25

Agents, iteration and introspection

25.1 OVERVIEW

Objects represent information equipped with operations. These are clearly defined concepts; no one would mistake an operation for an object.

For some applications — graphics, numerical computation, iteration, writing contracts, building development environments, and "introspection" (a system's ability to explore its own properties) — you may find the *operations* so interesting that you will want to define *objects* to represent them, and pass these objects around to software elements, which can use these objects to execute the operations whenever they want. Because this separates the place of an operation's *definition* from the place of its *execution*, the definition can be incomplete, since you can provide any missing details at the time of any particular execution.

agent *your_routine*

You can create **agent** objects to describe such partially or completely specified computations. Agents combine the power of higher-level functionals — operations acting on other operations — with the safety of Eiffel's static typing system.

Agents are not for the beginning Eiffel user. If this is your first reading, you should most likely skip this chapter.

25.2 A QUICK PREVIEW

Why do we need agents? Here are a few example uses. This preview omits many details, so if this is your first brush with agents some of it may look mysterious; it will, however, give you an idea of the mechanism's power, and by chapter end all the details will be clear.

Let's start with a typical need of graphical user interface (GUI) programming. Using the style of EiffelVision, ISE's multi-platform graphical library, you would write

```
your_button.click_actions.extend (agent your_routine)
```

to add *your_routine* (a routine of your application, executing some useful operation of your "Business Model") to the list of actions executed when a mouse click occurs on *your_button*. This is all you need to do to set up your application's response in this case.

The argument to *extend*, **agent** *your_routine*, is an **agent expression**. The keyword **agent** avoids confusion with an actual routine call: when calling *extend*, you don't want to call *your_routine* yet! Instead you pass to *extend* an "agent", which *extend* adds to the *click_actions* list for *your_button*, enabling EiffelVision to call *your_routine* for every subsequent occurrence of a click event on the button. The agent includes any context information that *your_routine* may need: cursor position, button number, pressure.

Now consider a numerical example. You want to integrate a function *g* (*x*: *REAL*): *REAL* over the interval [0, 1]. With *your_integrator* of a suitable type *INTEGRATOR* (detailed later), just use the expression

```
your_integrator.integral (agent g (?), 0.0, 1.0)
```

Again this doesn't call the routine *g*, but enables *integral* to call *g* when it pleases, as often as it pleases, on whatever values it pleases. We must tell *integral* where to substitute such values for *x*, at the places where its algorithm will need to evaluate *g* to approximate the integral. This is the role of the question mark **?**, replacing the argument to *g*.

You may use the same scheme in

```
your_integrator.integral (agent h (u, ?, v), 0.0, 1.0)
```

to compute the integral $\int_0^1 h(u, x, v)\, dx$, where *h* is a three-argument function *h* (*a*: *T1*; *x*: *REAL*; *b*: *T2*): *REAL* and *u* and *v* are arbitrary values. As before you will use a question mark at the "open" position, corresponding to the integration variable *x*. Two "closed" positions show actual values *u* and *v*.

Note the flexibility of the mechanism: it allows you to use the same routine, *integral*, to integrate a one-argument function such as *f* as well as functions such as *h* involving an arbitrary number of extra values.

You can rely on a similar structure to provide **iteration** mechanisms on data structures such as lists. Assume a class *CC* with an attribute

```
intlist: LINKED_LIST [INTEGER]
```

and a function

```
integer_property (i: INTEGER): BOOLEAN
```

returning true or false depending on a property involving *i*. You may write

```
intlist.for_all (agent integer_property (?))
```

to denote a boolean value, true if and only if every integer in the list *intlist* satisfies *integer_property*. This expression might be useful, for example, in a class invariant. It will work for any kind of *integer_property*, even if this function involves attributes or other features of *CC*, that is to say, arbitrary properties of the current object.

Now assume that in *CC* you also have a list of employees:

```
emplist: LINKED_LIST [EMPLOYEE]
```

and that class *EMPLOYEE* has a function *is_married*: *BOOLEAN* with no argument, telling us about the current employee's marital status. Then you may also write in *CC* the boolean expression

```
emplist.for_all (agent {EMPLOYEE}.is_married)
```

to find out whether all employees in the list are married. The argument to *for_all* is imitated from a normal feature call *some_employee.is_married*, but instead of specifying a particular employee we just give the type *{EMPLOYEE}*, to indicate where *for_all* must evaluate *is_married* for successive targets taken from the the list.

The *{EMPLOYEE}* notation replaces the question mark of the previous examples. Those examples used an argument as the open operand — the place where the routine will be evaluated — as in *integer_property* (**?**), where the argument type is clear from the declaration of *integer_property*. But with *is_married* the open argument is the target, so we need to specify the type: many classes may have a function called *is_married*.

Note again the flexibility of the iteration mechanism and its adaptation to the object-oriented form of computation: you can use the same iteration routine, here *for_all* from *LINKED_LIST*, to iterate actions applying to either:

- The **target** of a feature, as with *is_married*, a feature of class *EMPLOYEE*, to be applied to its *EMPLOYEE* target.
- The **actual argument** of a feature, as with *integer_property* which evaluates a property of its argument *i* — and may or may not, in addition, involve properties of its target, an object of type *CC*.

It seems mysterious that a single iterator mechanism can handle both cases equally well. We will see how to write *for_all* and other iterators accordingly. The trick is that they simply work on their open operands; when calling them, you choose what to leave open: either the argument as with *integer_property* and *integral*, or the target as with *is_married*.

Now assume that you want to pass to some object the mechanisms needed to execute the cursor resetting and advance operations, *start* and *forth*, on a particular list. Here nothing is left open: you fix the list, and the operations have no arguments. You may write

This is the iterator style of the C++ STL (Standard Template Library).

```
object.operation (agent your_list.start, agent your_list.forth)
```

All operands — target and arguments — of the agents passed to *object* are "closed", so *object* can execute call operations on such objects without providing any further information.

At the other extreme, you might leave an agent expression fully open, as in

```
object.operation(agent {LINKED_LIST [T]}.extend (?))
```

so that *object*, when it desires to apply a call operation, will have to provide both a linked list and an actual argument to execute *extend*. When as here all the arguments are open, you may omit the argument list, writing just **agent** *{LINKED_LIST [T]}.extend*. Such an agent is a "**routine object**": an object representating the routine *extend* from *LINKED_LIST*, such as could be used by browsing tools or other *introspective* facilities.

To use an agent, a routine such as *operation* can apply to it the procedure *call*, passing a tuple of values for the open operands. This will have the same effect as an execution of the original feature — *f*, *h*, *integer_property*, *is_married*, *start*, *forth*, *extend* … — on all the operands, closed and open.

The notation provides an extra degree of flexibility by letting you define **inline agents**, which instead of referring to a feature of the class define a routine text as part of the agent declaration. Inline agents have the same form as a Routine body, as in

```
(i: INTEGER): BOOLEAN do Result := integer_property (i) end
        -- Means the same as: agent integer_property (?)
(e: EMPLOYEE): BOOLEAN do Result := e.is_married end
        -- Means the same as: agent {EMPLOYEE}.is_married
```

In these examples the previous forms were simpler and shorter, but inline agents are useful when you want to express the computation just for the agent, and not give it the status of a routine of the enclosing class. For example you may define the inline agent

```
(i: INTEGER): BOOLEAN
    do Result := (item (i) = a.item (i) + b.item (i)) end
```

which could be useful in a postcondition

```
summed: (lower |..| upper).for_all
    ((i: INTEGER): BOOLEAN
        do Result := (item (i) = a.item (i) + b.item (i)) end)
```

This states that for every element *i* of the interval *lower* |..| *upper* the value of the item at position *i* (in a structure such as an array or list) is the sum of the corresponding values in *a* and *b*. To obtain the same semantics without agent arguments, you would need to express the agent as **agent** *is_sum_of* (?, *a*, *b*) and define a function *is_sum_of* such that *is_sum_of* (*i*, *x*, *y*) is true if and only if *item* (*i*) = *x*.*item* (*i*) + *y*.*item* (*i*). The semantics is the same, but if you have many properties of this kind — for example in contracts — the inline form avoids introducing many specialized functions such as *is_sum_of*.

In this example the agent represents a function, with an expression as its body: *item* (*i*) = *a*.*item* (*i*) + *b*.*item* (*i*). It is also possible to use an inline form for a procedure agent, as in

```
emplist.do_all ((e: EMPLOYEE) do sum := sum + e.salary end)
```

where *do_all* applies its agent argument to all successive elements in a list; this increases *sum* by the total of all employees' salaries.

For an agent involving a single routine such as *integer_property*, *integral*, *is_married*, *extend* and the other previous examples, the original non-inline form is shorter, more abstract, and usually preferable.

You may wonder how this can all work in a type-safe fashion. So it is time to stop this preview and cut to the movie.

25.3 FROM CALLS TO AGENTS

Feature calls and their operands

First we should remind ourselves of the basic properties of **feature calls**. When programming with Eiffel we rely all the time on this fundamental mechanism of object-oriented computation. We write things like

← Feature calls were studied in chapter 23 and their type properties in chapter 24.

[Q]	*a0*.*f* (*a1*, *a2*, *a3*)

to mean: call feature *f* on the object attached to *a0*, with actual arguments *a1*, *a2*, *a3*. In Eiffel this is all governed by type rules, checkable statically: *f* must be a feature of the base class of the type *a0*; and the types of *a1* and the other actuals of the call must all conform to the types specified for the corresponding formals in the declaration of *f*.

