "Groovy Builders are cool!"
    ];
]
```

The calls to methods head, title, body, and h1 would be redirected to the object referenced by b or to a newly created object such as HeadBuilder or BodyBuilder. This redirection would be made by the “father” method in the tree. That is, the html method would redirect to b any calls inside its context block parameter. The calls are to methods head: and body:.
Method `evalSelfContext` is added by the compiler to every prototype. It also can be used to simulate Groovy builders:

```groovy
:b = Builder new;
b evalSelfContext: (:self Builder) [
  book: [
    author: [
      firstName: "Isaac";
      surname: "Newton";
    ],
    title: "Philosophiae Naturalis Principia Mathematica"
  ];
];
```

The compiler would check whether the message sends to `self` made inside this context block refer to methods declared in prototype `Builder`. Then `book: Block, author: Block, and so on should be methods of `Builder`.

In Cyan methods and fields can be added to objects (Section 8.4). Using this feature, a prototype `Builder` could allow the definition of tree-like structure whose node names are not defined at compile-time. That would be very useful for defining a XML builder for example.

```groovy
:xml XMLBuilder;
xml evalSelfContext: (:self XMLBuilder) [
  root: "booklist";
  ?book: [
    ?author: "Isaac Newton"
    ?title: "Philosophiae Naturalis Principia Mathematica"
    ?year: "1687";
  ];
  ?book: [
    ?author: "Johann Carl Friedrich Gauss"
    ?title: "Disquisitiones Arithmeticae"
    ?year: "1801";
  ];
]
```

This method call would build a XML code in the form of an abstract syntax tree (AST), which is an internal representation of the XML code. When a message “`asString`” is sent to the `xml` variable, the string returned would be

```xml
<booklist>
  <book>
    <author> Isaac Newton </author>
    <title> Philosophiae Naturalis Principia Mathematica </title>
    <year> 1687 </year>
  </book>
  <book>
    <author> Johann Carl Friedrich Gauss </author>
    <title> Disquisitiones Arithmeticae </title>
    <year> 1801 </year>
  </book>
</booklist>
```

The only method `XMLBuilder` has is `root` (plus possible some auxiliary methods). When message

```groovy
?book: ?author: ... ?title: ... ?year
```
is sent to xml, method doesNotUnderstand create objects to represent the XML element

```xml
<book>
  <author> Isaac Newton </author>
  <title> Philosophiae Naturalis Principia Mathematica </title>
  <year> 1687 </year>
</book>
```

That would be made with every non-checked dynamic message send (those starting with ?).

### 9.9 A Problem with Grammar Methods

There is a problem with grammar methods, related to blocks, that can only be properly understood after reading Chapter 10.

```plaintext
object BlockBox
  public fun (add: Block)* :t Array<Block> [ 
    b = t[0];
  ]
  public fun do [
    b eval;
  ]
  :b Block;
end
...
if ( 0 < 1 ) [
  :i Int = 0;
  BlockBox add: [ ++i ]
]
BlockBox do;
```

Here block [ ++i ] is passed as a parameter to method add: which assigns the block to instance variable b. When method do is called in the last line, b receives message eval which causes the execution of the block which accesses variable i causing a runtime error: this variable does not exist anymore. However, this error will never happens because: a) there cannot exist object Array<Block> and b) assignment “b = t[0]” is illegal because r-blocks cannot be assigned to instance variables. However, the restrictions on the use of blocks limit too much the use of grammar methods taking blocks as parameters. A switch grammar method declared as below would cause a compile-time error.

```plaintext
public fun ( switch: 
  (case: (T)+ do: Block)+
  (else: Block)?
) :t UTuple<Any, Array<UTuple<Array<T>, Block>>, UUnion<Block>> [ 
  // method body
]
```

It is necessary to use Block instead of UBlock to allow access to local variables:

```plaintext
:lifePhase;

n switch:
  case: 0, 1, 2 do: [
```
lifePhase = "baby"
]
case: 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 do: [
    lifePhase = "child"
]
case: 13, 14, 15, 16, 17, 18, 19 do: [
    lifePhase = "teenager"
]
else: [
    lifePhase = "adult"
];

There are several solutions to this problem, none of them ideal:

(a) change the definition of blocks. Any local variable used inside a block without % is allocated in the heap. This causes performance problems but otherwise this is an ideal solution. Local variables are usually allocated in the stack which is very fast. Note that both the variables and the objects they refer to would be heap-allocated;

(b) restrict the way the single parameter t of a grammar method can be used. This can take two forms. In the first one, any assignment from and to any field of t, even the nested ones, should be prohibited if there is any Block type appearing in the parameter type. The assignments are made using methods. So, if t has type

\[
\text{UTuple<UTuple<Array<Int>, Float>, UUnion<Int, UTuple<String, Block>>>}
\]

then message sends

1 t = u;
2 t f1: aif;
3 aNumber = (t f1) f2;
4 t f2: newUU;
5 newUU = t f2;
6 (t f2) f2: c;
7 k = ((f f2) f2) f2;
8 ((f f2) f2) f2: = gg;

would be illegal. That is too radical but simple. It is this restriction that is adopted by Cyan.

A less restrictive rule would be to prohibit assignments only in the path from t to any type Block. In this case, assignments of lines 2 and 3 would be legal.

Section h (page 170) makes a proposal for correcting this problem. For short, Array<T> will be a restricted array whenever T is a restricted block. This should probably work.

### 9.10 Limitations of Grammar Methods

There are two limitations of grammar methods:

(a) polymorphism does not apply to them because all grammar methods are implicitly “final”. It is illegal to redefine a grammar method in a sub-prototype. So one cannot have multiple implementations of a Domain Specific Language and select one of them dynamically using a message send;
(b) grammar methods cannot be declared in an interface.

There is no technical problem (till I know) in removing these limitations. They only exist to make the compiler simpler. Probably they will be lifted in the future.
Chapter 10

Blocks

Blocks of Cyan are similar to blocks of Smalltalk or closures of other languages. A block is a literal object — an object declared explicitly, without being cloned of another object. A block may take arguments and can declares local variables. The syntax of a literal block is:

```
[ | ParamRV | code ]
```

ParamRV represents the declaration of parameters and the return value type (optional items). A block is very similar to a function definition — it can take parameters and return a value. For example,

```
b = [ | :x Int -> Int | ^ x*x ];
```

declares a block that takes an Int parameter and returns the square of it. Symbol `^` is used for returning a value. However, to `b` is associated a block, not a return value, which depends of the parameter. Although blocks are very similar to functions, they are objects. The block body is executed by sending to the block message `eval:` with the parameters the block demands or `eval` if it does not take parameters. For example,

```
y = b eval: 5;
```

assigns 25 to variable `y`. The `eval:` methods are similar to Smalltalk´s `value` methods. We have chosen a method name different from that of Smalltalk because in Cyan a block may not return a value when evaluated. In Smalltalk, it always does.

The block `[ | :x Int | ^ x*x ]` is similar to the object

```
object LiteralBlock001
    public fun eval: (:x Int) -> Int [
        ^ x*x;
    ]
end
```

For every block the compiler creates a prototype like the above. Then two identical blocks give origin to two different prototypes. There are important differences between the block and this prototype which will be explained in due time.

The return value type of a block can be omitted. In this case, it will be the same as the type of the return value of the expression returned — all returned values should be of the same type. For example,

```
[ | :x Int :y Int | 
    :r Int;
    r = sqrt: ((x-x0)*(x-x0) + (y-y0)*(y-y0));
    ^ r ]
```

declares a block which takes two parameters, `x` and `y`, declares a local or temporary variable `r`\(^1\) and

\(^1\)Which of course can easily be removed as the block can return the expression itself.
returns the value of r (therefore the return value type is Int). Assume that this block is inside an object which has a method called sqrt:. Variables x0 and y0 are used inside the block but they are neither parameters nor declared in the block. They may be instance variables of the object or local variables of blocks in which this literal block is nested. These variables can be changed in the block.

The language does not demand that the return value type of a block be declared. In some situations, the compiler may not be able to deduce the return type:

:b = [~b];

To prevent this kind of error, when a block is assigned to a variable b in its declaration, as in this example, b is only considered declared after the compiler reaches the beginning of the next statement. Then in this code the compiler would sign the error “b was not declared”. In the general case, in an assignment “:v = e” variable v cannot be used in e.

Sometimes a block should return a value for the method in which it is instead of returning a value for the call to eval or eval:. For example, in an object Person that defines a variable age, method getLifePhase should return a string describing the life phase of the person. This method should be made using keyword return as shown below.

```kotlin
public fun getLifePhase -> String [
    if ( age < 3 ) [ return "baby" ]
    else if ( age <= 12 ) [ return "child" ]
    else if ( age <= 19 ) [ return "teenager" ]
    else [ return "adult" ]
]
```

If ^ were used, this would be considered to be the return of the block, not the return of the method. A return statement causes a return to the method that called the current method, as usual.

Generic arrays of Cyan have a method foreach that can be used to iterate over the array elements. The argument to this method is a block that takes a parameter of the array element type. This block is called once for each array element:

```kotlin
:firstPrimes Array<Int> = {# 2, 3, 5, 7, 11 #};
// prints all array elements
firstPrimes foreach: [ |:e Int|
    Out println: e
];
:sum = 0;
// sum the values of the array elements
firstPrimes foreach: [ |:e Int|
    sum = sum + e
];
Out println: sum;
```

An statement ^ expr is equivalent to return expr when it appears in the level of method declaration; that is, outside any block inside a method body. See the example:

```kotlin
public fun aMethod: (:x Int, :y Int) [
    :b = [ ~ x < 0 || y < 0 ];
    // method does not return in the next statement
    (b eval) ifTrue: [ Error signal: "wrong coordinates" ];
    // method returns in the next statement
    ^ sqrt: ((Math sqr: x) * (Math sqr: y));
]
10.1 Problems with Closures

Closures, called Blocks in Cyan, are extremely useful features. They are supported by many functional and object-oriented languages such as Scheme, Haskell, Smalltalk, D, and Ruby. However, this feature causes a runtime error when

(a) a closure accesses a local variable that is destroyed before the closure becomes inaccessible or is garbage collected. Then the body of the closure may be executed and the non-existing local variable may be accessed, causing a runtime error;

(b) a block with a return statement live past the method in which it was declared. When the closure body is executed, there will be a return statement that refers to a method that is no longer in the call stack.

We will give examples of these errors. Assume that “Block” is the type blocks that does not take parameters and returns nothing.

```kotlin
object Test
    public fun run []
        prepareError;
        makeError;
    ]
    public fun prepareError []
        block = [ return ];
        return;
    ]
    public fun makeError []
        block eval;
    ]
    private :block Block
end
```

In `makeError`, the block stored in the instance variable receives message `eval` and statement `return` is executed. This is a return from method `prepareError` that is no longer in the stack. There is a runtime error.

```kotlin
object Test
    public fun run []
        returnBlock eval
    ]
    public fun returnBlock -> Block []
        return [ return ];
    ]
end
```

Here `returnBlock` returns a block which receives message `eval` in `run`. Again, statement `return` of the block is executed in method `run` and refers to `returnBlock`, which is not in the call stack anymore.

Assume that `Block<Int>` is the type of blocks that return an `Int`.

---

2 This is not exactly true and this definition will soon be corrected.
object Test
    public fun run [ 
        prepareError;
        makeError;
    ]
    public fun prepareError [ 
        :x = 0;
        block = [ ~x ];
    ]
    public fun makeError [ 
        Out println: (block eval);
    ]
    private :block Block<Int>
end

In statement “block eval” in method `makeError`, the block body is executed which accesses variable `x`. However, this variable is no longer in the stack. It was when the block was created in `prepareError` because `x` is a local variable of this method. There is again a runtime error.

object Test
    public fun run [ 
        :a1 = 1;
        :b1 Block;
        if ( a1 == 1 ) [ 
            :a2 = 2;
            :b1 = [ Out println: a2 ];
        ];
        b1 eval
    ]
end

Here a block that uses local variable `a2` is assigned to variable `b1` that outlives `a2`. After the if statement, `a2` is removed from the stack and message `eval` is sent to `b1`, causing an access to variable `a2` that no longer exists.

`Block<Block<Int>>` is the type of blocks that return objects of type `Block<Int>`.

object Test
    public fun run [ 
        :a1 = 1;
        :b1 Block<Block<Int>>;
        if ( a1 == 1 ) [ 
            :a2 = 2;
            :b1 = [ ^[^a2 ] ]
        ];
        (b1 eval) eval;
    ]
end

After the execution of “:b1 = [ ^[^a2 ] ]”, `b1` refers to a block that refers to local variable `a2`. In statement `(b1 eval) eval`, variable `a2`, which is no longer in the stack, is accessed causing a runtime error.
There are some unusual use of blocks that would not cause runtime errors:

```kotlin
object Test
public fun run [ :a1 = 1; :b1 Block<Int>; ]
    if ( a1 == 1 ) [ :b2 = [ :b1 = [ ^a1 ] ]; b2 eval; ]
b1 eval
end
```

No error occurs here because `b1` and `a1` are create and removed from the stack at the same time.

```kotlin
object Test
public fun run [ :a1 = 1; :b1 Block<Block<Int>>; ]
    if ( a1 == 1 ) [ :b2 = [ [ ^[ ^a1 ] ] ]; Out println: ( (b1 eval) eval ); ]
end
```

Here `(b1 eval) eval` will return the value of `a1` which is in the stack. No error will occur.

```kotlin
object Test
public fun run [ ]
    Out println: test
]
public fun test -> Int [ :b1 Block; [ :b2 = [ :b1 = [ return 0 ]; ] ]; b2 eval; ] eval;
b1 eval;
Out println: 1
]
end
```

After message send “b2 eval” a block is assigned to b1. After “b1 eval” statement “return 0” is executed and method test returns. The last statement is never reached. Note that block

```kotlin
[ return 0 ]
```

is a block that does not return a value. Therefore its type is `Block`.

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10.2 Some More Definitions

A Cyan block is a closure, a literal object that can close over the variables visible where it was defined. More rigorously, the syntax `\[ |params| stats \]` creates a closure at runtime for the linking with the instance and local variables is only made dynamically. An object is created each time a closure appears at runtime. Therefore the code

```plaintext
:x Int;
v Array<UBlock<Void><Int>>
1 to: 5 do: [ |:i Int|
   v[i] = \[^ i*i \]
];
```

creates five blocks, each of which captures variable `x`.

Variables used inside a block can be preceded by a `%` to indicate that a copy of them should be made at the block creation. Then any changes of the values of these variables are not propagated to the environment in which the block is. See the example.

```plaintext
public fun test -> Int [
   :x = 0;
   :y = 0;
   :b = [
      %x = %x + 1;
      Out println: %x;
      y = y + 1;
   ];
   assert: (x == 0 && y == 0);
   b eval;
   assert: (x == 0 && y == 1);
   return x + y;
]
```

%\(x\) inside the block means a copy of the local variable \(x\). The \(y\) inside the block means the local variable \(y\). The changes to it caused by statement `b eval` will remain. It is illegal to use both \(x\) and %\(x\) in a block. It is illegal to use `%` with a parameter — since parameters are read only, it is irrelevant to use `%` with them.

10.3 Classifications of Blocks: u-Blocks and r-Blocks

Before studying blocks in depth, it is necessary to define what is “scope”, “variable of level k”, and “block of level k”. Each identifier is associated to a scope, the region of the source code in which the identifier is visible (and therefore can be used). A scope can be the region of a method or of a block, both delimited by [ and ]. The scope of a local variable is starts just after its declaration and goes to the enclosing “]” of the block in which it was declared. A scope will be called “level 1” if the delimiters [ and ] are that of a method. “level 2” is the scope of a block inside level 1. In general, scope level \(n+1\) is a block inside scope \(n\):

```plaintext
public fun test: (:n Int) [  
   // scope level 1  
   :a1 Int = n;
   (n < 0) ifFalse: [
```
We will call “variable of level k” a variable defined in scope level “k”. Therefore variable \( a_i \) of this example is a variable of level \( i \). The level of parameters is considered -1. There is no variable of level 0.

The variables \textit{external} to a block are those declared outside the code between \([\text{ and }\] that delimits the block. For example, \( a_1 \) is external to the block passed as parameter to selector \texttt{ifFalse:} in the previous example (any of the \texttt{ifFalse:} selectors). And \( a_1 \) and \( a_2 \) are external to the block that is argument to the selector \texttt{ifTrue:}.

A block is called “block of level \(-1\)” if it

(a) only accesses external local variables using \%;
(b) possibly uses parameters (always without \% because it is illegal to use \% with parameters);
(c) possibly uses instance variables;
(d) does not have return statements;

By “access” a local variable we mean that a local variable appear anywhere between the block delimiters, which includes nested blocks. In the example that follows, the block that starts at line 3 and ends at line 7 \textit{accesses} local variable \( a_1 \) which is external to the block. This access is made in the block of line 5 which is inside the block of lines 4-6 which is inside the 3-7 block. Therefore 3-7 is not a block of level \(-1\). And neither is the block of lines 4-6 or the block of line 5. However, the block that is the body of method \texttt{test} (lines 1-8) is a block of level \(-1\).

1. \texttt{public fun test [}
2. \quad :a1 = 1;
3. \quad [ :a2 = 2; // start
4. \quad \quad [ :a3 = 3;
5. \quad \quad \quad [ ++a1 ] eval;
6. \quad \quad ] eval;
7. \quad ] eval // end
8. ]

Let \( v_1, v_2, ..., v_n \) be the external \textit{local} variables accessed in a block \( B \) without \% — \( B \) is a block, not a variable that refers to a block. Instance variables and parameters are not considered. If \( m \) is the level in which \( B \) is defined, then \( B \) can only access external local variables defined in levels \( \leq m \). But not all variables of levels \( \leq m \) are visible in \( B \) for some of them may belong to sister blocks or they may be defined after the definition of \( B \). Variables defined in levels \( > m \) are either inaccessible or internal to the block. The following example explains these points.

\texttt{public fun test [}
1. // level 1
Block B2 is defined at level 2 but it cannot access variable \texttt{a22} of level 2 — it is defined after B2. Variable \texttt{a5} defined at level 4 is not visible at block B2.

The important thing to remember is “B defined at level m can only access external local variables defined in levels \( \leq m \)”, although not all variables of levels \( \leq m \) are accessible at B. The example of Figure 10.1 should clarify this point. Ellipses represent blocks. A solid arrow from block C to block B means that C is inside B. A dashed arrow from C to B means that C uses local variables declared in B.

