CHAPTER 6
SYSTEM DESIGN NOTATION

6.1. INTRODUCTION

The emphasis of this work up to now has been on the representation of small programming problems. This chapter looks at problems related to system design.

The system notation used in this chapter is Buhr's design notation. His original notation, referred to as Buhr diagrams (1984), is well-understood and accepted in the system design community. His later notation, MachineCharts, (1990), is less well-known. MachineCharts are designed to address time-based issues of complex system design, and for that reason contain many interesting visual conventions for representing sequences and interactions. Buhr's work is most closely linked with the programming language Ada, but contains many constructs that don't map to Ada 83. Ada 9X contains structures anticipated by MachineCharts, but also contains concepts that are difficult to express in Buhr notation.

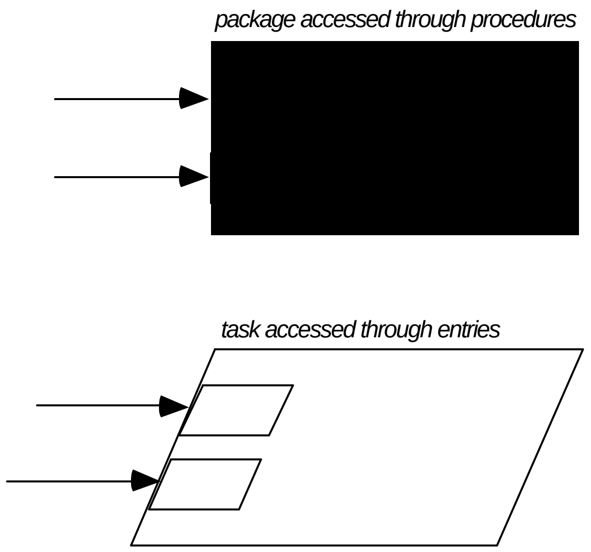
As a way of understanding the power of visual techniques in system design, we look at Buhr notation as it exists, and attempt to apply it to Ada 9X constructs. In some cases we propose extensions or changes to the MachineChart notation.

6.2. Buhr's Original Notation

Buhr (1984) created a notation for Ada programming that allows for the internal and external structure of packages and tasks to be represented in graphs. He writes:

> Our pictorial notation provides a hardware-like metaphor for systems as collections of black boxes connected together by plugs and sockets.

Throughout his work there is an emphasis on mechanical or electrical analogs for computer programs. He differentiates the black boxes into the Ada language constructs of tasks and packages:


package accessed through procedures
task accessed through entries
Figure 6.1. Buhr package and task notation.

The notation emphasizes the interface points, the sockets through which data and control flow:

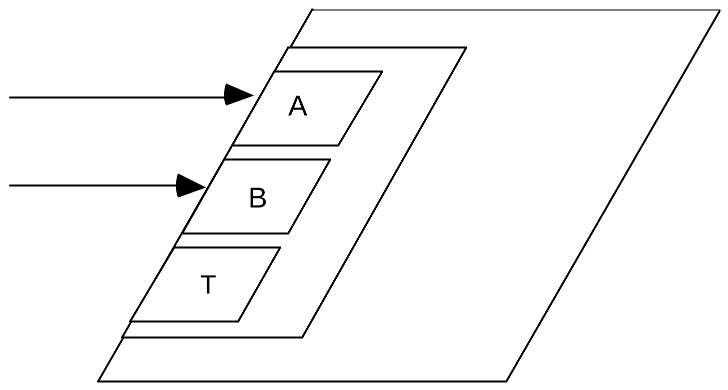


Figure 6.2. Sockets in a task.

In the above diagram, nested boxes are used to show the alternate selections possible by the server task in response to requests from clients.

The text equivalent of figure 6.2 is:

```
select
     accept A do ... end
     -- other processing
or
     accept B do .. end
     -- other processing
or
     delay T;
     -- DELAY PROCESSING
end select;
```

6.3. BUHR'S MACHINECHARTS: ROBOTS AND REACTORS

In MachineCharts Buhr (1990) changes his terminology. Black boxes are differentiated into boxes and robots, instead of packages and tasks.

Buhr makes a distinction between an active robots, called actors, and passive robots, called reactors. Reactors model objects that provide mutual exclusion. Reactors can serve as glue between actors to allow for asynchronous communication. And reactors may be implemented without the overhead of mechanisms such as rendezvous.

