ActorScript™ extension of C#®, Java®, Objective C®, JavaScript®, and SystemVerilog using iAdaptive™ concurrency for antiCloud™ privacy and security

Carl Hewitt

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ActorScript™ extension of C#®, Java®, Objective C®, C++, JavaScript®, and SystemVerilog using iAdaptive™ concurrency for antiCloud™ privacy and security[i]

Carl Hewitt

This article is dedicated to Alonzo Church, John McCarthy, Ole-Johan Dahl and Kristen Nygaard.

ActorScript™ is a general purpose programming language for efficiently implementing robust applications[ii] using iAdaptive™ concurrency that manages resources and demand. It is differentiated from previous languages by the following:

- Universality
    - Ability to directly specify exactly what Actors can and cannot do
    - Everything is accomplished with message passing using types including the very definition of ActorScript itself.
    - Messages can be directly communicated without requiring indirection through brokers, channels, class hierarchies, mailboxes, pipes, ports, queues *etc.* Programs do not expose low-level implementation mechanisms such as threads, tasks, locks, cores, *etc*. Application binary interfaces are afforded so that no program symbol need be looked up at runtime. Functional, Imperative, Logic, and Concurrent programs are integrated.
    - A type in ActorScript is an interface that does not name its implementations (contra to object-oriented programming languages beginning with Simula that name implementations called "classes" that are types). ActorScript can send a message to any Actor for which it has an (imported) type.
    - Concurrency can be dynamically adapted to resources available and current load.

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[i] C# is a registered trademark of Microsoft, Inc.
Java and JavaScript are registered trademarks of Oracle, Inc.
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[ii] with no single point of failure

- Safety, security and readability
  - Programs are *extension invariant*, *i.e.*, extending a program does not change the meaning of the program that is extended.
  - Applications cannot directly harm each other.
  - Variable races are eliminated while allowing flexible concurrency.
  - Lexical singleness of purpose. Each syntactic token is used for exactly one purpose.
- Performance[i]
  - Imposes no overhead on implementation of Actor systems in the sense that ActorScript programs are as efficient as the same implementation in machine code. For example, message passing has essentially same overhead as procedure calls and looping.
  - Execution dynamically adjusted for system load and capacity (*e.g.* cores)
  - Locality because execution is not bound by a sequential global memory model
  - Inherent concurrency because execution is not limited by being restricted to communicating *sequential* processes
  - Minimize latency along critical paths

ActorScript attempts to achieve the highest level of performance, scalability, and expressibility with a minimum of primitives.

Message passing using types is the foundation of system communication:

- Messages are the unit of communication
- Types[ii] enable secure communication with Actors

Computer software should not only work; it should also appear to work.[1]

---

[i] Performance can be tricky as illustrated by the following:

- "Those who would forever give up correctness for a little temporary performance deserve neither correctness nor performance." [Philips 2013]
- "The key to performance is elegance, not battalions of special cases" [Jon Bentley and Doug McIlroy]
- "If you want to achieve performance, start with comprehensible." [Philips 2013]
- Those who would forever give up performance for a feature that slows everything down deserve neither the feature nor performance.

[ii] Each type is an Actor. However, it may be the case that a type will work some places and not others. For example, to be used in message passing, the type of an address may require access to particular hardware.

Introduction

ActorScript is based on the Actor mathematical model of computation that treats "*Actors*" as the universal conceptual primitive of digital computation [Hewitt, Bishop, and Steiger 1973; Hewitt 1977; Hewitt 2010a]. Actors have been used as a framework for a theoretical understanding of concurrency, and as the theoretical basis for several practical implementations of concurrent systems.

ActorScript

ActorScript is a general purpose programming language for implementing massive local and nonlocal concurrency.

This paper makes use of the following typographical conventions that arise from underlying namespaces for types, messages, language constructs, syntax categories, *etc.*[i]

- type identifiers (*e.g.,* **Integer**)
- program variables (*e.g.,* **aBalance**)
- message names (*e.g.,* **getBalance**)
- reserved words[2] for language constructs (*e.g.,* **Actor**)
- structures (*e.g.,* **[** and **]**)
- argument keyword (e.g., **to**)
- logical variables (e.g., *x*)
- comments in programs (e.g. /* this is a comment */)

There is a diagram of the syntax categories of ActorScript in an appendix of this paper in addition to an appendix with an index of symbols and names along with an explanation of the notation used to express the syntax of ActorScript.[3]

Actors

ActorScript is based on the Actor Model of Computation [Hewitt, Bishop, and Steiger 1973; Hewitt 2010a] in which all computational entities are Actors and all interaction is accomplished using message passing.

The Actor model is a mathematical theory that treats "*Actors*" as the universal conceptual primitive of digital computation. The model has been used both as a framework for a theoretical understanding of concurrency, and as the theoretical basis for several practical implementations of concurrent systems. Unlike previous models of computation, the Actor model was inspired by physical laws. The advent of massive concurrency through client-cloud

[i] The choice of typography in terms of font and color has no semantic significance. The typography in this paper was chosen for pedagogical motivations and is in no way fundamental. Also, only the abstract syntax of ActorScript is fundamental as opposed to the surface syntax with its many symbols, e.g., $\mapsto$, etc.

computing and many-core computer architectures has galvanized interest in the Actor model.

An Actor is a computational entity that, in response to a message it receives, can concurrently:

- send messages to addresses of Actors that it has
- create new Actors
- designate how to handle the next message it receives.

There is no assumed order to the above actions and they could be carried out concurrently. In addition two messages sent concurrently can be received in either order. Decoupling the sender from communication it sends was a fundamental advance of the Actor model enabling asynchronous communication and control structures as patterns of passing messages.

The Actor model can be used as a framework for modeling, understanding, and reasoning about, a wide range of concurrent systems. For example:

- Electronic mail (e-mail) can be modeled as an Actor system. Mail accounts are modeled as Actors and email addresses as Actor addresses.
- Web Services can be modeled with endpoints modeled as Actor addresses.
- Object-oriented programing objects with locks (e.g. as in Java and C#) can be modeled as Actors.

Actor technology will see significant application for coordinating all kinds of digital information for individuals, groups, and organizations so their information usefully links together. Information coordination needs to make use of the following information system principles:

- ***Persistence***. *Information is collected and indexed.*
- ***Concurrency***: *Work proceeds interactively and concurrently, overlapping in time.*
- ***Quasi-commutativity***: *Information can be used regardless of whether it initiates new work or becomes relevant to ongoing work.*
- ***Sponsorship***: *Sponsors provide resources for computation, i.e., processing, storage, and communications.*
- ***Pluralism***: *Information is heterogeneous, overlapping and often inconsistent. There is no central arbiter of truth.*
- ***Provenance***: *The provenance of information is carefully tracked and recorded.*

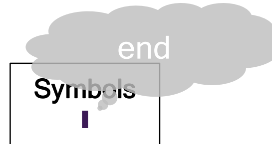
The Actor Model is designed to provide a foundation for inconsistency robust information coordination.

Notation

To ease interoperability, ActorScript uses an intersection of the orthographic conventions of Java, JavaScript, and C++ for words[i] and numbers.

Expressions

ActorScript makes use of a great many symbols to improve readability and remove ambiguity. For example the symbol “▮” is used as the top level terminator to designate the end of input in a read-eval-print loop. An Integrated Development Environment (IDE) can provide a table of these symbols for ease of input as explained below:[ii]



Expressions evaluate to Actors. For example, 1+3▮[iii] is equivalent[iv] to 4▮.

Parentheses “(” and “)” can be used for precedence. For example using the usual precedence for operators, 3*(4+2)▮ is equivalent to 18▮, while 3*4+2▮ is equivalent to 14▮,

Identifiers, e.g., x, are expressions that can be used in other expressions. For example if x is 1 then x+3▮ is equivalent to 4▮. The formal syntax of identifiers is in the following end note: **4.**

Types

Types are Actors. In this paper, Type names are shown in green, *e.g.,* **Integer**.

The formal syntax for types is in the following end note: **5.**

---

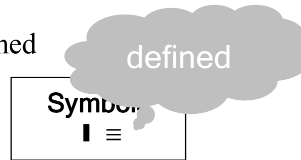
[i] sometimes called “names”

[ii] Furthermore, all special symbols have ASCII equivalents for input with a keyboard. An IDE can convert ASCII for a symbol equivalent into the symbol. See table in an appendix to this article.

[iii] An IDE can provide a box with symbols for easy input in program development. The grey callout bubble is a hover tip that appears when the cursor hovers above a symbol to explain its use.

[iv] in the sense of having the same value and the same effects

Definitions, *i.e.,* ≡



An identifier definition has an identifier to be defined followed by “≡” followed by the definition. For example, x≡3▮ defines the identifier x to be the Actor 3.

The formal syntax of an identifier definition is in the end note: **6.**

A procedure is an Actor that can receive a list of Actors in a message and return an Actor as its value, which can be defined using a procedure name followed by “▪”, a list of formal arguments, and return type. For example,

Double▪[v:Integer]:Integer ≡ v+v▮

The formal syntax of a procedure definition is in the end note: **7.**

Sending messages to procedures, *i.e.,* **▪[ ]**

Sending a message to a procedure (*i.e.* “calling” a procedure with arguments) is expressed by an expression that evaluates to a procedure followed by “▪”[8] followed by a message with arguments delimited by “[” and “]”. For example, Square▪[2+1]▮ means send Square[i] the message [3]. Thus Square▪[2+1]▮ is equivalent to 9▮.

The formal syntactic definition of procedural message sending is in the end note: **9.**

---

[i] As a convenience, the procedure Square can be defined to as follows: Square▪[x:Integer]:Integer ≡ x*x▮

Patterns

Patterns are fundamental to ActorScript. For example,

- 3 is a pattern that matches 3
- “abc” is a pattern that matches “abc”.
- _ is a pattern that matches anything[i]
- $$x is a pattern that matches the value of x.
- $$(x+2) is a pattern that matches the value of the expression x+2.
- < 5 is a pattern that matches an integer less than 5
- **x suchThat** Factorial▪**[x]>120** is a pattern that matches an integer whose factorial is greater than 120

Identifiers[ii] can be bound using patterns as in the following examples:

- x is a pattern that matches “abc” and binds x to “abc”

[i] e.g., _ matches 7

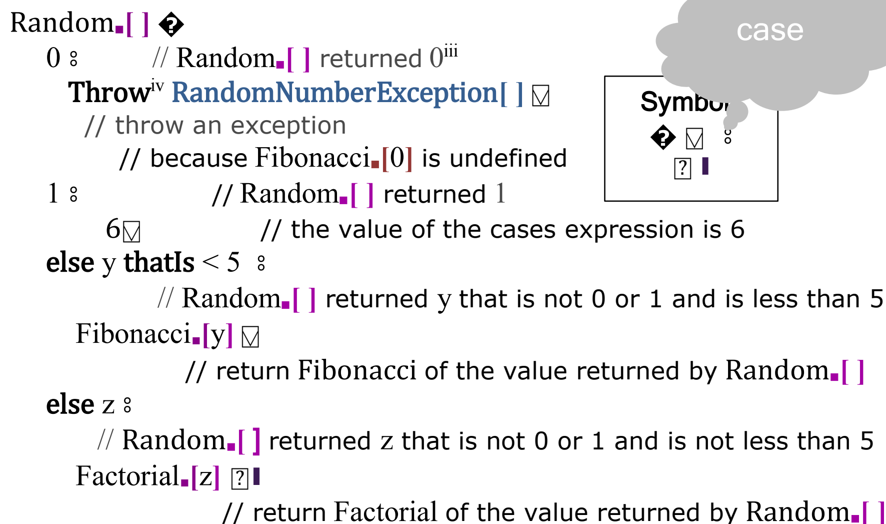
[ii] An identifier is a name that is used in a program to designate an Actor

Cases, *i.e.*, � ⦂ , ⦂ ⍰

Cases are used to perform conditional testing. In a Cases Expression, an expression for the value on which to perform case analysis is specified first followed by "�"[i] and then followed by a number of cases separated by "⍌" terminated by "⍰".[10] A case consists of

- a pattern followed by "⦂" and an expression to compute the value for the case. *All of the patterns before an* **else** case must be disjoint; *i.e.*, it must not be possible for more than one to match.
- optionally (at the end of the cases) *one or more* of the following cases: "**else**" followed by an optional pattern, "⦂", and an expression to compute the value for the case. An **else** case applies *only* if none of the patterns in the preceding cases[ii] match the value on which to perform case analysis.

As an arbitrary example purely to illustrate the above, suppose that the procedure Random, which has no argument and returns **Integer**, in the following example:



The formal syntax of cases is in the following end note: **11.**

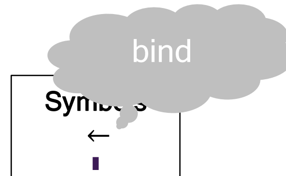
---

[i] "�" is fancy typography for "**?**"
[ii] *including* patterns in previous else cases
[iii] As is standard, ActorScript uses the token "//" to begin a one-line comment.
[iv] Reserved words are shown in bold black.

Binding locals, ***i.e.*****, Let ← 。**

Local identifiers can be bound using "**Let**" followed by a list of bindings separated by commas and terminated with "。" Each binding consists of a pattern, "←", and an expression for the Actor to be matched. For example, aProcedure▪["G", "F", "F"]▮ is equivalent to the following:

Let x ← "F"。   // x is "F"
  aProcedure▪["G", x, x]▮



Dependent bindings (in which each can depend on previous ones) can be accomplished by nesting **Let**. For example:

Let x ←"F"。   // x is "F"
 Let y ← aProcedure▪["G", x, x]。
        // y is aProcedure▪["G", "F", "F"]
   anotherProcedure▪[x, y]▮

The above is equivalent to
anotherProcedure▪["F", aProcedure▪["G", "F", "F"]]▮

The formal syntax of bindings is in the following end note: **12.**

General Message-passing interfaces

Procedure interfaces are a special case of general message-passing interfaces.

A message handler signature consists of a message name followed by argument types delimited by "[" and "]", "↦", and a return type. For example

Interface Account **with** getBalance[ ]↦Currency,
                    deposit[Currency]↦Void,
                    withdraw[Currency]↦Void▮

The formal syntactic definition of named-message sending is in the following end note: **13**

Actors that change, *i.e.,* **Actor** and ≔

Using the expressions introduced so far, actors do not change. However, some Actors change behaviors over time.

An Actor can be created using "**Actor**" optionally followed by the following:

- constructor name with formal arguments delimited using brackets
- declarations of variables[i] terminated by "。"
- implementations of interface(s).

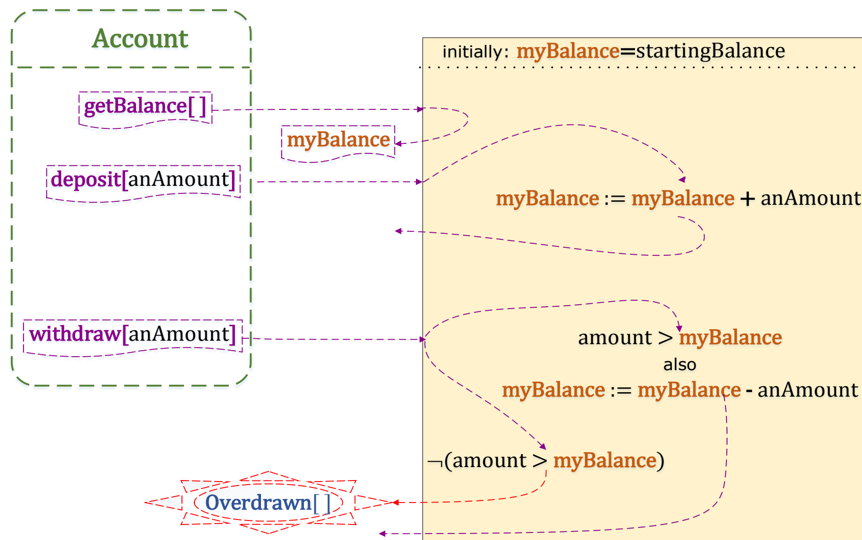
Message handlers in an Actor execute mutually exclusively while in a region of mutual exclusion which is called "cheese." In this paper assignable variables are colored orange, which by itself has no semantic significance, i.e., printing this article in black and white does not change any meaning. The use of assignments is strictly controlled in order to achieve better structured programs.[14]

ActorScript is referentially transparent in the sense that a variable never changes while in a continuous part of the cheese.[15] For example, in the **deposit** message handler change is accomplished using the following:

Void afterward myBalance ≔ myBalance+anAmount

which returns **Void** and updates myBalance for the *next* message received.

Below is a diagram for an Actor, which implements **Account**:



[i] variable declarations separated by commas

Variable races are impossible in ActorScript

The implementation of Account above can be expressed as follows:

```
Actor SimpleAccount.[startingBalance:Euro]
        // SimpleAccount is a constructor and not a type[i]
    myBalance ≔ startingBalance。
    // myBalance is an assignable variable initialized with startingBalance
    implements Account using
      getBalance[ ] →  myBalance¶
      deposit[anAmount] →
        Void                                                    // return Void
            afterward  myBalance ≔ myBalance+anAmount¶
                          // the next  message is processed with
                               //  myBalance reflecting the deposit
      withdraw[anAmount] →
        (amount > myBalance) �
           True ⸰ Throw  Overdrawn[ ] ⍌
           False ⸰ Void                                         // return Void
                    afterward myBalance ≔ myBalance−anAmount ⍰§▮
                  // the next message is processed with updated myBalance
```

The formal syntax of **Actor** expressions is in the following end note: **16.**

---

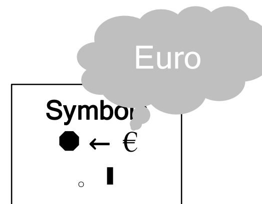
[i] SimpleAccount:[Euro]↦Account

Antecedents, Preparations, and Necessary Concurrency, *i.e.*, ☐

Concurrency can be controlled using preparation that is expressed in a continuation using preparatory expressions, "⬣" and an expression that proceeds only *after* the preparations have been completed.

The following expression creates an account anAccount with initial balance €6 and then concurrently withdraws €1 and €2 in preparation for reading the balance:

```
Let anAccount ← SimpleAccount▪[€6]◦  //€ is a reserved prefix operator
  Prep anAccount▪withdraw[€1],
       anAccount▪withdraw[€2]⬣◦
         //proceed only after both of the
         // withdrawals have been acknowledged
     anAccount▪getBalance[ ]▮
```



The above expression returns €3.

Operations are quasi-commutative to the extent that it doesn't matter in which order they occur.

Quasi-commutativity can be used to tame indeterminacy while at the same time facilitating implementations that run exponentially faster than those in the parallel lambda calculus.[i]

The formal syntax of compound expressions is in the following end note: **17**

An expression can be annotated for concurrent execution by preceding it with "☐" indicating that the following expression must be considered for concurrent execution if resources are available. For example ☐Factorial▪[1000]+☐Fibonacci▪[2000]▮ is annotated for concurrent execution of Factorial▪[1000] and Fibonacci▪[2000] both of which *must* complete execution. This does not require that the executions of Factorial▪[1000] and Fibonacci▪[2000] actually overlap in time.[18]

The formal syntax of explicit concurrency is in the following end note: **19.**

[i] For example, implementations using Actors of Direct Logic can be exponentially faster than implementations in the parallel lambda calculus.