This Figure represents the blocks of the example that follows. The root is the block of the method itself which is represented by the top-level ellipse in the Figure. The numbers that appear in the ellipses are the return values of the blocks. This number is used to identify the blocks (we will say block 0 for the block that returns 0). The values returned by all the blocks are not used (the return value of a method may be ignored. Statements like “1 + 2” are legal).
public fun test [ 
  :v0 = 0;  
  [ 
    :v1 = 1;  
    [ 
      ++v1;  
      ++v0;  
      ^3  
    ] eval;  
    :v11 = 2;  
    [  
      ++v0;  
      ^4  
    ] eval;  
    ^1  
  ] eval;  
  [  
    :v2 = 2;  
    [  
      [  
        ++v0;  
        ++v2;  
        ^6  
      ] eval;  
    ] eval;  
    ^2  
  ] eval;  
  ^0  
]

By the scope rules of Cyan, a block B can only access its own local variables or variables from blocks
that are ancestors of B. Only variables declared before B are accessible. In this example, the block
that returns 3 cannot access v11 even though this variable is declared in an outer block (because the
declaration appears after the declaration of block 3). In the Figure, a block B may access local variables
of block A if there is a path in solid arrows from A to B (we will write just path from A to B).

When method eval or eval: of a block A is called, the runtime system pushes to the stack the local
variables of A. Till the method returns, these local variables are there and they can be accessed by blocks
declared inside A. Using the Cyan example above and the Figure, when method eval of block 0 is called,
itis pushes its local variables to the stack. Then block 1 is called and this block calls block 4 that accesses
variable v0 declared at block 0. No error occurs because v0 is in the stack. To call block 4 it was first
necessary to call block 1 and, before this, block 0 which declares variable v0.

However, this example could be modified in such a way that block 3 is assigned in block 1 to a variable
b1 declared at block 0 (suppose this is legal — it is not as we will see).

// unimportant blocks were removed
public fun test [ 
  :v0 = 0;  
  :b1 Block<Void><Int>; 
  ^3X is an ancestor of Y if Y is textually inside X.
\[
\begin{array}{l}
:v1 = 1; \\
b1 = [ \\
\quad ++v1; \\
\quad ++v0; \\
\quad ~3 \\
]; \\
:v11 = 2; \\
~1 \\
] eval; \\
// compile-time correct, runtime error \\
b1 eval; \\
~0 \\
\end{array}
\]

\[b1\] is visible in block 1 by the scope rules of Cyan. After blocks 3 and 1 are removed from the stack and control returns to method \texttt{eval} of 0, \(b1\) receives an \texttt{eval} message. Since \(b1\) refers to block 3, the method called will try to access variable \(v1\) declared in block 1. This variable is no longer in the stack. There would be a runtime error. However, the rules of Cyan will not allow block 3 be assigned to variable \(b1\) of block 0. A block variable \(b\) will never refer to a block that uses external variables that live less than \(b\).

Inner blocks may be assigned to variables of outer blocks without causing runtime errors:

\begin{verbatim}
public fun test [ 
  :a1 = 1; 
  :b Block; 
  [ 
    :a2 = 2; 
    [ 
      
        b = [ ++a1; ] 
      ] eval 
    ] eval; 
  ] eval; 
  b eval; 
]
\end{verbatim}

Here a block \([ ++a1 ]\) is assigned to variable \(b\) declared at level 1. This does not cause errors because the block only refer to variables of level 1. Variable \(b\) and \(a1\) will be removed from the stack at the same time. There is no problem in this assignment. In this example, if the block used \(a2\) instead of \(a1\), there would be a runtime error at line \(\texttt{b eval}\). Variable \(a2\) that is no longer in the stack would be accessed. To prevent runtime errors of the kind “reference to a variable that is no longer in the stack” Cyan only allows an assignment \(\texttt{b = B}\), in which \(B\) is a block, if the variables accessed in \(B\) will live as much as \(b\). This is guaranteed by the rules given in the next section.

Blocks are classified according to the external local variables they access and if they have or not return statements. To a block \(B\) is associated a number \(bl(B)\) called “the level of block \(B\)” found according to the following rules.

\begin{enumerate}
  \item A block that accesses local variables only using \% and that do not have return statements (even considering nested blocks) are called “blocks of level -1”. This kind of block may access parameters;
2. Blocks that access at least one external local variable (excluding parameters) without using % have their number $b_l(B)$ calculated as

$$b_l(B) = \max\{\lev(v_1), \lev(v_2), \ldots, \lev(v_n)\}$$

$\lev(v)$ be the level of variable $v$. $v_1, v_2, \ldots, v_n$ are the external local variables accessed in block $B$ without %. The “block level” of $B$ is $b_l(B)$.

3. A block that do not access any local variables (excluding parameters) without % but that does have a return statement (even in nested blocks) is called “block of level 0”. This block may access variables with %.

For short, a block that have a return statement is at least of level 0. A block that has a reference to an external local variable of level $k$ is at least a block of level $k$. However, it may be a block of level $\geq k$ (if it accesses an external variable, without %, of a superior level). The use of instance variables or parameters is irrelevant to the calculus of the level of a block. Instance variables are not created with the method or when the block receives message eval or eval:. And parameters are read only — it is as if every parameter were used with %.

The definition of $b_l(B)$, the level of a block, is different from the definition “block defined or declared at level $k$” used previously. A block defined at level $k$ is a block that is textually at level $k$. The block level of a block depends on the external local variables that appear in its body (including the nested blocks inside it).

The higher the level of a local variable a block accesses, the more restrictive is the use of the block. For example, block B3 in the next example can be assigned to any of the local block variables $b_i$ of this example. But B4 cannot. If it is assigned to $b_2$, for example, the message send “b2 eval” would access a local variable $a_{31}$ that is no longer in the stack.

```java
public fun test [ // level 1
    // level 1
    :a1 = 1;
    :b1 Block;
    [ // start of block B1
        // level 2
        :a2 = 2;
        :b2 Block;
        [ // start of block B2
            // level 3
            :a31 = 31;
            :b31 Block;
            :b31 = [ ++a1 ]; // block B3
            :b32 Block;
            b32 = [ ++a31 ]; // block B4
            b2 = [ ++a2 ];
        ] eval;
        b2 eval;
    ] eval;
    b1 eval;
] 4
```

---

4Use the variable without %.
The example below should clarify the definition of “block level k”.

```plaintext
public fun test: (:p Int) -> Int [  
    // level 1
    :a1 = 1;
    :b1_1 = [ ~a1 ]; // block of level 1, defined at level 1
    :b1_2 = [ ~0 ]; // block of level -1, defined at level 1
    :b1_3 = [ // block of level 1 because it uses a1  
              // level 2
        :a2 = 2;
        :b2_1 = [ ~a1 ]; // block of level 1, defined at level 2
        :b2_2 = [ a2 = 1 ]; // block of level 2, defined at level 2
        :b2_3 = [ return p ]; // block of level 0, defined at level 2
        :b2_4 = [ Out println: %a2 ]; // block of level -1, defined at level 2
        :b2_5 = [ // block of level 2 because it uses a2  
                  // level 3
        :a3 = 3;
        :b3_1 = [ b1_1 eval ]; // block of level 1, defined at level 3
        :b3_2 = [ ++a2; return ]; // block of level 2, defined at level 3
        :b3_3 = [ ~a3 ]; // block of level 3, defined at level 3
        :b3_4 = [ return ]; // block of level 0, defined at level 3
        :b3_5 = [ ~p ]; // block of level -1, defined at level 3
    ]
]

b1_3 eval;
return 0
]
```

A block of level -1 may access local variables using %, parameters without using %, and instance variables. Blocks of level -1 are called *u-blocks* or *unrestricted-use blocks*. There is no restriction on the use of u-blocks: they may be passed as parameters, returned from methods, returned from blocks, assigned to instance variables, or assigned to any variable. They only have the type restrictions of regular objects.

Blocks of levels 0 and up are called *r-blocks* or *restricted-use blocks*. There are limitations in their use: they cannot be stored in instance variables, returned from methods and blocks, and there are limitations on the assignment of them to local variables. This will soon be explained.

An r-block that takes parameters of types T1, T2, ..., Tn and returns a value of type R inherits from prototype `AnyBlock<T1, T2, ..., Tn><R>` and implements interface `@restricted interface Block<:T1, :T2, ..., :Tn><:R>`

```plaintext
@restricted interface Block<:T1, :T2, ..., :Tn><:R>
    fun eval: (T1, T2, ..., Tn) -> R
end
```

`@restricted` is a pre-defined metaobject that restricts the way this kind of block is used — see Section[10.4] These restrictions apply to this interface only. It does not apply to

(a) interfaces that extend it;

(b) prototypes that implements it.

Prototype `AnyBlock<T1, T2, ..., Tn><R>` is defined as

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An r-block that does not take any parameters implements

```java
@restricted interface Block<:R>
    fun eval -> R
end
```

and inherits from

```java
@restricted abstract object AnyBlock<:R>
    public abstract fun eval -> R
end
```

There is a special prototype `AnyBlock<Boolean>` with methods `whileTrue:` and `whileFalse:`:

```java
@restricted abstract object AnyBlock<:R>
    public abstract fun eval -> Boolean
    public fun whileTrue: (:aBlock Block) [
        (self eval) ifTrue: [
            aBlock eval;
            self whileTrue: aBlock
        ]
    ]
    public fun whileFalse: (:aBlock Block) [
        (self eval) ifFalse: [
            aBlock eval;
            self whileFalse: aBlock
        ]
    ]
end
```

These methods implement the `while` construct as explained in Section 3.6. Interface `Block<Boolean>` declares methods `whileTrue:` and `whileFalse:`.

An r-block that does not take any parameters and returns `Void` implements

```java
@restricted interface Block
    fun eval
end
```

and inherits from `AnyBlock`.

```java
@restricted abstract object AnyBlock
    public abstract fun eval
    public fun loop [
        self eval;
        self loop
    ]
    public fun repeatUntil: (:test Block<Boolean>) [
        self eval;
        (test eval) ifFalse: [
            self repeatUntil: test
        ]
    ]
end
```
Method `loop` implements an infinite loop and `repeatUntil` implements a loop that ends when the block parameter evaluates to `true`.

The compiler replaces any uses of `Block<Void>` and `AnyBlock<Void>` by `Block` and `AnyBlock`, respectively. That makes sense since these are different names for the same interface.

An u-block that takes parameters of types `T1, T2, ..., Tn` and returns a value of type `R` inherits from prototype `AnyUBlock<T1, T2, ..., Tn><R>` and implements interface

```
@unrestricted interface UBlock<:T1, :T2, ..., :Tn><:R>
    extends Block<T1, T2, ..., Tn><R>
end
```

Therefore the above interface also defines a method

```
fun eval: (T1, T2, ..., Tn) -> R
```

Prototype `AnyUBlock<T1, T2, ..., Tn><R>` is defined as

```
@unrestricted abstract object AnyUBlock<:T1, :T2, ..., :Tn><:R>
    extends AnyBlock<T1, T2, ..., Tn><R>
end
```

An u-block that does not take any parameters implements

```
@unrestricted interface UBlock<:R> extends Block<R>
    fun eval -> R
end
```

and inherits from

```
@unrestricted abstract object AnyUBlock<:R> extends AnyBlock<R>
end
```

There is a special prototype `AnyUBlock<Boolean>` with methods `whileTrue:` and `whileFalse:` inherited from `AnyBlock<Boolean>`.

```
@restricted abstract object AnyUBlock<Boolean> extends AnyBlock<Boolean>
end
```

An u-block that does not take any parameters and returns `Void` implements

```
@unrestricted interface UBlock extends Block
end
```

and inherits from

```
@unrestricted abstract object AnyUBlock extends AnyBlock
end
```

The compiler replaces any uses of `UBlock<Void>` and `AnyUBlock<Void>` by `UBlock` and `AnyUBlock`, respectively.
Every block has its own prototype that inherits from one of the AnyBlock or AnyUBlock objects and that implements one of the Block or UBlock interfaces. When the compiler finds a block

\[
\text{[ } \ ^{\text{n}} \text{ ]}
\]

it creates a prototype Block001 that inherits from AnyBlock<Void'><Int> and implements Block<Void'><Int> (assume that n is a local Int variable). The name Block001 was chosen by the compiler and it can be any valid identifier. If this block is assigned to a variable in an assignment,

\[
:b = \text{[ } \ ^{\text{n}} \text{ ]}
\]

the type of b will be Block001. Of course, Block001 is declared with the @restricted metaobject. As another example, the type of variable add in

\[
:add = \{ \text{[ } \ ^{\text{n}} \text{ Int} | \ ^{\text{n}} + 1 \text{ ]}
\]

could be UBlock017. Since this block inherits from AnyUBlock<Int><Int> and implements UBlock<Int><Int>, we can declare add before assigning it a value as

\[
// Or use UBlock<Int><Int> here
:add AnyUBlock<Int><Int>;
\]

\[
add = \{ \text{[ } \ ^{\text{n}} \text{ Int} | \ ^{\text{n}} + 1 \text{ ]}
\]

Note that there are two pairs of <...> in Block<T1, ... Tn><R>. This is only possible with blocks, block interfaces, and the ContextObject interface which deserve a special treatment in Cyan\(^5\).

All methods of a block but eval: are regular methods. eval: methods of blocks are called \emph{primitive} methods. A primitive method is not an object. The only allowed operation on a primitive method is to call it.

\(^5\)For short, the power of separating arguments in a generic prototype or interface is not given to the programmer. Maybe this will change in the future.
Figure 10.2 shows a hierarchy of block prototypes. Block005 is a literal r-block such as
[ ++n ]
that does not take parameters and returns Void. The compiler creates a new object for each block and we can assume blocks are named block001, block002, and so on. This block inherits from AnyBlock and implements interface Block as show in the Figure. Interfaces are inserted in dashed boxes. Assume n is a local variable.

Figure 10.3 shows the hierarchy of an u-block that takes an Int as parameter and returns a Char such as
[ |:n Int -> Int| ~ Char cast: n ]
Assume the compiler gave to this block the name UBlock008. This object inherits from AnyUBlock<Int><Char> and implements interface UBlock<Int><Char>.

Blocks are them a special kind of object, one that has a method, eval: or eval that is not an object. Only eval: or eval methods of blocks are primitive methods. However, all prototypes that implement interface UBlock or Block can be passed as an argument to a method that expect an UBlock or Block as a real parameter. For example, an Int array defines a foreach: method that expects an r-block as parameter that accepts an Int parameter and returns Void. One can pass as parameter a regular object:

```object
object Sum implements UBlock<Int><Void>
    public :sum = 0
    public fun eval: (:elem Int) [
        sum = sum + elem
    ]
end
...
:v Array<Int> = {# 2, 3, 5, 7, 11, 13 #};
:v foreach: Sum;
Out println: "array sum = " + (Sum s);
```

### 10.4 Type Checking Blocks

Now it is time to unveil the rules that make blocks statically typed in Cyan. Any restriction that applies to Block with any real argument types also applies to AnyBlock with the same argument types. The rules are:

(a) there is no restriction on the use of u-blocks and variables whose type is UBlock<...,<R>, UBlock<>, AnyUBlock<...,<R>, or AnyUBlock<>. An instance variable can have type UBlock<...,<R>;

(b) instance variables cannot have type Block<T1, ..., Tn><R> or Block<R>;

(c) methods and blocks cannot have Block<T1, ..., Tn><R> or Block<R> as the return type;

(d) a variable r declared at level k whose type is Block<T1, ..., Tn><R> (or Block<R>) may receive in assignments:

- a variable s of level m if m ≤ k and the type of s is Block<T1, ..., Tn><R> (or Block<R>) or one of its subtypes, including UBlock<T1, ..., Tn><R> (or UBlock<R>);
- an r-block of level m if m ≤ k and this r-block implements interface Block<T1, ..., Tn><R> (or Block<R>);
• an u-block that implements interface UBlock<T1, ... Tn><R>;

(e) a parameter whose type is Block<T1, ... Tn><R> (or Block<R>) is considered a variable of level 0. The real argument corresponding to this parameter may be a variable or block of any level. Of course, the type of the variable or block should be Block<T1, ... Tn><R> (Block<R>) or one of its subtypes;

(f) a variable or parameter whose type is Any cannot receive as real argument any r-block. Unfortunately this introduces an exception in the subtype hierarchy: a sub-prototype may not be a sub-type. For example, Block is not subtype of Any. Although a block like [ ^0 ] inherits from Any (indirectly), its type is not considered subtype from Any. The only way of correcting this is allocating the local variables in the stack — see Section 10.12. But that is inefficient to say the least.

Based on the rules for type checking blocks, one can conclude that:

(a) instance variables can be referenced by both u-blocks and r-blocks;

(b) a block that has a return statement but does not access any local variables is a block of level 0. Its type is Block<T1, ... Tn><R> (or Block<R>) for some types Ti and R;

(c) the restriction “methods and blocks can have UBlock<T1, ... Tn><R> (or UBlock<R>) as the return type (but not Block<T1, ... Tn><R> or Block<R>)” could be changed to “a method can only return u-blocks and a block defined at level k can only return a block if it is of level m with m ≤ k”. In the same way, a block defined at level k can have a variable as the return value if this variable is of level m with m ≤ k. However, we said “could”, these more liberal rules are not used in Cyan;

(d) since parameters are read-only, it is not possible to assign a variable or block to any of them;

(e) both r-blocks and u-blocks can access instance variables since their use do not cause any problems — instance variables belong to objects allocated in the heap, a memory space separated from the stack. Then it is legal to return a block that accesses an instance variable or to assign such a block to any UBlock variable:

```java
object Person
    @init(name, age)
    public fun init [ ]
        private fun blockCompare -> UBlock<Person><Boolean> [ 
            return [ |:p Person| ^age > (p age) ]
        ]
    public :name String = "noname"
    public :age Int = 99
end
...
:myself = Person new;
    // method name: String age: Int is automatically created
myself name: "José" age: 14;
if ( (Person blockCompare) eval: myself ) [ 
    Out println: "Person is older than José";
]
```
(f) the type of an instance variable or return method value cannot be an r-block. But it can be an u-block. Therefore there will never be an instance variable referring to a block that has a reference to a local variable. And a block returned by a method will never refer to a local method variable;

(g) a parameter that has type Block<Type1, ... TypeN,R> cannot be assigned to any variable of the same type because this variable is of level at least 1 and the parameter is of level -1;

(h) the generic prototype Array<T> declares an instance variable of type T. Therefore the generic array instantiation Array<Block<Type1, ... TypeN,R>> causes a compile-time error — r-blocks cannot be types of instance variables. In the same way, Block<Type1, ... TypeN,R> cannot be the parameter to most generic containers (yet to be made) such as Hashtable, Set, List, and so on.