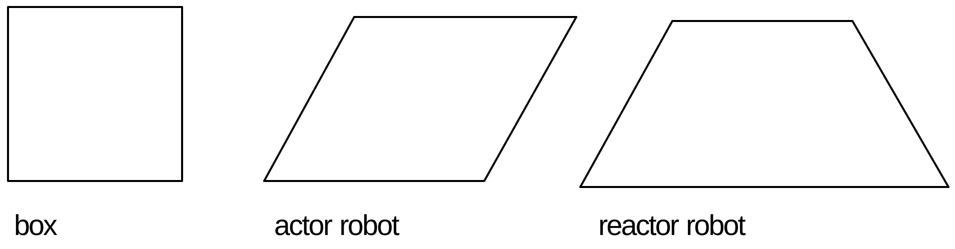


Figure 6.3. MachineChart distinctions.

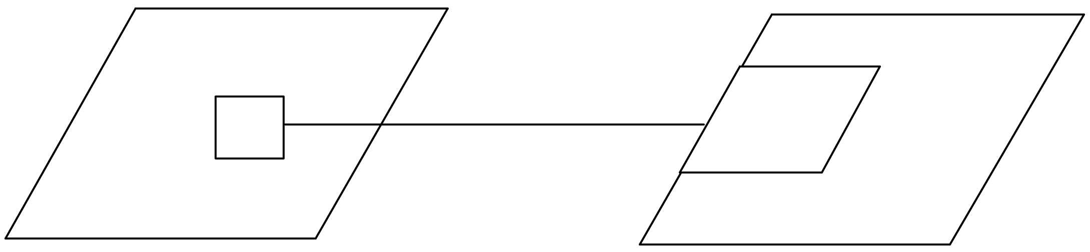


Figure 6.4. A visit from an engine in an actor robot to the button of an actor robot.

Visits take place through buttons on black boxes. Procedure calls, RPC calls, and Ada rendezvous can all be considered visits; Buhr is generalizing his notation so that it can be applied to any time-based problems implemented in any language.

6.3.1. Buhr's reactor

The following is an example from Buhr of how reactors can be used:

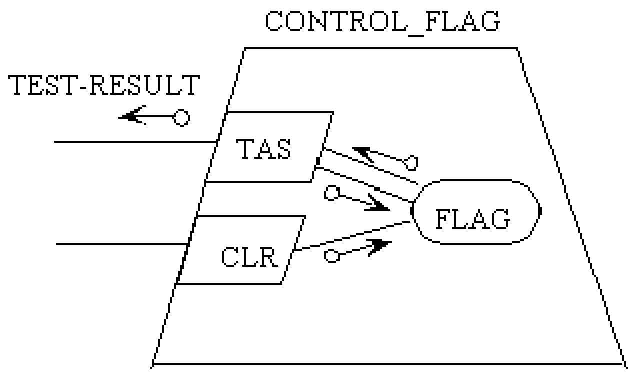


Figure 6.5. A control flag as a reactor.

Essentially, the trapezoid-shaped box signifies that mutual exclusion is assured. The corresponding Ada code for this is:

```
type FLAGTYPE is range 0..1;
task CONTROL_FLAG is
        entry TAS (TEST_RESULT: out FLAGTYPE);
        entry CLR;
end CONTROL_FLAG;

task body CONTROL_FLAG is
        FLAG:FLAGTYPE;
        begin
                loop
                        select
                                accept TAS(TEST_RESULT: out FLAGTYPE)
                                        do TEST_RESULT := FLAG;
                                        FLAG := 1; end;
                        or
                                accept CLR
                                        do FLAG := 0; end;
                        end select
                end loop
        end CONTROL_FLAG
```

6.3.2. Buhr's time extensions

Buhr has added timing diagrams to his notation system to help visually present the behavior of software machines. The following presents an expected visit scenario for the test and set example above:

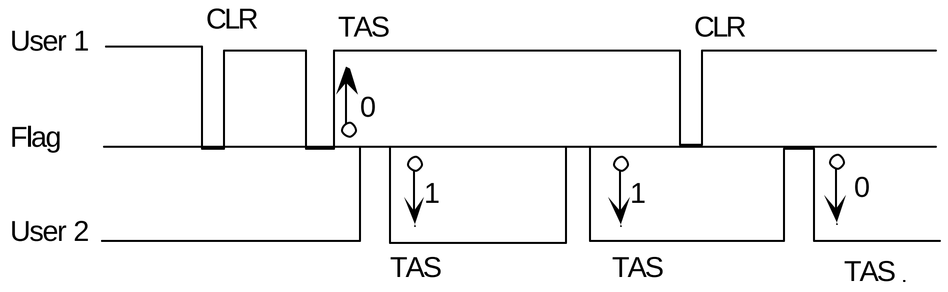


Figure 6.6. Expected visit timing diagram for test and set.