Implementing multiple interfaces , *i.e.*, ⍰⍰ and also implements

The above implementation of Account can be extended as follows to provide the ability to revoke some abilities to change an account.[20] For example, AccountSupervisor below implements both the Account and AccountRevoker interfaces as an extension of the implementation SimpleAccount:

As illustrated below, a qualified address of an Actor can be expressed using "⍰⍰" followed by the name of the qualifier.[21]

```
Actor SimpleAccountSupervisor▪[initialBalance:Euro]
            // SimpleAccountSupervisor is a constructor and not a type^i
  extends SimpleAccount[initialBalance]
              // extends implementation SimpleAccount[initialBalance]^22
    withdrawableIsRevoked ≔ False,
    depositableIsRevoked ≔ False。
    implements AccountSupervisor using
      getRevoker[ ]→ ⍰⍰AccountRevoker¶
      getAccount[ ] → ⍰⍰Account¶
      withdrawFee[anAmount] →
                Void afterward myBalance ≔ myBalance–anAmount§
                      // withdraw fee even if balance goes negative^23
    also partially reimplements exportable Account using
      withdraw[anAmount] →
        withdrawableIsRevoked �
          True ⦂ Throw  Revoked[ ] ⍌
           False ⦂ ⍰⍰SimpleAccount▪withdraw[anAmount] ⍰¶
      deposit[anAmount] →
         depositableIsRevoked �
           True ⦂ Throw  Revoked[ ] ⍌
           False ⦂ ⍰⍰SimpleAccount▪deposit[anAmount] ⍰§
    also implements exportable AccountRevoker using
      revokeDepositable[ ] →
          Void afterward depositableIsRevoked ≔ True¶
      revokeWithdrawable[ ] →
          Void afterward withdrawableIsRevoked ≔ True§▮
```

[i] SimpleAccountSupervisor:[Euro]↦AccountSupervisor

For example, the following expression returns *negative* €3:

```
Let anAccountSupervisor ← SimpleAccountSupervisor.[€3]。
  Let anAccount ← anAccountSupervisor.getAccount[ ],
      aRevoker ← anAccountSupervisor.getRevoker[ ]。
    Prep anAccount.withdraw[€2]●                 // the balance is €1
         aRevoker.revokeWithdrawable[ ]●
                                 // withdrawableIsRevoked in is True
         Try anAccount.withdraw[€5]        // try another withdraw
           catch� _ ⦂ Void ●              // ignore the thrown exception24
                                          // the balance remains €1
           anAccountSupervisor.withdrawFee[€4]●。
               // €4 is withdrawn even though withdrawableIsRevoked
      anAccount.getBalance[ ]▮    // the balance is negative €3
```

The formal syntax of the programs below is in the following end note: **25**

Swiss cheese

Swiss cheese [Hewitt and Atkinson 1977, 1979; Atkinson 1980][26] is a generalization of mutual exclusion with the following goals:

- *Generality:* Ability to conveniently program any scheduling policy
- *Performance:* Support maximum performance in implementation, e.g., the ability to minimize locking and to avoid repeatedly recalculating a condition for proceeding.
- *Understandability:* Invariants for the variables of a mutable Actor should hold whenever entering or leaving the cheese.
- *Modularity:* Resources requiring scheduling should be encapsulated so that it is impossible to use them incorrectly.

By contrast with the nondeterministic lambda calculus, there is an always-halting Actor Unbounded that when sent a [ ] message can compute an integer of unbounded size. This is accomplished by creating a Counter[i] with the following variables:

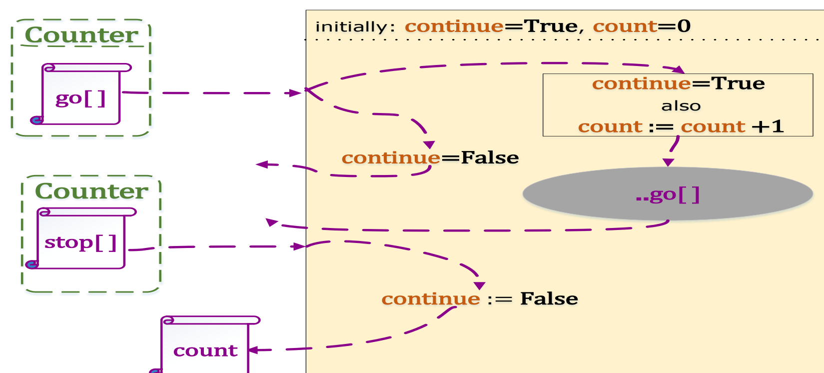
- count initially **0**
- continue initially **True**

and concurrently sending it both a stop[ ] message and a go[ ] message such that:

- When a go[ ] message is received:
  1. if continue is **True**, increment count by 1 and return the result of sending this counter a go[ ] message.
  2. if continue is **False**, return **Void**
- When a stop[ ] message is received, return count and set continue to **False** for the next message received.

By the Actor Model of Computation [Clinger 1981, Hewitt 2006], the above Actor will eventually receive the stop[ ] message and return an unbounded number.

A diagram is shown below for an implementation of Counter. In the diagram, a hole in the cheese is highlighted in grey and variables are shown in orange. The color has no semantic significance.



---

[i] Interface Counter with go[ ]↦ Void,
stop[ ]↦ Integer▮

```
CreateUnbounded.[ ]:Integer ≡
   Let aCounter ← SimpleCounter.[ ]。   // let aCounter be a new Counter
     Prep □aCounter.go[ ]。  // send aCounter a go message and concurrently
       □aCounter.stop[ ]▮  // return the result of sending aCounter stop[ ]
```

As a notational convenience, when an Actor receives message then it can send an arbitrary message to itself by prefixing it with ".." as in the following example for the Actor implementation SimpleCounter:

```
Actor SimpleCounter.[ ]
   count := 0,        // the variable count is initially 0
   continue := True。
   implements Counter using
     stop[ ] →
       count                                   // return count
         afterward continue := False¶
           // continue is updated to False for the next message received
     go[ ] →
       continue �
         True ⦂ Prep count := count+1⬣。      // increment count
                 hole ..go[ ] ⍌               // send go[ ] to this counter
         False ⦂ Void ⍰§▮            // if continue is False, return Void
```

Symbols
≡ → ⦂
。⍰ ¶ § ▮

The formal syntax of the programs above is in the following end note: **27**

Coordinating Activities

Coordinating activities of readers and writers in a shared resource is a classic problem. The fundamental constraint is that multiple writers are not allowed to operate concurrently and a writer is not allowed operate concurrently with a reader.

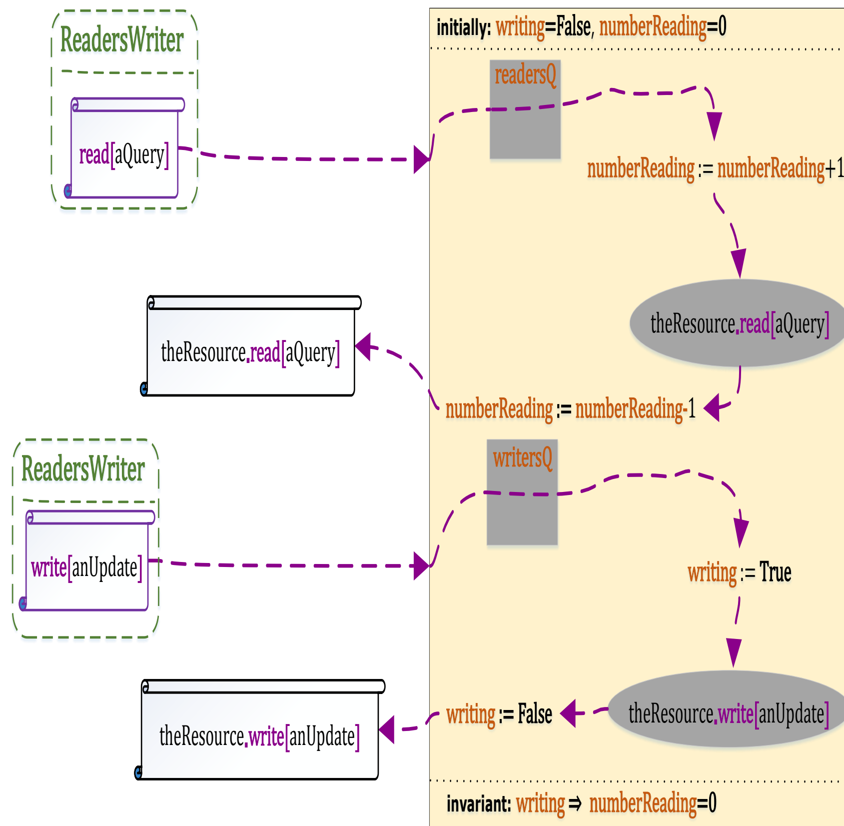
Below are two implementations of readers/writer guardians for a shared resource that implement different policies:[28]

1. *ReadingPriority:* The policy is to permit maximum concurrency among readers without starving writers.[29]
    - *a.* When no writer is waiting, all readers start as they are received.
    - *b.* When a writer has been received, no more readers can start.
    - *c.* When a writer completes, all waiting readers start even if there are writers waiting.
2. *WritingPriority:* The policy is that readers get the most recent information available without starving writers.[30]
    - *a.* When no writer is waiting, all readers start as they are received.
    - *b.* When a writer has been received, no more readers can start.
    - *c.* When a writer completes, just one waiting reader is permitted to complete if there are waiting writers.

The interface for the readers/writer guardian is the same as the interface for the shared resource:

```
Interface ReadersWriter with read[Query]↦ QueryAnswer,
                             write[Update]↦ Void▮
```

Cheese diagram for **ReadersWriter** implementations:



Note:

1. At most one activity is allowed to execute in the cheese.
2. The value of a variable[i] changes only when leaving the cheese.[ii]

When an exception is thrown exogenously by an activity that is in a queue (*e.g.*, **readersQ**, **writerQ**), a **backout** handler can be used to clean up cheese variables before rethrowing the exception.

The formal syntax of the programs below is in the following end note: **31**

[i] A variable is orange in the diagram

[ii] Of course, other external Actors can change.

In the implementations below, preconditions present are commentary for error checking. An exception is thrown if a precondition is not met at runtime. A precondition has no operational effect.

```
Actor ReadingPriority▪[theResource:ReadersWriter]
  invariants writing⇨ numberReading=0。
  queues readersQ, writersQ。     // readersQ and writersQ are initially empty
  writing ≔ False,
  numberReading:PositiveInteger ≔ 0。
                // PositiveInteger ≡ Integer thatIs ≧0
 implements ReadersWriter using
   read[query]→
     Prep (writing ∨ ¬IsEmpty writersQ) �
          True ⦂ Enqueue readersQ●  // leave cheese while in readersQ
                  backout (¬writing ∧ numberReading=0 ∧ IsEmpty readersQ) �
                            True ⦂ Void permit writersQ⍂
                            False ⦂ Void ⍰
                   Void ⍂
           False ⦂ Void ⍰●。
        Preconditions ¬writing。          // commentary for error checking
          Prep numberReading++ ●。        // increment numberReading
            permit readersQ
              hole theResource▪read[query]   // leave cheese while reading
                afterward
                  (IsEmpty writersQ) �
                     True ⦂ Permit readersQ also numberReading--⍂ 32
                     False ⦂ numberReading=1 �
                               True ⦂ Permit writersQ also numberReading--⍂
                               False ⦂ numberReading-- ⍰ ⍰¶
  write[update]→
    Prep (numberReading>0 ∨ ¬IsEmptyreadersQ ∨ writing ∨ ¬IsEmpty writersQ) �
         True ⦂ Enqueue writersQ●     // leave cheese while in writersQ
                    backout (IsEmpty writersQ ∧¬writing) �
                              True ⦂ Void permit readersQ⍂
                              False ⦂ Void ⍰
                 Void ⍂
         False ⦂ Void ⍰●。
      Preconditions33 numberReading=0, ¬writing。
                                       // commentary for error checking
        Prep writing ≔ True ●。       // record that writing is happening
          hole theResource▪write[update]  // leave cheese while writing
           afterward (IsEmpty readersQ) �
                     True ⦂ Permit writersQ also writing ≔ False⍂
                      False ⦂ Permit readersQ also writing ≔ False⍰§▮
```

Symbols
≡ → � ⦂ ⍂ ∧ ∨ ¬
⍰ ¶ § ▮

Illustration of writing-priority:

```
Actor WritingPriority.[theResource:ReadersWriter]
   invariants writing⇨numberReading=0。
   queues readersQ, writersQ。
   writing := False,
   numberReading:PositiveInteger:= 0。
   implements ReadersWriter using
    read[query]→
      Prep (writing ∨ ¬Empty writersQ) �
             True ⦂ Enqueue readersQ⬣      //  leave cheese while in readersQ
                    backout ¬writing ∧ numberReading=0 ∧ IsEmpty readersQ �
                                 True ⦂ Void permit writersQ⍌
                                 False ⦂ Void ⍰
                    Void⍌
             False ⦂ Void ⍰⬣。
        Preconditions ¬writing。    // commentary for error checking
          Prep numberReading++。
            permit IsEmpty writersQ �
                           True ⦂ readersQ⍌
                           False ⦂ Void ⍰⬣
               hole theResource.read[query]  //  leave cheese while reading
                 afterward
                   (IsEmpty writersQ) �
                      True ⦂  Permit readersQ also numberReading--⍌
                      False ⦂ numberReading=1 �
                               True ⦂  Permit writersQ also numberReading--⍌
                               False ⦂ numberReading--⍰ ⍰¶
    write[update]→
     Prep (numberReading>0 ∨ ¬IsEmpty readersQ ∨ writing ∨ ¬IsEmpty writersQ)�
            True ⦂ Enqueue writersQ⬣            //  leave cheese while in writersQ
                     backout  (IsEmpty writersQ  ∧ ¬writing) �
                                True ⦂ Void permit readersQ⍌
                                 False ⦂ Void ⍰
                    Void ⍌
            False ⦂ Void ⍰⬣。
       Preconditions numberReading=0, ¬writing。 [34]
          Prep writing := True。
            hole theResource.write[update]  //  leave cheese while writing
             afterward
               (IsEmpty readersQ) �
                  True ⦂ Permit writersQ also writing := False⍌
                  False ⦂ Permit readersQ also writing := False⍰§▮
```

Symbols
≡ → � ⦂ ⍌ ∧ ∨ ¬
⍰ ¶ § ▮

Conclusion

Before long, we will have billions of chips, each with hundreds of hyper-threaded cores executing hundreds of thousands of threads. Consequently, GOFIP (Good Old-Fashioned Imperative Programming) paradigm must be fundamentally extended. ActorScript is intended to be a contribution to this extension.

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[i] In the sense that the implementation holds a hardware lock.

ActorScript is intended to provide a foundation for information coordination in client-cloud computing that protects citizens sensitive information [Hewitt 2009b].

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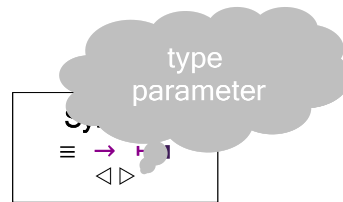
Appendix 1. Extreme ActorScript

Parameterized Types, *i.e.,* ◁ , ▷



Parameterized Types are specialized using other types delimited by "◁" and "▷":

Double◁aType⊒Arithmetic▷[x:aType]:aType ≡ → x+x §▮
// addition for **aType** that is **Arithmetic**

The formal syntax of parameterized types is in the following end note: **35 .**

Type Discrimination, *i.e.,* **Discrimination,** ⧁ and ⧀

A discrimination definition is a type of alternatives differentiated by type using "**Discrimination**" followed by a type name, "**between**", types separated using "**,**" terminated by "▮".

A discriminate can be injected into a discrimination using an expression for the discriminate followed by "⧀" and the discrimination.

A discriminate can be projected as follows:

- In an expression, by using an expression for a discrimination followed by "⧁" and the type to be projected. Also, a discrimination can be tested if it holds a discrimination of a certain type with a expression for the discrimination followed by "⧁?"and the type to be tested.
- In a pattern, by using a pattern followed by "⧁" and the type to be projected

For example, consider the following definition:

Discrimination IntegerOrFloat **between** Integer, Float▮

Consequently,

- (3⧀IntegerOrFloat)⧁Integer▮ is equivalent to 3▮.
- (3.0⧀IntegerOrFloat) ⧁Integer▮ throws an exception because Integer is not the same as the discriminant Float.
- (3⧀IntegerOrFloat) ⧁?Integer▮ is equivalent to **True**▮.
- The pattern x⧁Float matches 3.0⧀IntegerOrFloat and binds x to 3.0.
- The expression below is equivalent to 4.0▮:
  3.0⧀IntegerOrFloat � y⧁Integer ⦂ y-1⍌
  x⧁Float ⦂ x+1 ⍰▮

A nullable is a discrimination:

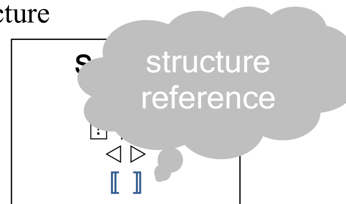
Discrimination Nullable◁aType▷ **between** aType, **Null**◁aType▷▮

A nullable can be created as follows:
Nullable x:aType ≡ x⊘Nullable◁aType▷

The formal syntax of type discrimination is in the following end note: **36.**

Structures, i.e., Structure

A structure can be defined using aa structure identifier by "[", parts separated by "," and "]".



For example, the structure Leaf can be defined as follows:

Structure Leaf◁aType▷[aType] **extends** Tree◁aType▷▮
// a terminal must be of **aType**

For example,

- The expression **Let** x[i] ← 3。 Leaf◁Integer▷[x]▮ is equivalent to Leaf◁Integer▷[3]▮
- The pattern Leaf◁Integer▷[x] matches Leaf◁Integer▷[3] and binds x to 3.

The formal syntax of structures is in the following end note: **37**

[i] x is of type Integer

Structures with named fields, i.e., ⊟ and :⊟
The structure Fork can be defined as follows:

```
Structure Fork◁aType▷[left⊟ ⊒Tree◁aType▷, right⊟ ⊒Tree◁aType▷]
   extends Tree◁aType▷
      flip[ ]:Fork◁aType▷ →                              // flip the branches
        Fork◁aType▷[left⊟ right, right⊟ left]▮
```

For example,

- The expression
  ```
  Let x ← 3。Fork◁Integer▷[left⊟ Leaf◁Integer▷[x],
                         right⊟ Leaf◁Integer▷[ x+1]])▮
  ```
  is equivalent to the following:
  ```
  Fork◁Integer▷[left⊟ Leaf◁Integer▷[3],
                right⊟ Leaf◁Integer▷[4]]▮
  ```
- The pattern Fork◁Integer▷[left⊟ x, right⊟ y] matches Fork◁Integer▷[Leaf◁Integer▷[6], Leaf◁Integer▷[6]] and binds x to Leaf◁Integer▷[5] and y to Leaf◁Integer▷[6].