This is regrettable. We cannot, for example, create an array of r-blocks:

```
:sum Float = 0;
:prod Float = 0;
:sumSqr Float = 0;
mySet applyAll: {# [[:it Float| sum += it ],
                     [:it Float| prod *= it ],
                     [:it Float| sumSqr += it*it ] #};
```

Future version of Cyan could employ a different rule: a restricted block or any restricted object could be the type of an instance variable of prototype P if P is a restricted object (declared with metaobject @restricted). Arrays, tuples, and the like would automatically be restricted or not according to the parameter type. So Array<Block<Int,R>> would be a restricted type but Array<UBlock<Int>> would not.

The rules for checking the use of r-blocks are embodied in metaobject @restricted. The compiler passes the control to this metaobject when type checking r-blocks. It then implements the above rules.

### 10.5 Some Block Examples

In the example that follows, some statements are never executed when message run is sent to A. In particular, when message eval is sent to b in (b eval == 0) the control returns to method run which prints 0. All the intervening methods are removed from the stack of called methods.

```object A
public fun run [ 
    Out println: (self m)
]
public fun m -> Int [ 
    p: [ return 0 ];
    Out println: "never executed";
]
public fun p: (:b Block<Void>) [ 
    t: b;
    Out println: "never executed";
]
public fun t: (:b Block<Void>) [ 
    (b eval == 0) ifTrue: [ 
        Out println: "never executed";
    ]
]```
In this example, an r-block is passed as a parameter. There is no runtime error.

```cyan
object A
  public fun aMethod [x Int;
    x = In readInt;
    Out println: (anotherMethod: [\:y Int \^y + x]);
  ]
  public fun anotherMethod: (:b Block<Int><Int>) -> Int [^yetAnotherMethod: b;]
  public fun yetAnotherMethod: (:b Block<Int><Int>) -> Int [
    ^b eval: 0;
  ]
...
end
```

Method `aMethod` calls `anotherMethod` which calls `yetAnotherMethod`. No reference to block `[^y Int \^y + x]` last longer than local variable `x`.

A parameter of type `Any` cannot receive an r-block as real argument. If it could, a runtime error would occur.

```cyan
object Test
  public fun test [n = 0;
    // block passed as parameter. The
    // real argument has type Any
    do: [ ++n ]
  ]
  public fun do: (:any Any) [self.any = any]
  public fun makeError [
    // access to local variable n
    // that no longer exists
    any ?eval
  ]
  private :any Any
end
```

### 10.6 Why Blocks are Statically-Typed in Cyan

This section does not present a proof that blocks in Cyan are statically typed. It just gives evidences of that.
To introduce our case we will use blocks $B_0, B_1, \ldots, B_n$ in which $B_i$ is defined at level $i$ and $B_{i+1}$ is defined inside $B_i$. So there is a nesting

$$B_n \subset B_{n-1} \subset \ldots \subset B_1 \subset B_0$$

It was used $\subset$ to mean “nested in”. Block $B_j$ declares a local variable $v_j$. Note that $B_0$ is the body of a method (blocks of level 0 are always methods).

Suppose $B_n$ uses external local variables $v_{i_1}, v_{i_2}, \ldots, v_{i_k}$ of blocks $B_{i_1}, B_{i_2}, \ldots, B_{i_k}$ with $i_1 < i_2 < \ldots i_{k-1} < i_k$. It is not important whether $B_n$ uses or not more than one variable of each block.

Let us concentrate on $B_{i_k}$ which defines variable $v_{i_k}$ accessed by $B_n$. Since there is a nesting structure, blocks $B_{i_k+1}, B_{i_k+2}, \ldots, B_{n-1}$ also have references to $v_{i_k}$ (because $B_n$ is nested inside these blocks). This fact is used in the following paragraph.

$B_n$ can be assigned to a block variable of $B_j$ with $i_k \leq j < n$. This does not cause a runtime error because a block $B_j$ with $i_k \leq j < n$ is only called when $B_{i_k}$ is in the stack. $B_j$ cannot be assigned to a variable $b_t$ of level $t$ with $t < i_k$ because $B_j$ also has a reference to $v_{i_k}$ and, by the rules, it can only be assigned to variables that appear in block $B_t$ with $i_k \leq t < j$.

$B_n$ also has a reference to variable $v_{i_{k-1}}$ of $B_{i_{k-1}}$. Therefore $B_n$ could not be assigned to block variables of blocks $B_j$ with $j < i_{k-1}$. Considering all cases, $B_n$ cannot be assigned to block variables of blocks $B_j$ with

- $j < i_1$
- $j < i_2$
- $\ldots$
- $j < i_{k-1}$
- $j < i_k$

Since $i_1 < i_2 < \ldots i_{k-1} < i_k$, we conclude that $B_n$ cannot be assigned to a block variable of block $B_{i_k}$. Then $B_n$ can only be assigned to a block variable of block $B_j$ with $j \geq i_k$. This is what one of the rules of Section 10.4 says. Therefore these rules prevent any runtime errors of the kind “access to a block variable that does not exist anymore” related to the assignment of r-blocks to local variables. It is not difficult to see that the other rules prevent all of the other kinds of errors related to r-blocks such as the passing of parameters, assignment of blocks to Any variables, assignment of r-blocks to instance variables (not allowed), and so on.

### 10.7 Blocks with Multiple Selectors

Regular blocks only have one selector, which is eval: or eval (when there is no parameter). It is possible to declare a block with more than one eval: selector. One can declare

```latex
:b = [ | eval: (:p_{11} T_{11}, :p_{12} T_{12}, \ldots, :p_{1k_1} T_{1k_1})
          eval: (:p_{21} T_{21}, :p_{22} T_{22}, \ldots, :p_{2k_2} T_{2k_2})
          \ldots
          eval: (:p_{n1} T_{n1}, :p_{n2} T_{n2}, \ldots, :p_{nk_n} T_{nk_n})
          \rightarrow R | ]
```

// block body

Consider a block with a method composed by n eval: selectors. The i\textsuperscript{th} eval selector has k\textsubscript{i} parameters. This block inherits from prototype

AnyBlock<T\textsubscript{11}, T\textsubscript{12}, \ldots, T_{1k_1}><T\textsubscript{21}, T\textsubscript{22}, \ldots T_{2k_2}>\ldots<T\textsubscript{n1}, T\textsubscript{n2}, \ldots T_{nk_n}><R>

and implements interface
A similar u-block inherits from the corresponding AnyUBlock generic prototype and implements the corresponding UBlock interface.

The eval method corresponding to the above block is

```java
public fun eval: (:p
11\ T
11, \ :p\ 12\ T\ 12, \ ..., \ :p\ 1k1\ T\ 1k1) 
  eval: (:p\ 21\ T\ 21, \ :p\ 22\ T\ 22, \ ..., \ :p\ 2k2\ T\ 2k2) 
  ... 
  eval: (:p\ n1\ T\ n1, \ :p\ n2\ T\ n2, \ ..., \ :p\ nk\ T\ nk)n) 
  \rightarrow R [ 
    // block body
  ]
```

As an example, one can declare a block

```java
:b Block<String><Int><Void>; 
b = [ | eval: (:key String) eval: (:value Int) |
  Out println: "key #key is #value"
]; 
// prints "key One is 1"
b eval: "One" eval: 1;
```

### 10.8 The Type of Methods and Methods as Objects

Methods are objects in Cyan although of a special kind: they are blocks. Then every method

```java
public fun s1: (:p
11\ T
11, \ :p\ 12\ T\ 12, \ ..., \ :p\ 1k1\ T\ 1k1) 
  s2: (:p\ 21\ T\ 21, \ :p\ 22\ T\ 22, \ ..., \ :p\ 2k2\ T\ 2k2) 
  ... 
  sn: (:p\ n1\ T\ n1, \ :p\ n2\ T\ n2, \ ..., \ :p\ nk\ T\ nk)n) 
  \rightarrow R [ 
    // block body
  ]
```

extends

AnyUBlock<T
11, \ T\ 12, \ ..., \ T\ 1k1>,<T\ 21, \ T\ 22, \ ... \ T\ 2k2>,...,<T\ n1, \ T\ n2, \ ... \ T\ nk>n><R>

and implements interface

UBlock<T
11, \ T\ 12, \ ..., \ T\ 1k1>,<T\ 21, \ T\ 22, \ ... \ T\ 2k2>,...,<T\ n1, \ T\ n2, \ ... \ T\ nk>n><R>

Cyan methods are then unrestricted blocks. A method of a specific object is got using the syntax "obj.{signature}" in which signature is the method signature (selectors, parameter types, and return value type).

Consider the Box prototype:

```java
object Box
  public fun get -> Int [ return value ]
  public fun set: (:other Int) [ value = other ]
  private :value Int = 0
end
```

Methods of this prototype and of objects created from it can be accessed as in
:getMethod UBlock<Int>;
:setMethod UBlock<Int><Void>;
:anotherGetMethod UBlock<Int>;

getMethod = Box.{get -> Int}.;
setMethod = Box.{set: Int}.;
:box = Box new;
box set: 10;

setMethod eval: 5;
   // prints 5
Out println: (getMethod eval);
   // prints 0
Out println: (box get);

This syntax can be used to set a method of a prototype such as

:local Int;
:b Box = Box new;
b.{get -> Int}. = [ ^0 ];
b.{set: Int}. = [ |:n Int| Out println: n ];
assert: (b get == 0);
   // method getDay of Date returns an Int
b.{get -> Int}. = Date.{getDay}.;

A method of a prototype may be set too. The existing objects of that prototype are affected — they will use the new method.

:before Box = Box new;
before set: 0;
Box.{get -> Int}. = [ ^1 ];
:after Box = Box new;
assert: (before get == 1);
assert: (after get == 1);

As seen before, eval: methods of blocks are not objects. They are called primitive methods. Although it is legal to call a primitive method, it is illegal to retrieve one using .{signature}.

:b UBlock<Int>;
:getMethod UBlock<Int>;

getMethod = Box.{get -> Int}.;
   // runtime error in the next line
b = getMethod.{eval -> Int}.;
   // runtime error in the next line
b = [ | -> Int | ^0];

Of course, the second runtime error will never occur because of the first. But you got the idea.

Although “b.{eval -> Int}.” has type UBlock<Int> (as variable b has), there is a runtime error: it is not legal to retrieve a primitive method as an object. They are not objects and cannot be treated as such.
Methods that access instance variables are duplicated for every object of the prototype (at least conceptually). If two objects of prototype Box are created then there are three instances that represent method get (and three for set too, of course). This occurs because the method object closes over the instance variables of the prototype in the same way a block closes over the local variables of a method. As there are three objects there are three instance variables called value and three methods for get, each one closing over one of the instance variables.

As an example of duplicating methods as objects, the following code compares two get methods of different Box objects. Since they come from different objects, they are different.

```plaintext
// create a get method for the new object
:box = Box new;
// create another get method for the new object
:other = Box new;
assert: box.{get -> Int}. != other.{get -> Int}.;
```

The same situation occurs with blocks:

```plaintext
:n = 0;
1..3 repeat: [
    :value Int = n;
    ++n;
    :getBlock = [ ^value ];
    Out println: (getBlock value);
]
```

Since the block that is parameter to repeat: is executed three times, three blocks objects [ ^value ] are created, each of them closes over the local variable value. Note that variable value is created three times since it is a local variable to the most external block.

A method defined as

```plaintext
public fun s1: (:p1_1 T_{11}, :p1_2 T_{12}, ..., :p1_k_1 T_{1k_1})
    s2: (:p2_1 T_{21}, :p2_2 T_{22}, ..., :p2_k_2 T_{2k_2})
    ...
    sn: (:p_n_1 T_{n1}, :p_n_2 T_{n2}, ..., :p_n_k_n T_{nk_n})
    -> R [ // block body
    ]
```

assigns to slot s1:s2: ...sn: an u-block with the same method parameters and same return value type as the method. This definition is equivalent to

```plaintext
public fun s1: s2: ... sn: = [ // block body
    eval: (:p1_1 T_{11}, :p1_2 T_{12}, ..., :p1_k_1 T_{1k_1})
    eval: (:p2_1 T_{21}, :p2_2 T_{22}, ..., :p2_k_2 T_{2k_2})
    ...
    eval: (:p_n_1 T_{n1}, :p_n_2 T_{n2}, ..., :p_n_k_n T_{nk_n})
    -> R |
    // statement list
]
```

Statements if and while use blocks without parameters or return values (type Block). Any block can be used with them:
:ok Boolean;
:aBlock Block = [ "bye" print ];

...  

    // regular message send
ok ifTrue: file.{open}. ifFalse: "bye".{print}. ;
if ( ok ) file.{open}. else "bye".{print}. ;

ok ifTrue: aBlock;
if ( ok ) aBlock;

while ( (In readInt) != 0 ) 
    "different from zero" print 
];

while ( (In readInt) != 0 ) 
    "different from zero".{print}. ;

10.9 Message Sends

When a message is sent, the runtime system looks for an appropriate method in the object that received
the message. This search has already been explained in Section [L11]. After finding the correct method
m, two actions may be taken:

(a) if m is an u-block, the primitive method eval: of the block is called;

(b) if m is a regular object, message eval or eval: ... that matches the original message is sent to m
(with the original parameters). In this case, m should implements one of the UBlock interfaces.

In the following example, MyMethod implements an u-block interface that is compatible with a method
that has two selectors taking an Int and a String as parameters and returning a String. Then it is
legal to assign MyMethod to method at:put: of Test.

object MyMethod implements UBlock<Int><String><String>
    public fun eval: (:index Int) eval: (:value String) -> String [
        Out println: "at #{index} we put #{value}";
        return value
    ]
end

object Test
    public fun run [
        self at: 0 put: "zero"
    ]
    public fun at:put: = MyMethod
end

When run is called, it calls method at:put: of Test. The runtime system sends message
eval: 0 eval: "zero"
to object MyMethod. It is as if we had defined at:put: as

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object Test
...
    public fun at: (:index Int) put: (:value String) -> String = [
        return MyMethod eval: index eval: value
    ]
end

In fact, that is how assignments of objects to methods are implemented.
Using methods as objects is very convenient in creating graphical user interfaces. Listeners can be regular methods. See the example.

object MenuItem
    public fun onMouseClick: (:b UBlock) [ ...
end

object Help
    public fun show [ ... ]
end

object FileMenu
    public fun open [ ... ]
end

...
:helpItem = MenuItem new;
helpItem onMouseClick: Help.{show}..;
:openItem = MenuItem new;
openItem onMouseClick: FileMenu.{open}..;
...

10.10 Methods of Blocks for Decision and Repetition

Objects Block<Boolean> and UBlock<Boolean> define some methods used for decision and iteration statements. The code of these methods is shown below.

object AnyBlock<Boolean>
    public fun whileTrue: (:aBlock Block) [
        (self eval) ifTrue: [
            aBlock eval;
            self whileTrue: aBlock
        ]
    ]
    public fun whileFalse: (:aBlock Block) [
        (self eval) ifFalse: [
            aBlock eval;
            self whileFalse: aBlock
        ]
    ]
end
10.11 Context Blocks

Prototype Any (Section 4.13) defines a grammar method for dynamically adding methods to prototypes. It is necessary to specify each selector, the types of all parameters, the return value type, and the method body. This grammar method has the signature

public fun (addMethod:
  (selector: String (param: (Any)+)?
  )+
  (returnType: Any)?
  body: ContextObject)

Suppose we want to add a print method dynamically to prototype Box:

object Box
  public fun get -> Int [return value]
  public fun set: (:other Int) [value = other]
  private :value Int = 0
end

We want to add a print method to every object created from Box or that has already been created using this prototype using new or clone (with the exception to those objects that have already added a print method to themselves). This method, if textually added to Box, would be

public fun print [Out println: get]

Note that Any already defines a print method. However, the method print we define has a behavior different from that of the inherited method.

A first attempt would to add print dynamically would be

Box addMethod:
  selector: #print
  body: [Out println: get];

However, there is a problem here: it is used get in the block that is parameter to selector body:. The compiler will search for a get identifier in the method in which this statement is, then in the prototype, and then in the list of imported prototypes, constants, and interfaces. Anyway, get will not be considered as a method of Box, which is what we want. A second attempt would be

Box addMethod:
  selector: #print
  body: [Out println: (Box get)];

Here it was used Box get instead of just “get”. But then the print method of every object created from Box will use the get method of Box:

:myBox = Box new;
myBox set: 5;
Since the print method was dynamically added, it has to be called using #. In this example, both calls to print used the get method of Box, which returns the value 0.

This problem cannot be solved with regular blocks. It is necessary to define a new kind of block, context block to solve it. A context block is declared as

\[ (:\text{self } T)[ \text{parameters and return type}\|\text{body} ] \]

Part “(:self T)” is new. It means that inside the method body self has type T. Therefore the identifiers visible inside the block body are those declared in the block itself and those accessible through T. Therefore a code like

\[ :b = (:\text{self } \text{Any})[ \sim n < 0 ] \]

is illegal even if there is a local variable or a unary method called n. Since this identifier is not a variable declared inside the block, it should be a unary method of Any. As it is not, there would be a compile-time error.

The print method can now be adequately added to Box.

Box addMethod:

```
selector: #print
body: (:\text{self } \text{Box})[ \text{Out println: get} ];
```

Now the print method will send message get to the object that receives message #print:

```
:myBox = \text{Box new};
myBox set: 5;
Box set: 0;
   // prints 0
Box print;
   // prints 5
myBox print;
```

Method addMethod: ... checks whether the context object passed in selector body: matches the selectors, parameters, and return value.

// error: block with parameter, selector without one

Box addMethod:

```
selector: #add
param: \text{Int}
returnType: \text{Int}
body: (:\text{self } \text{Box})[ \text{\sim get asString} ];
```

The compiler creates a context object\[6\] from a context block. For example, from context block

\[ (:\text{self } \text{Box})[ \text{Out println: get} ] \]

---

\[6\]Chapter 11 define context objects, which are a generalization of blocks.
the compiler creates the context object

```plaintext
object ContextObject001{newSelf %Box}
    implements UBlock<Void>, ContextObject<Box><Void>

    public fun newObject: (:newSelf Box) -> UBlock<Void> [  
        return ContextObject001 new: newSelf
    ]
    public fun eval [  
        Out println: (newSelf get)
    ]
end
```

which is further transformed, internally, into the regular object

```plaintext
object ContextObject001 implements UBlock<Void>, ContextObject<Box><Void>
    public fun new: (:newSelf Box) -> ContextObject001 [  
        :newObj = self primitiveNew;
        newObj bind: newSelf;
        return newObj;
    ]
    public fun newObject: (:newSelf Box) -> UBlock<Void> [  
        // the return is type correct because  
        // ContextObject001 is subtype of UBlock<Void>
        return ContextObject001 new: newSelf
    ]
    public bind: (:newSelf Box) [  
        self.newSelf = newSelf
    ]

    private :newSelf Box

    public fun eval [  
        Out println: (newSelf get)
    ]
end
```

Both `new:` and `newObject:` are necessary because `new:` is not part of the object interface. It cannot be called on an instance of this prototype.

Generic interface `ContextObject` with three parameter types is declared as

```plaintext
interface ContextObject<:T><:P><:R> extends ContextObject
    fun newObject: (:newSelf T) -> UBlock<P><R>
end
```

Interface `ContextObject` is just

```plaintext
interface ContextObject
end
```

There are `ContextObject` generic interfaces with two parameters, used when the context block does not take arguments:

```plaintext
interface ContextObject<:T><:R> extends ContextObject
```
At compile time a metaobject `checkAddMethod` checks whether the parameter to `body:` implements generic interface `ContextObject` for some parameters `T`, `P`, and `R`. In fact, there are other variations of this generic object and each one of them corresponds to one variation of generic object `UBlock`. For example,

```plaintext
interface ContextObject<:T><:P1, :P2><:P3><:R>
    fun newObject: (:newSelf T) -> UBlock<P1, P2><P3><R>
end
```

Metaobject `checkAddMethod` also checks whether the `ContextObject` instantiation implemented by the `body` parameter matches the selectors, parameters, and return value specified in this message send. In our example,

Box `addMethod:`
- selector: `#print`
- body: `(:,self Box)[ Out println: get ]`

the compiler creates a `ContextObject001` prototype from this context block and this prototype implements

```plaintext
ContextObject<Box><Void>
```

that defines a method

```plaintext
  public fun newObject: (:newSelf Box) -> UBlock<Void>
```

As expected, `ContextObject001` also implements an interface `UBlock<Void>` that matches the selectors (just one, `print`), parameters (none), and return value (`Void`) specified in the call to `addMethod:` ...

In a more general case, when the compiler finds the context block

```plaintext
(:,self T)[ [:p P -> R| body ]
```

it creates the context object

```plaintext
object ContextObject002(:newSelf %T) extends UBlock<P><R>, ContextObject<T><P><R>

    public fun newObject: (:newSelf T) -> UBlock<P><R> [ return ContextObject002 new: newSelf ]

    public fun eval: (:p P) -> R [ body ]
end
```

which is further transformed, internally, into the regular object

```plaintext
object ContextObject002 extends UBlock<P><R>, ContextObject<T><P><R>

    public fun new: (:newSelf T) -> ContextObject002 [ :newObj = self primitiveNew; newObj bind: newSelf; return newObj; ]

    public fun newObject: (:newSelf T) -> UBlock<P><R> [
```
Let us see an example of use of context blocks.