In a frequent special case *a0*, the **target** of the call, is just *Current*, denoting the current object. Then we may omit the dot and and the target altogether, writing the call as just

[U]	*f* (*a1*, *a2*, *a3*)

which assumes that *f* is a feature of the class in which this call appears. The first form, with the dot, is a *qualified* call; the second form is *unqualified* (hence the names [Q] and [U] given to our two examples).

In either form the call is syntactically an expression if *f* is a function or an attribute, and an instruction if *f* is a procedure. If *f* has been declared with no formals (as in the case of a function without arguments, or an attribute) we omit the list of actuals, (*a1*, *a2*, *a3*).

The effect of executing such a call is to apply feature *f* to the target object, with the actuals given if any. If *f* is a function or an attribute, the value of the call expression is the result returned by this application.

To execute properly, the call needs the value of the target and the actuals, for which this chapter needs a collective name:

Operands of a call

The operands of a call include its target (explicit in a qualified call, implicit in an unqualified call), and its arguments if any.

In the examples the operands are *a0* (or *Current* in the unqualified version [U]), *a1*, *a2* and *a3*. Also convenient is the notion of *position* of an operand:

Operand position

The target of a call (implicit or explicit) has position 0. The *i*-th actual argument, for any applicable *i*, has position *i*.

Positions, then, range from 0 to the number of arguments declared for the feature. Position 0, the target position, is always applicable.

Delaying calls

For a call such as the above, we expect the effect just discussed to occur as a direct result of executing the call instruction or expression: the computation is immediate. In some cases, however, we might want to write an expression that only *describes* the calls intended computation, and to *execute* that description later on, at a time of our own choosing, or someone else's. This is the purpose of agent expressions, which may be described as **delayed calls**.

Why would we delay a call in this way? Here are some typical cases:

A •We might want the call to be applied to all the elements of a certain structure, such as a list. In such a case we will specify the agent expression once, and then execute it many times without having to re-specify it in the software text. The software element that will repeatedly execute the same call on different objects is known as an **iterator**. Function *for_all*, used earlier, was an example of iterator.

B •In an iterator-like scheme for numerical computation, we might use a mechanism that applies a call to various values in a certain interval, for example to approximate the integral of a function over that interval. The first example in this chapter relied on such an *integral* function.

C •We might want the call to be executed by another software element: passing an agent object to that element is a way to give it the right to operate on some of our own data structures, at a time of its own choosing. This was illustrated with the calls passing to *object* some agent expressions representing operations applicable to *your_list*. GUI examples also belong to that category: to state that a certain action must be executed whenever a certain event (such as mouse click) occurs on a certain graphical object (such as a button), we add an agent representing the action to a list of agents associated with the object and the event.

D •We might want to ensure that the call is executed only when and if needed, and then only once for any particular object. This would give us a “once per object” mechanism along the lines of “once functions” (which are executed once per system).

Once functions see “ROUTINE BODY”, 8.6, page 148. The once per object mechanism using agents is described below.

E •Finally, we may be interested in the agent as a way to gain information about the feature itself, whether or not we ever intend to execute the call. This may be part of the more general goal of providing **introspective** capabilities: ways to enable a software system to explore and manipulate information about its own properties.

Introspection is also called **reflection**, *but the first term appears more appropriate.*

These examples illustrate one of the differences between an agent expression and a plain feature call: to execute a feature call we need the value of all its operands (target and actuals); but for an agent expression we may want to leave some of the operands open for later filling-in. This is clearly necessary for cases A and B, in which the iteration or integration mechanism will need to apply the feature repeatedly, using different operands each time. In an integration

$$\int_{x=a}^{x=b} g(x)\, dx$$

we will need to apply g to successive values of the interval $[a, b]$.

Agents and their operands

For an agent we need to distinguish between two moments:

DEFINITIONS

Construction time, call time

The **construction time** of an agent object is the time of evaluation of the agent expression defining it.

Its **call time** is when a call to its associated operation is executed.

Since the only way to obtain an agent initially is through *agent expressions*, as specified next, it is meaningful to talk about the "agent expression defining it".

For a normal call the two moments are the same. For an agent we will have one construction time (zero if the expression is never evaluated), and zero or more call times. At construction time, we may leave some operands unspecified; they they will be called the *open* operands. At call time, however, the execution needs all operands, so the call will need to specify values for the open operands. These values may be different for different executions (different call times) of the same agent expression (with a single construction time).

→ A precise definition of "open" and "closed" operands appears on page 586.

Readers familiar with lambda calculus may think of open as "free" and closed as "bound".

There is no requirement to make **all** operands open at construction time: you may provide some operands, which will be closed, and leave some others open. In the example of computing, for some values u and v, the integral

$$\int_{x=a}^{x=b} h(u,\ x, v)\, dx$$

where h is a three-argument function, we pass to the integration mechanism an agent that is closed on its first and last operands, u and v, but open on x.

Nothing forces you, on the other hand, to leave **any** operand open. An agent with all operands closed corresponds to the kind of application called C above, in which we don't want to execute the call ourselves but let another software element carry it out when it is ready. We choose the construction time, and package the call completely, including all the information needed to carry it out; the other software element chooses the call time. This style is used by iterators in the C++ STL library.

At the other extreme, an agent with **all operands open** has no information about the target and actuals, but includes all the relevant information about the feature. This is useful in application E: passing around information about a feature for introspection purposes, enabling a system to deliver information about its own components.

25.4 AGENT TYPES

A normal call is a syntactical component — instruction or expression — meant only for one thing: immediate execution. If it is an expression (because the feature is a function), it has a value, computed by the execution, and so it denotes an object.

An agent expression has a different status. Since construction time is separate from call time, the agent expression can only **denote an object**. That object (an agent) contains all the information needed to execute the call later, at various call times. This includes in particular:

- Information about the routine itself and its base type.
- The values of all the closed operands.

What is the type of an agent expression? Four Kernel Library classes are used to describe such types: *ROUTINE*, *PROCEDURE*, *FUNCTION* and *PREDICATE*. Their class headers start as follows:

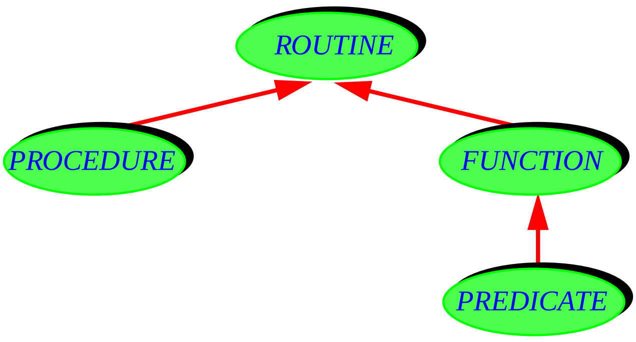
```
deferred class ROUTINE [BASE, OPEN –> TUPLE]

class PROCEDURE [BASE, OPEN –> TUPLE] inherit
        ROUTINE [BASE, OPEN]

class FUNCTION [BASE, OPEN –> TUPLE, RES] inherit
        ROUTINE [BASE, OPEN]

class PREDICATE [BASE, OPEN –> TUPLE] inherit
        FUNCTION [BASE, OPEN, BOOLEAN]
```

In the actual class texts, the formal generic matters have names *BASE_TYPE*, *OPEN_ARGS* and *RESULT_TYPE* to avoid conflicts with programmer-chosen class names. This chapter uses shorter names for simplicity.

→ *A.6.27 to A.6.29 in the ELKS chapter, starting on page 834.*

If the associated feature is a procedure the agent will be an instance of *PROCEDURE*; for a function or attribute, we get an instance of *PREDICATE* when the result is boolean, of *FUNCTION* with any other type. Here for ease of reference is a picture of the inheritance hierarchy:

Agent classes



The role of the formal generic parameters is:

- *BASE*: type (class + generics if any) to which the feature belongs.
- *OPEN*: tuple of the types of open operands, if any.
- *RES*: result type for a function.

One of the fundamental features of class *ROUTINE* is

```
call (v: OPEN) is
        -- Call feature with all its operands, using v for the open operands.
```

In addition, *FUNCTION* and *PREDICATE* have the feature

```
last_result: RES
        -- Function result returned by last call to call, if any
```

and, for convenience, the function *item* combining *call* and *last_result*, with the following specification:

```
item (v: like open_operands): RES is
            -- Result of calling feature with all its operands,
            -- using v for the open operands.
            -- (Uses call for the call.)
    ensure
            set_by_call: Result = last_result
```

The formal generic parameters for *ROUTINE*, *PROCEDURE*, *FUNCTION* and *PREDICATE* provide what we need to make the agent mechanism statically type-safe. *OPEN*, a tuple type, gives the exact list of open operand types; since the argument to *call* and *item* is of type *OPEN*, it is possible from the software text to check that the actual arguments to *call* will at call time be of the proper types, conforming to the original feature's formal argument types at the open positions. The actuals at closed positions are set at construction time, again with type checking. So the combination of open and closed actuals will be type-valid for the feature.

ROUTINE, *PROCEDURE*, *FUNCTION* and *PREDICATE* have more features than listed above; in particular, they provide introspection facilities, describing properties of the associated routines and discussed below. For a complete interface specification, see the corresponding sections in the presentation of Kernel Library classes.

→ *Sections A.6.27 to A.6.29, starting on page 834.*

25.5 CALL AGENTS

How do we obtain agent objects? The most common construct is a *call agent* expression. (We will see the other case, *inline agents*, in a later section.)

→ *"USING INLINE AGENTS", 25.8, page 573*.