The formal syntax structures with named fields is in the following end note: **38.**

Processing Exceptions, *i.e.,* **Try catch� ⦂ , ⦂ ⍰** *and* **Try cleanup**

It is useful to be able to catch exceptions. The following illustration returns the string "This is a test.":

```
  Try Throw Exception["This is a test." ] catch�
     Exception[aString] ⦂ aString ⍰▮
```

The following illustration performs Reset.[ ] and then rethrows Exception["This is another test."]:

```
   Try Throw Exception["This is another test."] cleanup Reset.[ ]▮
```

The formal syntax of processing exceptions is in the following end note: **39.**

Runtime Requirements, *i.e.,* **Preconditions** and **postcondition**
A runtime requirement throws exception an exception if does not hold.
For example, the following expression throws an exception that the requirement x≥0 doesn't hold:

Let x ← −1◦
  Preconditions x≥0◦   // commentary for error checking
  SquareRoot▪[x]▮

Post conditions can be tested using a procedure. For example, the following expression throws an exception that **postcondition** failed because square root of 2 is not less than 1:

SquareRoot▪[2] **postcondition** [y:Float]→ y<1▮

The formal syntax requirements is in the following end note: **40**.

Multiple implementations of a type

For example, Cartesian Actors that implement Complex[i] can be defined as follows:

```
Actor Cartesian.[myReal:Float default 0, myImaginary:Float default 0]
  implements Complex using      // construct a Cartesian of type Complex
    realPart[ ]→ myReal¶
    imaginaryPart[ ]→ myImaginary¶
    magnitude[ ]→
        SquareRoot.[myReal*myReal + myImaginary*myImaginary]¶
    angle[ ]→
      Let theta ← Arcsine.[myImaginary/..magnitude[ ]]。
            // ..magnitude[ ] is the result of sending magnitude[ ] to this Actor
        myReal>0 �
          True ⦂ theta⍌
          False ⦂ myImaginary >0 �
                      True ⦂180°−theta⍌41
                      False ⦂180°+theta ⍰ ⍰¶
    plus[argument]→
      Let argumentRealPart ← argument.realPart[ ],
          argumentImaginaryPart ← argument.imaginaryPart[ ]。
       Cartesian.[myReal+argumentRealPart,
                  myImaginary+argumentImaginaryPart]¶
    times[argument]→
      Let  argumentRealPart ← argument.realPart[ ],
           argumentImaginaryPart ← argument.imaginaryPart[ ]。
        Cartesian.[myReal*argumentRealPart
                     – myImaginary*argumentImaginaryPart,
                    myImaginary*argumentRealPart
                      + myReal*argumentImaginaryPart]¶
    equivalent[z] →                 //  test if x is an equivalent complex number
      myReal=z.realPart[ ] ∧ myImaginary=z.imaginaryPart[ ]§▮
```

---

[i] Interface Complex with realPart[ ] |••> Float,

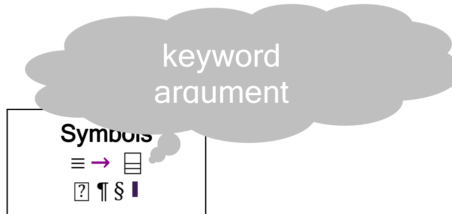
```
                          imaginaryPart[ ] |••> Float,
                          magnitude[ ] |••> Float,
                          angle[ ] |••> Degrees,
                          plus[Complex] |••> Complex,
                          times[Complex] |••> Complex,
                          equivalent[Complex]|••> Boolean▮
```

Consequently,

- Cartesian▪[1, 2]▪realPart[ ]▮ is equivalent to 1▮
- Cartesian▪[3, 4]▪magnitude[ ]▮ is equivalent to 5.0▮
- Cartesian▪[0, 1]▪times[Cartesian▪[0, 1]]▮ is equivalent to Cartesian▪[-1, 0]▮[42]

Arguments with named fields, *i.e.*, ⌸ and :⌸

Polar Actors that implement Complex with named arguments angle and magnitude can be defined as follows:




```
Actor Polar▪[angle ⌸ Degrees default 0º,
                    // angle of type Degrees  is a named argument of Polar with
                      // default 0º
                magnitude ⌸ Length]
  implements Complex using
    angle[ ]→ angle¶
    magnitude[ ]→ magnitude¶
    realPart[ ]→ magnitude*Sine▪[angle]¶
    imaginaryPart[ ]→ magnitude*Cosine▪[angle]¶
    plus[argument]→
      Cartesian▪[argument▪realPart[ ] + ▪▪realPart[ ],
                // ▪▪realPart [ ] is the result of sending realPart [ ] to this Actor
                         argument▪imaginaryPart[ ] + ▪▪imaginaryPart[ ]]¶
    times[argument]→
       Polar▪[angle⌸ angle+argument▪angle[ ],
              magnitude⌸ magnitude*argument▪magnitude[ ]]¶
    equivalent[z]→
       ▪▪realPart[ ]=z▪realPart[ ] ∧  ▪▪imaginaryPart[ ]=z▪imaginaryPart[ ]§▮
```

Consequently,

- Polar▪[theAngle ⌸ 0º, theMagnitude ⌸ 1]▪realPart[ ]▮ is equivalent to 1
- (Polar▪[theMagnitude ⌸ 1])▪equivalent[Cartesian▪[1, 0]]▮ is equivalent to **True▮**

Lists, *i.e.,* **[ ] using Spread,** *i.e.,* **[⩛]**

A list expression begins with "**List**" followed by the type of list element[i] and expressions for list elements[ii]. Similarly "**Lists**" is used for a list of lists. The prefix operator "⩛" can be sued to spread the elements of a list. For example

- [1, ⩛[2, 3], 4]▮ is equivalent to [1, 2, 3, 4]▮.
- [[1, 2], ⩛[3, 4]]▮ is equivalent to [[1, 2], 3, 4]▮
- If y is [5, 6], then [1, 2, y, ⩛y]▮ is equivalent [1, 2, [5, 6], 5, 6]▮
- [1, 2] is the list of integers of type **Integer** with just 1 and 2.

The formal syntax of list expressions is in the following end note: **43.**

Within a list, "⩛"is used to match the pattern that follows with the list zero or more elements. For example:

- [[x, 2], ⩛y:[**Integer***]] is a pattern that matches [[1, 2], 3, 4] and binds x to 1 and y to [3, 4]
- if y:is [3, 4] then [[1, 2], ⩛$$y] matches [[1, 2], 3, 4]
- [⩛x, ⩛y] is an illegal pattern because it can match ambiguously

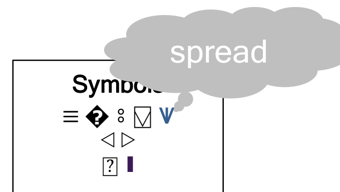
The formal syntax of patterns is in the following end note: **44.**

---

[i] delimited by ◁ and ▷

[ii] delimited by "[" and "]"

As an example of the use of spread, the following procedure returns every other element of a list beginning with the first:




```
AlternateElements◁aType▷▪[aList:[aType*]]:[aType*] ≡
 aList �
  [ ] ⦂ [ ] ⍌
  [anElement] ⦂ [anElement] ⍌
  [firstElement, secondElement] ⦂ [firstElement] ⍌
  else ⦂
    [firstElement, secondElement, ∨remainingElements] ⦂
       [firstElement, ∨AlternateElements▪[remainingElements]] ⍰▮
```

Consequently,

- AlternateElements◁Integer▷▪[[ ]]▮ is equivalent to [ ]:[Integer*]▮
- AlternateElements◁Integer▷▪[[3]]▮ is equivalent to [3]▮
- AlternateElements◁Integer▷▪[[3, 4]]▮ is equivalent to [3]▮
- AlternateElements◁Integer▷▪[[3, 4, 5]]▮ is equivalent to [3, 5]▮

Sets, *i.e.*, { } **using spreading,** *i.e.*, { ∨ }

A set is an unordered structure with duplicates removed.

The formal syntax of sets is in the following end note: **45.**

Multisets, *i.e.*, {| |} **using spreading,** *i.e.*, {| ∨ |}

A set is an unordered structure with duplicates allowed.

The formal syntax of multisets is in the following end note: **46.**

Maps, *i.e.,* **Map{ }**
A map is composed of pairs. For example Map{ [3, “a”], [“x”, “b”]}▮

Pairs in maps are unordered, *e.g.*, Map{[3, “a”], [“x”, “b”]}▮ is equivalent to Map{[“x”, “b”], [3, “a”]}▮.

However, the expression Map{[“y”, “b”], [“y”, “a”]} throws an exception because a map is univalent. As another example, for the contact records of 1.1 billion people, the following can compute a list of pairs from age to average number of social contacts of US citizens sorted by increasing age:

```
  Age ≡ Integer thatIs ≧0≦130▮

  AgeToAverageOfNumberOfContactsPairsSortedByAge
            ▪[records:Set◁ContactRecord[i]▷]:[[Age, Float]*] ≡[47]
    records▪filter[ii][[aRecord:ContactRecord] ⋅⋅>
                          aRecord⟦citizenship⟧ �
                               “US” ⦂ True ⍌
                               else ⦂ False ⍰]
             ▪collect[iii][[aRecord:ContactRecord] ⋅⋅>
                   [aRecord⟦yearsOld⟧,
                    aRecord⟦numberOfContacts⟧]
             ▪reduceRange[iv]
                 [[aSetOfNumberOfContacts:{Integer*}] ⋅⋅>
                    aSetOfNumberOfContacts▪average[v][ ]]
             ▪sort[vi][LessThanOrEqual]▮
```

---

[i] Structure ContactRecord[yearsOld ⌸ Age,
numberOfContacts ⌸ Integer,
citizenship ⌸ String]▮

[ii] {ContactRecord*}has filter[[ContactRecord] |⋅⋅> Boolean]
|⋅⋅> {ContactRecord*}▮

[iii] {ContactRecord*}has
collect [SingleArgumentToPair◁ContactRecord, Age, Integer▷] |⋅⋅>
Map◁Age, Set◁Integer▷▷▮
Interface SingleArgumentToPair◁Type1, Type2, Type3▷ with
[Type1] |⋅⋅> [Type2, Type3]▮

[iv] Map◁Age, Set◁Integer▷▷has
reduceRange[FromTo◁{Integer*}, Float ▷] |⋅⋅> Map◁Age, Float▷▮
Interface FromTo◁Type1, Type2▷ with [Type1] |⋅⋅> Type2▮

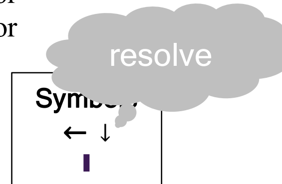
[v] {Number*}has average[ ] |⋅⋅> Float▮

[vi] Map◁Age, Float▷has sort[PairTo◁Age, Age, Boolean▷] |⋅⋅> [[Age, Float]*]▮
Interface PairTo◁Type1, Type2, Type3▷ with [Type1, Type2] |⋅⋅> Type3▮

The formal syntax of maps is in the following end note: **48.**

Futures, *i.e.*, Future and **↓**

A future [Baker and Hewitt 1977] for an expression can be created in ActorScript by using "**Future**" preceding the expression. The operator "↓" can be used to "resolve" a future by returning an Actor computed by the future or throwing an exception. For example, the following expression is equivalent to Factorial.[9999]▮




```
Let aFuture[i] ←Future Factorial.[9999]。
  ↓aFuture▮      // do not proceed until Factorial.[9999] has
                 //  resolved[ii]
```

Futures allow execution of expressions to be adaptively executed indefinitely into the future.[49] For example, the following returns a future

```
Let aFuture ←Future Factorial.[9999],
     g ← ([afuture:Future◁Integer▷]:Integer → 5)。
                                  // g returns 5 regardless of its argument
   g.[aFuture])▮
        // return 5 regardless of whether Factorial.[9999] has completed[iii]
```

Note that the following are all equivalent:

- ↓**Future** (4+Factorial.[9999])▮
- 4+↓**Future** Factorial.[9999]▮
- 4+□Factorial.[9999]▮
- □(4+Factorial.[9999])▮

Also □Factorial.[9999]+ □Fibonacci.[9000]▮ is equivalent to the following:

```
Let  n[iv] ←□Factorial.[9999],
       m ←□Fibonacci.[9000]。
   n+m▮   // return Factorial.[9999]+Fibonacci.[9000]
```

---

[i] f is of type Future◁Integer▷

[ii] i.e. returned or threw an exception

[iii] *i.e.* Factorial.[1000] might not have returned or thrown an exception when 5 is returned. The future f will be garbage collected.

[iv] n is of type Integer

In the following example, Factorial.[9999] might never be executed if readCharacter.[ ] returns the character 'x':

```
Let aFuture ← Future Factorial.[9999]。
  readCharacter.[ ] �
      'x' ⦂ 1⍌                          // readCharacter.[ ] returned 'x'
      else ⦂ 1+ ↓aFuture ⍰▮
                   // readCharacter.[ ] returned something other than 'x'
```

In the above, program resolution of aFuture is highlighted in yellow.

The procedure Size below can compute the size of a FutureList◁String▷[i] concurrently with its being created:

```
Size.[aFutureList:FutureList◁String▷]:Integer ≡
   aFutureList �
     [ ] ⦂ 0⍌
     [first, ∨rest] ⦂ first.length[ ] + Size.[↓rest] ⍰▮
                         // resolving a FutureList resolves only the head
```

Below is the definition of a procedure that computes a FutureList that is the "fringe" of the leaves of tree.[ii]

```
Fringe◁aType▷.[aTree:⊒Tree◁aType▷]:FutureList◁aType▷ ≡
   aTree �
     Leaf◁aType▷[x] ⦂ [x] ⍌
     Fork◁aType▷[tree1, tree2] ⦂
           [∨Fringe.[tree1], ∨Postpone[50] Fringe◁aType▷.[tree2]] ⍰▮
```

The above procedure can be used to define SameFringe that determines if two lists have the same fringe [Hewitt 1972]:

```
SameFringe◁aType▷
      .[aTree:⊒Tree◁aType▷, anotherTree:⊒Tree◁aType▷]:Boolean ≡
                              //  test if two trees have the same fringe
   Fringe◁aType▷.[aTree] = Fringe◁aType▷.[anotherTree]▮
      // = resolves futures in the fringes
```

---

[i] An instance of FutureList◁aType▷ is *either*

1. the empty list of type FutureList◁aType▷ *or*
2. a list whose first element is of aType and whose rest is of Future◁FutureList◁aType▷▷.

[ii] See definition of Tree above in this article.

The procedure below given a list of futures returns a **FutureList** with the same elements resolved:

```
FutureListOfResolvedElements◁aType▷
        .[aListOfFutures:[◁Future◁aType▷*]]:FutureList◁aType▷ ≡
  aListOfFutures �
    [ ] ⦂ [ ]⍌
    [aFirst, ⩛aRest] ⦂
      [↓aFirst,
       ⩛Future FutureListOfResolvedElements◁aType▷.[↓aRest]] ⍰▮
```

The formal syntax of futures is in the following end note: **51.**

In-line Recursion (*e.g.*, looping) , *i.e.*   .[← , ←] ≜

Inline recursion (often called looping) is accomplished using an initial invocation with identifiers initialized using "←" followed by "≜" and the body.[i]

Below is an illustration of a loop Factorial with two loop identifiers n and accumulation. The loop starts with n equals 9 and value equal 1. The loop is iterated by a call to Factorial with the loop identifiers as arguments.

```
Factorial.[n ←9, accumulation ←1] ≜
  n � 1 ⦂ accumulation⍌
      (> 1) ⦂ Factorial.[n−1, n∗ accumulation] ⍰▮
```
[ii]

The above compiles as a loop because the call to Factorial in the body is a "tail call" [Hewitt 1970, 1976; Steele 1977].

---

[i] This construct takes the place of **while**, **for**, *etc*. loops used in other programming languages.

[ii] equivalent to the following:

```
Factorial.[n:Integer ←9, accumulation:Integer ←1]:Integer ≜
  n � 1 ⦂ accumulation⍌
      (> 1) ⦂ Factorial.[n−1, n∗ accumulation] ⍰▮
```

The following expression returns a list of ten times successively calling the parameterless procedure P[i] (of type To◁Integer▷[ii]):

FirstTenSequentially▪[n ←10]:[Integer*] ≜
  n=1 � True ⦂ [P▪[ ]] ⍌
    False ⦂ Let x ← P▪[ ]●。
      [x, ⩛FirstTenSequentially▪[n−1]] ⍰▮

The following returns one of the results of concurrently calling the procedure P[iii] (which has no arguments and returns Integer) ten times with no arguments:

OneOfTen▪[n ←10]:[Integer*] ≜
  n=1 � True ⦂ P▪[ ] ⍌
    False ⦂ □P▪[ ] either □OneOfTen▪[n−1]] ⍰▮

The formal syntax of looping is in the following end note: **52.**

Strings

Strings are Actors that can be expressed using "**String**", "[", string arguments, and "]". For example,

- String['1', "23", '4']▮ is equivalent to "1234"▮.
- String['1', '2', "34", "56"]▮ is equivalent to "123456"▮.
- String[String['1', '2'], "34"]▮ is equivalent to "1234"▮.
- String[ ]▮ is equivalent to ""▮.

String patterns are delimited by "**String**", "[" and "]". Within a string pattern, "⩛" is used to match the pattern that follows with the list zero or more characters.

For example:

- String[x, '2', ⩛y] is a pattern that matches "1234" and binds x to '1' and y to "34".
- String['1', '2', ⩛$$y] is a pattern that only matches "1234" if y is "34".
- String[⩛x, ⩛y] is an illegal pattern because it can match ambiguously.

---

[i] The procedure P may be indeterminate, *i.e.*, return different results on successive calls.

[ii] **Interface** To◁aType▷ **with** [ ]↦ aType▮

[iii] The procedure P may be indeterminate, *i.e.*, return different results on different calls.

As an example of the use of spread, the following procedure reverses a string:[53]

Reverse.[aString:String]:String ≡
  aString �
   String[ ] ⦂ String[ ] ⍌
   String[first, ⩛rest] ⦂ String[rest, first] ⍰▮

Symbols
≡ � ⦂ ⍌ ⩛
⍰ ¶ § ▮

The formal syntax of string expressions is in the following end note: **54.**

General Messaging, *i.e.*, . and ⊡

The syntax for general messaging is to use an expression for the recipient followed by "." and an expression for the message.

For example, if anExpression is of type Expression◁Integer▷ then,
 anExpression.eval[anEnvironment]▮
is equivalent to the following:
 Let aMessage[i] ← eval⊡Expression◁Integer▷[anEnvironment]◦
  anExpression.aMessage▮

The formal syntax of general messaging is in the following end note: **55.**

[i] aMessage:Message◁Expression◁Integer▷▷

Language extension, *i.e.,* ⦅ ⦆

The following is an illustration of language extension that illustrates postponed execution:[56]

```
⦅"Postpone" anExpression:Expression ◁aType▷⦆:Postpone◁aType▷ ≡
  Actor implements Expression◁Future◁aType▷▷ using
    eval[anEnvironment]→
      Future Actor implements aType using
              aMessage[i]→        // aMessage received
                Let postponed ← anExpression.eval[anEnvironment]。
                  postponed.aMessage
                          // return result of sending aMessage to postponed
                    become postponed§▮
                        //  become the Actor postponed for
                          //  the next message received[ii]
```

The formal syntax of language extension is in the following end note: **57**.