```
:myContextBlock = (:self Box)[ |:p Int -> Int| ^get + p ];
Box set: 5;
:b Block<Int><Int> = myContextBlock newObject: Box
assert: (b eval: 3) == 8;
```

```
:anotherBox = Box new;
anotherBox set: 1;
b = myContextBlock newObject: (anotherBox);
assert: (b eval: 3) == 4;
```

In one of the examples given above, a print method is added to prototype Box through addMethod: .... When this grammar method is called at runtime, method print will be added to all instances of Box that have been created and that will created afterwards. However, if an instance of Box has added another print method, it is not affected:

```
:myBox = Box new;
myBox set: 10;
myBox addMethod:
    selector: #print
    body: (:self Box)[ Out println: "value = #{get}" ];
Box addMethod:
    selector: #print
    body: (:self Box)[ Out println: get ];
    // will print "value = 10" and not just "10"
myBox print;
```

Another method that takes a parameter and returns a value can be added to Box:

```
Box addMethod:
    selector: #returnSum
    param: Int
    returnType: Int
    body: (:self Box)[ |:p Int -> Int| ^get + p ];
```

The metaobject attached to this grammar method checks whether the number of selectors (one), the parameter type, and the return value type matches the context block. It does in this case.
assert (myBox ?returnSum: 3) == 8;

As another example, one can add methods to change the color of a shape:

```plaintext
object Shape
  public :color Int;
  public abstract fun draw ...
end ...
```

:colors = {# "blue", "red", "yellow", "white", "black" #};
  // assume that hexadecimal integer numbers can
  // be given in this way
:colorNumbers = {# ff_Hex, ff0000_Hex, ffff00_Hex, ffffff_Hex, 0 #};
:i = 0;
colors foreach: [
  |:elem String|
  Shape addMethod:
    selector: elem
    body: (:self Shape)[ color: colorNumbers[i] ];
    ++i;
];

Methods blue, red, yellow, white, and black are added to Shape. So we can write

```plaintext
:myShape Shape;
...
myShape ?blue;
  // draws in blue
myShape draw;
myShape ?red;
  // draws in red
myShape draw;
  // Square is a sub-object of Shape
:sqr Square = Square new;
...
:sqr ?black;
  // draws in black
:sqr draw;
```

Assume that draw of sub-prototypes use the color defined in Shape.

We could have got the same result as above by adding all of these methods to Shape textually. For example, method blue would be

```plaintext
public fun blue [ color: ff_Hex ]
```

The object passed as argument to the selector body: of the grammar method addMethod: ... can also be a context object. That is explained in Chapter [11].

Suppose you want to replace a method by a context block that calls the original method after printing a message. Using the Box prototype, we would like something like this:

```plaintext
object Box
```
```plaintext
public fun get -> Int [ return value ]
public fun set: (:other Int) [ value = other ]
private :value Int = 0
end

...
Box set: 0;
Box addMethod:
    selector: #get
    returnType: Int
    body: (:self Box)[
        Out println: "getting #value";
        self get
    ];
It is a pity this does not work. In a call “Box get” made after the call to addMethod: ..., the context block will be called. It prints
    getting 0
as expected but them it calls get, which is a recursive call. There is an infinity loop. What we would like is to call the original get method. That cannot be currently achieved in Cyan. However, it will be possible if context blocks are transformed into “literal dynamic mixins” (LDM) or “literal runtime metaobjects” (LRM). This feature is not yet supported by Cyan. But the description of it would be as follows.

The syntax of LRM’s would be the same as that of context blocks except that “super” could be used as receiver of messages. Calls to super are calls to the original object. Then the code above can be written as
Box set: 0;
Box addMethod:
    selector: #get
    returnType: Int
    body: (:self Box)[
        Out println: "getting #value";
        super get
    ];
In this way a call “Box get” would print “getting 0” and the original get method would be called. Exactly what we wanted.

We are unaware of any language that allows literal runtime metaobjects. That would be one more innovation of Cyan.

This feature has not been introduced into Cyan because:

(a) it seems to be difficult to implement (which may not be a good reason). The compiler being built generates Java code and literal runtime metaobjects probably demand code generation at runtime, which would be difficult with Java (although not impossible);

(b) there are some questions on what is the type of a LDM/LRM. This is the same question of “what is the type of a mixin prototype?”.
```
10.12 Implementing r-Blocks as u-Blocks

There is a way of implementing every block as an u-block. It is only necessary to allocate all local variables used in blocks in the heap. That is, not only the objects the local variables refer to are dynamically allocated. Space for the variables should also be put in the heap. Usually local variables are put in the stack. Then if local variable n of type Int is used inside a block, n will refer to an object that has a reference to an integer. There will be a double indirection. We will explain how to allocate variables in the heap using an example.

:n Int;
n = 0;
:k Int;
k = n;
assert: (n == 0);
:b = [ ++n ];
b eval;
assert: (n == 1);

Since Cyan is targeted to the Java Virtual Machine, we will show the translation of this code to Java.

IntBox n = new IntBox();
n.value = 0;
int k;
k = n.value;
assert(n == 0);
Closure00001 b = new Closure00001(n);
b.eval(); // ++b.n.value
assert(n == 1);

IntBox is just a box for an int value. It is this class that implements the double indirection.

class IntBox {
    public int value;
}

Each block such as [ ++n ] is translated to a Java class with an eval method:

    // [ ++n ]
class Closure00001 {
    public Closure00001(IntBox n) { this.n = n; }
    public void eval() { ++n.value; }
    private IntBox n;
}

The assignment k = n is translated into k = n.value since to k is assigned the integer value of n. The Java class generated by [ ++n ] contains an object of IntBox. Its instance variable n represents the variable n used inside the block, which should be a mirror of the local variable n. This is achieved by declaring both variables, the instance and the local variable, as objects of IntBox. Both variables refer to the same IntBox object. Changes in the value of the n variable in the Cyan code, be it the local variable or the instance variable, are translated as changes in the attribute value of this IntBox object. Since the IntBox variable is referred to by both variables, changes in it are seen by both variables.

Using this kind of block implementation, there would not be any runtime error in returning a block that accesses a local variable:
public fun canWithdraw -> Block<Float><Boolean> [  
    :limit = getLimit;  
    return [ |:amount Float| ^amount < limit ]  
]

Since several blocks would access the same variable, unusual objects can be dynamically created:

...  
// n is a local Int variable  
:n Int = 0;  
:h = Hashtable<String><Block> key: "inc" value: [ ++n ]  
    key: "dec" value: [ --n ]  
    key: "show" value: [ Out println: n ];  

h["inc"] eval;  
assert: (n == 1);  
h["inc"] eval;  
assert: (n == 2);  
h["sub"] eval;  
// prints 1  
h["show"] eval;

The only disadvantage of allocating local variables accessed by blocks in the heap would be efficiency. But in most cases in which blocks are used the compiler could optimize the code. Most of the time blocks are passed as parameters to methods of objects Boolean or to methods of another blocks (such as whileTrue:), which do not keep any references to them. Therefore in all of these common cases the compiler would not allocate local variables in the heap.

The Cyan compiler will generate Java code. This language does not support pointers to local variables, which are needed in order to efficiently implement blocks in Cyan. Neither do the Java Virtual Machine. Therefore the Cyan compiler will allocate in the heap, as shown above, all local variables accessed in blocks without %. Unfortunately.
Chapter 11

Context Objects

A Cyan block is a closure for it can access variables from its context as in the example:

```csharp
// sum the vector elements
:sum = 0;
v foreach: [ | :x Int | sum += x ];
```

Here the sum of the elements of vector `v` is put in variable `sum`. But `sum` is not a local variable or parameter of the block. It was taken from the environment. Then to use a block it is necessary to bind (close over) the free variables to some variables that are visible at the block declaration. `self` is visible in the closure and messages can be sent to it:

```csharp
v foreach: [ | :x Int | sum += self calc: x ];
```

Although blocks are tremendously useful, they cannot be reused because they are literal objects. A block that accesses local and instance variables is specific to a location in the source code in which those variables are visible. Even if the programmer copy-and-past the block source code it may need to be modified because the variable names in the target environment may be different. A generalization of blocks would make the free variables and the message sends to `self` explicit. That is what context objects do.

In Cyan it is possible to define a context object with free variables that can be bounded to produce a workable object. For example, the context object

```csharp
object Sum(:sum &Int) implements Block<Int><Void>

public fun eval: (:x Int) [

    sum += x

] end
```

defines method `eval:` and uses a free `Int` variable `sum`. Since there is a free variable, a message send `eval:` to object `Sum` would cause a runtime error — `sum` does not refer to anything (it refers to the `noObject` value). The type of `sum` is prefixed by `&`. That means any changes to `sum` are also made in the variable bound to it. It is as if `sum` and the variable bound to it were the same variable.

A context object cannot define any `init`, `init:`, `new new:`, or `clone` methods. The only way of creating a context object is by using a `new:` method created by the compiler (this will soon be explained).

A free variable of a context object such as `Sum` can be bounded by method `bind`. The free variables should be given as parameters:

```csharp
:v Array<Int> = {# 1, 2, 3 #};
...
The syntax `Sum(s)` means the same as

```
(Sum new: s)
```

which is the creation of an object from `Sum` passing `s` as a parameter. However, this is not a regular parameter passing — it is passing by reference as we will soon discover.

When the type of a context object parameter is preceded by `&`, the real argument should be a local variable. It cannot be a parameter of the current method or an instance variable.

### 11.1 Using Instance Variables as Parameters to Context Objects

In the last example, the free variables passed as parameters should be local variables of the method. They cannot be instance variables. Instance variables can only be passed as parameters if the parameter type is prefixed with `*`.

**object Sum(:sum *Int) implements Block<Int><Void>**

```
public fun eval: (:x Int) [
    sum += x
]
end
```

**object Test**

```
public fun totalSum: (:array Array<Int>) [
    array foreach: Sum(total)
]
public fun getTotal -> Int [
    ~total
]
private :total Int;
end
```

The next example shows object `IntSet` and context object `ForEach`. This last one works as an “inner class” or a “nested class” of the former. Whenever method `getIter` of an object `Obj` of type `IntSet` is called, it returns a new object `ForEach` that keeps a reference to the instance variable `intArray` of `Obj`.

**object ForEach(:array *Array<Int>) implements Iterable<Int>**

```
public fun foreach: (:b Block<Int><Void>) [
    0..(array size - 1) foreach: [
        |:index Int|
        b eval: array[index]
    ]
]
// a set of integers
object IntSet
    public fun init [  
        intArray = Array<Int> new  
    ]
    public fun getIter -> ForEach [  
        ^ForEach(intArray)  
    ]
    // methods to add, remove, etc.

    private :intArray Array<Int>
end

One could write
:set = IntSet new;
set add: 0 add: 1 add: 2;
:iter = set getIter;
iter foreach: [  
    |:elem Int|
    Out println: elem + " "
];

11.2 Passing Parameters by Copy

As with blocks, it is possible to use % to mean “a copy of the value of s”. However, % should be put only before the parameter type.

object DoNotSum(:sum %Int)
    public fun eval: (:x Int) [  
        sum = sum + x  
    ]
end
...

:s Int = 0;
v foreach: DoNotSum(s);
assert: (s == 0);

Here a copy of the value of s, 0, is passed as a parameter to the context object. This “parameter” is then changed. But the value of the original variable s remains unchanged. Parameters whose type is preceded by % will be called “copy or % parameters”. Parameters whose type is preceded by * are the “instance variable parameters” or * parameters. The ones preceded by & will be called “reference parameters” or & parameters.

A context object with a copy parameter may have any expression as real argument:

v foreach: DoNotSum(0);
{# 0, 1, 2 #} foreach: DoNotSum(Math factorial: 5);
Therefore, method parameters can be real arguments to DoNotSum. If no symbol is put before the parameter type of a context object, it is assumed that it is a copy parameter.

11.3 What the Compiler Does With Context Objects

The context object Sum is transformed by the compiler into a prototype

```c
object Sum implements Block<Int><Void>
    public fun new: (:sum &Int) -> Sum [
        :newSum = self primitiveNew;
        newSum bind: sum;
        return newSum
    ]
    public bind: (:sum &Int) [
        self.sum = sum
    ]
    private :sum &Int
    public fun eval: (:x Int) [
        sum += x
    ]
end
```

Symbol & put before a type means a “reference type”. It is the same concept as a pointer to a type in language C. To make Cyan type-safe, reference types can only be used in the declaration of parameters of context objects. But the compiler can use them as in the production of the above Sum prototype from the original Sum context object. By restricting the way reference types are used, the language guarantees that no runtime type error will ever happens due to a reference to a variable that is no longer in memory. In language C, one of these errors would be

```c
int *f() { int n; return &n; }
void main() {
    printf("%d\n", *f());
}
```

A local variable n which is no longer in the stack would be referenced by expression “*f()”.

We can use Sum(s) to call the new: method of prototype Sum built by the compiler, as usual (See page 68). The compiler will take the code of prototype DoNotSum and transform it internally in the following object:

```c
object DoNotSum
    public fun new: (:sum Int) -> DoNotSum [
        :newSum = self primitiveNew;
        newSum bind: sum;
        return newSum
    ]
    public fun bind: (:sum Int) [
        self.sum = sum
    ]
    private :sum Int
    public fun eval: (:x Int) [
```
An instance variable parameter is transformed by the compiler, internally, into two variables: a reference to the variable and a reference to the object in which it is. So prototype `ForEach` will be transformed into

```plaintext
object ForEach
  public fun new: (:array &Array<Int>, :otherSelf Any) -> ForEach [
    :newObj = self primitiveNew;
    newObj bind: array;
    self.otherSelf = otherSelf;
    return newObj
  ]
  @checkSelfBind public fun bind: (:array &Array<Int>, Any otherSelf) [
    self.array = array;
    self.otherSelf = otherSelf;
  ]
  private :array &Array<Int>
  private :otherSelf Any

  public fun foreach: (:b Block<Int><Void>) [
    0..(array size - 1) foreach: [
      |:index Int|
      b eval: array[index]
    ]
  ]
end
```

An expression `ForEach(intArray)` is transformed internally by the compiler into `ForEach(intArray, self)`.

It is necessary to pass self as parameter in order to prevent the garbage collector to free the memory of the object while there is a pointer to one of its instance variables, `intArray`. If self is not passed as parameter, they may be the case that an object of `ForEach` has a reference to an instance variable `intArray` of a `IntSet` object and there is no other reference to this object. Then the garbage collector could free the memory allocated to this object.

Metaobject `checkSelfBind` checks, in this example, whether the second real argument to `bind:` is self. There would be a compiler error if it is not:

```plaintext
:f = ForEach bind: intArray, 0
```

0 is a subtype of Any. But it is not self.

Object `ForEach` could have been implemented as a regular object because:

(a) instance variable `intArray` of `IntSet` always refer to the same object. Therefore `intArray` could be passed by copy to `ForEach`;

(b) `ForEach` does not assign a new object to `intArray`.

A copy or % parameter of a context object may be preceded by keywords `public`, `protected`, or `private` to mean that the parameter should be declared as an instance variable with that qualification.
// prod is also a copy parameter
object Test(public :sum Int, protected :prod Int) implements Block<Int><Void>
   public fun eval: (:elem Int) [  
      sum = sum + elem;
      prod = prod*elem
   ]
   public fun getProd -> Int [ ^prod ]
end
...
:s = 0;
:p = 1;
{# 1, 2, 3 #} foreach: Test(s, p);
   // call to public method sum
Out println: "Sum is #{Test sum}"
Out println: "Product is #{Test getProd}"
...
The default qualifier is private. Prototype Test would be transformed by the compiler into

object Test implements Block<Int><Void>
   public fun new: (:sum Int, :prod Int) -> Test [  
      :newText = primitiveNew;
      newText bind: sum, prod;
      return newText
   ]
   public bind: (:sum Int, :prod Int) [  
      self.sum = sum;
      self.prod = prod
   ]
   public fun eval: (:elem Int) [  
      sum = sum + elem;
      prod = prod*elem
   ]
   public fun getProd -> Int [ ^prod ]
public :sum Int
protected :prod Int
end
Reference (&) and instance variable (*) parameters are always private.

11.4 Type Checking Context Objects

There are two kinds of context objects:

(a) the ones with at least one reference parameter such as Sum. These are called restricted context objects, r-co for short;

(b) the ones with no reference parameter. These have one or more instance variable or copy parameters (with * or %). These are called unrestricted context objects, u-co for short.
There is no restriction on the use of unrestricted context objects (as expected!). They can be types of variables, instance variables, return values, and parameters. u-co are a generalization of u-blocks.

Restricted context objects are a generalization of r-blocks. Both suffer from the same problem: a context object could refer to a dead local variable:

```plaintext
:mySum Sum;
:b = [
  :sum1 Int = 0;
  mySum = Sum(sum1);
];
b eval;
mySum eval: 1;
```

The message send “b eval” makes mySum refer to a context object that has a reference to sum1. In the last message send, “mySum eval: 1”, there is an access to sum1, which no longer exists.

Another error would be to return a r-co from a method:

```plaintext
object Program
  public fun run [
    {1, 2, 3} foreach: makeError
  ]
  public fun makeError -> Sum [
    :sum = 0;
    return Sum(sum);
  ]
```

Here Sum(sum) has a reference to a local variable sum. When foreach: calls method eval: of the object Sum(sum), variable sum is accessed causing a runtime error.

To prevent this kind of error, r-co have exactly the same set of restrictions as r-blocks. In particular, the compiler would point an error in the assignment “mySum = Sum(sum1)” of the example above.

A context object that does not inherit from anyone inherits from Any, as usual. Both r-co’s and u-co’s can inherit from any prototype and implement any interface. However, there are restrictions on assignments mixing restricted and unrestricted types. A r-co RCO that inherits from an unrestricted prototype P or implements an unrestricted interface I is not considered a subtype of P or I. That is, if p is a variable of type P or I, an assignment

```plaintext
p = RCO;
```

is illegal.

Apart from the rules for type checking, context objects are regular objects. For example, they may be abstract, have shared variables, and inherit from other prototypes. Inheritance demands some explanations. When a context object with parameter x is inherited by another context object, this last one should declare x in its list of parameters with the same symbol preceding the type (*, %, or &) as the super-prototype. x should precede the parameters defined only in the sub-prototype. After the keyword “extends” there should appear the super-prototype with its parameters.