The basic form of a call agent is very simple: just add the keyword **agent** at the beginning of a normal feature call. This yields an agent with operands all closed. To specify open operands, you may:

- Use a question mark **?** in lieu of an argument.
- Use a type in braces, {*TYPE*}, in lieu of an argument or the target.
- Omit the argument list altogether, to make all arguments open.

Let's examine these variants and the associated semantics.

All-closed agents

If you start from a valid call, either qualified or unqualified

```
[Q]        a0.f (a1, a2, a3)
[U]        f (a1, a2, a3)
```

you get an agent expression in each case by adding the keyword **agent**:

```
agent a0.f (a1, a2, a3)
agent f (a1, a2, a3)
```

Such an agent expression is not a call (instruction or expression) any more, but an expression of a new syntactic kind, Feature_agent, denoting an agent, of a *PROCEDURE* type if *f* is a procedure. and a *FUNCTION* or *PREDICATE* type if *f* is a function. Both of these examples have no arguments, so they are closed on all operands; we will start adding arguments soon.

You can do with an agent expression all you are used to do with other expressions. You can assign it to an entity of the appropriate type; assuming *f* is a procedure of a class *CC*, you may write, in class *CC* itself:

This example assumes that CC is non-generic, so that it is both a class and a type.

```
p: PROCEDURE [CC, TUPLE]
…
p:= agent a0.f (a1, a2, a3)
…
p.call ([ ])
```

Since all operands are closed — we have specified the target *a0* and all the arguments *a1*, *a2*, *a3* — the second formal generic is just *TUPLE*, and the call to *call* takes an empty tuple [ ].

More commonly than assigning a call expression to an entity as here, you will pass it as actual argument to a routine, as in

```
object. do_something (agent a0.f (a1, a2, a3))
```

where *do_something*, in the corresponding class, takes a formal *p* declared as

```
p: PROCEDURE [CC, TUPLE]
```

or just

```
p: PROCEDURE [ANY, TUPLE]
```

presumably to call *call* on *p* at some later stage, as we will shortly learn to do. This was the scheme called C in the presentation of example applications: passing a completely closed agent to another component of the system, to let it execute the call when it chooses to. For example you can pass **agent** *your_list*.*start* or **agent** *your_list*.*extend* (*some_value*).

← Scheme C was on page 552.

Keeping operands open

The examples just seen are still of limited interest because all their operands are closed. But you may want to keep some operands open for latter filling-in at call time, for example by an iteration or integration mechanism.

To specify an open target, you will replace the target by its type in braces, {*TARGET_TYPE*}. This is the **brace convention**. To specify an open argument, you may use the brace convention too, but if you are happy to stay with the declared type of the argument you can just use the **question mark convention**: just replace the target by a question mark **?**.

Here are some examples, obtained by starting from the call *a0*.*f* (*a1*, *a2*, *a3*) and opening the target or some arguments.

```
        -- Start with an agent closed on all operands:
s:= agent a0.f (a1, a2, a3)
        -- Next, individually open the target and each successive argument:
t:= agent {T0}.f (a1, a2, a3)
u:= agent a0.f (?, a2, a3)
v:= agent a0.f (a1, ?, a3)
w:= agent a0.f (a1, p, ?)
        -- An example with two open arguments, target closed:
x := agent a0.f (a1, ?, ?)
        -- Arguments all open, target still closed:
y := agent a0.f (?, ?, ?)
        -- Finally, open everything:
z := agent {T0}.f (?, ?, ?)
```

The respective types of these call expressions are, assuming that *f* is a procedure declared in the base class of *T0*, having formals declared of types *T1*, *T2* and *T3*:

```
s:  PROCEDURE [T0, TUPLE]
t:  PROCEDURE [T0, TUPLE [T0]]
u:  PROCEDURE [T0, TUPLE [T1]]
v:  PROCEDURE [T0, TUPLE [T2]]
w:  PROCEDURE [T0, TUPLE [T3]]
x:  PROCEDURE [T0, TUPLE [T2, T3]]
y:  PROCEDURE [T0, TUPLE [T1, T2, T3]]
z:  PROCEDURE [T0, TUPLE [T0, T1, T2, T3]]
```

If *f* were a function, the types would use *FUNCTION* instead of *PROCEDURE*, with an extra generic parameter representing the result type (except for a boolean-valued function, which would use *PREDICATE*).

The first generic parameter, *T0* in all of these examples, represents the current type (class with generic parameters if any) of the underlying feature. Here we assume for simplicity that *f* comes from a non-generic class *T0*.

→ *"THE BASE CLASS AND TYPE", 25.10, page 577*.

← *"CURRENT TYPE, FEATURES OF A TYPE", 12.8, page 266*

The second generic parameter, a tuple type, represent the sequence of types of open operands. For the first example, *t*, it's just *TUPLE* with no parameters, since the agent has no open operands. For the other examples the parameters of the *TUPLE* type represent the types of the open operands.They indicate what argument types are permissible in calls to *call* (or *item* for a function) on the corresponding agents.

Here indeed are examples of valid uses of *call* on the previous agent examples. For each of them, the comment on the next line shows how we would have obtained the same effect through a normal call (call time same as construction time, not using agents).

```
val_0: T0; val_1: T1; val_2: T2; val_3: T3
… Assign values to val_0, val_1, val2, val_3 …
s. call ([ ])        -- Note empty tuple: no open operands
        -- a0. f (a1, a2, a3)
t. call ([val_0])
        -- val_0. f (a1, a2, a3)
u. call ([val_1])
        -- a0. f (val_1, a2, a3)
```

```
v. call ([val_2])
        -- a0.f (a1, val_2, a3)
w. call ([val_3])
        -- a0.f (a1, a2, val_3)
x. call ([val_2, val_3])
        -- a0.f (a1, val_2, val_3)
y. call ([val_1, val_2, val_3])
        -- a0.f (val_1, val_2, val_3)
z. call ([val_0, val_1, val_2, val_3])  -- Must provide all operands
        -- val_0.f (val_1, val_2, val_3)
```

It should be clear by now how mechanisms such as *for_all* can manage to work on operations that work on their target, such as *is_married*, as well as others that work on an argument, such as *is_positive*. The type of an agent only describes, through the *OPEN* parameter, the tuple of types of operands. It doesn't make any difference whether these open operands come from a target or an argument.

For example, both of the following boolean expressions

```
emplist. for_all (agent {EMPLOYEE}. is_married)
emplist. for_all (agent object.is_married (?))
```

will be valid if:

- Class *EMPLOYEE* has, as previously assumed, a feature *is_married*: *BOOLEAN*.
- *object* is of type *SOME_TYPE*, and *SOME_TYPE* has a feature *is_married* (*e*: *BOOLEAN*).

The brace convention

Two of the examples used the brace convention to keep the target open:

Applicable in any class text.

```
t:= agent {T0}.f (a1, a2, a3)
z := agent {T0}. f (?, ?, ?)
        -- Also expressible (see below) as just: agent {T0}. f
```

For the target, as noted, the question mark convention is not applicable, since the feature name does not suffice to identify the target type: many classes may have a feature called *f*.

For arguments we have no such problem since once we know *f* and its class we know the declared type of each of *f*'s formal arguments. This justifies the question mark convention for arguments.

You may, however, use the brace convention for arguments too, as in

```
x := agent a0.f (a1, {T2}, {T3} )
        -- Equivalent to what was expressed ealier as
        --      x:= agent a0.f (a1, ?, ? )
```

For such an example the question mark convention is simpler; the only reason for using the brace convention would be to emphasize the type for clarity. A more realistic case arises when you want to prescribe a specific type for an open argument, as in

```
r := agent a0.f (a1, {U2}, {U3})
```

where type *U2* must conforms to *T2* (the declared type for the second argument of *f*) and *U3* to *T3*. Where question marks would denote implicit open arguments of the exact corresponding formal argument types, *T2* and *T3* in this example, specifying a type in braces enables you to require more specific types, here *U2* and *U3*.

The resulting type in such a case is

```
r: PROCEDURE [T0, TUPLE [U2, U3]]
```

Omitting the argument list

A further simplification of the notation is available when *all* arguments are open, as in **agent** *a0*.*f* (**?**, **?**, **?**). Then you may omit the parenthesized argument list, as in

```
agent a0.f
        -- Abbreviates agent a0.f (?, ?, ?)
```

A call of the form *a0*.*f* would be invalid, since *f* always requires three actual arguments. But with an **agent** expression the convention of omitting arguments creates no ambiguity; it simply means that we consider an agent built from *f* with all arguments open.

This fully abbreviated form has the advantage of conveying the idea that the denoted agent is a true "feature object", carrying properties of the feature in its virginal state, not tainted by any particular choice of actual argument. The last two variants shown do not even name a target. This is the kind of object that we need for such *introspective* applications as writing a system that enables its users to browse through its own classes.

A summary of the possibilities

Summarizing the preceding discussion, here is a general definition of how to build a call agent:

Syntactical form of a call agent

A call agent is of the form

agent *agent_body*

where *agent_body* is a Call, qualified (as in *x*.*f* (…)) or unqualified (as in *f* (…)) with the following possible variants:

- You may replace any argument by a question mark **?**, making the argument open.
- You may replace any argument, or the target, by {*TYPE*} where *TYPE* is the name of a type, making the operand open.
- You may remove the argument list (…) altogether, making all arguments open.