[i] aMessage:Message◁aType▷

[ii] this is allowed because postponed is of type aType

Atomic Operations, *i.e.* **Atomic compare update updated notUpdated**
For example, the following example implements a lockable that spins to lock:[58]

Symbols
≡ → � ⍌ ⦂
⍰ ¶ § ▮

```
Actor SpinLock▪[ ]
   locked ≔ False。            // initially unlocked
   implements Lockable[i] using
     lock[ ]→ Attempt▪[ ] ≜       // perform the loop Attempt as follows
              Atomic locked compare False update True �
                // attempt to atomically update locked from False to True
               updated ⦂ Preconditions locked=True。
                                    // locked must have contents True
                           Void⍌     // if updated return Void
               notUpdated ⦂ Attempt▪[ ] ⍰¶     // if not updated, try again
     unLock[ ]→
       Preconditions locked =True。     // locked must have contents True
         Void afterward locked ≔ False §▮    // reset locked to False
```

The formal syntax of atomic operations is in the following end note: **59.**

---

[i] Interface Lockable with lock[ ]↦ Void,
unLock[ ]↦ Void▮

Enumerations, *i.e.,* **Enumeration of** using **Qualifiers,** *i.e.,* ⊡

An enumeration definition provides symbolic names for alternatives using "**Enumeration**" followed by the name of the enumeration, "**of**", a list of distinct identifiers terminated by "▮".

For example,

Enumeration DayName **of** Monday, Tuesday, Wednesday, Thursday,
Friday, Saturday, Sunday▮

From the above definition, an enumerated day is available using a qualifier, *e.g.,* Monday⊡DayName. Qualifiers provide structure for namespaces.

The formal syntax of qualifiers is in the following end note: **60**.

The procedure below computes the name of following day of the week given the name of any day of the week:

```
UsingNamespace DayName▮
FollowingDay.[aDay:DayName]:DayName ≡
  aDay � Monday ⸰ Tuesday,
         Tuesday ⸰ Wednesday,
         Wednesday ⸰ Thursday,
         Thursday ⸰ Friday,
         Friday ⸰ Saturday,
         Saturday ⸰ Sunday,
         Sunday ⸰ Monday ⍰▮
```

The formal syntax of enumerations is in the following end note: **61.**

Native types, e.g., JavaScript, JSON, Java, and XML

Object can be used to create JavaScript Objects. Also, **Function** can be used to bind the reserved identifier **This**. For example, consider the following ActorScript for creating a JavaScript object aRectangle (with length 3 and width 4) and then computing its area 12:

```
    Let aRectangle[i] ← Object {"length": 3, "width": 4]},
        aFunction ← Function [ ]→ This⟦"length"⟧ * This⟦"width"⟧。
      Prep Rectangle⟦"area"⟧ ≔ aFunction●。
        aRectangle⟦"area"⟧.[ ]▮
```

The setTimeout JavaScript object can be invoked with a callback as follows that logs the string "later" after a time out of 1000:

```
 setTimeout◻JavaScript.[1000,
                       Function [ ]→
                             console◻JavaScript.["log"].["later"]]▮
```

JSON is a restricted version of **Object** that allows only Booleans, numbers, strings in objects and arrays.[ii]

Native types can also be used from Java. For example (s:String◻Java).substring[3, 5][iii] is the substring of s from the 3rd to the 5th characters inclusive.

Java types can be imported using **Import**, *e.g.*:

Namespace mynamespace▮
Import java.math.BigInteger▮
Import java.lang.Number▮

After the above, BigInteger.new["123"].instanceof[Number]▮ is equivalent to **True**▮.

---

[i] aRectangle is of type Object◻JavaScript
[ii] *i.e.* the following JavaScript types are not included in JSON: Date, Error, Regular Expression, and Function.
[iii] substring is a method of the String class in Java

The following notation is used for XML:[62]

XML <“PersonName”> <“First”>“Ole-Johan” </“First”>
<“Last”> **“**Dahl”</“Last”> </“PersonName”>

and could print as:

<PersonName> <First> Ole-Johan </First>
<Last> Dahl </Last> </PersonName>

XML Attributes are allowed so that the expression

XML <“Country” “capital”=“Paris”> “France” </“Country”>

and could print as:

<Country capital=**“**Paris**”**> France </Country>

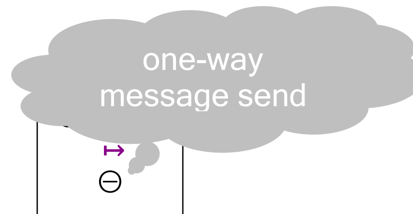
XML construction can be performed in the following ways using the append operator:

- **XML** <“doc”> 1, 2, ⩛[3] </“doc”>]▮ is equivalent to **XML** <“doc”>1, 2, 3</“doc”>▮
- **XML** <“doc”>1, 2, ⩛[3], ⩛[4] </“doc”>]▮ is equivalent to **XML** <“doc”> 1, 2, 3, 4 </“doc”>▮

One-way messaging, *e.g.*, ⊖, ↞, and ↠
One-way messaging is often used in hardware implementations.

Each one-way named-message send consists of an expression followed by "↞", a message name, and arguments delimited by "[" and "]".

The following is a interface for a customer that is used in request/response message passing for return type aType:[63]



Interface Customer◁aType▷ with
return [aType] ↦ ⊖,
throw [anException] ↦ ⊖▮

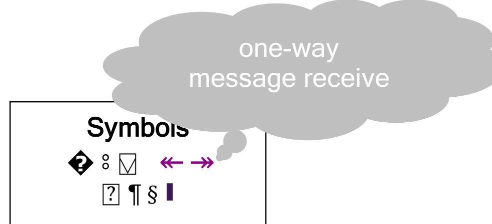
For example, if aCustomer is of type Customer◁Integer▷, then 3 can be returned to aCustomer using aCustomer↞return[3].

The formal syntactic definition of one-way named-message sending is in the end note: **64**

Each one-way message handler implementation consists of a named-message declaration pattern followed by "↠" and a body for the response which must ultimately be "⊖" which denotes no response.

The formal syntactic definition of one-way named-message implementation is in the following end note: **65**

The following is an implementation of an arithmetic logic unit that implements **jumpGreater** and **addJumpPositive** one-way messages:




```
Actor ArithmeticLogicUnit◁aType▷.[ ]
 implements ALU◁aType▷[i] using
   jumpGreater[x:aType, y:aType,
                    firstGreaterAddress:Address, elseAddress:Address]↠
          InstructionUnit↞Execute[(x>y) �
                                          True ⸮ firstGreaterAddress⍌
                                          False ⸮ elseAddress ⍰]¶
   addJumpPositive[x:aType, y:aType, sumLocation:Location◁aType▷,
                          positiveAddress:Address, elseAddress:Address]↠
        Let z ← (x+y)。
         sumLocation �
           aVariableLocation:VariableLocation◁aType▷[ii] ⸮
              Prep VariableLocation.store[z]●。
                                 // continue after acknowledgement of store
                 (z >0) � True ⸮ InstructionUnit↞execute[positiveAddress] ⍌
                              False ⸮ InstructionUnit↞execute[elseAddress] ⍰⍌
           aTemporaryLocation:TemporaryLocation◁aType▷[iii] ⸮
              aTemporaryLocation↞write[z],
                              // continue concurrently with processing write
              (z >0) � True ⸮ InstructionUnit↞execute[positiveAddress] ⍌
                           False ⸮ InstructionUnit↞execute[elseAddress] ⍰ ⍰§▮
```

Arrays

Arrays are lists of locations that can be updated using **swap** messages.

They are included to provide backward compatibility and to support certain kinds of low level optimizations. An array element can be referenced using the array followed by array indices enclosed by "⟦" and "⟧".

In the in-place implementation of QuickSort[66] (below), left is the index of the leftmost element of the subarray, right is the index of the rightmost element

---

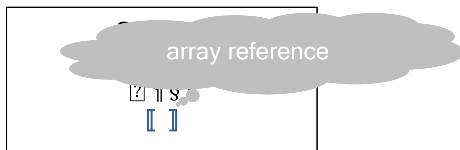
[i] **Interface** ALU◁aType▷ **with** jumpGreater [aType,] ↦ ⊖,
addJumpPositive [anException] ↦ ⊖▮

[ii] VariableLocation◁aType▷ **has** store[aType]↦ **Void**▮

[iii] TemporaryLocation◁aType▷ **has** write[aType] ↦ ⊖▮

of the subarray (inclusive), and the number of elements in the subarray is right-(left+1).

```
QuickSort▪[anArray:Array◁Number▷, left:Integer, right:Integer]:Void ≡
  Preconditions anArray▪lower[ ]≦left≦right≦anArray▪upper[ ]。
    (left<right) � True ⦂                          // If the array has 2 or more items
                        Let pivotIndex ←
                            Partition▪[anArray, left, right, left+(right-left)/2]⬣。
                          Preconditions  left≦pivotIndex≦right。
                            □QuickSort▪[anArray, left, pivotIndex-1],
                                 // Recursively sort elements smaller than the pivot
                            □QuickSort▪[anArray, pivotIndex+1, right] ⍌
                                        // Concurrently recursively sort elements at
                                                       //   least as big as pivot
                      False ⦂ Void ⍰▮
```




```
Partition▪[anArray:Array◁Number▷, left:Integer, right:Integer,
           pivotIndex:Integer]:Integer ≡
  Preconditions anArray▪lower[ ]≦left≦pivotIndex≦right≦anArray▪upper[ ]。
    Let pivot← anArray⟦pivotIndex⟧⬣。
      Prep anArray▪swap[pivotIndex, right]⬣。[67]
        Let  finalStoreIndex ←
              Move▪[iterationIndex:Integer ← left,
                     storeIndex:Integer ←left]:Integer ≜
                Preconditions  left≦storeIndex≦iterationIndex≦right。
                  iterationIndex<right �
                    True ⦂
                      anArray⟦iterationIndex⟧≦pivotValue �
                        True ⦂
                          Prep anArray▪swap[iterationIndex, storeIndex]⬣。
                            Move▪[iterationIndex+1, storeIndex+1] ⍌
                        False ⦂ Move▪[iterationIndex+1, storeIndex] ⍰⍌
                    False ⦂ storeIndex ⍰⬣。

          Prep anArray▪swap[finalStoreIndex, right]⬣。  // Move to its final place
            finalStoreIndex▮
```

For example, consider:

```
        Let anArray ← Array▪[3, 2, 1]。
          Prep  QuickSort▪[anArray, 0, 2]⬣。
            anArray▮
```

The above returns Array[1, 2, 3]▮.

Inconsistency Robust Logic Programs

Logic Programs[68] can logically infer computational steps.

Forward Chaining

Forward chaining is performed using ⊢

> ⦅"⊢"$_{Theory}$ *PropositionExpression*⦆
> Assert *PropositionExpression* for *Theory*.

> ⦅"**When**" "⊢"$_{Theory}$ aProposition:*Pattern* "→" *Expression*⦆
> When aProposition holds for *Theory*, evaluate *Expression*.

Illustration of forward chaining:

$\vdash_t$ Human[Socrates]▮

When $\vdash_t$ Human[*x*] → $\vdash_t$ Mortal[*x*]▮

will result in asserting Mortal[Socrates] for theory t

Backward Chaining

Backward chaining is performed using ⊩

> ⦅"⊩"$_{Theory}$ aGoal:*Pattern* "→" *Expression*⦆
> Set aGoal for *Theory* and when established evaluate *Expression*.

> ⦅"⊩"$_{Theory}$ aGoal:*Pattern*⦆:*Expression*
> Set aGoal for *Theory* and return a list of assertions that satisfy the goal.

> ⦅"**When**" "⊩"$_{Theory}$ aGoal:*Pattern* "→" *Expression*⦆
> When there is a goal that matches aGoal for *Theory*, evaluate *Expression*.

Illustration of backward chaining:

$\vdash_t$ Human[Socrates]▮

When $\Vdash_t$ Mortal[x] → ($\Vdash_t$ Human[$$$x$] → $\vdash_t$ Mortal[x])▮

$\Vdash_t$ Mortal[Socrates]▮

will result in asserting Mortal[Socrates] for theory t.

SubArguments

This section explains how subarguments[i] can be implemented in natural deduction.

When $\Vdash_s$ (*psi* $\vdash_t$ *phi*) →

Let t' ← extension▪[t]◦

$\vdash_{t'}$ *psi*,

$\Vdash_{t'}$ *phi* → $\vdash_s$ (*psi* $\vdash_t$ *phi*)▮

Note that the following hold for t' because it is an extension of t:

- **when** $\vdash_t$ *theta* → $\vdash_{t'}$ *theta*▮
- **when** $\Vdash_{t'}$ *theta* → $\Vdash_t$ *theta*▮

[i] See appendix on Inconsistency Robust Natural Deduction.

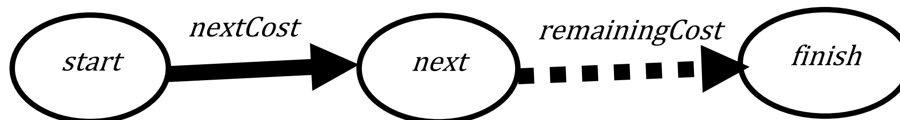
Aggregation using Ground-Complete Predicates

Logic Programs in ActorScript are a further development of Planner. For example, suppose there is a ground-complete predicate[69] Link[*aNode*, *anotherNode*, *aCost*] that is true exactly when there is a path from *aNode* to *anotherNode* with *aCost*.

When ⊪ Path[*aNode*, *aNode*, *aCost*]→
// when a goal is set for a cost between *aNode* and itself
⊢ *aCost*=0▮ // assert that the cost from a node to itself is 0

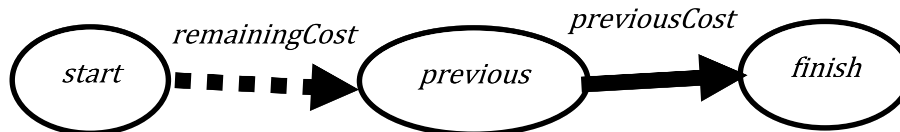
The following goal-driven Logic Program works forward from *start* to find the cost to *finish*:[70]

When ⊪ Path[*start*, *finish*, *aCost*]→
⊢ *aCost*=**Minimum** {*nextCost* + *remainingCost*
| ⊨ Link[*start*, *next*≠*start*, *nextCost*],
Path[*next*, *finish*, *remainingCost*]}▮
// a cost from *start* to *finish* is the minimum of the set of the sum of the
// cost for the next node after *start* and
// the cost from that node to *finish*



The following goal-driven Logic Program works backward from *finish* to find the cost from *start*:

When ⊪ Path[*start*, *finish*, *aCost*]→
⊢ *aCost*= **Minimum** {*remainingCost* + *previousCost*
| ⊨ Link[*previous*≠*finish*, *finish*, *previousCost*],
Path[*start*, *previous*, *remainingCost*]}▮
// the cost from *start* to *finish* is the minimum of the set of the sum of the
// cost for the previous node before *finish* and
// the cost from *start* to that Node



Note that all of the above Logic Programs work together concurrently providing information to each other.

Appendix 2: Meta-circular definition of ActorScript

It might seem that a meta-circular definition is a strange way to define a programming language. However, as shown in the references, concurrent programming languages are not reducible to logic. Consequently, an augmented meta-circular definition may be one of the best alternatives available.

The message eval

John McCarthy is justly famous for Lisp. One of the more remarkable aspects of Lisp was the definition of its interpreter (called Eval) in Lisp itself. The exact meaning of Eval defined in terms of itself has been somewhat mysterious since, on the face of it, the definition is circular.[71]

The basic idea is to send an expression an **eval** message with an environment to instead of the Lisp approach of send the procedure Eval the expression and environment as arguments.

Each **eval** message has an environment with the bindings of program identifiers:

```
    Interface Expression◁aType▷ with
                    eval[Environment]↦ aType▮
```

The tokens ⦅ and ⦆ are used to delimit program syntax.

```
⦅anIdentifier:Identifier◁aType▷⦆:Expression◁aType▷ ≡
  eval[anEnvironment]→ anEnvironment.lookup[anIdentifier]▮
```

The interface Type

The interface **Type** is defined as follows:

```
    Interface Type with
            extensionFrom?[Type] |••> Boolean
            has?[MethodSignature] |••> Boolean▮
```

```
⦅anotherType:Type◁anotherType▷ "⊒" aType:Type◁aType▷⦆
                                        :Expression◁Boolean▷ ≡
 eval[anEnvironment]→
    (anotherType.eval[anEnvironment])
          .extensionFrom?[aType.eval[anEnvironment]]▮
```

```
⦅anotherType:Type◁anotherType▷ "has" aSignature:Signatture⦆
                                        :Expression◁Boolean▷ ≡
 eval[anEnvironment]→
   (anotherType.eval[anEnvironment])
        .has?[aSignature.eval[anEnvironment]]▮
```

Meta expressions

Meta followed by an Actor is an Actor of type MetaType where

Interface MetaType **with**
of?[Type] |••> Boolean,
ofExtensionFom?[Type] |••> Boolean▮

```
⦅"Meta" anExpression:Expression◁aType▷⦆
                                   :Expression◁MetaType▷ ≡
 eval[anEnvironment]→
   Actor implements  MetaType using
     of?[anotherType] ••>
          aType = anotherType,
     ofExtensionFom?[anotherType] ••>
          aType ⊒ anotherType▮
```

```
⦅anExpression:Expression◁anotherType▷ ":?" aType:Type◁aType▷⦆
                                        :Expression◁Boolean▷ ≡
 eval[anEnvironment]→
   (Meta anExpression.eval[anEnvironment])
        .of?[aType.eval[anEnvironment]]▮
```

```
⦅anExpression:Expression◁anotherType▷ ":⊒?" aType:Type◁aType▷⦆
                                        :Expression◁Boolean▷ ≡
 eval[anEnvironment]→
   (Meta anExpression.eval[anEnvironment])
        .ofExtensionFrom?[aType.eval[anEnvironment]]▮
```

Future, ↓, and □

The interface Future is used for futures:

Interface Future◁aType▷ **with** resolve[ ]↦ aType▮

```
⦅"Future" anExpression:Expression◁aType▷⦆
                                        :Expression◁Future◁aType▷▷ ≡
  Actor implements Expression◁Future◁aType▷▷ using
    eval[anEnvironment]→
      Let aFuture:Future◁aType▷ ←
            Future Try anExpression▪eval[anEnvironment]
                       catch�
                        anException ⩴
                            Actor
                             implements Future◁aType▷
                                resolve[ ]→Throw anException。⍰。
         Actor implements Future◁aType▷using
               resolve[ ]→ ↓aFuture §▮
```

```
⦅"↓" anExpression:Expression◁Future◁aType▷▷⦆
                                              :Expression◁aType▷ ≡
  Actor implements Expression◁aType▷ using
    eval[anEnvironment]→
       anExpression▪eval[anEnvironment]▪resolve[ ] §▮
```

```
⦅"□" anExpression:Expression◁aType▷⦆
                                              :Expression◁aType▷ ≡
  Actor implements Expression◁aType▷ using
    eval[anEnvironment]→
       ↓Future anExpression▪eval[anEnvironment] §▮
```