```plaintext
object A(:x Int)
  ...
end

object B(:x Int, :y %Int, :z &String) extends A(x)
  ...
end
```
Since \( A \) is a r-co, \( B \) is a r-co too. A context object cannot be inherited from a regular prototype.

A context object can also be a generic object. \( \text{Sum} \) can be generalized:

```java
object Sum<T> (:sum &T) implements Block<T><Void>
    public fun eval (:x T) [
        sum = sum + x
    ]
end
```

```
... :intSum = 0;
:floatSum Float = 0;
:abc String = ""
{# 1, 2, 3 #} foreach: Sum<Int>(intSum);
{# 1.5, 2.5, 1 #} foreach: Sum<Float>(floatSum);
{# "a", "b", "c" #} foreach: Sum<String>(abc);
assert: (floatSum == 5);
assert: (intSum == 6);
assert: (abc == "abc");
```

### 11.5 Adding Context Objects to Prototypes

Section [10.11] explain how to use the `addMethod:` ... grammar method of `Any` to add methods to a prototype.

```java
public fun (addMethod:
    (selector: String ( param: (Any)+ )?
    )+
    (returnType: Any)?
    body: ContextObject)
```

A context object can be used instead of a context block. One has just to implement `ContextObject`. So, instead of defining a context block as in the example

Box `addMethod`:
    `selector`: #print
    `body`: (:self Box) [ Out println: get ];

one could declare the context object explicitly

```java
object PrintBox(:newSelf %Box)
    implements UBlock<Void><Void>, ContextObject<Box><Void><Void>

    public fun newObject (:newSelf Box) -> UBlock<Void><Void> [
        return PrintBox new: newSelf
    ]
    public fun eval [
        Out println: (newSelf get)
    ]
end
```

The `eval` method would be assigned to `print` by a call to `addMethod:` ... as usual:
Box addMethod:
  selector: #print
  body: PrintBox;

There could be libraries of context objects that implement methods that could be added to several different prototypes. For example, there could be a `Sort` context object to sort any object that implements an interface

```
interface Indexable‹T>:
f  at: Int -> T
  at: Int put: T
  size -> Int
end
```

A context object used to add a method to an object could have more methods than just an `eval`.

```
object PrintFormatedBox(:newSelf %Box)
  implements UBlock<Void><Void>, ContextObject<Box><Void><Void>

  public fun newObject: (:newSelf Box) -> UBlock<Void><Void> [
    return PrintBox new: newSelf
  ]

  /* one could not declare a context block
     with one more method like format:
     this method fills the first positions
     with 0. Then
     format: 123
     should produce "0000000123"
   */
  private fun format: (:n Int) -> String [
    :strn = (n asString);
    return ("0000000000" trim: (10 - strn size)) + str
  ]

  public fun eval [
    Out println: (format: (newSelf get))
  ]
end
```

`format:` is a method that can only be used by the method `print` that is added to `Box`. It is like a private method of `print`.

### 11.6 Passing Parameters by Reference

Some languages such as C++ support passing of parameters by reference. In this case, changes in the parameter are reflected in the real argument, which should be a variable (it cannot be an expression). Cyan does not support directly this construct. However, it can be implemented using the generic context object `Ref`:

```
object Ref‹T>:(:v &T)
  public fun value -> T [ ^v ]
  public fun value: (:newValue T) [ v = newValue ]
end
```

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Now if you want to pass a parameter by reference, use `Ref`:

```cayn
private object CalcArea
    // it is as if parameter to selector area: were by reference
    public fun squareSide: (:side Float) area: (:refSqrArea Ref<Float>) [
        // by calling method value: we are changing the parameter
        // of the context object
        refSqrArea value: side*side
    ]
end

public object Program
    public fun run [
        :side = In readFloat;
        :sqrArea Float;

        /* encapsulate the reference parameter inside a
           context object. That is, use "Ref<Float>(sqrArea)"
           instead of just "sqrArea".
           Local variable "sqrArea" is changed inside
           method squareSide:area: of prototype CalcArea when message
           value: is sent to refSqrArea
        */
        CalcArea squareSide: side area: Ref<Float>(sqrArea);

        Out println: "Square side = #side";
        Out println: "area = #sqrArea"
    ]
end
```

Of course, the “passing by reference” syntax in Cyan is not straightforward. However, it has two advantages:

(a) it does not need a special syntax;

(b) and, most importantly, it is type-safe. Context objects use the same rules as the static blocks of Cyan. That means, for example, that an instance variable of prototype `Calc` cannot refer to a parameter of type `Ref<Float>`. That guarantees there will never be a reference to local variable of `run` of `Program` after this method is removed from the stack.

There will never be an error in Cyan equivalent to the following error in a C program, in which pointer `mistake` refers to a local variable that has been removed from the stack.

```c
#include <stdio.h>

const float pi = 3.141592;

float *mistake;
void calc(float radius, float *area) {
    mistake = area;
    *area = pi*radius*radius;
}
```
```java
void run() {
    float area;
    calc(1, &area);
}

float useStack() { float ten = 10; return area; }
int main() {
    run();
    useStack();
    // mistake refers to a variable that has been
    // removed from the stack
    // 10 is printed in some compilers
    printf("%f\n", *mistake);
    return 0;
}
```

### 11.7 Should Context Objects be User-Defined?

An alternative definition of Cyan could get rid of context objects. They could not be defined as shown in this text. Instead, one could use *reference types* like `&Int` to declare a restricted prototype directly. So the programmer could define a prototype like

```java
object Sum implements Block<Int><Void>
    public fun new: (:sum &Int) -> Sum [
        :newSum = self primitiveNew;
        newSum bind: sum;
        return newSum
    ]
    public bind: (:sum &Int) [
        self.sum = sum
    ]
    private :sum &Int
    public fun eval: (:x Int) [
        sum += x
    ]
end
```

This new version of Cyan would have a concept called "*restricted type*" defined inductively as:

(a) a *reference type* is a *restricted type*;

(b) any prototype that declares an instance variable of a restricted type is a *reference type*.

All the restriction on the use and type checking defined nowadays for context objects would apply to *reference types*.

With this feature, the programmer herself would explicitly create her own context objects. And this alternative Cyan would solve a problem related to grammar methods presented at the end of Chapter 9.9 at page 150. The solution comes from the fact that an array of a reference type would be a reference type too. Idem for tuples and unions: `Array<Block<Int>>`, `UTuple<String, Block>`, and `UTuple<Int, UUnion<Block<Int><Char>, Char>, String>` would be reference types.

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11.8 More Examples

The example of trees of page 68 can be made even more compact with context objects:

```plaintext
object Tree
end

object BinTree(public :left Tree, public :value Int, public :right Tree) extends Tree
end

object No(public :value Int) extends Tree
end
...

:tree = BinTree( No(-1), 0, BinTree(No(1), 2, No(3)) );
Out println: ((tree left) value);
```

When the compiler finds a class like `BinTree`, it creates a regular class with public instance variables `left`, `value`, and `right`:

```plaintext
object BinTree extends Tree
  public fun new: (:left Tree, :value Int, :right Tree) -> BinTree [
    :newObj = self primitiveNew;
    newObj bind: left, value, right;
    return newObj
  ]
  public bind: (:left Tree, :value Int, :right Tree) [
    self.left = left;
    self.value = value;
    self.right = right;
  ]
  public :left Tree
  public :value Int
  public :right Tree
end
```

Suppose there is a sport `Car` prototype that has two doors, left and right. The colors of these doors should always be the same as the main color of the car. One way of assuring that is declaring in the `CarDoor` prototype an instance variable that is a reference (a C-language pointer) to the instance variable of the `Car` that keeps the color. Since Cyan does not have C-like pointers, we can use context objects.

```plaintext
object CarDoor(public :color *Int)
...
end

object Car
  public fun init [
    leftDoor = CarDoor(_color);
    rightDoor = CarDoor(_color);
  ]
  public fun color: (:newColor Int) [ _color = newColor ]
```
public fun color -> Int [ ^ _color ]
private :_color Int
public :leftDoor, :rightDoor CarDoor
end

...
Car color: 255;
   // prints "color = 255"
Out println: "color = {Car leftDoor) color}";

(Car rightDoor) color: 0;
   // prints "color = 0"
Out println: "color = {Car color}";

inject:into: methods in Smalltalk are used to accumulate a result over a loop. For example,
   :sum = (1 to: 10) inject: 0 into: [ :total :elem | total + elem ]
accumulates the sum from 1 to 10. Initially total receives 0, the argument to the selector inject:. Then
the block is called passing total and the current index (from 1 to 10). In each step, the value returned
from the block, total + elem, is assigned to total (Smalltalk returns the last block expression).

The basic types of Cyan support a Smalltalk-like inject method and another form made to be used
with context objects.

object InjectInto<:T>(:total %T) implements InjectObject<T>
   public fun eval: (:elem T) [ 
      total = total + elem
   ]
   public fun result -> T [ 
      "total
   ]
end

Now the total is kept in the context object and we can write

:inj = InjectInto<Int>(0);
1 to: 10 do: inj;
Out println: "Sum = #{inj result}";

print the sum of the numbers from 1 to 10.

11.9 A New Feature for Context Objects?

Cyan could support a more compact version of object ForEach defined in page 188. The language could
allow IntSet and ForEach to be declared as

   // ForEach is of the same type as a method that takes
   // a Block<Int><Void> as parameter and returns nothing

object ForEach(:array *Array<Int>) implements UBlock< Block<Int><Void> ><Void>
   public fun eval: (:b Block<Int><Void>) [ 
      0...(array size - 1) foreach: [ 
         |:index Int|
   ]
end
b eval: array[index]
]
end

// a set of integers
object IntSet
  public fun init [
    intArray = Array<Int> new
  ]
  // both method foreach: and ForEach have type
  // UBlock< Block<Int><Void> ><Void>

  public fun foreach: (:b Block<Int><Void>) = ForEach(self.intArray)

  // methods to add, remove, etc.
  private :intArray Array<Int>
end

...:

:set = IntSet new;
set add: 0 add: 1 add: 2;
  // set itself has a foreach: method
set foreach: [
  |:elem Int|
    Out println: elem + " "
];

The meaning of the line
  public fun foreach: (:b Block<Int><Void>) = ForEach(self.intArray)
could be “to each object of IntSet”, call
  ForEach new: self.intArray
to create a new object of ForEach (remember that ForEach(self.intArray) is just an abbreviation of the line above).

Using this syntax, it would be possible to easily add tailored methods to objects. The above example cannot be implemented in Cyan nowadays. But an equivalent result can be obtained by calling method
  addMethod: ... of prototype Any. This call should be in method init of IntSet:

object IntSet
  public fun init [
    intArray = Array<Int> new
    self addMethod:
      selector: #foreach:
      param: Block<Int><Void>
      body: ForEach(self.intArray);
  ]

  public fun foreach: (:b Block<Int><Void>) [ /* empty */ ]
// methods to add, remove, etc.
private :intArray Array<Int>
end
Chapter 12

The Exception Handling System

Exception handling systems (EHS) allow the signalling and handling of errors or abnormal situations. There is a separation from the detection of the error and its treatment which can be in different methods or modules. The exception handling systems of almost all object-oriented languages are very similar. An exception is thrown by a statement such as “throw e” or “raise e” and caught by one or more catch clauses. We will show an example in Java. Assume there is a MyFile class with methods for opening, reading and closing a file and that methods open and readCharArray of this class may throw exceptions OpenException and ReadException.

```java
char []charArray;
MyFile f = new MyFile("input.txt");
try {
    f.open();
    charArray = f.readCharArray();
    if ( charArray.length == 0 )
        throw new ZeroException();
} catch ( OpenException e ) {
    System.out.println("Error opening file");
}
catch ( ReadException e ) {
    System.out.println("Error reading file");
}
finally {
    f.close();
}
```

An exception is thrown by statement throw (see line 7). We can also say that an error is signalled by a throw statement. The class of the object following throw should be a direct or indirect subclass of class Throwable. In this example, all statements that can throw exceptions are put in a try block (which is between lines 4 and 7). The exceptions thrown inside the try block at runtime will be treated by the catch clauses that follow the try block. There are two catch clauses and one finally clause. Each catch clause accepts a parameter and treats the error associated to that parameter. Therefore

```java
catch ( OpenException e ) {
    System.out.println("Error opening file");
}
catch ( ReadException e ) {
    System.out.println("Error reading file");
}
finally {
    f.close();
}
```

will treat the error associated to the operation of opening a file.

If file f cannot be read, method readCharArray throws exception ReadException with a statement

```java
throw new ReadException(filename);
```

After that, the runtime system starts a search for an appropriate handler for this exception. A handler
is a piece of code, given in a catch clause, that can treat the exception. This search starts in method readCharArray which does not have any catch clauses. It continues in the stack of called methods. Therefore an appropriate handler (or catch clause) is looked for in the code above. The runtime system checks whether the first catch clause can accept an object of ReadException, the one thrown by the throw statement. It cannot. Then it checks whether the second catch clause can accept this object as parameter. It can. Then method readCharArray is terminated and control is transferred to the catch clause

```java
    catch ( ReadException e ) {
        System.out.println("Error reading file");
    }
```

Parameter e receives the object “new ReadException(filename)” which was the parameter to statement throw and the body of the clause is executed. After that the execution continues in the finally clause, which is always executed — it does not matter whether an exception is thrown or not in the try block. When an exception is thrown, the stack of called methods is unwound till an appropriated catch clause is found and the control is transferred to this catch clause.

The exception handling system (EHS) of Cyan is similar in several aspects of the model just described. However, it was based on the object-oriented exception handling system of Green [10] and it is object-oriented in nature. The throwing of an exception is a message send, exception treatment(catch clauses) can be put in prototypes and inherited, and polymorphism applies to exception treatment. All the arsenal of object-oriented programming can be used with exception signalling and treatment, which is not possible possible, to our knowledge, in other languages but Green. The exception handling system (EHS) of Cyan goes well beyond that of Green which is awkward to use if local variables should be accessed to treat the error. In Cyan the EHS is both easy to use and powerful. However, it is not a checked exception system like that of Java or Green. An exception may be thrown and not caught as in C++ or C#.

The Java example in Cyan would be

```java
1: charArray Array<Char>;
2: f = MyFile new: "input.txt";
3: [
4:    f open;
5:    charArray = f readCharArray;
6:    if ( charArray size == 0 )
7:        throw: ZeroException;
8:    ] catch: [ |:e OpenException| Out println: "Error opening file" ]
9:    catch: [ |:e ReadException| Out println: "Error reading file" ]
10: finally: [
11:        f close
12:    ]
```

An exception is thrown by sending message throw: to self as in line 7:

```java
    throw: ZeroException;
```

throw: is a final method defined in Any (therefore inherited by all prototypes). ZeroException is a prototype that inherits from CyException, the super-prototype of all exception objects. Since this exception does not demand any useful additional information, the prototype does not have any instance variables:

```java
object ZeroException extends CyException
```

end
Every exception prototype should inherit from `CyException`, which inherits from `Any` and does not define any methods.

In the above Cyan example, block

```
[f open; charArray = ... ]
```

receives message

```
catch: ... catch: ... finally: [ f close ]
```

at runtime. The method executed will be a grammar method (more about that will soon be explained). This method calls the block body (sends message `eval` to it) and catches the exceptions it throws. That is almost the same as in the Java code. When an exception is thrown in the block body, as `ReadException`, the runtime system searches for an adequate handler in the parameters to the `catch:` methods. First it checks whether method `eval:` of the first block,

```
[:e OpenException| Out println: "Error opening file"]
```

can accept an object of `ReadException` as real argument. It cannot. Then the search continues in the second `catch:` selector. Since

```
[:e ReadException| Out println: "Error reading file"]
```

can accept a `ReadException` object, message `eval` is sent to this block. Then the block that is parameter to `finally:` is called and the execution continues in the first statement after the original block. This works exactly the same as the exception system of Java/C++ and many other object-oriented languages.

In Cyan there may be one or more `catch:` selectors and an optional `finally:` selector. Every `catch:` selector accepts as argument an object that has at least one method

```
eval: (:e E)
```

in which `E` is a prototype that inherits from `CyException` (directly or indirectly). Blocks

```
[:e OpenException| Out println: "Error opening file"]
[:e ReadException| Out println: "Error reading file"]
```

satisfy these requirements. For example, the first block has a method

```
eval: (:e OpenException) [ Out println: "Error opening file"]
```

It is not necessary that `E` be a block or implements any block interfaces. The `catch:` selectors may receive an r-block as parameter. This does not cause any runtime errors because the method neither store a reference to the object that is the real argument nor passes a reference to this object to another method.

The parameter to method `throw:` should not be a restricted context object. That is checked by metaobject `checkThrow` attached to this method. If a restricted context object is parameter to `throw:`, a runtime error could occur:

```
object ContextException(public :number &Int) extends CyException
end
```

```
object Test
  public fun run [
    [
      test
    ] catch: [:e ContextException|
      // "number" refer to "n" which does not
      // exist anymore
      Out println: (e number)
    ]
  ]
```

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12.1 Using Regular Objects to Treat Exceptions

Each catch: selector may receive as argument an object that has more than one eval: method.