25.6 USING AGENTS

Although we have studied only one of the two syntactical forms of agents, call agents (the other is inline agents), and not yet taken the trouble to look at the syntax, validity rules and precise semantics, we have enough background to explore applications of agents, starting with the examples sketched at the very beginning of this chapter, which we can now revisit and extend. We'll see how to make them work in practice: not just the client side — registering an action to be executed for a certain GUI event, integrating a function, iterating an operation — but the suppliers too: the event processing, the integrator, the iterators.

→ *The rules staart with "AGENT SYNTAX", 25.11, page 578.*

GUI programming: establishing a direct connection to the Business Model

The first example illustrated the EiffelVision style of GUI programming. We wrote

The actual EiffelVision events are select and pointer_button_press..

```
your_button.click_actions.extend (agent your_routine)
```

to specify that *your_routine* must be executed whenever the *button_press* event occurs on *your_button* during execution. Here is how things work. In your application, *your_button* denotes a graphical object, variously known as a "control" (the Windows terminology), a "widget" (the X Windows terminology) or a "context"; *click* denotes one of the events that may occur on this control. The list *your_button*.*click_actions* contains agents, representing the actions to be executed when the event occurs on the control. This is a plain list (from the EiffelBase library), to which we may, as here, apply the procedure *extend*, adding a new item at the end.

When EiffelVision detects that the event has occurred on the button, it will execute, for every element *item* of the list of agents, a call such as

The actual version needs arguments to your_routine; see next..

```
item.call ([])
```

For the list *item* that represents *your_routine*, this will produce what we wanted: a call to *your_routine* in response to the event.

This setup assumes that *your_routine* is a routine without arguments. In reality, a routine to be executed as a result of a mouse event, such as a click, may need the *x, y* mouse coordinates of the event. Let's call it *your_routine2*. What EiffelVision actually executes is

```
item.call ([mouse_horizontal, mouse_vertical])
```

using as arguments the cursor coordinates, part of the event's information recorded in the event. This assumes of course that *your_routine2* can deal with these arguments. If *your_routine2* indeed takes two real values as arguments, the previous form of registering the agent

```
your_button. click_actions.extend (agent your_routine2)
```

is still applicable; as you will remember, it is a shortcut for

```
your_button. click_actions.extend (agent your_routine(?, ?))
```

Now assume that *your_routine* is a routine from the "Business Model" part of your application, meaning the part of the software that takes care of doing the real processing, independently of any GUI. The *x* and *y* values might be only some of the arguments that *our_routine* needs. For example *your_routine* might be the procedure

```
compute_stats (country: COUNTRY; year: INTEGER; x, y: REAL)
```

which, in a cartographical application, computes statistics for a certain *year* for the city closest to positions *x* and *y* on the map for a certain *country*. When loading the map for that country you may register *compute_stats*:

```
your_button. click_actions.extend
                         (agent compute_stats (Usa, 2002, ?, ?))
```

The beauty of the notion of closed and open arguments is that you can set some values (here the country and the year) at construction time, and leave others (here the mouse coordinates) to be filled in at call time.

To the EiffelVision mechanism, there is no difference between this case using *compute_stats* — a routine with four arguments, two of which we have closed at construction time — and the previous one involving *your_routine2* and its two open arguments. The call executed by the EiffelVision side, shown above as

```
item.call ([mouse_horizontal, mouse_vertical])
```

works properly in both cases.

This scheme, relying on open and closed arguments, has crucial practical consequences for the programming of GUI applications. Following the MVC model introduced by Smalltalk, it is often stated that GUI applications should include three components:

- *Model* (the acronym's M), called the **Business Model** above: this is the part that does the actual computation, data manipulation and processing. A routine such as *compute_stats*, describing some important operation of the Business Model, belongs to this part of the system.
- *View* (the "V"): the purely graphical part of the application, taking care of presenting information visually and interacting with users. Notions such as buttons, other controls and events belong to that part.
- *Controller* (the "C"): software elements that connect the model with the view, by specifying what operations from the model must be executed in response to what user interface events.

Without agents, the Controller part, serving as glue between Model and View, can take up a significant amount of code, based for example on **command classes**. As the last example indicates, using agents can bring the need for such glue code down to a minimum, or even remove it altogether. The only Controller element that we used in this example to connect the button and event to the routine *compute_stats* from our model was the agent **agent** *compute_stats* (*Usa*, *2002*, **?**, **?**). You don't have to write any other code: no new class, not even any special instructions.

The command class technique is described in detail in the book "Object-Oriented Software Construction, 2nd edition.

This is one of the great benefits of agents for GUI programming, as used extensively in EiffelVision: **you directly connect elements from the Business Model to elements from the User Interface**, without requiring any "glue code". The notion of open and closed operands gives us remarkable flexibility: as long as a routine from the Business Model, such as *compute_stats*, takes arguments representing the coordinates, it doesn't matter what positions these arguments have in the routine, and what others it may have. Just leave the *x* and *y* arguments open when you connect the routine to the interface.

This ability to plug elements of the Business Model directly into the user interface is one of the principal attractions of the agent model.

One of the uses of command classes is to support **undoing and redoing** in an interactive system. It is easy to see how to provide this through agents too: just pass *two* agents, one representing the "do" operation and the other representing the "undo". This technique — whose details the reader is invited to spell out — is used in many of ISE's interactive products supporting undo and redo.

Integrating a function

The next set of examples was about integration. We assumed functions

```
g (x: REAL): REAL
h (x: REAL; a: T1; b: T2): REAL
```

and wanted to integrate them over a real interval such as [0, 1], that is to say, approximate the two integrals

$$\int_{x=0}^{x=1} g(x)\,dx \qquad\qquad \int_{x=0}^{x=1} h(x, u, v)\,dx$$

We declare

```
your_integrator: INTEGRATOR
```

and, with the proper definition of function *integral* in class *INTEGRATOR*, to be seen shortly, we will obtain the integrals through the expressions

```
your_integrator.integral (agent g (?), 0.0, 1.0)
your_integrator.integral (agent h (?, u, v), 0.0, 1.0)
```

The question mark indicates, in each case, the open argument: the place where *integral* will substitute various real values for *x* when evaluating *g* or *h*.

Note that if we wanted in class *D* to integrate a real-valued function from class *REAL*, such as *abs* which is declared in *REAL* as

```
abs: REAL is
            -- Absolute value
      do … end
```

we would obtain it simply through

```
your_integrator.integral (agent {REAL}.abs, 0.0, 1.0)
```

Let us now see how to write function *integral* to make all these uses possible. We use a primitive algorithm — this is not a treatise on numerical methods — but what matters is that any integration technique will have the same overall form, requiring it to evaluate *f* for various values in the given interval. Here class *INTEGRATOR* will have a real attribute *step* representing the integration step, with an invariant clause stating that *step* is positive. Then we may write *integral* as:

```
integral
        (f: FUNCTION [ANY, TUPLE [REAL], REAL];
        low, high: REAL): REAL is
                        -- Integral of f over the interval [low, high]
        require
                meaningful_interval: low <= high
        local
                x: REAL
        do
                from
                        x := low
                invariant
                        x >= low ; x <= high + step
                        -- Result approximates the integral over
                        -- the interval [low, low.max (x – step)]
                until x > high loop
                        Result := Result + step ∗ f.item ([x])
                        x := x + step
                end
        end
```

The boxed expression is where the algorithm needs to evaluate the function *f* passed to *integral*. Remember that *item*, as defined in class *FUNCTION*, calls the associated function, substituting any operands (here *x*) at the open positions, and returning the function's result.The argument of *item* is a tuple (of type *OPEN*, the second generic parameter of *FUNCTION*); this is why we need to enclose *x* in brackets, giving a one-argument tuple: [*x*].

In the first two example uses, **agent** *g* (**?**) and **agent** *h* (**?**, *u*, *v*), this argument corresponds to the question mark operands to *g* and *h*. In the last example the call expression passed to *integral* was **agent** {*REAL*}.*abs*, where the open operand is the target, represented by {*REAL*}, and successive calls to *item* in *integral* will substitute successive values of *x* as targets for evaluating *abs*.

In the case of *h*, the closed operands *u* and *v* are evaluated at the time of the evaluation of the expression **agent** *h* (**?**, *u*, *v*), and so they remain the same for every successive call to *item* within a given execution of *integral*.

Note the type *FUNCTION* [*ANY*, *TUPLE* [*REAL*], *REAL*] declared in *integral* for the argument *f*. It means that the corresponding actual must be a call expression describing a function from any class (hence the first actual generic parameter, *ANY*) that has one open operand of type *REAL* (hence *TUPLE* [*REAL*]) and returns a real result (hence *REAL*). Each of the three example functions *g*, *h* and *abs* can be made to fit this bill through a judicious choice of open operand position.

Iteration examples

The next set of initial examples covered iteration. In a class *CC* we want to manipulate both a list of integers and a list of employees

```
intlist: LINKED_LIST [INTEGER]
emplist: LINKED_LIST [EMPLOYEE]
```

and apply the same function *for_all* to both cases:

```
if intlist.for_all (agent is_positive (?)) then … end
if intlist.for_all (agent over_threshold (?)) then … end

if emplist.for_all (agent {EMPLOYEE}.is_married) then … end
```

The function *for_all* is one of the iterators defined in class *TRAVERSABLE* of EiffelBase, and available as a result in all descendant classes describing traversable structures, such as *TREE* and *LINKED_LIST*. This boolean-valued function determines whether a certain property holds for every element of a sequential structure. The property is passed as argument to *for_all* in the form of a call expression with one open argument.