The message match

Patterns are analogous to expressions, except that they take receive match messages:

```
Interface Pattern◁aType▷ with
   match [aType, Environment]↦ Nullable◁Environment▷,
   mustMatch [aType, Environment]↦ Environment▮
```

```
⦅anIdentifier:Identifier ◁aType▷⦆:Pattern ◁aType▷ ≡
   match[anActor:aType, anEnvironment]→
      anEnvironment.bind[anIdentifier, to ⌸ anActor]▮
```

```
⦅“_”⦆:UniversalPattern ◁aType▷ ≡
  match[anActor:aType, anEnvironment]→ anEnvironment▮
```

```
⦅“$$” anExpression:Expression◁Type▷⦆
                              :ValuePattern ◁aType▷ ≡
  match[anActor, anEnvironment]→
   (anActor = anExpression.eval[anEnvironment]) �
      True ⦂ Nullable anEnvironment⍔
      False ⦂ Null ◁Environment▷⍰▮
```

```
⦅aPattern:Pattern◁aType▷
      “:” anExpression:Type◁aType▷⦆
                              :TypedPattern ◁anotherType▷ ≡
  match[anActor, anEnvironment]→
   (anActor :⊒? anExpression.eval[anEnvironment]) �
      True ⦂ aPattern.match[anActor, anEnvironment⍔
      False ⦂ Null ◁Environment▷⍰▮
```

```
⦅ “⊒” anExpression:Type◁aType▷⦆:TypedPattern ◁anotherType▷≡
  match[anActor, anEnvironment]→
   (anActor :⊒? anExpression.eval[anEnvironment]) �
      True ⦂ Nullable anEnvironment⍔
      False ⦂ Null ◁Environment▷⍰▮
```

Message sending, *e.g.*, ▪

```
⦅procedure:Expression◁argumentsType↦returnType▷
      "▪"  "[" arguments:Arguments◁argumentsType▷ "]"
         ":" returnType⦆
                 :ProcedureSend◁argumentsType, returnType▷ ≡
   eval[anEnvironment]→
      (procedure▪eval[anEnvironment])
         ▪[∀(expressions▪eval[anEnvironment])]§▮
```

```
⦅recipient:Expression◁recipient▷ "▪"
     name:MessageName"[" ∀arguments
                                  :Arguments◁argumentsType▷ "]"⦆
                           :NamedMessageSend◁expressionType▷ ≡
   eval[anEnvironment]→
     Let aRecipient ← recipient▪eval[anEnvironment]。
      aRecipient
        ▪Message[QualifiedName[name recipientType],
                   [∀arguments▪eval[anEnvironment]]]§▮
```

```
⦅recipient:Expression◁recipientType▷
      "▪" aMessage:Message◁Message◁recipientType▷▷⦆
                          :UnnamedMessageSend◁expressionType▷ ≡
   eval[anEnvironment]→
      (recipient▪eval[anEnvironment])
         ▪(aMessage▪eval[anEnvironment])§▮
```

List Expressions and Patterns

```
⦅"[" firstExpression:Expression◁aType▷
    "," secondExpression:Expression◁aType▷"]"⦆
                              :ListExpression◁aType▷ ≡
   eval[anEnvironment]→
     Let  first ← firstExpression▪eval[anEnvironment],
          second ← secondExpression▪eval[anEnvironment]。
      [first, second]§▮
```

```
⟬“[” firstExpression:Expression◁aType▷
   “,”  “⩛” restExpression:Expression◁aType▷ “]”⟭
                                      :ListExpression◁aType▷ ≡
 eval[anEnvironment]→
    Let  first ← firstExpression▪eval[anEnvironment],
         rest ← restExpression▪eval[anEnvironment]。
      [first, ⩛rest]§▮
```

```
⟬“[” firstPattern:Pattern◁aType▷
                          “,”  “⩛” restPattern:ListPattern◁aType▷ “]”⟭
                                              :ListPattern◁aType▷  ≡
 match[anActor:aType, anEnvironment]→
     anActor �
       [first, ⩛rest] ⫶
        firstPattern▪match[first, anEnvironment] �
           ⦸⦸Null Environment ⫶
               Null ◁Environment▷,
           aNewEnvironment⦸Environment ⫶
               restPattern▪match[restValue, aNewEnvironment] ⍰⍔
       else ⫶ Null ◁Environment▷⍰§▮
```

Exceptions

```
⟬“Try” anExpression:Expression◁aType▷
  “catch�”  exceptions:ExpressionCases◁Exception, aType▷ “⍰”⟭
                                           :TryExpression◁aType▷ ≡
 eval[anEnvironment]→
     Try anExpression▪eval[anEnvironment] catch�
       anException:Exception ⫶ CasesEval▪[anException,
                                            exceptions,
                                            anEnvironment] ⍰§▮
```

Try … catch�

```
⟬“Try” anExpression:Expression◁aType▷
          “cleanup” aCleanup:Expression◁aType▷⟭
                                          :TryExpression◁aType▷  ≡
   eval[anEnvironment]→
      Try anExpression▪eval[anEnvironment] catch�
        _ ⫶  Prep aCleanup▪eval[anEnvironment]●。
             Rethrow⍰§▮
```

Continuations using perform

A continuations is a generalization of expression for executing in cheese, which receives perform messages:

```
Interface Continuation◁aType▷ with
        perform [Environment, CheeseQ]↦ aType▮
Discrimination Construct◁aType▷ between
        Continuation◁aType▷, Expression◁aType▷▮
```

```
Execute.[aConstruct:Construct◁aType▷,
         anEnvironment:Environment,
         aCheeseQ:CheeseQ]:aType ≡
  aConstruct � aContinuation⧁Continuation◁aType▷ ⦂
                    aContinuaton.perform[anEnvironment,
                                         aCheeseQ] ⍌
               anExpression⧁Expression◁aType▷ ⦂
                    anExpression.eval[anEnvironment] ⍰▮
```

Atomic compare and update

```
⦅"Atomic" location:Expression◁Location◁anotherType▷,
            "compare"  comparison:Expression◁anotherType▷
            "update" update:Expression◁anotherType▷ "�"
            "updated" "⦂"
                compareIdentical:ContinuationList◁aType▷ "⍌"
             "notUpdated" "⦂"
                compareNotIdentical:ContinuationList◁aType▷⦆
                                                  :Atomic◁aType▷ ≡
   perform[anEnvironment, aCheeseQ]→
     (location.eval[anEnvironment])
       .compareAndConditionallyUpdate[comparison.eval[anEnvironment],
                                          update.eval[anEnvironment]] �
         True ⦂ compareIdentifical.perform[anEnvironment, aCheeseQ] ⍌
         False ⦂
           compareNotIdentifical.perform[anEnvironment, aCheeseQ] ⍰▮

Actor SimpleLocation◁anotherType▷.[initialContents]
  contents ≔ initialContents。
  implements Location◁anotherType▷ using
    compareAndConditionallyUpdate[comparison, update]→
      (contents = comparison) �
         True ⦂ True afterward contents ≔ update⍌
         False ⦂ False ⍰§▮
```

Cases

```
(anExpression:Expression◁anotherType▷ "�"
                    cases:ExpressionCases◁anotherType, aType▷ "⍰")
                                        :CasesExpression◁ aType▷ ≡
   eval[anEnvironment]→
      CasesEval.[anExpression.eval[anEnvironment],
                  cases,
                  anEnvironment]§▮

CasesEval.[anActor:anotherType,
           cases:[◁ExpressionCase◁anotherType, aType▷*],
           anEnvironment:Environment]:aType ≡
 cases �
   [ ] ⦂ Throw NoApplicableCase[ ],
   [first, ⩛rest] ⦂
     first � (aPattern:Pattern◁anotherType▷ "⦂"
                  anExpression:Expression◁aType▷)
                                  :ExpressionCase◁aType▷ ⦂
              aPattern.match[anActor, anEnvironment] �
                ⊝⊝Null Environment ⦂
                   CasesEval.[anActor, rest, anEnvironment] ⍌
                newEnvironment⊝Environment ⦂
                   anExpression.eval[newEnvironment] ⍰⍌
            (("else" elsePattern:Pattern◁anotherType▷"⦂"
                  elseExpression:Expression◁aType▷)
                                  :ExpressionElseCase◁aType▷ ⦂
              elsePattern.match[anActor, anEnvironment] �
                 ⊝⊝Null Environment ⦂
                      Throw ElsePatternMustMatch[ ] ⍌
                 newEnvironment⊝Environment ⦂
                      elseExpression.eval[newEnvironment] ⍰⍌
            (("else" "⦂"
                  elseExpression:Expression◁aType▷)
                                  :ExpressionElseCase◁aType▷ ⦂
               elseExpression.eval[anEnvironment] ⍌
            else ⦂ Throw NoApplicableCase[ ] ⍰⍰▮
```

```
⦅anExpression:Expression◁anotherType▷ "�"
                    cases:ContinuationCases◁anotherType, aType▷ "⍰"⦆
                                        :CasesContinuation◁aType▷ ≡
   perform[anEnvironment, aCheeseQ]→
      CasesPerform.[anExpression.eval[anEnvironment], cases,
                    anEnvironment, aCheeseQ]§▮
CasesPerform. [anActor:anotherType,
               cases:[ContinuationCase◁aType▷*],
               anEnvironment:Environment,
               aCheeseQ:CheeseQ]:aType ≡
 cases �
  [ ] ⦂ Throw NoApplicableCase[ ],
  [first, ⱯVrest] ⦂
   first �  ⦅aPattern:Pattern◁anotherType▷"⦂"
                aContinuation:Continuation◁aType▷⦆
                              :ContinuationCase◁aType▷ ⦂
             aPattern.match[anActor, anEnvironment] �
               ⍉⍉Null Environment ⦂
                 CasesPerform.[anActor,
                               rest,
                                anEnvironment,
                                aCheeseQ] ⍌
               newEnvironment⍉Environment ⦂
                 aContinuation.perform[newEnvironment,
                                       aCheeseQ] ⍰⍌
            ⦅"else"
                 elsePattern:Pattern
                  ◁anotherType▷ "⦂"
                     elseContinuation:Continuation◁aType▷⦆
                                  :ContinuationElseCase◁aType▷ ⦂
                elsePattern.match[anActor, anEnvironment] �
                  ⍉⍉Null Environment ⦂
                    Throw ElsePatternMustMatch[ ] ⍌
                  newEnvironment⍉Environment ⦂
                     elseContinuation.eval[newEnvironment] ⍰⍌
            ⦅"else" "⦂"
                elseContinuation:Continuation◁aType▷⦆
                                 :ContinuationElseCase◁aType▷ ⦂
             elseContinuation.perform[anEnvironment, aCheeseQ] ⍌
            else ⦂ Throw NoApplicableCase[ ] ⍰⍰▮
```

Holes in the cheese

```
⦅anExpression:Expression◁aType▷
   "afterward" someAssignments:Assignments"。"⦆
                                          :Continuation◁aType▷ ≡
  perform[anEnvironment, aCheeseQ]→
    Let anActor ← anExpression▪eval[anEnvironment]●。
      Prep someAssignments▪carryOut[anEnvironment, aCheeseQ]●
           aCheeseQ▪leave[ ]●。
        anActor§▮
```

```
⦅aVariable:Variable◁aType▷
          ":=" anExpression:Expression◁aType▷⦆:Assignment ≡
 carryOut[anEnvironment]→
   anEnvironment▪assign[aVariable,
                        to ⌸ anEpression▪eval[anEnvironment]]§▮
```

```
⦅"Hole" anExpression:Expression◁aType▷⦆:Hole◁aType▷ ≡
  perform[anEnvironment, aCheeseQ]→
    Let frozenEnvironment ← anEnvironment▪freeze[ ]●。
      // create frozen environment so that subsequent assignments
      // subsequent assignments do not affect evaluating anExpression
      Prep aCheeseQ▪leave[ ]●。
        anExpression▪eval[frozenEnvironment§▮
```

```
⦅"Prep" aPreparation:Preparation"。"
          anExpression:Expression◁aType▷⦆:Continuation◁aType▷ ≡
  perform[anEnvironment, aCheeseQ]→
    Let frozenEnvironment ← anEnvironment▪freeze[ ]●。
      // create frozen environment so that
         // preparation does not affect evaluating anExpression
       Prep aPreparation▪carryOut[anEnvironment, aCheeseQ]●
           aCheeseQ▪leave[ ]●。
         anExpression▪eval[frozenEnvironment] §▮
```

```
⦅"Hole" anExpression:Expression◁anotherType▷
   "afterward" anAfterward:AfterwardContinuation◁aType▷ "⍰"⦆
                                              :Continuation◁aType▷ ≡
perform[anEnvironment, aCheeseQ]→
  Let frozenEnvironment ← anEnvironment.freeze[ ]●。
   Prep  aCheeseQ.leave[ ]●。
     Try Let anActor ← anExpression.eval[frozenEnvironment]●。
           Prep aCheeseQ.enter[ ]●
                 anAfterward
                       .perform[anEnvironment, aCheeseQ]]●
                 aCheeseQ.leave[ ]。
              anActor
        catch�
           anException ⦂
            Prep aCheeseQ.enter[ ]●
                 anAfterward
                    .perform[anEnvironment, aCheeseQ]●
                 aCheeseQ.leave[ ]。
              throw anException afterward ⍰§▮
```

```
⟦"Hole" anExpression:Expression◁anotherType▷
   "returned�"
        returnedCases:ContinuationCases◁anotherType, aType▷ "⍰"
   "threw�"
        threwCases:ContinuationCases◁anotherType, aType▷ "⍰"⟧
                                   :Continuation◁anotherType, aType▷ ≡
  perform[anEnvironment, aCheeseQ]→
     Let frozenEnvironment ← anEnvironment.freeze[ ]⬤。
       Prep aCheeseQ.leave[ ]⬤。
         Try Let anActor ← anExpression.eval[frozenEnvironment]⬤。
              Prep aCheeseQ.enter[ ]⬤。
                 CasesPerform.[anActor,
                                returnedCases,
                                anEnvironment,
                                aCheeseQ]
            catch� anException:ApplicationException ⸽
                       Prep aCheeseQ.enter[ ]⬤。
                         CasesPerform.[anException,
                                        threwCases,
                                        anEnvironment,
                                        aCheeseQ] ⍰§▮
```

```
⟦"Enqueue" anExpression:QueueExpression "⬤"⟧
                                      :Enqueue◁aType▷ ≡
  perform[anEnvironment, aCheeseQ]→
    Let anInternalQ ← anExpression.eval[anEnvironment]。
      anInternalQ.enqueueAndLeave[ ] §▮
```

```
⟦"Enqueue" anExpression:QueueExpression "⬤"
    aContinuation:Continuation◁aType▷⟧:Enqueue◁aType▷ ≡
  perform[anEnvironment, aCheeseQ]→
    Let anInternalQ ← anExpression.eval[anEnvironment]。
       Prep anInternalQ.enqueueAndLeave[ ]⬤。
         aContinuation.perform[anEnvironment, aCheeseQ] §▮
```

Type Discrimination, *i.e.,* **Discrimination, ⊜ and ⊝**

```
⦅"Discrimination" aDiscrimination "between"
        typeExpressions:Expressions◁Type▷ "▮"⦆:Definition ≡
   Actor implements Definition using
     eval[anEnvironment]→
       Let types:List◁Type▷ ←
                      typeExpressions▪eval[anEnvironment]。
         Let  aDiscrimination[aType:Type] ≡
               aType∈types �
                  True ⦂ DiscriminationInstance▪[x, aType] ⍌
                  False ⦂ Throw NotADiscidminant[aType] ⍰
            DiscriminationInstance▪[x:aType, aType:Type] ≡
               Actor implements aDiscrimination using
                  discriminate[anotherType]→
                     anotherType �
                        aType ⦂  x⍌
                        else ⦂
                          Throw WrongDisciminant[anotherType] ⍰,
            ⦅discrimination:Expression◁aDiscrimination▷
               "⊜" discriminant:Expression◁Type▷⦆
                                       :Expression◁discriminant▷ ≡
               Actor implements Expression◁discriminant▷ using
                  eval[anEnvironment]→
                    (discrimination▪eval[anEnvironment])
                      ▪discriminate[discrimination
                                     ▪eval[anEnvironment]],
             ⦅aPattern:Pattern◁aType▷
                "⊜" discriminant:Expression◁Type▷⦆⦆
                                       :Pattern◁aDiscrimination▷  ≡
                Actor implements Pattern◁aDiscrimination▷ using
                   match[anActor:aType, anEnvironment]→
                      apattern▪match[anActor
                                        ⊝(discriminant
                                            ▪eval[anEnvironment]),
                                     anEnvironment]。
          Void▮
```

A Simple Implementation of Actor

The implementation below does not implement queues, holes, and relaying.

```
⦅"Actor" declarations:ActorDeclarations
     "implements" Identifier◁aType▷
     "using" handlers:Handlers◁anInterface▷ "§"⦆:Actor◁aType▷ ≡
  Actor implements Expression◁anInterface▷ using
   eval[anEnvironment]→
     Initialized▪[anInterface▪eval[anEnvironment],
                  handlers,
                  declarations▪initialize[anEnvironment],
                  SimpleCheeseQ▪[ ]]§▮
```

```
Initialized▪[anInterface:aType,
             handlers:List◁Handler◁aType▷▷,
             anEnvironment:Environment,
             cheeseQ:CheeseQ]:aType ≡
  Actor implements anInterface using
   receivedMessage:Message◁aType▷ →
                                    // receivedMessage received for anInterface
     Prep aCheeseQ▪enter[ ]⚫◦
       Let aReturned ← Try Select▪[receivedMessage,
                                   handlers,
                                   anEnvironment,
                                   aCheeseQ]
                         cleanup aCheeseQ▪leave[ ]⚫◦
                                 // leave cheese and rethrow exception
        Prep aCheeseQ▪leave[ ]⚫◦
          aReturned§▮
```

```
Select.[receivedMessage:Message◁aType▷,
         handlers:List◁Handler◁aType▷▷,
         anEnvironment:Environment,
         aCheeseQ:CheeseQ]:aType ≡
   handlers �
     [ ] ⦂ Throw NotApplicable[ ] ⍌
     [⦅aMessageDeclaration:MessageDeclaration◁aType▷ “→”
          body:Continuation◁aType▷⦆
                                          :ContinuationHandler◁aType▷⍌
      ⩛restHandlers] ⦂
         aMessageDeclaration.match[receivedMessage,
                                       anEnvironment] �
            ⍄⍄Null Environment ⦂ Select.[receivedMessage,
                                              restHandlers,
                                              anEnvironment,
                                              aCheeseQ] ⍌
                                  // process next handler
            newEnvironment⍄Environment ⦂
               Execute.[body, newEnvironment, aCheeseQ] ⍰⍰▮
                        //  execute body with extension of anEnvironment
```