```cyan
object CatchFileException
  public fun eval: (:e OpenException) [ Out println "Error opening file" ]
  public fun eval: (:e ReadException) [ Out println "Error reading file" ]
  public fun eval: (:e WriteException) [ Out println "Error writing to file" ]
end
```

Prototype CatchFileException treats all errors associated to opening, reading, and writing to files (but not to closing a file). This kind of object, to treat exceptions, will be called catch objects. It can be used as

```cyang
:charArray Array<Char>;
:f = MyFile new: "input.txt";
[
  f open;
  charArray = f readCharArray;
  if ( charArray size == 0 )
    throw: ZeroException;
] catch: CatchFileException
finally: [
  f close
]
```

When an exception is signaled in the block, the runtime system starts a search for an eval: method (a handler) in the nearest argument to catch:, which is CatchFileException. Supposing that there was a read error, the correct eval: method should accept a ReadException object as parameter. The runtime system searches for the eval: method in CatchFileException using the same algorithm used for searching for a method after a message is send to an object. That is, the runtime system tries to send message eval: with a ReadException as argument to object CatchFileException. By the regular algorithm, the second textually declared method of CatchFileException,

```cyang
  public fun eval: (:e ReadException) [ Out println "Error reading file" ]
```

is found and called. After that the block that is argument to selector finally: is called and computation continues in the first statement after the outer block in the example.

12.2 Selecting an eval Method for Exception Treatment

A Cyan program starts its execution in a method called run of a prototype designed at compile-time. For this example, suppose this prototype is Program. To start the execution, method run is called inside a block that receives a catch: message:
Method `eval:` of prototype `RuntimeCatch` just prints the stack of called methods:

```kotlin
object RuntimeCatch
  public fun eval: (:e CyException) [ /* prints the stack of called methods and ends the program */ ]
end
```

Maybe we may will add a `finally:` selector to the `catch:` message allowing some code to be executed before the program ends.

When a message with at least one `catch:` selector is sent to a block, a grammar method is called. We will call this grammar method `catch-finally` (this is just a name for explaining this text). Method `catch-finally` pushes the parameters to `catch:` in a stack `CatchStack` in the reverse order in which they appear in the call. So

```kotlin
[ ...
] catch: c1
    catch: c2
    catch: c3;
```

pushes `c3`, `c2`, and `c1` into the stack, in this order. Therefore `c1` is in the top. When an exception is thrown by the message send `throw: obj`, method `throw:` of `Any` searches the stack `CatchStack` from top to bottom until it finds an `eval:` method that accepts `obj` as parameter. Inside each stack object the search is made from the first declared `eval:` method (in textual order) to the last one. `CatchStack` is a prototype that just implements a stack. It cannot be changed by regular programming. But programmers will be able to inspect its contents:

```kotlin
object CatchStack
  public fun asArray -> Array<Any> [ ^stack clone ]
  private fun push: (:catchObj Any) [ ... ]
  private fun pop -> Boolean [ ... ]
  ...
  private :stack Array<Any>
end
```

Consider the catch objects¹ and the example that follow.

```kotlin
// number < 0, == 0, > 1000, or even
private object NumException extends CyException end

// when the number is == 0
private object ZeroException extends NumException end
```

¹Objects with `eval:` methods that treat exceptions.
// when the number is < 0
private object NegException extends NumException
end

// when the number is > 1000
private object BigException extends NumException
end

// when the number is even
private object EvenException extends NumException
end

private object CatchZeroBig
  public fun eval: (:e ZeroException) [
    Out println: "zero number";
  ]
  public fun eval: (:e BigException) [
    Out println: "big number";
  ]
end

private object CatchNeg
  public fun eval: (:e NegException) [
    Out println: "negative number";
  ]
end

private object CatchEven
  public fun eval: (:e EvenException) [
    Out println: "even number";
  ]
end

private object CatchNum
  public fun eval: (:e NumException) [
    Out println: "number < 0, == 0, > 1000, or even";
  ]
end

object Program
  private const MaxN = 1000;

  public fun run: (:args Array<String>) [
    // 1
    :n = In readInt;
    // 2
process: n
] catch: CatchZeroBig
catch: CatchEven
catch: CatchNum;
// 5
Out println: "this is the end"
]
private fun process: (:n Int) [
// 3
    check: n;
    if ( n > MaxN )
        throw: BigException;
] catch: CatchNeg
// 6
]
private fun check: (:n Int) [
// 4
    if ( n == 0 )
        throw: ZeroException;
    if ( n < 0 )
        throw: NegException;
    if ( n%2 == 0 )
        throw: EvenException;
]
end

There are four exceptions, ZeroException, NegException, BigException, and EvenException that inherit from NumException and four catch objects, CatchZeroBig, CatchEven, CatchNeg, and CatchNum. The program execution starts at point “// 1”. At line // 2, message catch:catch:catch: has been send and the block that has just “process: n” has been called. At point // 2, CatchStack has objects CatchNum, CatchEven, and CatchZeroBig (last on top).

Inside the block that starts at // 2, if message “throw: exc” is sent to self, the search for a method would start at CatchZeroBig and proceeds towards CatchNum at the bottom of the stack. First method throw: would check whether object exc is sub-object of ZeroException. If it is not, it would test whether object exc is a sub-object of BigException. If it is not, the search would continue in CatchEven.

At line marked as // 3, object CatchNeg has already been pushed into the stack CatchStack. At point // 4 in the code, if statement throw: EvenException is executed, there is a search for an eval: method that can accept EvenException as parameter, starting at the CatchNeg object. This method is found in object CatchEven pushed in the run: method. Therefore control is transferred to the first statement after the message send

[ // 2
    process: n
] catch: CatchZeroBig
catch: CatchEven
catch: CatchNum;

which is “Out println: "this is the end"”. This is exactly like the exception handling system of almost all object-oriented languages.
Before returning, the `throw` method of `Any` removes the objects pushed into `CatchStack` together and after `CatchEven`.

Every block of type `Block` or `UBlock` has a method

```cayenne
@checkCatchParameter
public fun ((catch:Any)+ finally: Block) :t [ ...
]
```

responsible for catching exceptions. The metaobject `checkCatchParameter` attached to this method checks whether each parameter to a `catch:` selector has at least one `eval:` method, each of them accepting one parameter whose type is sub-prototype of `CyException`.

### 12.3 Other Methods and Selectors for Exception Treatment

Blocks have a method `hideException` that just eats every exception thrown in them:

```cayenne
n = 0;
[
    n = (In readString) asInt
] hideException;
```

Of course, this method should be rarely used.

Selectors `retry` or `retry:` may be used after all `catch:` selectors in order to call the block again if an exception was caught by any object that is argument to any of the `catch:` selectors. If selector `retry:` is used, it should have a block as parameter that is called before the main block is called again.

```cayenne
// radius of a circle
:radius Float;
[
    radius = In readFloat;
    if ( radius < 0 ) [
        throw: RadiusException(radius)
    ]
] catch: CatchAll
    retry: [
        Out println: "Negative radius. Type it again"
    ];
```

`CatchAll` has a method

```cayenne
public fun eval: (:e CyException) [ ]
```

that catches all exceptions. This prototype is automatically included in every file. It belongs to package `cyan.lang`.

One can just write `retry:` without any `catch:` selectors. If any exception is thrown in the block, the `eval` method of the argument to `retry:` is called and the block is called again. If `retry` is used, the block is called again if an exception is thrown in the block.

```cayenne
// radius of a circle
:radius Float;
[
    radius = In readFloat;
    if ( radius < 0 ) [
        throw: RadiusException(radius)
    ]
] finally: [[
    Out println: "Negative radius. Type it again"
];
```
throw: RadiusException(radius)
]
else if ( radius == 0 ) [
    // end of input
return 0
]
] retry: [
    Out println: "Negative radius. Type it again"
];

Selector tryWhileTrue: may be put after the catch: selectors in order to control how many times
the block is retrieved. The argument to tryWhileTrue: should be a Block<Boolean> block. If an
exception was thrown in the block and the argument to tryWhileTrue: evaluates to true, the block is
called again.

numTries:= 0;
[
    // may throw an exception ConnectFailException
    channel connect;
    ++numTries;
] catch: CatchAll
tryWhileTrue: [ ^ numTries < 5 ];

The above code tries to connect to a channel five times. Each time the connection fails an exception is
thrown by method connect. Each time the block after tryWhileTrue: is evaluated. In the first five times
it returns true and the main block is called again. If no exception is thrown by connect, the argument
to tryWhileTrue: is not called. Again, the catch: selectors are optional. Selector tryWhileFalse: is
similar to tryWhileTrue.

Prototype CatchIgnore could be used instead of CatchAll:

object CatchIgnore<:T>
    public fun eval: T [ ]
end

...
numTries:= 0;
[
    // may throw an exception ConnectFailException
    channel connect;
    ++numTries;
] catch: CatchIgnore<ConnectFailException>
tryWhileTrue: [ ^ numTries < 5 ];

This example can be made more compact with the use of a context object to count the number of
efforts:

object Times(:numTries %Int) extends UBlock<Boolean>
    public fun eval -> Boolean [ 
        --numTries;
        return numTries > 0;
    ]
end
A future improvement to the EHS of Cyan would be to make it support features of the EHS of Common Lisp (conditions and restarts). That would be made by allowing communication between the error signaling and the error handling. This could be made using a variable “exception”. A catch object could have other meaningful methods besides “eval: T”. For example, a catch object could have an “getInfo” method describing the error recovery to be chosen afterwards:

```lisp
object CatchStrategy
  public fun getInfo -> CySymbol [ ~ retry ]
end

object Test
  public fun test [
    [  
      connectToServer;  
      buildSomething  
    ] catch: CatchStrategy
  ]
  public fun connectToServer [
    [  
      :fail Boolean = true;  
      ...  
      // if connection to server failed, signal  
      // an exception  
      if ( fail ) [  
        throw: ConnectionException
      ]  
    ] catch: [ |:e ConnectionException|  
      // if connection to server failed,  
      // consult getInfo for advice.  
      if ( exception getInfo == #retry ) [  
        connectToServer
      ]  
    ]
  ]
end

Maybe there should be another method that obeys automatically instructions given by objects like CatchStrategy. Maybe catch itself should automatically retry when “exception getInfo” demands it:

```lisp
public fun connectToServer [
  [  
    ...  
  ]
]
fail Boolean = true;
...
// if connection to server failed, signal // an exception
if ( fail ) [
  exception eval: ConnectionException
]
] catch: CatchIgnore<ConnectionException>

12.4 Why Cyan Does Not Support Checked Exceptions?

Cyan does not support checked exceptions as Java in which the exceptions a method may throw are described in its declaration:

// this is how method "check" of Program // would be declared in Java
private void check(int n)
  throws ZeroException, NegException, EvenException {
    // 4
    if ( n == 0 )
      throw new ZeroException();
    if ( n < 0 )
      throw new NegException();
    if ( n%2 == 0 )
      throw new EvenException();
  }

Here method check may throw exceptions ZeroException, NegException, and EvenException. We could add a syntax for that in Cyan following language Green [10]:

private fun check: (:n Int)
  :exception EvalZeroNegEven [
    // 4
    if ( n == 0 )
      exception eval: ZeroException;
    if ( n < 0 )
      exception eval: NegException;
    if ( n%2 == 0 )
      exception eval: EvenException;
  ]

Pseudo-variable exception would be declared after all regular method parameters. Inside the method this variable is type-checked as a regular variable. Then there would be an error if there was a statement exception eval: ReadException in method check because there is no eval: method in EvalZeroNegEven that can accept a ReadException object as parameter. Interface EvalZeroNegEven is
interface EvalZeroNegEven
  fun eval: ZeroException
  fun eval: NegException
  fun eval: EvenException
end

Green employs a mechanism like this, which works perfectly in a language without blocks.

But think of method ifTrue: of blocks of types Block<Boolean><Void> and UBlock<Boolean><Void>:

public fun ifTrue: (:b Block)
  :exception T [
    if ( self == true ) [
      b eval
    ]
  ]

What is the type T of exception? In
(i < 0) ifTrue: [
  throw: ReadException;
]

T should be

interface InterfaceReadException
  fun eval: ReadException
  // possibly more methods
end

But in another call of this method T should be different:

(i <= 0) ifTrue: [
  if ( openError ) [
    throw: OpenException
  ]
  else if ( i == 0 ) [
    throw: ZeroException
  ]
]

In this case T should be

interface InterfaceOpenZeroException
  fun eval: OpenException
  fun eval: ZeroException
  // possibly other methods
end

Then the type of T depends on the exceptions the block may throw. We have a solution for that but it is too complex to be added to a already big language. Without explaining too much, method ifTrue: would be declared as

public fun ifTrue: (:b Block)
  :exception b.{eval}. .exception [
if ( self == true ) [
    b eval
]

The declaration means that the type of exception in ifTrue: is the type of variable exception of the method eval of block b at the call site. If ifTrue: could throw exceptions by itself, these could be added to the type “b.{eval}. .exception” using the type concatenator operator “++” (introduced just for this use here).

For short, we could have checked exceptions in Cyan but it seems they are not worthwhile the trouble.

12.5 Synergy between the EHS and Generic Prototypes

Generic prototype instantiations can be used as parameters to catch: message sends. With them, one can reuse code for common tasks as shown in the following example.

object CatchExit::<T>
    public fun eval: (:e T) [
        Out println: "Fatal error";
        System exit
    ]
end

object CatchWarning::<T>
    public fun eval: (:e T) [
        Out println: "Exception " + (T prototypeName) + " was thrown"
    ]
end
...

[ line = In readLine;
if ( line size == 0 ) [
    throw: EmptyLineException
] else if ( line size > MaxLine ) [
    throw: LineTooBigException(line)
];
Out println "line = " + line
] catch: CatchExit<LineTooBigException>
    catch: CatchWarning<EmptyLineException>;

Object CatchExit<LineTooBigException> treats exception LineTooBigException because it has an eval: method that accepts this exception as parameter. This method prints an error message and ends the program execution.

Object CatchWarning<EmptyLineException> treats exception EmptyLineException. Method eval of this object just prints a warning message.

Generic object CatchIgnore accepts any number of parameters up to ten. The eval: methods of this object do nothing. The definition of CatchIgnore with two parameters is
object CatchIgnore<:T1, :T2>
    public fun eval: T1 [ ]
    public fun eval: T2 [ ]
end

If we want to ignore two exceptions and treat a third one, we can write something like

[ line = In readLine;
if ( line size == 0 ) [
    throw: EmptyLineException
] else if ( line size > MaxLine ) [
    throw: LineTooBigException(line)
] else if ( line[0] == ' ' ) [
    throw: WhiteSpaceException
];
Out println "line = " + line
] catch: CatchIgnore<LineTooBigException, EmptyLineException>
catch: [ !:e WhiteSpaceException|Out println: "line cannot start with white space";
        System exit
];

With generic prototypes, it is easy to implement the common pattern of encapsulating some exceptions in others. When an exception Source is thrown, a catch: method captures it and throws a new exception from prototype Target.

object ExceptionConverter<:Source, :Target>
    public fun eval: (:e Source) [
        throw: Target()
    ]
end...
[
    ...
] catch: ExceptionConverter<NegNumException, OutOfLimitsException>;

ExceptionConverter can be defined for 2, 4, 6, etc. parameters.

Another common pattern of exception treatment is to encapsulate exceptions in an exception container.

object ExceptionEncapsulator<:Item, :Container>
    public fun eval: (:e Item) [
        throw: Container(e)
    ]
end...
[
    // NegNumException may be thrown here
    ...
] catch: ExceptionEncapsulator<NegNumException, ArithmeticException>;
Whenever \texttt{NegNumException} is thrown in the block, it is packed into an exception of \texttt{ArithmeticException} and thrown again.

Several exceptions that have the same treatment can be treated equally using the generic context object \texttt{CatchMany}. This prototype can take up to ten generic parameters. Here we show the version of it with two parameters.

\texttt{object CatchMany<:T1, :T2>(:b UBlock)}
\begin{verbatim}
  public fun eval: (:e T1) [ b eval ]
  public fun eval: (:e T2) [ b eval ]
end
\end{verbatim}

\begin{verbatim}
[ line = In readLine;
  if ( line size == 0 ) [ throw: EmptyLineException ]
  else if ( line size > MaxLine ) [ throw: LineTooBigException(line) ]
  else if ( line[0] == ' ' ) [ throw: WhiteSpaceException ];
  Out println "line = " + line
] catch: CatchMany<EmptyLineException, LineTooBigException>(
  [ Out println: ("Limit error in line " + %line) ] )
catch: CatchMany<WhiteSpaceException, ReadException>(
  [ Out println: "Other error happened" ]);
\end{verbatim}

We used \% in the declaration of the parameter of \texttt{b} of \texttt{CatchMany} in order to allow expressions to be parameters to this context object.\footnote{It was used \texttt{UBlock} instead of \texttt{Block} as the type of the parameter \texttt{b} because \texttt{b} is declared by the compiler as an instance variable of this prototype (see Section \[11.3]. Although this syntax is not too complex, it is not as clean as the equivalent feature of the new version of Java:}

\begin{verbatim}
try {
  ...
} catch ( EmptyLineException | LineTooBigException e) { ... }
catch ( WhiteSpaceException | ReadException e) { ... }
\end{verbatim}

A catch object can declare a grammar method with alternative parameters:

\texttt{object CatchLineExceptions}
\begin{verbatim}
  public fun (eval: EmptyLineException | LineTooBigException) :t [
    Out println: ("Limit error in line " + %line)
  ]
\end{verbatim}

\footnote{The default qualifier is \%. Then we could have omitted this symbol in the declaration of parameter \texttt{b}.}
line = In readLine;
if ( line size == 0 ) [
    throw: EmptyLineException
] else if ( line size > MaxLine ) [
    throw: LineTooBigException(line)
] else if ( line[0] == ' ' ) [
    throw: WhiteSpaceException
];
Out println "line = " + line
] catch: CatchLineExceptions
    catch: CatchMany<WhiteSpaceException, ReadException>(
        [ Out println: "Other error happened" ]);

The effect is the same as the previous code.
If alternative types were allowed in the declaration of a block, we could catch several exceptions with a single block:
[ ...
] catch: [ |:e EmptyLineException | LineTooBigException|
    Out println: "Limit error in line " + line
] catch: [ |:e WhiteSpaceException | ReadException |
    Out println: "Other error happened"
];
Of course, there would be an ambiguity in the symbol “|”.

12.6 More Examples of Exception Handling

One can design a MyFile prototype in which the error treatment would be passed as parameter:

object MyFile
    public fun new: (:filename String) [ ... ]
    public fun catch: (:catchObject CatchFileException) do: (:b Block<String><Void>) [ [ open;
        // readAsString read the whole file and put it in a String,
        // which is returned
        b eval: readAsString;
        close;
    ] catch: catchObject
]
end

Context object Throw implements UBlock and has an eval method that throws the exception that is the parameter of the context object.
object Throw(:e CyException) implements UBlock
    public fun eval [  
        throw: e  
    ]
end

It makes it easy to throw some exceptions:

[  
    line = In readLine;

    if ( line size == 0 ) Throw(EmptyLineException)
    else if ( line size > MaxLine ) Throw(LineTooBigException(line))
    else if ( line[0] == ' ' ) Throw(WhiteSpaceException)

    Out println "line = " + line
] catch: CatchIgnore<LineTooBigException, EmptyLineException>
    catch: [ ::e WhiteSpaceException|  
        Out println: "line cannot start with white space";
        System exit  
    ];

Prototype CatchWithMessage catches all exceptions. It prints a message specific to the exception thrown and prints the stack of called methods:

object CatchWithMessage  
    public fun eval: (:e CyException) [  
        Out println: "Exception #{e prototypeName} was thrown";
        System printMethodStack;
        System exit  
    ]
end

An exception prototype may define an eval: method in such a way that it may be used as a catch parameter:

object ZeroException extends CyException  
    public fun eval: (:e ZeroException) [  
        Out println: "Zero exception was thrown";
        System exit  
    ]
end

...  

// inside some method
[
    n = In readInt;
    if ( n == 0 ) [ throw: ZeroException ];
    ...  
] catch: ZeroException;
This is confusing. But somehow it makes sense: the exception, which represents an error, provides its own treatment (which is just a message). Guimarães [10] suggests that a library that may throw exceptions should also supply catch objects to handle these exceptions. It could even supply an hierarchy of exceptions for each set of related exceptions. For example, if the library has a prototype for file handling, it should also have a catch prototype with a default behavior for the exceptions that may be thrown. And sub-prototypes with alternative treatments and messages.

Since exceptions and theirs treatment are objects, they can be put in a hash table used for choosing the right treatment when an exception is thrown.