Our examples use three such properties of a very different nature. The first two are functions of the client class *CC*, assessing properties of their integer argument. The result of the first depends only on that argument:

```
is_positive (i: INTEGER): BOOLEAN is
            -- Is i positive?
      do Result := (i > 0) end
```

Alternatively the property may, as in the second example, involve other aspects of *CC*, such as an integer attribute *threshold*:

```
over_threshold (i: INTEGER): BOOLEAfsN is
            -- Is i greater than threshold?
      do Result := (i > threshold) end
```

Here *over_threshold* compares the value of *i* to a field of the current object. Surprising as it may seem at first, function *for_all* will work just as well in this case; the key is that the call expression **agent** *over_threshold* (**?**), open on its argument, is closed on its target, the current object; so the agent object it produces has the information it needs to access the *threshold* field.

In the third case, the argument to *for_all* is **agent** {*EMPLOYEE*}**.***is_married*; this time we are not using a function of *CC* but a function *is_married* from another class *EMPLOYEE*, declared there as

```
is_married: BOOLEAN is do ... end
```

Unlike the previous two, this function takes no argument since it assesses a property of its target; We can still, however, pass it to *for_all*: it suffices to make the target open.

The types of the call expressions are the following:

```
PREDICATE [CC, TUPLE [INTEGER]]
        -- In first two examples (is_positive and over_threshold)

PREDICATE [EMPLOYEE, TUPLE [EMPLOYEE]]
        -- In the is_married example
```

This assumes again that CC is non-generic, so that it is both a class and a type. Remember that a PREDICATE is a FUNCTION with a BOOLEAN result type.

You may also apply *for_all* to functions with an arbitrary number of arguments, as long as you leave only one operand (target or argument) open, and it is of the appropriate type. You may for example write the expressions

```
intlist.for_all (agent some_criterion (e1, ?, e2, e3))
emplist.for_all (agent {EMPLOYEE}.some_function (e4, e5))
```

assuming in *CC* and *EMPLOYEE*, respectively, the functions

```
some_criterion (a1: T1; i: INTEGER; a2: T2; a3: T3)        -- In CC
some_function (a4: T4; a5: T5)                        -- In EMPLOYEE
```

for arbitrary types *T1*, ..., *T5*. Since operands *e1*, ..., *e5* are closed in the calls, these types do not in any way affect the types of the call expressions, which remain as above: *PREDICATE* [*CC*, *TUPLE* [*INTEGER*]] and *PREDICATE* [*EMPLOYEE*, *TUPLE* [*EMPLOYEE*]].

Let us now see how to write the iterator mechanisms themselves, such as *for_all*. They should be available in all classes representing traversable structures, so they must be introduced in a high-level class of EiffelBase, *TRAVERSABLE* [*G*]. Some of the iterators are unconditional, such as

```
do_all (action: ROUTINE [ANY, TUPLE [G]]) is
            -- Apply action to every item of the structure in turn.
    require
            … Appropriate preconditions …
    do
            from start until off loop
                    action.call ([item])
                    forth
            end
    end
```

This uses the four fundamental iteration facilities, all declared in the most general form possible as deferred features in *TRAVERSABLE*: *start* to position the iteration cursor at the beginning of the structure; *forth* to advance the cursor to the next item in the structure; *off* to tell us if we have exhausted all items (**not** *off* is a precondition of *forth*); and *item* to return the item at cursor position.

Descendants of TRAVERSABLE effect these features in various ways to provide iteration mechanisms on lists, hash tables, trees and many other structures.

The argument *action* is declared as *ROUTINE* [*ANY*, *TUPLE* [*G*]], meaning that we expect a routine with an arbitrary base type, with an open operand of type *G*, the formal generic parameter of *TRAVERSABLE*, representing the type of the elements of the traversable structure. Feature *item* indeed returns a result of type *G* (representing the element at cursor position), so that it is valid to pass as argument the one-argument tuple [*item*] in the call *action*. *call* ([*item*]) that the loop repeatedly executes.

We normally expect *action* to denote a procedure, so its type could be more accurately declared as *PROCEDURE* [*ANY*, *TUPLE* [*G*]]. Using *ROUTINE* leaves open the possibility of passing a function, even though the idea of treating a function as an action does not conform to the Command-Query Separation principle of the Eiffel method.

Where *do_all* applies *action* to all elements of a structure, other iterators provide conditional iteration, selecting applicable items through another call expression argument, *test*. Here is the “while” iterator:

```
while_do
        (action: ROUTINE [ANY, TUPLE [G]]
         test: PREDICATE [ANY, TUPLE [G]]) is
                -- Apply action to every item of structure up to,
                -- but not including, first one not satisfying test.
                -- If all satisfy test, apply to all items and move off.
        require
                … Appropriate preconditions …
        do
                from start until
                        off or else not action. test ([item])
                loop
                        action. call ([item])
                        forth
                end
        end
```

Note how the algorithm applies *call* to *action*, representing a routine (normally a procedure), and *item* to *test*, representing a boolean-valued function. In both cases the argument is the one-element tuple [*item*].

The iterators of *TRAVERSABLE* cover common control structures: *while_do*; *do_while* (same as *while_do* but with "test at the end of the loop", that is to say, apply *action* to all items up to *and including* first one satisfying *test*); *until_do*; *do_until*; *do_if*.

Yet another iterator of *TRAVERSABLE* is *for_all*, used in earlier examples. It is easy to write a *for_all* loop algorithm similar to the preceding ones. Here is another possible definition, in terms of *while_do*:

```
for_all (test: PREDICATE [G, TUPLE [G]]): BOOLEAN is
            -- Do all items satisfy test?
      require
            … Appropriate preconditions …
      do
            while_do (agent nothing (?), test)
            Result := off
      end
```

using a procedure *nothing* (*x*: *G*) which has no effect (but needs an argument *x* for typing reasons, since the first argument of *while_do* must be of type *ROUTINE* [*ANY*, *TUPLE* [*G*]]). It is trivial to define *nothing* in terms of procedure *do_nothing*, from class *ANY*. We apply *nothing* as long as *test* is true of successive items; if we find ourselves *off*, we return true; otherwise we have found an element not satisfying the *test*.

→ do_nothing is cited in 32.6, page 732.

It is possible to avoid defining a procedure nothing by using an inline agent.

Assuming a proper definition of *do_until*, the declaration of *exists*, providing the second basic quantifier of predicate calculus, is nicely symmetric with *for_all*:

```
exists (test: PREDICATE [G, TUPLE [G]]): BOOLEAN is
            -- Does at least one item satisfy test?
      require
            … Appropriate preconditions …
      do
            do_until (agent nothing (?), test)
            Result := not off
      end
```

25.7 TWO ADVANCED EXAMPLES

Before moving on to the last details of the agent mechanism, let’s gain further appreciation for its power and versatility by looking at two interesting applications, error processing and “once per object” (followed in the next section by examples of the inline form).

Error processing without the mess

The first example addresses a frequent situation in which we perform a sequence of actions, each of which might encounter an anomaly that prevents continuing as hoped. The problem here is that it’s difficult to avoid a complex, deeply nested control structure, since we may have to get out at any step. The straightforward implementation will look like this:

```
action1
if ok1 then
        action2
        if ok2 then
                action3
                ... More processing, more nesting ...
        end
end
```

For example we may want to do something with a file of name *path_name*. We first test that that *path_name* is not void. Then that the string is not empty. Then that the directory exists. Then that the file exists. Then that it is readable. Then that it contains what we need. And so on. A negative answer at any step along the way must lead to reporting an error situation and aborting the whole process.

The problem is not so much the nesting itself; after all, some algorithms are by nature complex. But often the normal processing is not complicated at all; it's the error processing that messes everything up, hiding the “useful” processing in a few islands lost in an ocean of error handling. If the error processing is different in each case (**not** *ok1*, **not** *ok2* and so on) we can't do much about it. But if it is always of the form: “Record the error source and terminate the whole thing”, then the above structure may seem too complicated. Although we may address this issue through exceptions, they are often overkill.

An agent-based technique is useful in some cases. It assumes that you write the various actions — *action1* ... *action3* above — as procedures, each with a body of the form

```
...Try to do what's needed...
controlled_check (execution_ok, "...Appropriate message...")
```

with *execution_ok* representing the condition that must be satisfied for the processing to continue. Then you can rewrite the processing above as just:

```
controlled_execute ([
        agent action1,
        agent action2 (...),
        agent action3 (...)
        ])
if controlled_glitch then
        warning (controlled_glitch_message)
                -- Procedure warning is an error reporting mechanism
end
```

This linear structure is much simpler than the original.

The features whose names start with *controlled_* come from the EiffelBase class *CONTROLLED_EXECUTION*, of which the class containing the above scheme should be a descendant. These procedures are not difficult to write; for example *controlled_check* sets *controlled_glitch* and *controlled_glitch_message*, and *controlled_execute* looks like this:

The routine as it appears in the library has a few extra instructions to record the glitch step and, on option, raise an exception.

```
controlled_execute
        (actions: ARRAY [PROCEDURE [ANY, TUPLE]]) is
                -- Execute actions, stopping if encountering a glitch.
        local
                i: INTEGER
        do
                from
                        controlled_glitch := False; i := actions.lower
                until i > actions.upper or else controlled_glitch loop
                        actions.item (i).call ([ ])
                        i := i + 1
                end
        end
```

Once per object

The second example, also supported by an EiffelBase class, provides a "once per object" mechanism.

You know, of course, Eiffel's "once routines", executed only once per system execution. They define a "once per class" mechanism: all instances of a class share the result of a once function. (All these concepts are applicable to procedures, but for this discussion we restrict ourselves to functions.) Now assume you need functions that compute a result specific to each instance of the class, and computed just once for that instance, the first time it's requested — if at all.