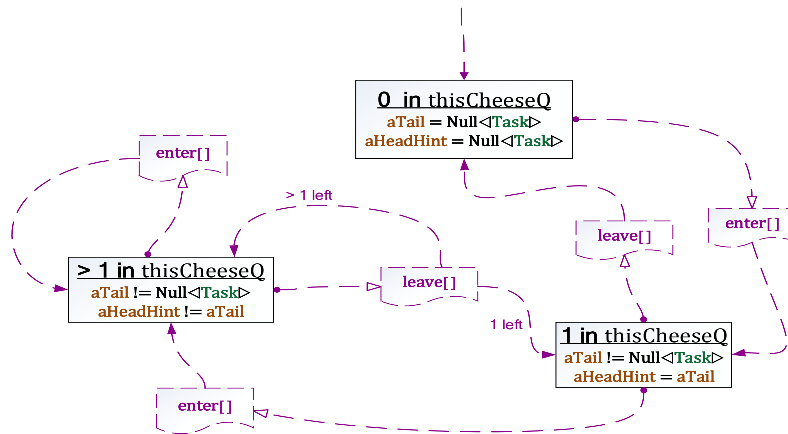
An implementation of cheese that never holds a lock

The following is an implementation of cheese that does not hold a lock:[72]

```
Actor SimpleCheeseQ.[ ]
    invariants aTail=Null ◁Activity▷⇨ previousToTail=Null ◁Activity▷。
    aHeadHint := Null ◁Activity▷,   // aHeadHint:Nullable◁Activity▷73
    aTail := Null ◁Activity▷。              // aTail:Nullable◁Activity▷74
    implements CheeseQ75 using nonexclusive
     enter[ ] in myActivity →76
       Preconditions myActivity⟦previous⟧=Null ◁Activity▷,
                     myActivity⟦nextHint⟧=Null ◁Activity▷。77
         attempt.[ ]:Void ≜
           Prep myActivity⟦previous⟧ := aTail●。  // set provisional tail of queue
             Atomic aTail compare aTail update myActivity �
                updated ⦂  // inserted myActivity in cheese queue with previous
                   myActivity⟦previous⟧=Null ◁Activity▷ �
                         True ⦂ Void⍌          // successfully entered cheese
                         False ⦂ Suspend ⍰⍌ // current activity is suspended
                notUpdated ⦂ attempt.[ ] ⍰¶        // make another attempt
      leave[ ] in myActivity →      // leave message received running myActivity
       Preconditions aTail !=Null ◁Activity▷。78// commentary for error checking
         Let ahead ← ⍠⍠SubCheeseQ.head[ ]●。
           Preconditions ahead=myActivity  // commentary for error checking
            Atomic aTail compare ahead update Null ◁Activity▷ �
               updated ⦂           // last activity has left this cheese queue
                 Void afterward aHeadHint := Null ◁Activity▷⍌
               notUpdated ⦂        // another activity is in this cheese queue
                  MakeRunnable ahead⟦nextHint⟧⦸Activity
                      afterward aHeadHint := ahead⟦nextHint⟧⍰§
   also implements internal SubCheeseQ79 using  nonexclusive
     head[ ] → Preconditions aTail != Null ◁Activity▷。
       findHead.[backIterator:Activity ←
                     aHeadHint = Null ◁Activity▷  �
                       True ⦂ aTail⦸Activity] ⍌
                       False ⦂ aHeadHint⦸Activity ⍰]:Activity ≜
         backIterator⟦previous⟧ �
           ⦸⦸Null Activity ⦂      // backIterator is head of this cheese queue
             Prep aHeadHint := Nullable backIterator●。
               backIterator⍌
           previousBackIterator⦸Activity ⦂
                              //  backIterator is not the head of this cheese queue
             Prep previousBackIterator⟦nextHint⟧ := Nullable backIterator●。
                                         // set nextHint of previous to backIterator
               findHead.[previousBackIterator] ⍰§▮
```

The algorithm used in the implementation of CheeseQ above is due to Blaine Garst [private communication] *cf.* [Ladan-Mozes and Shavit 2004].

There is a state diagram for the implementation below:



```
Actor SimpleInternalQ.[aCheeseQ:CheeseQ]
  aHead ≔ Null ◁Activity▷,          // aHead:Nullable◁Activity▷
  aTail ≔ Null ◁Activity▷。
  implements InternalQ80 using nonexclusive
    enqueueAndLeave[ ]  in myActivity →
             // enqueueAndLeave message received in myActivity
         Prep ⍠⍠SubInternalQ▪remove[myActivity]⬣
               aCheeseQ.leave[ ]⬣。    // myActivity is the head of aCheeseQ
           Suspend¶
             // myActivity is suspended and when resumed returns Void ¶
    enqueueAndDequeue[anInternalQ] in myActivity →
          Preconditions ¬anInternalQ.empty?[ ]。// commentary for error checking
           Prep ⍠⍠SubInternalQ▪add[myActivity]⬣
               ▪▪dequeue[ ]⬣。
            Suspend¶
    dequeue[ ]  in myActivity → Preconditions ¬ ▪▪empty?[ ]。
           Prep aCheeseQ.leave[ ]⬣。        // myActivity is the head of aCheeseQ
             MakeRunnable ⍠⍠SubInternalQ▪remove[ ]¶
                                      // make runnable the removed activity
    empty?[ ] → aTail =Null ◁Activity▷§
  also implements internal SubInternalQ81 using nonexclusive
     add[anActivity] →
        aTail �
          ⦸⦸Null Activity ⦂
            Void afterward aHead ≔ Nullable anActivity,
                            aTail ≔ Nullable anActivity⍌
          theTail⦸Activity ⦂ Void afterward theTail[[rest]] ≔ anActivity ⍰¶
     remove[ ] →  Preconditions ¬ ▪▪empty?[ ]。// commentary for error checking
       Let theFirst ← aHead⦸Activity⬣。
        aTail=aHead �
          True ⦂ theFirst afterward aHead ≔ Null ◁Activity▷,
                                    aTail ≔ Null ◁Activity▷⍌
          False ⦂ theFirst afterward aHead ≔ (aHead⦸Activity)[[rest]] ⍰§▮
```

Appendix 3. ActorScript Symbols with Readings. IDE ASCII, and Unicode code points

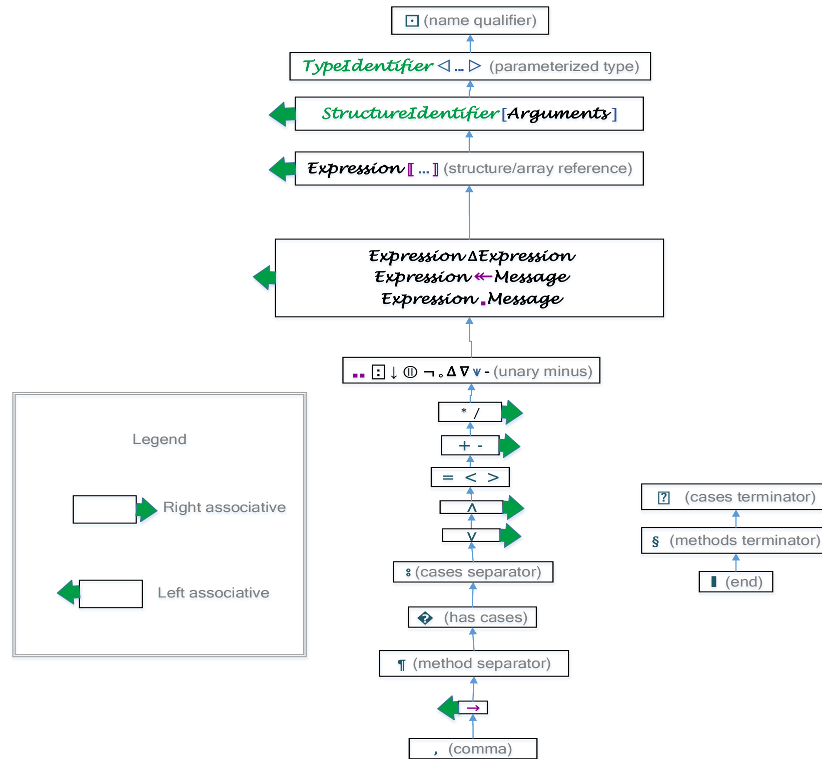
Symbol	IDE ASCII[i]	Read as	Category	Matching Delimiters	Unicode (hex)
▮	;;	end	top level terminator		25AE
:	:	of specified type	infix		
:?	:?	of tested type	infix		
:⊒?	:[>=]?	of extension from type	infix		
⍠	[:]	cast	infix		2360
⍠⍠	[:][:]	this Actor with interface (aspect)	prefix		
⧀	(<)	injection	infix		29C0
⧁	(>)	expression/ pattern projection	infix		29C1
↓	\/	resolve	prefix		2139
⊡	[.]	qualified by	infix		22A1
▪	.	is sent	infix		
▪▪	..	delegate to this Actor	prefix		
☐	|_|	necessarily concurrent	prefix		29B7
↦	|->	message type returns type[82]	infix		21A6
|••>	|..>	cacheable message type returns type			
⟶	-->	message received[83]		¶	2192
←	<--	be[84]	infix		2190
�	?	cases	separator	⍰	FFFD
⦶	[\/]	alternative case	separator	� and ⍰	29B6
⍰	[?]	end cases	terminator	� and catch�	2370
¶	\p	another message handler	separator for handlers	⟶	00B6
§	\s	end handlers	terminator	**implements**	00A7
⦂	(:)	case	separator for case		2982
⬤	_/	before	separator	Let binding, preparation, Enqueue,	00C4

[i] These are only examples. They can be redefined using keyboard macros according to personal preference.

<table>
<tr><td>｡</td><td>(.)</td><td>end</td><td>terminator</td><td>preparations, Preconditions, and ⦂</td><td>FF61</td></tr>
<tr><td>≡</td><td>===[85]</td><td>defined as</td><td>infix</td><td></td><td>2261</td></tr>
<tr><td>≜</td><td>=/\=</td><td>to be</td><td>infix</td><td></td><td>225C</td></tr>
<tr><td>≔</td><td>:=</td><td>is assigned</td><td>infix</td><td></td><td>2254</td></tr>
<tr><td>$$</td><td>$$</td><td>matches value of[86]</td><td>prefix</td><td></td><td></td></tr>
<tr><td>=</td><td>=</td><td>same as?</td><td>infix</td><td></td><td></td></tr>
<tr><td>⌸</td><td>[=]</td><td>keyword or field</td><td>infix</td><td></td><td>2338</td></tr>
<tr><td>:⌸</td><td>:[=]</td><td>assignable field</td><td>infix</td><td></td><td></td></tr>
<tr><td>◁</td><td><|</td><td>begin type parameters</td><td>left delimiter</td><td>▷ (Unicode hex: 0077)</td><td>0076</td></tr>
<tr><td>⩛</td><td>\|/</td><td>spread[87]</td><td>prefix</td><td></td><td>2A5B</td></tr>
<tr><td>{</td><td>{</td><td>begin set</td><td>left delimiter</td><td>}</td><td></td></tr>
<tr><td>[</td><td>[</td><td>begin list</td><td>left delimiter</td><td>]</td><td></td></tr>
<tr><td>⦃</td><td>{|</td><td>begin multi-set</td><td>left delimiter</td><td>⦄</td><td>2983</td></tr>
<tr><td>⟦</td><td>[|</td><td>array reference</td><td>left delimiter</td><td>⟧ (Unicode hex: 27E7)</td><td>27E6</td></tr>
<tr><td>(</td><td>(</td><td>begin grouping</td><td>left delimiter</td><td>)</td><td></td></tr>
<tr><td>⦅</td><td>(|</td><td>begin syntax</td><td>left delimiter</td><td>⦆ (Unicode hex: 2986)</td><td>2985</td></tr>
<tr><td>⊝</td><td>(-)</td><td>nothing[88]</td><td>expression</td><td></td><td>229D</td></tr>
<tr><td>↞</td><td><<–</td><td>one-way send</td><td>infix</td><td></td><td>219E</td></tr>
<tr><td>↠</td><td>–>></td><td>one-way receive</td><td>infix</td><td>¶</td><td>21A0</td></tr>
<tr><td>⊔</td><td>|_|</td><td>join</td><td>infix</td><td></td><td>2294</td></tr>
<tr><td>⊑</td><td>[<=]</td><td>constrained by</td><td>infix</td><td></td><td>2291</td></tr>
<tr><td>⊒</td><td>[>=]</td><td>extends</td><td>infix</td><td></td><td>2292</td></tr>
<tr><td>⇒</td><td>==></td><td>logical implication</td><td>infix</td><td></td><td>21E8</td></tr>
<tr><td>⇔</td><td><=></td><td>logical equivalence</td><td>infix</td><td></td><td>21D4</td></tr>
<tr><td>∧</td><td>/\</td><td>logical conjunction</td><td>infix</td><td></td><td>00D9</td></tr>
<tr><td>∨</td><td>\/</td><td>logical disjunction</td><td>infix</td><td></td><td>00DA</td></tr>
<tr><td>¬</td><td>-|</td><td>logical negation</td><td>prefix</td><td></td><td>00D8</td></tr>
<tr><td>⊢</td><td>|-</td><td>assert</td><td>prefix and infix</td><td></td><td>22A2</td></tr>
<tr><td>⊩</td><td>||-</td><td>goal</td><td>prefix and infix</td><td></td><td>22A9</td></tr>
<tr><td>//</td><td>//</td><td>begin 1-line comment</td><td>prefix</td><td>EndOfLine</td><td></td></tr>
<tr><td>/*</td><td>/*</td><td>begin comment</td><td>prefix</td><td>*/</td><td></td></tr>
</table>

Appendix 4. Grammar Precedence

In the diagram below, if there is no precedence relationship, then parentheses *must* be used.



For example, parentheses *must* be used in the following examples:

- (t[p]).m[x]
- (x � p1 ⁑ y1 ?) � p2 ⁑ y2 ?

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End Notes

---

[1] Quotation by the author from late 1960s.

[2] to use a reserved word as an identifier it could prefixed, *e.g.,* _actor

[3] The delimiters ⦅ and ⦆ are used to delimit program syntax with the character “ and the character ” to delimit tokens. For example, ⦅3 “+” 4⦆ is an expression that can be evaluated to 7. A special font is used for syntactic categories.

For example,

⦅x:*Numerical* “+” y:*Numerical*⦆:*Numerical*▮
Numerical⊑*Expression*▮

Also,

⦅*Numerical* “-” *Numerical*⦆:*Numerical*▮
⦅“-” *Numerical*⦆:*Numerical*▮
⦅*Numerical* “*” *Numerical*⦆:*Numerical*▮
⦅*Numerical* “/” *Numerical*⦆:*Numerical*▮
⦅“**Remainder**” *Numerical* “/” *Numerical*⦆:remainder:*Numerical*▮
⦅“**QuotientRemainder**” *Numerical* “/” *Numerical*⦆
:[*Numerical*, *Numerical*]▮
⦅“**True**” ⊔ “**False**” ⦆:*Expression*◁**Boolean**▷▮
⦅*Expression*◁**Boolean**▷ “∧” *Expression*◁**Boolean**▷⦆
:*Expression* ◁**Boolean**▷▮
⦅*Expression* “∨” *Expression*⦆:*Expression*◁**Boolean**▷▮
⦅ “¬” *Expression*◁**Boolean**▷⦆:*Expression*◁**Boolean**▷▮
⦅ “**Throw**” *Expression*⦆:*Expression*▮

[4] See explanation of syntactic categories above. A word must begin with an alphabetic character and may be followed by one or more numbers and alphabetic characters.

Identifier ⊑ *Word* ⊑ *Expression* ▮

// an *Identifier* is a *Word*, which is a subcategory of *Expression*

⦅⦅*Expression* ⊔ *Definition* ⊔ *Judgment*⦆⦆ "▮"⦆:*Top* ▮

[5] *Type* ⊑ *Expression* ◁**Type**▷ ▮

⦅ aType:*Type* ⦅ "↦" ⊔ "|••>"⦆ anotherType:*Type*⦆:*Type* ▮

⦅ "[" *Types* "]" ⦆:*Type* ▮

⦅ ⊔ *MoreTypes*⦆:*Types* ▮

⦅*Type* ⊔ ⦅*Type* "," *MoreTypes*⦆⦆:*MoreTypes* ▮

[6] ⦅*Identifier*◁**aType**▷ "≡" *Expressions* ◁**aType**▷⦆:*Definition* ◁**Identifier**▷ ▮

⦅⦅*Expression* ◁**aType**▷ ⦅ ⊔ "。"⦆⦆

⊔ ⦅*Expression* ⦅"," ⊔ "⬤"⦆ *MoreExpressions* ◁**aType**▷⦆⦆

:*Expressions* ◁**aType**▷ ▮

⦅⦅*Expression*◁**aType**▷ "。"⦆

⊔ ⦅*Expression* ⦅"," ⊔ "⬤"⦆ *MoreExpressions*◁**aType**▷⦆⦆

:*MoreExpressions* ◁**aType**▷ ▮

[7] *ProcedureName* "."

"[" *ArgumentDeclarations* "]" ⦅ ":" *Type* ◁**aType**▷⦆ "≡"

Expression ◁**aType**▷⦆:*Definition* ▮

ProcedureName ⊑ *Expression* ▮

⦅ ⊔ *MoreDeclarations*⦆:*ArgumentDeclarations* ▮

⦅*SimpleDeclaration* ⦅ ⊔ ⦅"," *MoreKeywordDeclarations*⦆⦆

⊔ ⦅*SimpleDeclaration* "," *MoreDeclarations*⦆⦆

:*MoreDeclarations* ▮

// Comma is used to separate declarations.

⦅⦅*Identifier*

⊔ ⦅*Identifier* ":" *Expression* ◁**Type**▷ ⦆⦆

⦅ ⊔ "**default**" *Expression*⦆⦆:*SimpleDeclaration* ▮

⦅*KeywordArgumentDeclaration*

⊔ ⦅*KeywordDeclaration* "," *MoreKeywordDeclarations*⦆⦆

:*MoreKeywordDeclarations* ▮

⦅*Keyword* "⌸" *SimpleDeclaration*⦆⦆:*KeywordDeclaration* ▮

Keyword ⊑ *Word* ▮

[8] The symbol . is fancy typography for an ordinary period when it is used to denote message sending.

[9] ⦅Recipient:*Expression* "." "[" *Arguments* "]" ⦆:*ProcedureSend* ▮

ProcedureSend ⊑ *Expression* ▮

// Recipient is sent a message with *Arguments*

⦅ ⊔ *MoreArguments*⦆:*Arguments* ▮

⦅⦅Expression ⦅ ⊔ ⦅“,” MoreKeywordArguments⦆⦆⦆
⊔ ⦅Expression “,” MoreArguments⦆⦆:MoreArguments▮
⦅KeywordArgument
⊔ ⦅KeywordArgument
“,” MoreKeywordArguments⦆⦆:MoreKeywordArguments▮
⦅Keyword “⌸” Expression⦆:KeywordArgument▮
⦅Identifier◁Procedure▷ “▪” “[”ArgumentDeclarations “]”
⦅ ⊔ ⦅“:” returntype:Type◁aType▷⦆⦆
“≡”Expressions◁aType▷ “▮”⦆:Definition◁Procedure▷▮

[10] ⍰ takes care of the infamous "dangling else" problem [Abrahams 1966].