```plaintext
object CatchTable
  public fun init [ // assume [* and *) delimit a literal hash table
table = [*
    ZeroException : CatchExit<ZeroException>,
    NegException : CatchAll,
    RadiusException: |:e RadiusException|
      Out println: "Radius #{e radius} is not valid"
    ],
    TriangleException: CatchTriangle
  ];
  public fun eval: (:e CyException) [
    table[e prototype] ?eval: e
  ]
  private :table Hashtable<CyException, Any>
end
```

CatchTable can be used as the catch object:

```plaintext
// inside some method[
...
] catch: CatchTable;
```

If an exception is thrown in the code “...”, method `eval:` of `CatchTable` is called (its parameter has type `CyException`, the most generic one). In this method, the hash table referenced by variable “table” is accessed using as key “e prototype”, the prototype of the exception. As an example, if the exception is an object of `TriangleException`, “e prototype” will return `TriangleException`. By indexing `table` with this value we get `CatchTriangle`. That is,

```plaintext
assert: table[e prototype] == CatchTriangle
```
in this case. Here `table[e]` returns the value associated to `elem` in the table.

Message `?eval: e` is then sent to object `CatchTriangle`. That is, method `eval:` of `CatchTriangle` is called. The result is the same as if `CatchTriangle` were put in a `catch:` selector as in the example that follows.

```plaintext
object TriangleException(public :a Double, public :b Double, public :c Double)
end
```

```plaintext
object CatchTriangle
  public fun eval: (:e TriangleException) [
```
// "e a" is the sending of message "a" to object "e"
// that returns the side "a" of the triangle
Out println: "There cannot exist a triangle with sides #{e a}, #{e b}, and #{e c}"
]
end

// inside some method
[
  ...  
  if ( a >= b + c || b >= a + c || c >= a + c ) [
    throw: TriangleException(a, b, c)
  ];
  ...
] catch: CatchTriangle;

Then we can replace catch: CatchTriangle in this code by “catch: CatchTable”. However, if an exception that is not in the table is thrown, there will be a runtime error: message eval: is sent to object nil, the object returned by the hash table when a key is not found. That is, “table[e prototype]” returns nil.

Exception StrException is used as a generic exception which holds a string message.

object StrException(public :message String) extends CyException
  public fun eval: (:e StrException) [
    Out println: message;
    System exit
  ]
end

It can be used as
[
  :s = In readString;
  if ( s size < 2 ) [
    throw: StrException("size should be >= 2")
  ] else if ( s size >= 10 ) [
    throw: StrException("size should be < 10")
  ];
] catch: StrException;
Chapter 13

User-Defined Literal Objects

Objects can be created in Cyan using methods clone and new. A literal object is an object created implicitly without using these two methods. For example, 1, 'a', 3.1415, "this is a string", and [^ x <= 1] are literal objects. The first three are objects from the basic types. The block [^ x <= 1] is a literal object of a compiler-created object as explained in Chapter[10]. And every user-defined prototype such as Person is a literal object.

Cyan will support literal objects through pre-defined metaobjects. We will give a glimpse of the syntax of these metaobjects, which will not be adequately specified and may be subject to change. So consider that this Chapter does not really define a language feature. It just gives an overview of a feature that will be supported by the language in the future.

13.1 Literal Numbers

Metaobject literalNumber is used for defining literal objects that start with a number. In Cyan, it is possible to define literals such as

100meters 50yards 50kg 30lb 3000reais 500dollars 2000_euros 10this_is_unknown 0_real_1img

These will be called literal numbers. When the compiler finds a token that starts with a number but ends with a sequence of letters, numbers, and underscore, it searches for a metaobject capable of treating that token. A metaobject that treats a literal number is declared using another metaobject, literalNumber:

@literalNumber<**
    endsWith: "bin", "Bin", "BIN"
    type: Int
    parser: BinaryNumberParser
**>

The body of this metaobject should contain a sequence of pairs tag-value. One of the tags is endsWith that specifies a sequence of letters, digits, and underscore (starting with a letter or underscore) that ends this literal number (before the sequence there should appear at least a digit). In this example, there are several alternatives: bin, Bin, or BIN. The parser tag specifies the Java class responsible for treating literal numbers ended by strings given in the endsWith tag. Then a number

101Bin

will be processed by the Java class BinaryNumberParser. Future versions of Cyan will use Cyan proto-types instead of Java classes. What happens is that, when the compiler finds a number ending by bin,
Bin, or BIN, it loads the Java class `BinaryNumberParser`, creates an object from it, and calls a method of this object passing string 
"101Bin"
and an object of class PCI as parameters (this will soon be explained). The method to be called depends on what interface `BinaryNumberParser` implements. If it implements `RetString`, method `parseRetString` is called. If it implements interface `RetASTExpr`, method `parseRetASTExpr` is called. It is an error to make this class implement both or none of these interfaces. Suppose that, in this case, `BinaryNumberParser` implements interface `RetString` and the compiler calls method `parseRetString` of the newly created `BinaryNumberParser` object.

Method `parseRetString` will return a string that will be passed to the Cyan compiler. This string will replace `101Bin`. It is expected that the string returned from `parseRetString` of `BinaryNumberParser` will be 5 in base 10. The Java class could be declared as

```java
public class BinaryNumberParser implements RetString {
    public String parseRetString(String text, PCI compiler) {
        // cut the last three characters, which is
        // bin, Bin, or BIN
        String number = text.substring(0, text.length() - 3);
        int n = 0;
        for(i = 0; i < number.length(); i++)
            n = 2*n + number.charAt(0);
        return n + "";
    }
}
```

Class `BinaryNumberParser` could have defined a method

```java
public Expr parseRetASTExpr(String text, PCI compiler) {
    // cut the last three characters, which is
    // bin, Bin, or BIN
    String number = text.substring(0, text.length() - 3);
    int n = 0;
    for(i = 0; i < number.length(); i++)
        n = 2*n + number.charAt(0);
    return new ExprLiteralInt(n, compiler.currentToken());
}
```

Class PCI is the `Public Compiler Interface`, which is a restricted view of the compiler class that compiles the Cyan program. Through the PCI object passed as parameter some compiler methods can be called and some compilation information can be obtained. In this example, no information is needed and no compiler method is called.

Tag `type` of the `literalNumber` call gives the type of the literal object. This tag may be omitted.

Class `BinaryNumberParser` could have defined a method

```java
Expr parseRetASTExpr(String text, PCI compiler)
```

that returns an object of the compiler AST representing an integer.
ExprLiteralInt is the AST class of the compiler that represents a literal integer. Both $n$ and the current token of the compiler is passed as arguments in the creation of the ExprLiteralInt object, which represents a literal number $n$. The current token of the compilation is an object of class Token representing 101Bin. This object is necessary when there is a compilation error for it contains the number of the line of the token.

A literal number should be defined outside any prototype. It may be declared private, protected, or public by tags private:, protected, and public: without arguments. A private literal can only be used in the source file in which it was declared. A protected literal can only be used in its package. A public one can be used in any package that imports the package in which it was defined.

In the future Cyan will replace Java as the metaobject protocol language. Then the Java AST expression will not be returned by the method. Line

```
return new ExprLiteralInt(n, compiler.currentToken());
```

would be replaced by something like

```
compiler exprLiteralInt: n;
```

This message send calls a grammar method that creates a literal Int which replaces the original expression (101Bin in the example). Using other grammar methods of parameter compiler, one will be able to create any Cyan expression.

Literal numbers may specify anything, not just numbers. For example, one could call literalNumber to create a graph with the syntax

```
:g Graph = 1_2_3_1_graph;
```

That would be the graph $G = \{(1,2), (2,3), (3,1)\}$.

### 13.2 Literal Objects between Delimiters

A metaobject call is delimited by a pair like <<+ and +>>. The rules of formation of these pairs were explained in Section 5.2. Metaobject literalObject allows one to define literal objects which are delimited by pairs like <<+ and +>> optionally preceded by an identifier. The language offers several examples of these literal objects:

```
// arrays
:v Array<Int> = {# 1, 2, 3 #};
// unnamed tuples
:t1 UTuple<String, Int> = [. "first", 0 .];
// named tuples
:t2 = [. university: "UFSCar" country: "Brazil" .];
```

Besides these ones, the programmer may define her own literal objects, which may be preceded by an identifier. So we could have things like

```
:g1 Graph = GraphBuilder<<+ (1, 2), (2, 3), (3, 1) +>>;
:g2 Graph = GraphBuilder(** (1, 2), (2, 3), (3, 1) **);
:dictionaryEnglishPortuguese Hashtable = Dict( "one":"um", "two":"dois" );
```

GraphBuilder is the name of the literal object. Its declaration, explained in the following paragraphs, defines the syntax of the code between <<+ and +>> and how it is used to create a Graph object. The delimiters are not attached to a particular literal object and the literal object is not attached to a particular pair of delimiters.

Literal object names have their own name space. So we can have a literal object name Graph and a literal object name Graph (instead of GraphBuilder as in the example).
A literal object may be specified in several different ways. The simplest one is by giving a start delimiter and a Java class for parsing the object:

@literalObject<<
    start: "<@"
    parse: ParseList
>>

When the compiler finds "<@", it loads the Java class ParseList, creates an object of this class, and calls a parseRetString method of this object passing to it the text between <@ and @> and a PCI object (Public Compiler Interface). The parseRetString method should return a string that creates an object that replaces

  <@ ... @>

For example, suppose we have

:myList = <@ "hi", 23, 3.14 @>;

and method parseRetString of ParseList returns

:tmp0001 = List new: 3;
tmp0001 add: "hi";
tmp0001 add: 23;
tmp0001 add: 3.14;

Then :myList = <@ "hi", 23, 3.14 @>; will be transformed into

:tmp0001 = List new: 3;
tmp0001 add: "hi";
tmp0001 add: 23;
tmp0001 add: 3.14;
:myList = tmp0001;

The type of the object resulting from the literal object may be given by tag type:

@literalObject<<
    start: "<@*
    parse: ParseIntSet
    type: Set<Int>
>>

The name of the literal object is given by tag name:. In this option, the start: tag should not be given.

@literalObject<<
    name: GraphBuilder
    parse: GraphParser
    type: Graph
>>

...:

g1 Graph = GraphBuilder<<+ (1, 2), (2, 3), (3, 1) +>>;
g2 Graph = GraphBuilder(** (1, 2), (2, 3), (3, 1) **);

Both named and unnamed literal objects may have a regexpr: tag. After this tag should appear a regular expression. The literal object should obey the grammar defined by this literal object which is composed by the regular expression operators, type names, and strings of symbols given between quotes. Each type means an expression of that type, just like in a method signature. Let us see an example.
@literalObject<<
    start: "<@"
    regexpr: ( String ":" Int )*
    type: ListStringInt
    parse: ParseListStringInt
>>
...
:myList = <@ "um": 1 "dois" : 2 @>;

The regular expression given after regexpr: matches pairs of strings and integers separated by ":". The literal object uses this regular expression to check the literal object before calling method parseRetString (or other equivalent to it) of ParseListStringInt. Therefore the checking is made twice by the metaobject literalObject and by the Java class.

Tag addAll allows one to easily define a literal object. The parse: tag should be omitted if we use a addAll: tag. Suppose we want a dictionary literal which should be an object of prototype Dict<String, String>. Assume this prototype defines a method

\texttt{addEverything: Array\langle UTuple\langle String, String \rangle \rangle}

Then the literal could be defined as

@literalObject<<*
    start: "{*"
    regexpr: (String ":" String)*
    type: Dict
    addAll: Dict\langle String, String \rangle .{ addEverything: Array\langle UTuple\langle String, String \rangle \rangle }.
*>>

And used as

:dict = {* "John" : "professor" "Peter":"engineer" "Anna":"artist" *};

Metaobject literalObject would create an object based on the real literal object given between \{* and *\}. The algorithms used in grammar methods would be used here. Then for the above example, the metaobject would create a object of

\texttt{Array\langle UTuple\langle String, String \rangle \rangle}

Then an object of Dict<String, String> would be created and the above object would be passed to method \texttt{addEverything} of this object. This method is specified in the tag addAll. Of course, the method name could be anyone such as \texttt{createFrom}.

Then the code

:dict = {* "John" : "professor" "Peter":"mechanic" "Anna":"artist" *};

would be converted into

:obj001 = Array\langle UTuple\langle String, String \rangle \rangle new: 3;
obj001[0] = [. "John", "professor" .];
obj001[1] = [. "Peter", "engineerer" .];
obj001[2] = [. "Anna", "artist" .];
.tmp0001 = Dict\langle String, String \rangle new;
tmp0001 addEverything: obj001;
:dict = tmp0001;

In the regular language

\((\text{ String ":" \text{ Int}))*\)
the most external operator is an *. Therefore we can choose to add one element at a time by using tag add: instead of addAll:.

@literalObject<<*
  start: "{*"
  regexpr: (String ":" String)*
  type: Dict
  add: Dict<String, String>.{ add: UTuple<String, String> }.
>>>

In this case,
```
:dict = {* "John" : "professor" "Peter" : "mechanic" "Anna": "artist" *};
```
would be converted into
```
:tmp0002 = Dict<String, String> new;
tmp0002 add: [. "John", "professor" .];
tmp0002 add: [. "Peter", "engineer" .];
tmp0002 add: [. "Anna", "artist" .];
:dict = tmp0002;
```

Annotations could be used to allow the literal object to be build using an AST as in grammar methods. So we could write

@literalObject<<*
  start: "{*"
  regexpr: (String ":" String)*
  type: Dict
  addAll: Dict<String, String>
>>>

if prototype Dict<String, String> has an annotation #f1 in method addEverything. The metaobject literalObject would then know that this method should be used in order to create the literal object. The root prototype could have references to other objects that should be annotated too, just like grammar methods. This feature makes small Domain Specific Languages very easy to implement.

By default, comments are allowed in the literal objects. This can be changed by using option comments off:

@literalObject<<*
  start: "{*"
  regexpr: (String ":" String)*
  type: Dict
  addAll: Dict<String, String>
  comment: off
>>>

A future improvement in literal objects would be to allow generic types. Like

@literalObject<<*
  start: "{*"
  genericType: T, U
  regexpr: (T ":" U)*
  type: Dict<T, U>
  addAll: Dict<T, U>.{addEverything: Array<UTuple<T, U>>>}
>>>
There is one special delimiter for literal objects: “\”. A literal object whose left delimiter is “\” ends with “\” too. Then a regular expression literal object can be easily defined:

\@literalObject<<
  start: "\\"
  parse: ParseRegularExpression
>>

Class ParseRegularExpression is very simple:

```java
@literalObject//
  start: "\\"
  parse: ParseRegularExpression
>>

Class ParseRegularExpression implements RetString {
  public String parseRetString(String text, PCI compiler) {
    // cut the first and last characters, which are \\String regExpr = text.substring(1, text.length() - 1);
    return "(RegExpr new: "\\" + regExpr + "\\")";
  }
}
```

Assume the existence of a RegExpr prototype for regular expressions. RegExpr has a method

```java
fun =~ (:str String) -> Boolean
```

that returns true if the regular expression that receives the message matches str. When the compiler finds a literal regular expression object

```
\reg-expr\
```

it replaces it by

```
(RegExpr new: "reg-expr")
```

The compiler only recognizes this literal object if the call to metaobject literalObject is in a package imported by the current source file — see Figure 13.1.

As an example of code,

```
if ( \[A-Za-z]+\\ =~ ident ) [
  Out println: "found an identifier";
]
```

would be replaced by

```
if ( (RegExpr new: ":[A-Za-z]+\") =~ ident ) [
  Out println: "found an identifier";
]
```

Literal objects could be used to embed small languages inside the Cyan source code. That is, literal objects can be used for implementing Domain Specific Languages. For example, a literal object named AwkCode could store code of language AWK:

```
Awk with: "fileName" do: AwkCode[#
  (\[A-Z]*\ ~$0) : [ v[n++] = $0 ]
  END : [ for (j = 0; j < n; j++) println v[j]; ]
#]
```

The same can be made for a small version of Prolog:
Prolog query: [? fat(5, X) ?] database: [+ 
 fat(0, 1).
 fat(N, F) :- N1 is N - 1, fat(N1, H), F is H*N.
 +] 

In the same vein, SQL code can easily be embedded in Cyan:

:v = [## select name, age from Person where age > 18 ##];

Cyan does allow nested comments. If it did not, comments delimited by /\* and \*/ could be easily be implemented as literal object.

@literalObject<<*

start: "/*"

parse: ParseComment

*>>

The parser should only return a single space character — in Cyan, any comment counts as a single space.

public class ParseComment implements RetString {
    public String parseRetString(String text, PCI compiler) {
        return " ";
    }
}

Generic prototypes may be defined as metaobjects. Then “P<T1, T2, ... Tn>” results in a compile-time call to a method createRealPrototype of metaobject P which would produce a real prototype that replaces “P<T1, T2, ... Tn>” in the source code. Tuples will be implemented in this way by the Cyan compiler. In this approach, generic prototypes are just functions that return a prototype or interface at compile-time.
For example, suppose we want to define metaobject `Tuple` for generic tuples. It would be a Java class with a method `createRealPrototype` that accepts the real arguments to the tuple type. This method would return the source code of the `Tuple` prototype (probably as an array of `Char`'s). For each set of real arguments there would be a different source code. The Java method `createRealPrototype` should generate the methods of a prototype `TupleT1T2...Tn` with those arguments. There should be a loop somewhere in this method that iterates on the real arguments because for each field there should be generated two methods (one for getting and the other for setting the field).

It would be nice to have a metaobject `genericPrototype` that helps the creation of metaobjects that represent generic prototypes. Metaobject `genericPrototype` could support a macro language\(^1\) that make it easy to generate code for the generic prototype. To define a prototype `Tuple` we could write

```
@genericPrototype<<<
  name: Tuple
  code: [**
    // code of Tuple with macro commands
    object Tuple...
    ...
    end
  **]>>
```

Tag “name” gives the name of the “generic prototype”, which is in fact a metaobject. Tag “code” accepts a code between “[**” and “**]” as shown above. This code would be the code of prototype `Tuple`. It would consist of Cyan code and commands of a macro language defined by the creator of `genericPrototype`. This language would have decision and repetition statements that would make it easy to generate code.

\(^1\)Following a suggestion of Rodrigo Moraes.
Chapter 14

The Cyan Language Grammar

This Chapter describes the language grammar. The reserved words and symbols of the language are shown between “” and “”. Anything between

- `{ and }` can be repeated zero or more times;
- `{ and }+` can be repeated one or more times;
- `[ and ]` is optional.

The program must be analyzed by unfolding the rule “Program”.

There are two kinds of comments:

- anything between /* and */. Nested comments are allowed.
- anything after // till the end of the line.

Of course, comments are not shown in the grammar.

The rule CharConst is any character between a single quote `. Escape characters are allowed. The rule Str is a string of zero or more characters surrounded by double quotes `. The double quote itself can be put in a string preceded by the backslash character \. Rule AtStr is @ followed by a string ended by double quotes. The backslash character cannot be used to introduce escape characters in this kind of string.

A literal number starts with a number which can be followed by numbers and underscore (_). There may be a trailing letter defining its type:

```
35b    // Byte number
2i     // Integer number
```

There should be no space between the last digit and the letter. User-defined literal numbers start with a digit and may contain digits, letters, and underscore:

```
100Reais 2_3_5_7_prime_0_2_4_even
```

All words that appear between quotes in the grammar are reserved Cyan keywords. Besides these words, the following words are reserved in the language: void, byte, short, int, long, float, double, char, boolean, stackalloc, heapalloc, match, enum, it, break, val, volatile, for, let, virtual, switch, and case.

Id is an identifier composed by a sequence of letters, digits, and underscore, beginning with a letter or underscore. But a single underscore is not a valid identifier. IdColon is an Id followed by a “:”, without space between them, such as “ifTrue:” and “ifFalse:”. InterIdColon is an Id followed by a “;” and preceded by “?” as in “?at:” (dynamic unchecked message send). InterId is an Id preceded by “?” such
as “?.name”. InterDotIdColon is an Id followed by a “;” and preceded by “?.” as in “?.at;”. (nil-safe message send). InterDotId is an Id preceded by “?.” as in “?.name”. TEXT is a terminal composed by any number of characters.

LeftCharString is any sequence of the symbols

= ! # $ % & * + - ^ ~ ? / : . \ [ ] { <

Note that >, ), ], and } are missing from this list. RightCharString is any sequence of the same symbols of LeftCharString but with >, ), ], and } replacing <, (, [, and {, respectively. The compiler will check if the closing RightCharString of a LeftCharString is the inverse of it. That is, if LeftCharString is

(*=<[ then its corresponding RightCharString should be

]>=*)

SymbolLiteral is a literal symbol (see page 63 for definition). UserDefUnOp is any user-defined operator starting with a “!” which is an unary operator. UserDefBinOper is any user-defined operator that does not start with “!” (which is always binary). User defined operators can only use the symbols defined in Section 4.9.

There are limitations in the sequences of symbols that are considered valid for literal objects and user-defined operators. They cannot start with (((, ))], [1, ([, ]], [[, ]], [:, :, ], [:, >, ], ]]>[^, :, , {, ]}, and : . For short, they cannot start with any sequence of symbols which can appear in a valid Cyan program. For example, [1 is illegal because we can have a block declared as

[1:n Int] ^ n*n ]

For the same reason, : is also illegal as a sequence of characters of a literal object or a user-defined operator.

SymUnary is a Cyan symbol #ident in which ident is a valid identifier. For example,

#get #b100 #array #size

SymColor is a Cyan symbol #ident: in which ident is a valid identifier. For example,

#set: #at: #do: #f34_34:

CompilationUnit ::= PackageDec ImportDec { CTMOCallList ProgramUnit }
PackageDec ::= “package” Id
ImportDec ::= { “import” IdList }
CTMOCallList ::= { CTMOCall }
ProgramUnit ::= [ QualifProtec ] ( ObjectDec | InterfaceDec )
QualifProtec ::= “private” | “public” | “protected”
CTMOCall ::= (“@” | “@@” ) Id [ LeftCharString TEXT RightCharString ]
ObjectDec ::= [“mixin” [ “( Type )” ] | “abstract” | “final” ]
    “object” Id { TemplateDec }
        [ ContextDec ]
        [ “extends” Type ]
        [ “mixin” TypeList ]
        [ “implements” TypeList ]
    { SlotDec } “end”
TemplateDec ::= “<” TemplateVarDecList “>”
TemplateVarDecList ::= TemplateVarDec { “,” TemplateVarDec }

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InterMethSig2 ::= Id |
    [ "[]" ] { IdColon [ InterParamDecList ] }+ |
    UnaryOp |
    BinaryOp ( SingleInterParamDec | "(" SingleInterParamDec ")" )
InterParamDecList ::= WithoutParentDecList | WithParentDecList
WithoutParentDecList ::= ParamTypeDecList { "," ParamTypeDecList }
ParamTypeDecList ::= [ ":" Id { "," ":? Id } ] Type
WithParentDecList ::= "(" WithoutParentDecList ")"
SingleInterParamDec ::= [ ":" Id ] Type

BasicType ::= "Byte" | "Short" | "Int" | "Long" |
    "Float" | "Double" | "Char" | "Boolean" | "Void"

StatementList ::= Statement { ";" Statement } | \epsilon
Statement ::= ExprStat | ReturnStat | VariableDec | CTMOCall | IfStat | WhileStat | NullStat

VariableDec ::= ":" Id [ Type ] [ ":=" Expr ] |
    ":" Id { "," ":? Id } Type
ReturnStat ::= "return" Expr | "~~" Expr
IfStat ::= "if" "(" Expr ")" BlockVoidVoid
    { "else" "if" "(" Expr ")" BlockVoidVoid }
    [ "else" BlockVoidVoid ]
WhileStat ::= "while" "(" Expr ")" BlockVoidVoid
BlockVoidVoid ::= "[" StatementList "]"
NullStat ::= ","
ExprStat ::= ( "super" | ExprUnaryUnMS ) MessageSendNonUnary |
    ExprOr { "," ExprOr } { "=~" ExprOr }
Expr ::= ( "super" | ExprPrimary ) MessageSendNonUnary |
    ExprOr
MessageSendNonUnary ::= { IdColon [ RealParameters ] }+ |
    
    [ InterIdColon [ RealParameters ] ]+ |
    [ InterDotIdColon [ RealParameters ] ]+ |
    BinaryOp ExprOr

BinaryOp ::= ShiftOp | BitOp | MultOp | AddOp | RelationOp |
    "||" | "!|!" | "&&" | ".." | UserDefBinOp

RealParameters ::= Expr { "," Expr }

ExprOr ::= ExprXor { "||" ExprXor }

ExprXor ::= ExprAnd { "&&" ExprAnd }

ExprRel ::= ExprRel [ RelationOp ExprRel ]

ExprRelInter ::= ExprAdd [ ".." ExprAdd ]

ExprAdd ::= ExprMult { AddOp ExprMult }

ExprMult ::= ExprBit { MultOp ExprBit }

ExprShift ::= ExprShift { BitOp ExprShift }

ExprUnaryUnMS ::= ExprUnaryUnMS { ShiftOp ExprUnaryUnMS }

ExprUnary ::= ExprUnary { UnaryId }

UnaryId ::= Id | InterId | InterDotId

ExprUnary ::= [ UnaryOp ] ExprPrimaryIndexed

ExprPrimaryIndexed ::= ExprPrimary [ Indexing ]

Indexing ::= "[" Expr "]" | "?[" Expr "]?

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UnaryOp ::= “+” | “−” | “++” | “−−” | “!” | “~” | UserDefUnOp

ExprPrimary ::= “self” [ “.” Id ] |
  “self” [ MethodAccess ] |
  “super” UnaryId |
  QualifId { “<” TypeList “>” }+ [ ObjectCreation ] |
  QualifId { “<” TypeList “>” }+ [ MethodAccess ] |
  “type” (” QualifId [ “<” TypeList “>” ] “) ” |
  ExprLiteral | (“(” Expr “)”) |

ObjectCreation ::= (“(” [ Expr { “,” Expr } ] “)”) |

MethodAccess ::= “.”{“ InterMethSig “.”} |

ExprLiteral ::= ByteLiteral | ShortLiteral | IntLiteral |
  LongLiteral | FloatLiteral | DoubleLiteral | CharLiteral |
  BooleanLiteral | Str | AtStr | SymbolLiteral | “nil” |
  “noObject” | LiteralArray | ClosureDec |
  LeftCharString TEXT RightCharString | LiteralTuple |

BooleanLiteral ::= “true” | “false” |

LiteralArray ::= “{#” [ Expr “,” { Expr } “}” “#}” |

LiteralTuple ::= “[.” TupleBody | UTupleBody “.]” |

TupleBody ::= IdColon Expr { “,” IdColon Expr } |

UTupleBody ::= Id Expr { “,” Id Expr } |

ShiftOp ::= “<.,<” | “>,<” | “>,>” |

BitOp ::= “&” | “|” | “^” |

MultOp ::= “/” | “∗” | “%” |

AddOp ::= “+” | “−” |

RelationOp ::= “==” | “<” | “>” | “<==” | “>=” | “!=” | “=” | “==” |

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Chapter 15

Opportunities for Collaboration

There are many research projects that could be made with Cyan and on Cyan:

(a) to implement metaobjects \texttt{@dynOnce} and \texttt{@dynAlways} and to design algorithms that help the transition of dynamically-typed Cyan to statically-typed Cyan. There are a great deal of work here, at least several master thesis. This work can involve the discovery of types statically (at least most of them), the use of a profiler to discover some types at runtime, the combination of static and dynamic type information, refactorings directed by the user (he/she chooses the type of each troublesome variable/parameter/return type, for example), help by the IDE, etc.

It would be very important to have a language in which the programmer could develop a program without worrying about types in variables/parameters/return values and then convert this program to statically-typed Cyan. I would say that this is one of the central points of the language;

(b) to design the metalevel appropriately. The design of the metalevel is of fundamental importance to the language. Usually metalevel programming is too difficult and regular programmers do not use it (not considering Lisp macros). The challenge is to design a “simple” metalevel. Maybe grammar methods may be useful here: instead of allowing the user to modify the abstract syntax tree of the code, she or he should change the code through one or more grammar methods. For example, to add a method to a prototype, one could use the code

\begin{verbatim}
Obj addMethod:
    selector: #sum:
    param: #a type: Int
    param: #b type: Int
    returnType: Int
    ASTbody:
        returnStat: (Expr add: #a, #b);
\end{verbatim}

This is a grammar method of prototype \texttt{Any}. This call would add method

\begin{verbatim}
    sum: (:a, :b Int) -> Int [ return a + b ]
\end{verbatim}

to object \texttt{Obj};

(c) implement some Design Patterns in Cyan with the help of: 1) compile-time metaobjects and b) literal objects. The use of literal objects makes it easy the codification of some design patterns. This is a good project and it seems one of the easy ones. The metaobject protocol could be improved to deal with the most used patterns. I said “improved”, not modified just to make the patterns more easily implemented;
(d) implement some literal objects which are the code of some small languages such as AWK and SQL. It would be nice if Cyan code could be used inside the code of the language;

(e) to use Cyan to implement a lot of small Domain Specific Languages;

(f) to use Cyan to investigate language-oriented programming [21];

(g) to implement a lot of small compile-time metaobjects for small tasks. One of my students [20] has already made some codegs. There are millions of interesting compile-time metaobjects to build;

(h) to add parallelism to the language and to design a library for distributed programming. That includes the implementation of patterns for parallel programming;

(i) to design code optimization algorithms for Cyan;

(j) to program the Cyan basic libraries for handling files, data structures, and so on;

(k) enumerated constants. They could be Java like or C# like — which would be better?
Chapter 16

The Cyan Compiler

Every Cyan program should be described by a project in xml. This project file should be in a directory with the same name as the file (without the extension xml). Every subdirectory of this directory corresponds to a package of the language. All the source files of a package should be in the same directory. For example, the following directory tree describes a program named myFirstProg which contains packages main and DS. Package main has source files Program.cyan, A.cyan, and B.cyan. DS has files Stack.cyan and List.cyan. We use right shift for sub-directories.

myFirstProg
  myFirstProg.xml
  main
    Program.cyan
    A.cyan
    B.cyan
  DS
    Stack.cyan
    List.cyan

The project file, myFirstProg.xml in this example, describes the Cyan program: author (tag author of xml, there may be more than one author), compiler options (attribute options of the root element, project), main package (tag mainPackage), main object (tag mainObject), path of other Cyan packages (tag cyanpath), path of Java files (tag javapath), and its packages (tag packageList). Each package is described by an element whose tag is package. The children of package can be name and sourcefile (one for each Cyan source file of the package). There may be an attribute options in each source file and in each package. The compiler options of a source file are the union of those defined in the project, package, and source file. The last ones have precedence over the options for project and package. And the package options have precedence over the ones of the project. For example, if the project has an option “-ue” and the source an option “+ue”, it is the last one that is valid in the tag sourcefile, if there is one. If there is none, the options are those of its package.

Let us see an example, file myFirstProg.xml:

<?xml version="1.0"?>
<!-- This is a comment -->
  <!-- options are the compiler options separated by spaces -->

<project options = "-ue -sfe">
  <author>
    Jose de Oliveira Guimaraes
  </author>
</project>
A package may be in a directory which is not subdirectory of the project directory (myFirstProg in the example). In this case, the package element in the XML file describing the project should have an attribute “dir” indicating the directory of the package. In the following example, package “ds” is in directory “c:\user\jose\ds”.

<?xml version="1.0"?>
<project>
  <author>
    Jose de Oliveira Guimaraes
  </author>
  <mainPackage> main </mainPackage>
  <mainObject> Program </mainObject>
  <cyanpath> c:\cyan\lang </cyanpath>

  <packageList>
    <package dir = "c:\user\jose\ds">
      <name> DS </name>
      <sourcefile> Stack.cyan </sourcefile>
      <sourcefile> List.cyan </sourcefile>
    </package>
  </packageList>
</project>
The source files of a package a.b.c.d should be in a directory d and the package name defines a directory tree:

C:\myProjects
  a
    b
      c
        d
          // source files of package d
        e
          // source files of c
    // source files of package c

There should be directories a, b, c, and d. But it is not necessary that packages a, b, and c exit.

There is one XML element called codegpath composed by a complete path of a single directory that should contain codegs. This element should appear in the same level as author. More than one cyanpath element can appear:

<?xml version="1.0"?>
<project>
  <author> Jose de Oliveira Guimaraes </author>
  <mainPackage> main </mainPackage>
  <mainObject> Program </mainObject>
  <cyanpath> c:\cyan\lang </cyanpath>
  <codegpath> D:\compilers\Cyan\lib\codeg </codegpath>
  <codegpath> E:\eu\cyan\codeg </codegpath>

  <packageList>
    <package>
      <name> main </name>
      <sourcefile> Program.cyan </sourcefile>
    </package>
  </packageList>
</project>
When a codeg MyCodeg is found by the Eclipse environment (with the codeg plugin), it searches for a Java class called MyCodegCodeg that will handle that codeg. This search is made in the following directories, in this order:

- CYANPATH\codeg, in which CYANPATH is an environment variable;
- the directories of the element codegPath, in the order they appear.

Using the above example, the compiler would search for, in this order:

- CYANPATH\codeg\MyCodegCodeg
- D:\compilers\Cyan\lib\codeg\MyCodegCodeg
- E:\eu\cyan\codeg\MyCodegCodeg

The current compiler options are:

1. “-cyanLang Path” in which Path is the path of the package cyan.lang. This package contains all the basic types, arrays etc;

2. “-add” that adds automatically the qualifier “public” for objects and methods declared without a qualifier and “private” for instance variables declared without qualifier. The compiler changes a source code like

```plaintext
package bank

object Account
    fun init: :client Client [ self.client = client ]
    fun print [ Out println: (client getName) ] :client Client
end

into

package bank

public object Account
    public fun init: :client Client [ self.client = client ]
    public fun print [ Out println: (client getName) ]
    private :client Client
end
```

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Chapter 17

Features That May Be Added, Features That May Be Changed

Some Cyan features may be changed and others may be added. This is a partial list of them:

1. A finally: selector may be added to the initial block that starts the program execution. That would allow finalizers, code that is called when the program ends. There could be a list of methods to be called when the program ends. This is odd, but someone will certainly like it.

```
[ ] catch: RuntimeCatch
   finally: [
      DoomsdayWishList foreach: [ |:elem UBlock| elem eval ];
   ];
```

In some other place:

```
DoomsdayWishList add: [ "Good bye!" print ];
```
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