← For an introduction to once routines see "ROUTINE BODY", 8.6, page 148.

A typical application would be large pieces of information associated with objects of a certain type, but stored in a database; for example each instance of a class *COMPANY* may have *stock_history* information, of type *HISTORY*, which may be huge. We only want to retrieve the information on demand; given the size of the information and the number of instances of the class, it is not acceptable to load everything ahead of time. Even if an instance of *COMPANY* is in memory, we want to retrieve the associated *HISTORY* from the database only when and if we need access to the company's *stock_history*.

Agents provide us with a general solution to all problems of this kind. In class *COMPANY* you will simply declare

```
stock_history: ONCE_PER_OBJECT [HISTORY]
```

and obtain the value, when and if needed, as

```
stock_history.item (agent retrieved_history)
```

Here *retrieved_history* is the function that computes the needed result — the one that you want to call once for each object. That's all you have to do! Note that this scheme allows you to have as many "once per object" functions as you like in any given class. It relies on a general-purpose EiffelBase class *ONCE_PER_OBJECT* of the following form:

```
expanded class
    ONCE_PER_OBJECT [G]
feature -- Access
    item (f: FUNCTION [ANY, TUPLE, G]): G is
                -- Value of f, computed once for each object;
                -- subsequent calls return same value for same object.
            do
                if not computed then
                    internal_result := f.item ([ ])
                    computed := True
                end
                Result := internal_result
            end
feature {NONE} -- Implementation
    computed: BOOLEAN
            -- Has item already been requested?
    internal_result: G
            -- Result, if already computed
end -- class ONCE_PER_OBJECT
```

25.8 USING INLINE AGENTS

The agents seen so far are of the Call_agent kind, relying on class features, such as *f* and *g* (integration examples), *integer_property* and *is_married* (iterator examples), *compute_stats* (EiffelVision example) and others.

***agent** is_positive means the same as **agent** is_positive (**?**).*

Sometimes, the *only* reason for writing a certain computation is to define an agent from it. To avoid adding a feature that will make the enclosing class more complicated, you may write the algorithm within the agent. The syntactical construct for this **inline** case, previewed at the beginning of this chapter, mirrors the definition of a routine — although, like any other agent construct, it is syntactically an expression. Here are some examples of inline agents, all to be used as expressions::

```
(i: INTEGER): BOOLEAN do Result := is_positive (i) end
                    -- Equivalent to agent is_positive (?)
(e: EMPLOYEE): BOOLEAN do Result := e.is_married end
                    -- Equivalent to agent {EMPLOYEE}.is_married
(e, f: EMPLOYEE): BOOLEAN do Result := (e.salary > f.salary) end
(e, f: EMPLOYEE; p: POSITION): BOOLEAN
        do Result := (e.job = p) and (f.job = p)) end
```

As noted in the comments, the first two of these examples have Call_agent equivalents, since they directly rely on existing routines of some class. But in the last two cases, there are no such routines.

The third agent (for example) denotes an object representing a boolean-valued operation that, for two objects of type *EMPLOYEE*, returns true if and only it the query *salary* yields a higher result for the first than for the second.

It is still possible to use a Call_agent in these cases, but this requires adding features to the enclosing class:

```
higher_salary (e, f: EMPLOYEE): BOOLEAN is
        -- Does e have a higher salary than f?
    do
        Result := (e.salary > f.salary)
    end

same_job (e, f: EMPLOYEE; pos: POSITION): BOOLEAN is
        -- Do e and f both have position pos?
    do
        Result := ((e.job = pos) and (f.job = pos))
    end
```

to enable rewriting the calls as **agent** *higher_salary* (abbreviating, as usual, **agent** *higher_salary* (**?**, **?**)) and **agent** *same_job*. But if the only use of the given little algorithms is to define the corresponding agents, for example to pass them to some iterators, then you may want to avoid burdening the enclosing class with such routines, using inline agents instead.

The inline agents shown so far denote functions (*FUNCTION* or *PREDICATE*). Here is an example that passes an inline procedure agent to an iterator, to raise by 50 percent the salary of every employee called "Tina":

```
emplist.do_all
        ((e: EMPLOYEE)
            require
                employee_exists: e /= Void
            do
                if equal (e.first_name, once "Tina") then
                    e.set_salary (1.5 * e.salary)
                end
            end)
```

→ Defining the string as **once** *is not strictly necessary but improves performance by avoiding repeated evaluations; see "Once strings and the semantics of manifest strings", page 618*

The **require** … **do** … **end** part is a specimen of Routine; an inline agent indeed uses exactly the same Routine construct as the declaration of a routine in a class; so it can have all the applicable clauses, such as Precondition here, but also Local_declarations, Postcondition and Rescue.

← "ROUTINE STRUCTURE", 8.5, page 146

We can use an inline agent to simplifiy the earlier definition of *for_all* in terms of *while_do*, which required a function *nothing (x: G)* because *do_nothing* from *ANY*, with no argument, has the wrong signature. An inline agent avoids this:

← Page 569

```
for_all (test: PREDICATE [G, TUPLE [G]]): BOOLEAN is
        -- Do all items satisfy test?
    do
        while_do ((x: G) do do_nothing end, test)
        Result := off
    end
```

Inline agents do not give us anything fundamentally new, since we can always use call agents instead. They are useful if you want to avoid features such as *same_job* and *nothing* whose only purpose is to define agents.

The *methodological advice* is clear: if the computation becomes complex, it is usually better to add a feature to the class. The agent passed as argument to *do_all* in the last example is already complex enough to justify writing a separate function instead.

The inline form is particularly useful to express advanced contract specifications. Here is an example. Assume that in a class describing sequential structures (such as *LIST* [*G*] in EiffelBase) you write a procedure that appends an element. It might include this postcondition:

```
extend (x: G) is
        -- Add x at end; keep other items
    require
        …
    do
        …
    ensure
        one_more: count = old count + 1
        added_at_end: item (count) = x
        others_unchanged:
            (1 |..| old count).for_all
                ((i: INTEGER): BOOLEAN
                    do Result := equal (item (i), (old twin). item (i)) end)
    end
```

In the last postcondition clause — the one of interest for this discussion — *1* |..| **old** *count* is the interval from 1 to **old** *count*, to whose items *for_all* applies the agent property on the next line. The property expresses that the item at position *i*, for arbitrary *i*, is equal to the original item at that position (more precisely, to the item at position *i* in **old** *twin*, a copy of the list taken on entry to the procedure). This is typical of how agents enable us to express non-trivial postcondition or invariant properties, stating that a whole set of items have not changed, or have a certain association with the corresponding set of items in another structure.

We could restate the inline agent (the argument to *for_all*) in non-inline form as **agent** *equal_item* (**old** *twin*, **?**), but this assumes a function

```
equal_item (l: like Current; i: INTEGER): BOOLEAN is
            -- Is item at position i equal to corresponding one in l?
        do
            Result := (item (i) = l.item (i))
        end
```

If you want to specify your software completely — expressing not only straightforward properties such as *item* (*count*) = *x*, but also those involving entire substructures — you may end up writing many such functions. Although they add interesting information, one may also feel that, being only used for assertions, they needlessly complicate the class. They may destabilize the software since any effort at better specification may cause the addition of a whole set of new features, used only in the assertions and of no other interest to clients of the class. Inline agents solve this problem.

Here is another example application. The agents described in this chapter represent delayed *calls*; you may have wondered whether we also need an expression construct to denote delayed *object creation*, perhaps something like **agent create** {*SOME_TYPE*}.*make* (*a1*,**?**). The answer is no, since we can achieve the intended effect (assuming we need it) by using a creation expression as part of an inline agent in

```
(b1: B) do create {SOME_TYPE}.make (a1, b1) end
```

where *B* is the type of *make*'s second argument.

You may view inline agents as **anonymous routines**, similar to anonymous *classes* (tuple types) and anonymous *objects* (tuples). This is particularly clear in the Routine case (…) … **do** … **end**, which has exactly the same form as a routine declaration:

```
r (…) is … do … end
```

(with, as noted, the possibility of including all relevant clauses, such as precondition, postcondition, rescue, local entity declarations). The only difference is that the inline agent doesn't use a routine name *r* — it doesn't need one. When such a routine is used with the sole purpose of being passed as argument to a routine expecting an agent, the anonymous form avoids cluttering the class with a full-status routine.

25.9 ACCESSING FEATURE PROPERTIES

Class *ROUTINE* and its descendants provide a starting point for many of the introspection needs that Eiffel applications may need.

The first introspection mechanism is a simple way, through class *ROUTINE* and its descendants, to gain access to the precondition and postcondition of a routine:

```
precondition (args: OPEN): BOOLEAN
        -- Do args satisfy routine's precondition in present state?

postcondition (args: OPEN): BOOLEAN
        -- Does current state satisfy routine's postcondition
        -- for operands args?
```

This enables you to check the precondition before you apply an agent, as in

```
if your_agent.precondition (your_operands) then
        your_agent.call (your_operands)
end
```

where *your_agent* is an agent expression and *your_operands* is a valid tuple of operands for that agent.

There is, as will be seen next, a similar facility for class invariants.

25.10 THE BASE CLASS AND TYPE

Introspection support is also one of the concerns behind the first generic parameter of *ROUTINE*, *PROCEDURE*, *FUNCTION* and *PREDICATE*. The specification

```
ROUTINE [BASE, OPEN –> TUPLE]
```

includes, as first generic parameter, the type *BASE* representing the type (class with generic parameters) to which an agent's feature belongs. This is the type of the target expected by the feature.