[11] ⦅test:Expression◁patternType▷ “�”
ExpressionCases◁patternType, aType▷ “⍰”⦆:Expression◁aType▷▮
⦅ExpressionCase◁patternType, aType▷
⊔ MoreExpressionCases◁patternType, aType▷⦆
:ExpressionCases◁patternType, aType▷▮
⦅ExpressionCase◁patternType, aType▷ ⊔
⦅ExpressionCase◁patternType, aType▷
“⍔” MoreExpressionCases◁patternType, aType▷⦆
⊔ ExpressionElseCases◁patternType, aType▷⦆
:MoreExpressionCases◁patternType, aType▷▮
⦅ ⊔ ExpressionElseCase◁patternType, aType▷
⊔ ⦅ExpressionElseCase◁patternType, aType▷
“⍔” MoreExpressionElseCases◁patternType, aType▷⦆⦆
:ExpressionElseCases◁patternType, aType▷▮
⦅ExpressionElseCase◁patternType, aType▷
⊔ ⦅ExpressionElseCase◁patternType, aType▷
“⍔” MoreExpressionElseCases◁patternType, aType⦆⦆
:MoreExpressionElseCases◁patternType, aType▷▮
⦅ ⦅“**else**” “⸾” Expressions◁aType▷⦆
⊔ ⦅“**else**” Pattern◁patternType▷ “⸾” Expressions◁aType▷⦆⦆
:ExpressionElseCase◁patternType, aType▷▮
// The else case is executed only if the patterns before
// the else case do not match the value of test.
⦅Pattern◁patternType▷ “⸾” Expressions◁aType▷⦆
:ExpressionCase◁aType▷▮

[12] ⦅“**Let**” MoreLetBindings “。”
result:Expressions◁aType▷⦆:Expression◁aType▷▮
// Bindings are independent of each other
⦅LetBinding ⊔ ⦅LetBinding “,” MoreBindings ⦆⦆
:MoreLetBindings▮

⦅*LetBinding*
⊔ ⦅*LetBinding* ⦅“,” ⊔ “●”⦆ *MoreDependentLetBindings* ⦆⦆
:*MoreDependentLetBindings* ▮
// Each binding before a “●” is completed before its successors
⦅*Pattern* “←” *Expression*⦆:*LetBinding* ▮

[13] ⦅recipient:*Expression*
“.” *MessageName* “[” *Arguments* “]”⦆:*NamedMessageSend* ▮
NamedMessageSend ⊑*Expression* ▮
// Recipient is sent message *MessageName* with *Arguments*
MessageName ⊑*Word* ▮
⦅“**Interface**” *Identifier*◁**Type**▷
⦅ ⊔ ⦅“**extends**” *Identifier*◁**anotherType**▷⦆⦆ “**with**”
MessageHandlerSignatures “▮”⦆:*InterfaceDefinition* ▮
InterfaceDefinition ⊑*Definition* ▮
⦅ ⊔ *MoreMessageHandlerSignatures* ⦆⦆
:*MessageHandlerSignatures* ▮
⦅*MessageHandlerSignature*
⦅ ⊔ *MoreMessageHandlerSignatures* ⦆⦆
:*MoreMessageHandlerSignatures* ▮
⦅*MessageName* “[” *ArgumentTypes* “]” ⦅“↦”⊔ “|••>”⦆
returnType:*TypeExpression*⦆:*MessageHandlerSignature* ▮
MessageHandlerSignature ⊑*Expression* ▮

[14] Dijkstra[1968] famously blamed the use of the goto as a cause and symptom of poorly structure programs. However, assignments are the source of much more serious problems.

[15] Continuations in ActorScript are related to continuations introduced in [Reynolds 1972] in that they represent a continuation of a computation. The difference is that a continuation of Reynolds is a procedure that takes as an argument the result of the preceding computation. Consequently, a continuation of Reynolds is closer to a customer in the Actor Model of computation.

[16] ⦅"**Actor**" *ConstructorDeclaration ActorBody*⦆:*Expression*▮
// The above expression creates an Actor with
// declarations for variables and message handlers
⦅ ⊔ ⦅ "**extends**" *ConstructorList* ⦆⦆⦆
⦅ ⊔ "**management**" *Expression*◁[aType]↦Manager▷⦆
NamedDeclaration
MessageHandlers
InterfaceImplementations⦆:*ActorBody*▮
⦅*Identifier* "[" *ArgumentDeclarations* "]"⦆
:*ConstructorDeclaration*▮
⦅*Constructor* ⦅ ⊔ "。"⦆
⊔ ⦅*Constructor* "," *MoreConstructors* "。" ⦆⦆:*ConstructurList*▮
⦅*Constructor*
⊔ ⦅*Constructor* "," *MoreConstructors*⦆⦆:*MoreConstructors*▮
⦅*ActorQueues NamesDeclarations*⦆:*NamedDeclaration*▮
⦅ ⊔ ⦅*MoreNameDeclarations* "。"⦆⦆:*NamesDeclarations*▮
⦅*NameDeclaration*
⊔ ⦅*NameDeclaration*
"," *MoreNamesDeclarations*⦆⦆:*MoreNameDeclarations*▮
⦅*Identifier*
⦅ ⊔ ⦅":" *Type*◁aType▷⦆⦆
"←" *Expression*◁aType▷⦆:*IdentifierDeclaration*▮
IdentifierDeclaration⊑*NameDeclaration*▮
⦅*Variable* ⦅ ⊔ ⦅":" *Type*◁aType▷⦆⦆
":=" *Expression*◁aType▷ *InstanceVariableAQualifications*⦆
:*VariableDeclaration*▮
VariableDeclaration⊑*NameDeclaration*▮
Variable⊑*Word*▮
InstanceIVariableQualifications⊑ *InstanceQualifications*▮
⦅ ⊔ *InstanceVariableQualification*
⊔ ⦅ *InstanceVariableQualification*
InstanceIVariableQualifications⦆
:*InstanceIVariableQualifications*▮
"**nonpersistent**"⊑*InstanceVariableQualification*▮
// A nonpersistent variable must be of type Nullable◁*aType*▷,
// and can be nulled out before a message is received
⦅ "**queues**" *QueueNames* "。"⦆ :*ActorQueues*▮
⦅*QueueName* ⊔ ⦅*QueueName* "," *QueueNames*⦆⦆:*QueueNames*▮
QueueName ⊑*Word*▮
QueueName ⊑*Expression*◁Queue▷▮
⦅"**Void**"⦆:*Expression*▮

⦅*InterfaceImplementation*
⦅ ⊔ *MoreInterfaceImplementations*⦆⦆
:*InterfaceImplementations* ▮

⦅"**also**" *InterfaceImplementation*
⦅ ⊔ *MoreInterfaceImplementations*⦆⦆
:*MoreInterfaceImplementations* ▮

⦅⦅ ⊔ "**partially**"⦆
⦅"**implements**" ⊔ "**reimplements**"⦆
⦅ ⊔ "**exportable**"⦆ *Type* ◁**aType**▷ "**using**"
⦅*MessageHandlers* "§"⦆⊔ *UniversalMessageHandler* ⦆
:*InterfaceImplementation* ◁**aType**▷ ▮

⦅*MessagePattern*
⦅ ⊔ ⦅":" *Type*⦆⦆
⦅ ⊔ ⦅"**sponsor**" *Identifier*◁**Sponsor**▷⦆⦆
"→" *ExpressionsContinuation*◁**aType**▷ ⦆
:*UniversalMessageHandler* ◁**aType**▷ ▮

⦅ ⊔ *MoreMessageHandlers*⦆:*MessageHandlers* ▮

⦅*MessageHandler*
⊔ ⦅*MessageHandler* "¶" *MoreMessageHandlers*⦆⦆
:*MoreMessageHandlers* ▮

// The message handler separator is ¶.

⦅*MessageName* "[" *ArgumentDeclarations* "]"
⦅ ⊔ ⦅ ":" returnType:*Type* ◁**aType**▷⦆
⦅ ⊔ ⦅"**sponsor**" *Identifier*◁**Sponsor**▷⦆⦆
"→" *ExpressionsContinuation*◁**aType**▷⦆:*MessageHandler* ▮

// For a message with *MessageName* with arguments,
// the response is *Continuation*

⦅*Expression* ◁**aType**▷
"**afterward**" *VariableAssignments*⦆:*Continuation* ◁**aType**▷ ▮

// Return *Expression* and afterward perform
// *MoreVariableAssignments*

⦅*VariableAssignment*
⊔ ⦅*VariableAssignment*
"," *MoreVariableAssignments* "。"⦆⦆
:*VariableAssignments* ▮

⦅*VariableAssignment*
⊔ ⦅*VariableAssignment*
"," *MoreVariableAssignments*⦆⦆
:*MoreVariableAssignments* ▮

⦅*Variable* ":=" *Expression* ◁**aType**▷⦆:*VariableAssignment* ◁**aType**▷ ▮

[17] ⦅"**Prep**" *MoreAntecedents* "。"
  Continuation◁aType▷ "。" ⦆:*Preparation*◁aType▷▮
 ⦅*Antecedent* ⊔ ⦅ *Antecedent* ⦅","⊔ "●"⦆ *MoreAntecedents*⦆⦆
          :*MoreAntecedents*▮
 Expression⊑*Antecedent*▮
 StructureAssignment⊑*Antecedent*▮
 ArrayAssignment⊑*Antecedent*▮

[18] For example, consider the following:

Actor SimpleNeedTwo.[ ]
  queues waiting。
  hasOne ≔ **False**。
  implements NeedTwo **using**
   [ ] → hasOne � **True** ⦂ **Void permit** waiting ⍌
          False ⦂ **Prep** hasOne ≔ **True**●。
             enqueue waiting●
              Void⍰§▮

The following expression must return **Void** because of mandatory concurrency:

  Let aNeedTwo ← SimpleNeedTwo.[ ]。
   Prep ☐aNeedTwo.[ ]●。
    aNeedTwo.[ ]▮

However following expression might never return because of optional concurrency:

  Let aNeedTwo ← SimpleNeedTwo.[ ]。
   Prep aNeedTwo.[ ]●。
    aNeedTwo.[ ]▮

[19] ⦅"☐" anExpression:*Expression*◁aType▷
  ⦅ ⊔ ⦅"**sponsor**" *Expression*◁Sponsor▷▮⦆⦆:*Expression*◁aType▷▮
 // Execute anExpression concurrently and respond with the outcome.
 // In every case, anExpression must complete before execution leaves
  // the lexical scope in which it appears.

[20] The ability to extend implementation is important because it helps to avoid code duplication.

[21] *cf*. [Crahen 2002, Amborn 2004, Miller, et. al. 2011]

[22] note the absence of "**.**" in the **implementation** subexpression

[23] equivalent to the following:

myBalance⊡SimpleAccount ≔ myBalance⊡SimpleAccount−anAmount

[24] ignoring exceptions in this way is *not* a good practice

[25] ⦅“**Enqueue**” *QueueExpression* “⬣”
Continuation◁aType▷⦆⦆⦆:*Continuation*◁aType▷▮
/*
1. Enqueue activity in *QueueExpression*
2. Leave the cheese
3. When the cheese is re-entered perform *Continuation*. */

⦅“**Prep**” *Preparation* “。”
“**enqueue**” *QueueExpression* “⬣”
Continuation◁aType▷⦆:*Continuation*◁aType▷▮
/*
1. Perform *Preparation*
2. Enqueue activity in *QueueExpression*
3. Leave the cheese
4. When the cheese is re-entered perform *Continuation*. */

Cases can be continuations:

⦅test:*Expression* “�”
ContinuationCases◁patternType, aType▷ “⍰”⦆
:*Continuation*◁aType▷▮

⦅*ContinuationCase*◁patternType, aType▷
⊔ ⦅*ContinuationCase*◁patternType, aType▷
“⍓” *MoreContinuationCases*◁patternType, aType▷⦆⦆
ContinuationElseCases⦆
:*ContinuationCases*◁patternType, aType▷ ▮

⦅*ContinuationCase*◁patternType, aType▷
⊔ ⦅*ContinuationCase*◁patternType, aType▷
“⍓” *MoreContinuationCases*◁patternType, aType▷⦆⦆
:*MoreContinuationCases*◁patternType, aType▷▮

⦅*Pattern*◁patternType▷ “⫶”
ExpressionsContinuation◁patternType, aType▷⦆
:*ContinuationCase*◁ patternType, aType▷▮

⦅ ⊔
MoreContinuationElseCases◁patternType, aType▷⦆
:*ContinuationElseCases*◁patternType, aType▷▮

⦅*ContinuationElseCase*◁patternType, aType▷
⊔ ⦅*ContinuationElseCase*◁patternType, aType▷
“⍓” *MoreContinuationElseCases*◁patternType, aType▷⦆⦆
:*MoreContinuationElseCases*◁patternType, aType▷▮

⦅⦅“**else**” “⫶” *ExpressionsContinuation*◁aType▷⦆
⊔ ⦅“**else**” *Pattern*◁patternType▷ “⫶”
ExpressionsContinuation◁patternType, aType▷⦆⦆
:*ContinuationElseCase*◁patternType, aType▷▮

⦅⦅*Continuation* ⦅ ⊔ “。”⦆⦆
⊔ ⦅*Expression* ⦅“,” ⊔ “⬣”⦆ *MoreExpressionsContinuation*⦆⦆
:*ExpressionsContinuation*▮

⦅⦅*Continuation*"。"⦆

⊔ ⦅*Expression*","*MoreExpressionsContinuation*⦆⦆

: *MoreExpressionsContinuation* ▮

[26] Swiss cheese was called "serializers" in the literature.

[27]⦅"▪▪" *Message* ◁aType▷⦆:*Expression* ◁aType▷▮

// Delegate message to this Actor.

⦅"**Prep**" *Preparation*"。"

"**hole**" *Expression*◁aType▷⦆:*Continuation* ◁aType▷▮

/*

1. Carry out *Preparation*
2. Leave the cheese
3. The result is the result of evaluating *Expression* */

[28] ReadersWriterConstraintMonitor defined below monitors a resource and throws an exception if it detects that ReadersWriter constraint is violated, *e.g.*, for a resource r using the above scheduler:

ReadingPriority[ReadersWriterConstraintMonitor[r]].

```
Actor ReadersWriterConstraintMonitor.[theResource:ReadersWriter]
     writing ≔ False,
     numberReading:(Integer thatIs ≥0) ≔ 0,
     implements ReadersWriter using
       read[query]→
      Preconditions ¬writing。        // commentary for error checking
         Prep numberReading++●。
            hole theResource.read[query]
               afterward numberReading--¶
       write[update]→
         Preconditions numberReading=0, ¬writing。
           Prep writing ≔ True●。
             hole theResource.write[update]
                afterward writing ≔ False● §▮
```

[29] A downside of this policy is that readers may not get the most recent information.

[30] A downside of this policy is that writing and reading may be delayed because of lack of concurrency among readers.

[31] ⦅"**Prep**" *Preparation* ◦
"**enqueue**" *QueueExpression*
⦅ ⊔ "**backout**" *Expressions* ⦆
Continuation ◁**aType**▷⦆⦆⦆:*Continuation* ◁**aType**▷▮

/*
1. Perform *Preparation*
2. Enqueue activity in *QueueExpression*.
3. Leave the cheese
4. If an exception is generated by the activity while in the queue, then reenter the cheese, perform *Expressions*, and leave the cheese.
5. If no exception is generated by the activity while in the queue, then when allowed to continue, re-enter the cheese to perform *Continuation*. */

Cases can be continuations:

⦅test:*Expression*◁**patternType**▷ "�"
ContinuationCases ◁**patternType**, **aType**▷ "⍰"⦆
:*Continuation* ◁**aType**▷▮

⦅*ContinuationCase* ◁**patternType**, **aType**▷
⊔ *MoreContinuationCases*◁**patternType**, **aType**▷⦆
:*ContinuationCases* ◁**patternType**, **aType**▷▮

⦅*ContinuationCase* ◁**patternType**, **aType**▷ ⊔
⦅*ContinuationCase* ◁**patternType**, **aType**▷
"⍔" *MoreContinuationCases* ◁**patternType**, **aType**▷⦆
⊔ *ContinuationElseCases*◁**patternType**, **aType**▷⦆
:*MoreContinuationCases* ◁**patternType**, **aType**▷▮

⦅ ⊔ *ContinuationElseCase* ◁**patternType**, **aType**▷
⊔ ⦅*ContinuationElseCase* ◁**patternType**, **aType**▷
"⍔" *MoreContinuationElseCases*◁**patternType**, **aType**▷⦆⦆
:*ContinuationElseCases*◁**patternType**, **aType**▷▮

⦅*ContinuationElseCase* ◁**patternType**, **aType**▷
⊔ ⦅*ContinuationElseCase* ◁**patternType**, **aType**▷
"⍔" *MoreContinuationElseCases* ◁**patternType**, **aType** ⦆⦆
:*MoreContinuationElseCases* ◁**patternType**, **aType**▷▮

⦅⦅"**else**" " း" *ContinuationList*◁**aType**▷⦆
⊔ ⦅"**else**" *Pattern* ◁**patternType**▷
" း"*ExpressionsContinuation*◁**aType**▷⦆⦆
:*ContinuationElseCase* ◁**patternType**, **aType**▷▮

// The else case is executed only if the patterns before
// the else case do not match the value of test.