→ For an inline agent, the agent's feature is its "associated feature"; see page 582.

The examples seen so far do not use *BASE* at all, because procedure *call* does not need it. If the agent is closed on its target, as in

```
y := agent a0.f (a1, ?, ?)
```

then it includes, here through *a0*, the target information that a later call to *call* may require. In the other case — open target — as in

```
t := agent {T0}.f (a1, a2, ?)
```

then the target type is specified, here *T0*, and provides the information needed to determine the right version of *f*. In this case the *BASE* generic parameter is in fact redundant, since it is identical to the first component of the tuple type corresponding to *OPEN*; the type of *t*, for example, is

```
ROUTINE [T0, TUPLE [T0, T3]]
```

where the two tuple components correspond to the two open operands: the target, and the last argument.

In both the closed target and open target cases, then, we don't need the *BASE* generic parameter if all we do with agents is execute *call* on them.

BASE is useful for other purposes. Without *BASE* a call closed on its target, as with *y* above, could not contain any information about the class (and associated type) where the call's associated feature is defined. To open the gate to full *introspection* services — enabling a system to explore its own properties — class *ROUTINE* uses a feature

```
base_type: TYPE [BASE]
```

that yields the type to which the agent's feature belongs. Class *TYPE* [*G*] from the Kernel Library provides information about a type *G* and its base class.

Class *TYPE* is, even more fundamentally than *ROUTINE* and its heirs, the starting place for introspection. Example features include:

- *name*: *STRING*, the upper name of the type's base class.

- *generics*: *ARRAY* [*TYPE* [*ANY*]], the actual generic parameters, if any, used in the type's derivation.
- *routines*: *ARRAY* [*ROUTINE* [*ANY, TUPLE*]], the routines of a class, each an instance of *PROCEDURE*, *FUNCTION* or *PREDICATE*.
- *attributes*: *ARRAY* [*FUNCTION* [*ANY*]], the attributes.
- *invariant* (*obj*: *G*): *BOOLEAN*, telling us whether an instance *obj* satisfies the invariant.

Class *ANY* has a feature

→ On ANY and universal features see chapter 32.

```
generator: TYPE [like Current]
```

which yields an object describing the type of the current object.

So within a class of which *f* is a feature, *generator* has the same value as (**agent** *f*)**.** *base_type*; if *a* is of type *T* and *f* is a feature of *T*, then *a***.***generator* has the same value as (**agent** {*T*}**.***f*)**.** *base_type*.

A more complete interface specification of *TYPE* appears in the description of the Kernel Library classes.

→ On class TYPE see A.6.31, page 838.

Thanks to the presence of *BASE* among the generic parameters of *ROUTINE* and its descendants, we can give a proper type to *base_type*, and as a result gain access to a whole library of introspection mechanisms.

25.11 AGENT SYNTAX

The rest of this chapter gives the precise syntax, validity and semantics of agent expressions. There will be no fundamentally new concept, so the hurried reader may skip to the next chapter.

The new construct is Agent, a variant of Expression:

```
      Agent ≜ Call_agent | Inline_agent
 Call_agent ≜ agent Call_agent_body
Inline_agent ≜ [Formal_arguments] [Type_mark] Routine
```

The two variants are call agents and inline agents. A Call_agent is the keyword **agent** followed by a Call_agent_body, similar to a call but with the possibility of using a question mark **?** or a type in braces {*TYPE*} in lieu of an argument. An Inline_agent is like an inline routine declaration. Let's detail both cases in turn.

Syntax of call agents

First three examples unqualified, last one qualified.

We have encountered numerous examples of Call_agent, such as

```
agent f (a1, a2, a3)
agent f (a1, ?, {U3})
agent f
agent {T0}.f (a1, ?, {U3})
```

A Call_agent starts with the keyword **agent**. The part that follows, called a Call_agent_body, closely resembles a Call; we can't just use that earlier construct, however, since we must allow for the question mark and brace conventions, which have no equivalent in normal calls:

← The syntax for Call was on page 502.

```
 Call_agent_body ≜ [Agent_target] Agent_unqualified
Agent_unqualified ≜ Feature_name [Agent_actuals]
     Agent_target ≜ Entity | Parenthesized | Type_descriptor
    Agent_actuals ≜ "(" Agent_actual_list ")"
Agent_actual_list ≜ {Agent_actual "," ...}*
     Agent_actual ≜ Actual | Type_descriptor | Placeholder
      Placeholder ≜ "?"
```

Actual was specified in the syntax of Call as

← Page 502.

```
Actual ≜ [Expression | Address
```

and Type_descriptor in the syntax of Multi_branch as

← Page 362.

```
Type_descriptor ≜ "{" Type "}"
```

The specification for Agent_target includes three possibilities: Entity, Parenthesized and Type_descriptor. The third (used in the last example) enables you to specify an open target by listing a type in braces. For an actual argument, you can use, besides an actual, a Type_descriptor or a Placeholder (question mark).

The possibility of using a Type_descriptor or Placeholder to specify open operands is the principal difference between agent calls and normal calls. There is another difference, not immediately obvious from the syntax. In a Call_agent as well as a normal Call, the argument list, Agent_actuals, is optional. But omitting it doesn't have the same effect. If *f* is declared as having one or more arguments, a call of the form *a*.*f*, or its unqualified variant *f*, are invalid since they violate the Argument rule: you must always specify actual arguments, as in *a0*. *f* (*a1*, *a2*, *a3*). For an agent call, however, corresponding forms such as

← The Argument rule was on page 538.

```
a0.f
f
{T0}.f
```

are valid; they are simply convenience abbreviations to indicate that all arguments are open, meaning respectively the same as

```
a0.f (?, ?, ?)
f (?, ?, ?)
{T0}.f (?, ?, ?)
```

You may in such a case omit the argument list, to indicate that all arguments (if any) are open. The Agent Call rule, introduced later in this chapter, explicitly allows this. It causes no ambiguity and (unless you prefer a fully explicit style) lets you avoid cluttering your class text with question marks.

→ Page 581 (see the explanation about clause 3 of the rule).

A final note on call agent syntax. You may build a Call_agent not only from identifier features as in these examples, but also from an operator feature, Infix or Prefix. Just designate the feature by its full Feature_name. The Feature Name Consistency principle allows you, if § is the operator of an infix feature, to treat **infix** "§" as a normal feature name and use it in any place where a feature identifier would be legal; same thing for **prefix** "‡" if ‡ is a prefix operator. So you can use agent expressions such as

← "Feature Name Consistency principle", page 87.

```
agent a.infix "+" (b)-- All closed
agent infix "+" (?)   -- Open on argument, closed on target
?.prefix "+"          -- All open (open on target, no argument)
```

Syntax of inline agents

We have seen that an Inline_agent is like a routine declaration, but given inline, without a name, as in

```
(e, f: EMPLOYEE): BOOLEAN
        -- Is the cumulated salary of e and f higher than threshold?
    require
        first_exists: e /= Void
        second_exists: e /= Void
    local
        salary_sum: REAL
    do
        salary_sum := e.salary + f.salary
        Result := (salary_sum > threshold)
    end
```

This is reflected by the syntax given on the previous page, which specifies:

- An optional Formal_arguments list, as (*e*, *f*: *EMPLOYEE*).
- An optional Type_mark, as in : *BOOLEAN*. If this part is present, the associated routine is a function; otherwise it is a procedure.
- A Routine, with all the possible trappings, including Precondition, Local_declarations,

As already noted, it is not recommended to have such extensive computations in inline agents: after all, an Agent is an expression, meant for example to be passed as argument to a routine. But this is just methodological advice; the whole Routine syntax is available if you wish to use it, including the optional Precondition, Local_declarations, Postcondition and Rescue clauses; even Header_comment and Obsolete. The only restriction (stated in the validity constraint given next) is that the routine must not be deferred.

25.12 AGENT VALIDITY

We may now add the validity rules. It is convenient to deal separately with Call_agent and Inline_agent cases.

Like the previous one, this section is not essential on first reading.

Validity of call agents

For call agents, it is useful first to define the notion of target type:

Target type of an agent call

The target type of a Call_agent is:

1 • If there is no Agent_target, the current type.

2 • If there is a Agent_target and it is an Entity or Parenthesized, its type.

3 • If there is a Agent_target and it is a Type_descriptor, the type that it lists (in braces).

← The "current type" is the enclosing class, with generic parameters added if necessary to make up a type. See "CURRENT TYPE, FEATURES OF A TYPE", 12.8, page 266.

The validity rule follows:

Call Agent rule *CPCA*

A Call_agent involving a Feature_name *f*, appearing in a class *C*, with target type *T0*, is valid if and only if it satisfies the following six conditions:

1 • *f* is the name of a feature of *T0*.

2 • If there is an Agent_target, *f* is export-valid for *T0* in *C*.

3 • If the Agent_actuals part is present, the number of elements in its Agent_actual_list is equal to the number of formals of *f*.

4 • Any Agent_actual of the Actual kind is of a type conforming to the type of the corresponding formal in *f*.

5 • Any Agent_actual that is a Type_descriptor lists, between the braces, a type conforming to the type of the corresponding formal in *f*.

6 • If *T0* is separate, any non-expanded formal of *f* is separate.

The rule's phrasing makes certain forms of the construct automatically valid:

- If any Agent_actual is of the Placeholder kind, represented simply by a question mark, neither clause 4 nor clause 5 applies, so the argument raises no type validity problem. This is as expected, since such an argument is left open for future filling-in.