⦅*Pattern* ◁**patternType**▷ " း" *ExpressionsContinuation*◁**aType**▷⦆
:*ContinuationCase* ◁**patternType**, **aType**▷▮

The following are allowed in the cheese for a response to message affecting the next message:

⦅*Expression*◁**aType**▷

⦅ ⊔ ⦅ "**permit**" aQueue:*Expression*⦆⦆

⦅ ⊔ ⦅"**afterward**" *Afterward*⦆⦆⦆:*Continuation*◁**aType**▷▮

/* If there are activities in *aQueue*, then the one of them gets the cheese next and also perform *Afterward*, then leave the cheese and return the value of *Expression*. /*

VariableAssignments:*Afterward*▮

⦅"**Permit**" aQueue:*Expression*⦅ ⊔ ⦅"**also**" *VariableAssignments*⦆⦆⦆

:*Afterward*▮

The following can be used temporarily leave the cheese:

⦅"**Hole**" *Expression*◁**aType**▷⦆:*Continuation*◁**aType**▷▮

/*

1. Leave the cheese
2. The response is the result of evaluating *Expression* */

⦅"**Prep**" *Preparation*"。"

hole *Expression*◁**aType**▷

⦅ ⊔ ⦅ "**afterward**" *Afterward*⦆:*Continuation*◁**aType**▷▮

/*

1. Carry out *Preparation*
2. Leave the cheese
3. Evaluate *Expression*
4. When a response is received, reacquire the cheese, carry out *Afterward* and the result is the result of evaluating *Expression* */

⦅"**Prep**" *Preparation*"。"

hole *Expression*◁**anotherType**▷

⦅ ⊔ ⦅ "**returned�**"

normal:*ContinuationCases*◁**anotherType**, **aType**▷ "⍰"⦆⦆

⦅ ⊔ ⦅ "**threw�**"

exceptional:*ContinuationCases*◁**anotherType**, **aType**▷

"⍰"⦆⦆

:*Continuation*◁**aType**▷▮

/*

1. Carry out *Preparation*
2. Leave the cheese
3. Evaluate *Expression*
4. When a response is received, reacquire the cheese
   - If *Expression* returns, continue using the returned Actor with normal.
   - If *Expression* throws an exception, continue using the exception with exceptional. */

[32] -- is postfix decrement

[33] Preconditions present for error checking

[34] // commentary for error checking

[35] ⦅*Identifier*◁**Type**▷
"◁" *ParametersDeclarations* "▷"
"≡" *Expressions* ⦆:*ParameterizedDefinition* ▮
ParameterizedDefinition⊑*Definition* ▮
// Parameterize definition with *ParametersDeclarations* ▮
⦅ ⊔ *MoreParameterDeclarations* ⦆:*ParametersDeclarations* ▮
⦅*ParameterDeclaration*
⊔ ⦅*ParameterDeclaration*
"," *MoreParameterDeclarations*⦆⦆
:*MoreParameterDeclarations* ▮
⦅*Identifier*◁**Type**▷ ⦅ ⊔ *Qualifier* ⦆⦆:*ParameterDeclaration* ▮
⦅ ⊔ ⦅"**extends**" *Identifier*◁**Type**▷ ⦆⦆:*TypeQualifier* ▮
⦅*Identifier*◁**Type**▷ "◁" *Parameters* "▷"⦆:*TypeExpression* ▮
⦅*Identifier*◁**Type**▷
⊔ ⦅ ⊔ ⦅*Identifier*◁**Type**▷ "," *Parameters* ⦆⦆:*Parameters* ▮

[36] ⦅"**Discrimination**" *Identifier*◁**Type**▷
MoreTypeDescriminations "▮" ⦆:*Definition* ▮
⦅*Identifier*◁**Type**▷
⊔ ⦅*Identifier*◁**Type**▷ ","*MoreTypeDescriminations*⦆⦆
:*MoreTypeDescriminations* ▮
⦅*Expression* ◁**aDiscriminationType**▷ "⧀" *Type* ◁**aType**▷⦆
:*Expression* ◁**aType**▷ ▮
// Discriminate to have the type *Type* ◁**aType**▷ if possible.
// Otherwise, an exception is thrown.
⦅*Pattern* ◁**aDiscriminationType**▷ "⧀" *Type* ◁**aType**▷⦆
:*Pattern* ◁**aType**▷ ▮
// If matching Actor is a discrimination that can be discriminated
// then *Pattern* must match the discriminate.
⦅"⧀⧀" *Type* ◁**aType**▷⦆:*Pattern* ◁**aType**▷ ▮
// Matching Actor must be discrimination that can be
// discriminated as **aType**

[37] ⦅*Identifier*◁**aType**▷ "[" *Arguments* "]"⦆:*Expression* ◁**aType**▷ ▮
⦅*Identifier*◁**aType**▷ "[" *Patterns* "]"⦆:*Pattern* ◁**aType**▷ ▮

[38] ⦅"**Structure**" *Identifier*◁**Type**▷ "[" *FieldDeclarations* "]"
⦅ ⊔ ⦅ "**extends**" *ConstructorList* ⦆⦆
NamedDeclaration
MessageHandlers
MoreInterfaceImplementations⦆:*Definition* ▮
// Structure definition with *StructureImplementation*
⦅ ⊔ *MoreFieldDeclarations* ⦆:*FieldDeclarations* ▮

⦅⦅*SimpleFieldDeclaration*
⦅ ⊔ ⦅“,” *MoreNamedFieldDeclarations*⦆⦆⦆
⊔ ⦅*SimpleFieldDeclaration*
“,” *MoreFieldDeclarations*⦆⦆:*MoreFieldDeclarations* ▌
⦅⦅*Identifier*
⊔ ⦅*Identifier* “:” *TypeExpression*⦆⦆
⦅ ⊔ “**default**” *Expression*⦆⦆:*SimpleFieldDeclaration* ▌
⦅*NamedFieldDeclaration*
⊔ ⦅*NamedFieldDeclaration*
“,” *MoreNamedFieldDeclarations*⦆⦆
:*MoreNamedFieldDeclarations* ▌
⦅*FieldName*
⦅“⌸” ⊔ “:⌸”⦆ *SimpleFieldDeclaration*⦆⦆
:*NamedFieldDeclaration* ▌
FieldName ⊑ *QualifiedName* ▌
// “:⌸” is used for assignable fields.
⦅⦅ ⊔ *Identifier*⦆ *ActorBody*⦆:*StructureImplementation* ▌
⦅*Expression* “⟦” *FieldName* “⟧” ⦆:*FieldSelector* ▌
// *FieldName* of *Expression* which *must* be a structure
FieldSelector ⊑ *Expression* ▌
⦅*StructureName* “[” *FieldExpressions* “]” ⦆:*StructureExpression* ▌
StructureExpression ⊑ *Expression* ▌
⦅ ⊔ *MoreFieldExpressions*⦆:*FieldExpressions* ▌
⦅⦅*SimpleFieldExpression* ⦅ ⊔ ⦅“,” *MoreNamedFieldExpressions*⦆⦆⦆
⊔ ⦅*SimpleFieldExpression*
“,” *MoreFieldExpressions*⦆⦆:*MoreFieldExpressions* ▌
⦅*NamedFieldExpression*
⊔ ⦅ *NamedFieldExpression*
“,” *MoreNamedFieldExpressions*⦆⦆
:*MoreNamedFieldExpressions* ▌
⦅*FieldName*
⦅“⌸” ⊔ “:⌸”⦆ *SimpleFieldExprression*⦆⦆
:*NamedFieldExpression* ▌
⦅*StructureName* “[” *FieldPatterns* “]” ⦆:*StructurePattern* ▌
StructurePattern ⊑ *Pattern* ▌
⦅ ⊔ *MoreFieldPatterns*⦆:*FieldPatterns* ▌
⦅⦅*SimpleFieldPattern* ⦅ ⊔ ⦅“,” *MoreNamedFieldPatterns*⦆⦆⦆
⊔ ⦅ *SimpleFieldPattern* “,” *MoreFieldPatterns*⦆⦆
:*MoreFieldPatterns* ▌
⦅*NamedFieldPattern*
⊔ ⦅ *NamedFieldPattern*
“,” *MoreNamedFieldPatterns*⦆⦆
:*MoreNamedFieldPatterns* ▌

⦅FieldName ⦅"⌸" ⊔ ":⌸"⦆ SimpleFieldExprression⦆⦆
:NamedFieldPattern▮

[39] ⦅"**Try**" anExpression:*Expression*◁aType▷
"**catch�**" *ExpressionCases*◁Exception, aType▷ "⍰"⦆
:*Expression*◁aType▷▮

/*

- If anExpression throws an exception that matches the pattern of a case, then the value of *TryExpression* is the value computed by *ExpressionCases*
- If anExpression doesn't throw an exception, then then the value of *TryExpression* is the value computed by anExpression. /*

⦅"**Try**" anExpression:*Expression*◁aType
"**catch�**" *ContinuationCases*◁Exception, aType▷"⍰"⦆
:*Continuation*◁aType▷▮

/*

- If anExpression throws an exception that matches the pattern of a case, then the response of *TryContinuation* is the response computed by the expression of the case.
- If aContinuation doesn't throw an exception, then then the response of *TryExpression* is the response computed by anExpression. */

⦅"**Try**" anExpression:*Expression*◁aType▷
"**cleanup**" cleanup:*Expression*◁aType▷⦆:*Expression*◁aType▷▮
*/

- If anExpression throws an exception, then the value of *TryExpression* is the value computed by cleanup.
- If anExpression doesn't throw an exception, then then the value of *TryExpression* is the value computed by anExpression. */

[40] ⦅"**Preconditions**" test:*Expressions Expressions*⦆:*Expression*▮
// Each of expressions in test must evaluate to **True** or
// an exception is thrown

⦅"**Preconditions**" *Expressions ExpressionsContinuation*⦆
:*Continuation*▮
// Each of expressions in *Expressions* must evaluate to **True** or
// an exception is thrown

⦅value:*Expression*◁aType▷
"**postcondition**" pre:*Expression*◁[aType]↦Boolean▷⦆
:*Expression*◁aType▷▮
// The expression pre must evaluate to **True** when sent value
// or an exception is thrown

[41] º is a reserved postfix operator for degrees of angle

[42] i.e., i*i=-1 where i is the imaginary number Cartesian[0, 1]

[43] ⦅"[" *ComponentExpressioons* "]"⦆:*Expression*◁List▷▮
// An ordered list with elements *ComponentExpressions*
⦅ ⊔ *MoreComponentExpressioons*⦆:*ComponentExpressioons* ▮
⦅⦅⦅ ⊔ "∨"⦆ *Expression*⦆
⊔ ⦅⦅ ⊔ "∨"⦆ *Expression*
"," *MoreComponentExpressioons*⦆⦆
:*MoreComponentExpressioons*▮
⦅"[" *TypeExpressions* "]"⦆:*TypeExpression*▮
⦅ ⊔ *MoreTypeExpressions*⦆:*TypeExpressions*▮
⦅*TypeExpression* ⊔ ⦅*TypeExpression* "," *MoreTypeExpressions*⦆⦆
:*MoreTypeExpressions*▮

[44] ⦅"_"⦆:*UnderscorePattern*▮
UnderscorePattern⊑*Pattern*▮
Identifier⊑*Pattern*▮
⦅*Pattern* "**suchThat**" *Expression*⦆:*SuchThat*▮
SuchThat⊑*Pattern*▮
⦅*Pattern* "**thatIs**" *Expression*⦆:*ThatIs*▮
ThatIs⊑*Pattern*▮
⦅"$$" *Expression*◁Type▷⦆:*Pattern*◁Type▷▮
⦅"[" *ComponentPatterns* "]"⦆:*Pattern*◁List▷▮
// A pattern that matches a list whose elements match
// *ComponentPatterns*
⦅ ⊔ *MoreComponentPatterns*⦆:*ComponentPatterns*▮
⦅*Pattern*
⊔ ⦅ "∨"*Pattern* ⦆
⊔ ⦅*Pattern* "," *MoreComponentPatterns*⦆⦆
:*MoreComponentPatterns*▮

[45] ⦅"{" *ComponentExpressioons* "}"⦆:*Expression*◁Set▷▮
// A set of Actors without duplicates
⦅"{" *ComponentPatterns* "}"⦆:*Pattern*◁Set▷▮

[46] ⦅"⦃" *ComponentExpressioons* "⦄"⦆:*Expression*◁Multiset▷▮
// A multiset of the Actors with possible duplicates
⦅"⦃" *ComponentPatterns* "⦄"⦆:*Pattern*◁Multiset▷▮

[47] Optimization of this program is facilitated because:

- The records are cacheable because their type is **Set◁ContactRecord▷**
- All of the operators are cacheable
- The operators are annotated as cacheable using "|••>"

[48] ⦅"**Map**" "{" *ComponentExpressioons* "}" ⦆:*Expression*◁**Map**▷▮

[49] It is possible to define a procedure that will produce a "bottomless" future. For example, f▪[ ]:**Future**◁**aType**▷ ≡ **Future** f▪[ ]▮

[50] ⦅**Postpone** *Expression*◁aType▷▮⦆:*Expression*◁Future◁aType▷▷▮
// postpone execution of the expression until the value is needed.

[51] ⦅"**Future**" aValue:*Expression*◁**aType**▷
⦅ ⊔ ⦅"**sponsor**" *Expression*◁**Sponsor**▷⦆⦆⦆
:*Expression*◁**Future**◁**aType**▷▷▮
// A future for aValue.
⦅"↓" *Expression***Future**◁**aType**▷▷⦆:*Expression*◁**aType**▷▷▮
// Resolve a future

[52] ⦅LoopName:*Identifier* "**.**" "[" *Initializers* "]"
⦅ ⊔ ⦅ ":" ReturnType:**aType** ⦆⦆
"≜" *Expression*◁**aType**▷ ⦆:*Expressions*◁**aType**▷▮
⦅ ⊔ *MoreInitializers*⦆:*Initializers*▮
⦅*Initializer* ⊔ ⦅*Initializer* "," *MoreInitializers*⦆⦆
:*MoreInitializers*▮
⦅*Identifier* ⦅ ⊔ ⦅":" *TypeExpression*⦆⦆ "←" *Expression*⦆:*Initializer*▮

[53] The implementation below requires careful optimization.

[54] ⦅"**String**" "[" *ComponentExpressioons* "]"⦆:*Expression*◁**String**▷▮
⦅"**String**" "[" *ComponentPatterns* "]"⦆:*Pattern*◁**String**▷▮

[55] ⦅recipient:*Expression*◁**recipientType**▷
"**.**" message:*MessageExpression*◁**recipientType**▷⦆:*Expression*▮
// Send recipient the message

[56] /* A **Postpone** expression does not begin execution of Expression_1 until a request is received. Illustration:
IntegersBeginningWith**.**[n:**Integer**]:◁**FutureList**◁**Integer**▷ ≡
[n, ∨**Postpone** IntegersBeginningWith**.**[n+1]]▮
Note: A **Postpone** expression can limit performance by preventing concurrency */

[57] ⦅ "⦅" *MoreGrammers* "⦆" ⦆:*Grammar*▮
⦅ "⦅"*Grammar*"⊔"*Grammar*"⦆" ⦆:*Grammar*▮
⦅*ReservedWord* ⦅ ⊔ *StartsWithIdentifier* ⦆⦆:*StartsWithReserved*▮
StartsWithReserved⊑*MoreGrammers*▮
⦅*Identifier* ⦅ ⊔ *StartsWithReserved* ⦆⦆⦆:*StartsWithIdentifier*▮
StartsWithIdentifier⊑*MoreGrammers*▮
⦅"\"" *Word* "\""⦆ :*ReservedWord*▮
// The use of \ escapes the next character in a string so
// that "\"" has just one character that is ".
⦅*Grammar* ":" *GrammarIdentifier* "▮"⦆:*Judgment*▮
⦅*Identifier*◁**Grammar**▷ "⊑"*Identifier*◁**Grammar**▷ "▮"⦆:*Judgment*▮

[58] The implementation below can be highly inefficient.

[59] ⦅"**Atomic**" aLocation:*Expression*
"**compare**" comparison:*Expression*
"**update**" update:*Expression* "�"
"**updated**" "⸬"
compareIdentical:*ExpressionsContinuation*◁**aType**▷ "⍌"
"**notUpdated**" "⸬"
compareNotIdenticial:*ExpressionsContinuation*◁**aType**▷ "⍰"⦆
:*Continuation*◁**aType**▷▮

/* Atomically compare the contents of aLocation with the value of comparison. If identical, update the contents of aLocation with the value of update and execute compareIdentical.

[60] ⦅*Identifier* "⊡" *Qualifier*⦆:*QualifiedName*▮
QualifiedName⊑*Expression*▮
Identifier⊑*QualifiedName*▮
⦅*Identifier*⊔⦅*Identifier* "⊡" *Qualifier*⦆⦆:*Qualifier*▮

[61] ⦅"**Enumeration**" *Identifier*◁**Type**▷
MoreEnumerationNames "。"⦆:*Definition*▮
⦅*EnumerationName*
⊔⦅*EnumerationName*
"," *MoreEnumerationNames*⦆⦆
:*MoreEnumerationNames*▮
EnumerationName⊑*Word*▮

[62] Declarations provide version number, encoding, schemas, *etc.*

[63] If a customer is sent more than one response (i.e., **return** or **throw** message) then it will throw an exception to the sender of the response.

[64] ⦅recipient:*Expression*
"↞" *MessageName* "[" *Arguments* "]"⦆:*Expression*◁**Void**▷▮

/* recipient is sent one-way message with *MessageName* and *Arguments*. Note that *Expression*◁⊖▷*cannot* be used to produce a value. */

[65] ⦅*MessageName* "[" *ArgumentDeclarations* "]"
⦅ ⊔ ⦅"**sponsor**" *Identifier*◁**Sponsor**▷ ⦆⦆▷⦆⦆
"↠" *ExpressionsContinuation*◁⊖▷⦆:*MessageHandler*▮

/* one-way message handler implementation with *ArgumentDeclarations* that has a one-way continuation that returns nothing */

⦅"⊖" ⦅ ⊔ ⦅"**permit**" aQueue:*Expression*⦆⦆
⦅ ⊔ ⦅"**afterward**" *Afterward*⦆⦆⦆:*Continuation*◁"⊖"▷▮

[66] Hoare[1962]. The implementation below is adapted from Wikipedia.

[67] // Move Actor at pivotIndex to end

[68] [Church 1932; McCarthy 1963; Hewitt 1969, 1971, 2010; Milner 1972, Hayes 1973; Kowalski 1973]. Note that this definition of Logic Programs does *not* follow the proposal in [Kowalski 1973, 2011] that Logic Programs be restricted only to clause-syntax programs.

[69] A ground-complete predicate is one for which all instances in which the predicate holds are explicitly manifest, *i.e.*, instances can be generated using patterns. See [Ross and Sagiv 1992, Eisner and Filardo 2011].

[70] Execution can proceed differently depending on how sets fit into computer storage units.

[71] /* Consider a dialect of Lisp which has a simple conditional expression of the following form:

⟦"(" "**if**" test:*Expression* then:*Expression* else:*Expression* ")" ⟧

which returns the value of then if test evaluates to **True** and otherwise returns the value of else.

The definition of Eval in terms of itself might include something like the following [McCarthy, Abrahams, Edwards, Hart, and Levin 1962]:

```
(Eval expression environment) ≡
                         // Eval of expression using environment defined to be
  (if (Numberp expression)              // if expression is a number then
     expression                                   // return expression else
     (if ((Equal (First expression) (Quote if))
                                            // if First of expression is "if" then
       (if (Eval (First (Rest expression) environment)
                              // if Eval of First of Rest of expression is True then
          (Eval (First (Rest (Rest expression)) environment)
                          // return Eval of First of Rest of Rest of expression else
          (Eval (First (Rest (Rest (Rest expression)) environment))
                      // return Eval of First of Rest of Rest of Rest of expression
     ...))
```

The above definition of Eval is notable in that the definition makes use of the conditional expressions using **if** expressions in defining how to evaluate an **if** expression! */

[72] The implementation CheeseQ uses activities to implement its queue where for type Activity the following holds:

Structure Activity[previous :⌸ Nullable◁Activity▷,
// if null then head of queue else,
// pointer to backwards list to head
nextHint :⌸ Nullable◁Activity▷]▮
// if non-null then pointer to next
// activity to get cheese after this one

[73] If non-null points to head with current holder of cheese

[74] If non-null, pointer to backwards list ending with head that holds cheese

[75] **Interface** CheeseQ **with** enter[ ] ↦ Void,
leave[ ] ↦ Void▮

[76] // enter message received running myActivity

[77] // commentary for error checking

[78] /* this cheese queue is not empty because myActivity is at the head of the queue */

[79] **Interface** SubCheeseQ **with** head[ ] ↦ Activity▮

[80] **Interface** InternalQ **with** enqueueAndLeave[ ] ↦ Void,
enqueueAndDequeue[InternalQ] ↦ Activity,
dequeue[ ] ↦ Activity,
empty?[ ] ↦ Boolean▮

[81] **Interface** SubInternalQ **with** add[Activity] ↦ Void,
remove[ ] ↦ Activity▮

[82] Used in type specifications for interfaces.

[83] Used in message handlers.

[84] Used to bind identifiers in **Let**.

[85] Three equal signs because two equal signs have a meaning in Java

[86] Used in patterns.

[87] Used in structures.

[88] Used in one-way message passing.