- If there is no Agent_actuals part, clauses 3 to 5 do not apply. If *f* has no formals, we are calling an argumentless feature with no actuals, as we should. If *f* has one or more formal arguments, we view the absence of explicit actuals of an abbreviation for actuals that are all of the Placeholder kind (question marks): assuming *f* takes three arguments, **agent** *a0*.*f* is simply an abbreviation for **agent** *a0*.*f* (**?**, **?**, **?**). In this case the implicit arguments are all open, and hence automatically valid.

Clause 3 differs from its counterpart for normal calls, which *required* actual argument list to match the formal list if any. Instead we explicitly allow omitting actuals altogether, to signify that all arguments are open.

← *“Argument rule”, page 538*.

Clause 6 is a consistency condition for concurrent computation, and parallels a similar clause discussed in the chapter on normal calls.

Validity of inline agents

To define the validity of inline agents (also their semantics), it is convenient to consider this case as equivalent to the previous one, Call_agent, by treating any inline agent as equivalent to **agent** *f* (...) where *f* is a fictitious routine added to the class. Here is the definition of this equivalence:

Associated feature of an inline agent

Every inline agent *ia* of a class *C* has an **associated feature**, defined as a fictitious routine of *C*, such that:

1 • The name of *f* is chosen not to conflict with any other feature name in *C* and its descendants.

2 • The formal arguments of *f* are those of *ia*, if any, and the formal arguments and local entities of the enclosing routine, if any, and of any enclosing agent.

3 • *f* is secret (available for call to no class).

4 • The Routine of *f* is defined by the Routine part of *i*.

5 • *f* is a function if *ia* has a Type_mark (its return type being given by the Type in that Type_mark), a procedure otherwise.

← *“Exported, selectively available, secret”, page 134*.

Clause 2 lists, as arguments to *f*, not only the arguments to the inline agent but also the local entities of the enclosing routine. The local entities will indeed serve as *closed* arguments; this will be specified in the semantics given in the next section.

The validity rule follows:

Inline Agent rule *CPIA*

An Inline_agent *a* of associated feature *f*, is valid in the text of a class *C* if and only if it satisfies the following three conditions:

1 • No formal argument or local entity of *a* has the same name as a formal argument or local entity of an enclosing routine or agent.

2 • *f*, if added to *C*, would be valid.

3 • *f* is not deferred.

There is no other condition, since in particular The Routine part must be valid on its own; in particular, the Entity rule states that any entity appearing in the Agent_body must be a formal argument of the inline agent itself, such as *other* and *i* in

← *"Entity rule", page 407*.

```
(other: like Current; i: INTEGER)
        do Result := (item (i) = other.item (i)) end
```

or a local entity of an enclosing agent or routine, or a feature of the enclosing class.

Here are some properties following from the Inline Agent rule, stated as another validity rule permitting compilers to issue more understandable error messages. It is not in the usual "if and only if" form (this is the business of the preceding rule, which is the official language rule), but the requirements given cover the most obvious possible errors:

Inline Agent Requirements *CPIR*

An Inline_agent *a* must satisfy the following conditions:

1 • No formal argument or local entity of *a* has the same name as a formal argument or local entity of an enclosing routine or agent, or as a feature of the enclosing class.

2 • Every entity appearing in the Routine part of *a* is the name of one of: a formal argument or local entity of *a*; a formal argument or local entity of an enclosing routine or agent; a feature of the enclosing class.

3 • The Routine_body of *a*'s Routine is not of the Deferred form.

25.13 AGENT SEMANTICS

(Like the previous two, this section may be skipped on first reading.) The final part of the specification addresses the semantics of agents. It is organized in three parts:

• Call-agent equivalent of an inline agent (enabling the next two parts to restrict themselves to the Call_agent part).

- Open and closed operands.
- Type and value of an agent.

Call-agent equivalent of an inline agent

To define the validity of an inline agent *a*, it was convenient to define its associated feature. Then *a* itself can be viewed as if it were a Call_agent:

Call-agent equivalent of an inline agent

An inline agent *ia* with *n* formal arguments ($n \geq 0$) has a **call-agent equivalent** defined as the Call_agent

agent *f* (**?**, **?**, …, **?**, $a1, a2, \ldots, a_m$)

using *n* question marks, where $a1, a2, \ldots, a_m$ ($m \geq 0$) are the formal arguments and local entities of the enclosing routine (if any) and any enclosing agents, and *f* is the associated feature of *ia*. (If both *n* and *m* are 0, the Call_agent is just **agent** *f*.)

The semantics of *ia* is the semantics of its call-agent equivalent.

Thanks to this rule, we can focus on call agents when defining the type and execution effect of agents.

Note how the formal arguments and local entities of the enclosing routine if any, and of any enclosing agents, serve as closed arguments to the agent. In reading earlier discussions of inline agents, you may have pondered two as yet unanswered questions:

- Is it permitted for an inline agent to refer to a local entity of the enclosing routine, and, if so, what does that mean?
- Call agents may have both closed and open operands. We have seen how to give an inline agent open operands: just specify them as arguments to the agent. But is there a way to give it closed operands too?

The rule just given answers both questions at once by giving a status to local entities of the enclosing routine: treat them as closed operands.

So a routine of the form

```
r is
        local
                n: INTEGER
        do
                n := 1
                your_list.do_all ((i: INTEGER) do print (i + n) end)
        end
```

will print the successive values in *your_list* (assumed to be of type *LIST [INTEGER]*) all incremented by 1, the value of the local entity *n* at construction time. As specified by the last rule, this is the same effect as if the call were

```
do_all (agent print_incremented_value (?, n))
```

where *print_incremented_value* is the "fictitious routine" introduced by the definition of "associated feature" of an inline agent:

```
print_incremented_value (i: INTEGER; n: INTEGER) is
        do
                print (i + n)
        end
```

In examining the above definition of call-agent equivalent, note that the validity rule on inline agents guarantees that there can be no name clash between the formal arguments and local entities of any enclosing agents and of the enclosing routine if any. (Nesting inline agents doesn't seem a desirable use of the mechanism, but no rule disallows it.)

← *"Inline Agent rule", page 583*.

The semantics of inline agents also requires a specific rule on the meaning of *Result*. An inline agent may be embedded in a function of the class, or even in another function agent, causing a potential ambiguity. We decide that *Result* always refers to the result of the innermost agent:

Use of *Result* in an inline function agent

In an agent of the Inline_routine form denoting a function, the local entity *Result* denotes the result of the agent itself.

← *"Open operand position" was defined on page 586*.

This is a rather specific case and another approach would be to disallow function agents within functions or other function agents, or to use a special notation to remove the ambiguity. The rule as given seems preferable. If you need to refer to an outer *Result*, you may assign its value to a local entity and use that local entity in the innermost agent scope. This causes a little extra work, but only in a rare and special case.

Open and closed operands

It is useful to define precisely what "open" and "closed" mean for the operands of an agent expression:

From the definition of call-agent equivalent form we deduce that for an inline agent:

- The open operands are the agent's formal arguments, if any.
- The closed operands are the local entities and formal arguments of the enclosing routine and any enclosing agents.

Open and closed operands

The **open operands** of a Call_agent include:

1 • Any Agent_actual that is a Type_descriptor or a Placeholder.

2 • The Agent_target if it is present and is a Type_descriptor.

The **closed operands** include all non-open operands.

← The operands of a call were defined on page 551 as including its target, and its arguments if any.

An earlier definition also introduced the notion of *operand position*, which we can now extend to a definition of open and closed positions:

← "Operand position" was defined on page 551: the target position is 0, and the argument positions start at 1.

Open and closed operand positions

The **open operand positions** of a Feature_agent are the operand positions of its open operands, and the **closed operand positions** those of its closed operands.

Type and value of an agent expression

The preceding definitions enable us to specify the semantics of an agent expression. It suffices to give it for a Call_agent:

Type and value of an agent expression

Consider a Call_agent a, whose associated feature f has a generating type $T0$. Let $i1$, …, im ($m \geq 0$) be its open operand positions, if any, and let T_{i1}, .., T_{im} be the types of f's formals at positions $i1$, …, im (taking T_{i1} to be $T0$ if $i1 = 0$).

The type of d is:

- *PROCEDURE* [*T0*, *TUPLE* [T_{i1}, .., T_{im}]] if f is a procedure;
- *FUNCTION* [*T0*, *TUPLE* [T_{i1}, .., T_{im}], *R*] if f is a function of result type *R* other than *BOOLEAN*.
- *PREDICATE* [*T0*, *TUPLE* [T_{i1}, .., T_{im}]] if f is a function of result type *BOOLEAN*.

Evaluating d at a certain *construction time* yields a reference to an instance D0 of the type of d, containing information identifying:

- f.
- The open operand positions.
- The values of the closed operands at the time of evaluation of d.

Although this will be an implicit consequence of the last rule, it doesn't hurt to state explicitly what some of the information in D0 is good for: enabling calls on agent objects.

Effect of executing *call* on an agent

Let D0 be an agent object with associated feature *f* and open positions *i1*, …, *im* ($m \geq 0$). The information in D0 enables a call to procedure *call*, executed at any **call time** posterior to D0’s construction time, with target D0 and (if required) actual arguments a_{i1}, .., a_{im}, to perform the following:

- Produce the same effect as a call to *f*, using the closed operands at the closed positions and a_{i1}, .., a_{im}, evaluated at call time, at the open positions.
- In addition, if *f* is a function, setting the value of the query *last_result* for D0 to the result returned by such a call.

← *last_result from class FUNCTION, giving the result of the last evaluation, was introduced on page 555.*