Timing diagrams are normal in engineering, but are uncommon in software design. Yet the diagram presents a scenario that is difficult to express textually. The best textual representation is a table as follows; note that such a representation makes it very difficult to get a sense of user overlap:

Scenario	*Intended Result*
User 1 CLR	
User 1 TAS	Flag = 0
User 2 TAS	Flag = 1
User 2 TAS	Flag = 1
User 1 CLR	
User 2 TAS	Flag = 0

Buhr suggests that a tool could be developed that could generate expected visit timing diagrams as output from interacting with a structure chart.

6.4. MAPPING TO ADA: TASKS AND PROTECTED RECORDS

Buhr's MachineCharts conventions were created prior to the Ada 9X mapping specification. Nevertheless, the visual conventions surrounding reactors map easily onto the proposal in Ada

9X for Protected Records. In Ada 83, the only way to achieve synchronization is through the overhead of a rendezvous. In order to reduce the overhead for real-time programming, Protected Records are defined so they can be implemented as efficient conditional critical regions. The specification of the record distinguishes between functions, procedures, and entries that may block. Intermetrics points out that these distinctions are essential for design and analysis.

Here is an example of a textual protected record from the Ada 9X Mapping Specification, followed by a visual representation using Buhr's MachineCharts.

```
protected type
COUNTING_SEMAPHORE(INITIAL_COUNT : INTEGER := 1) is
function COUNT return INTEGER;
procedure RELEASE;
entry ACQUIRE;
  private record
     CURRENT_COUNT : INTEGER := INITIAL_COUNT;
end COUNTING_SEMAPHORE;

protected body COUNTING SEMAPHORE is
function COUNT return INTEGER is
begin
     return CURRENT_COUNT;
end COUNT;

procedure RELEASE is
begin
     CURRENT_COUNT := CURRENT_COUNT + 1;
end RELEASE;

entry ACQUIRE when CURRENT_COUNT > 0 is
begin
     CURRENT_COUNT := CURRENT_COUNT - 1;
end ACQUIRE;
end COUNTING_SEMAPHORE;
```

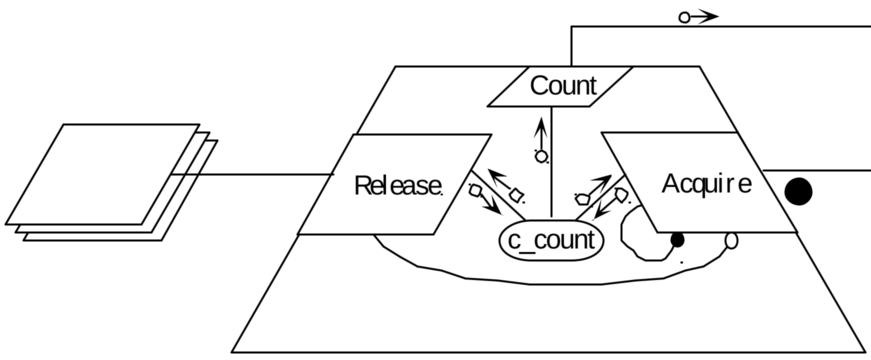


Figure 6.7. A counting semaphor.

The Protected Record is represented as a trapezoid, a reactor. Current_count, labeled as c_count, is shown as a variable that is updated by Release and Acquire. The function Count returns this number on a query.

The visual representation makes it easy to differentiate between entries, functions, and procedures. The large dot outside the Acquire button indicates a waiting position in the design; it is possible requests are queued waiting for the semaphore. In the case of Ada, this indicates that Acquire is an entry. Data flows are indicated by small arrows with a circle at the tail. It is easy to determine from these arrows that Count is a function and Release is a procedure.

The curved lines on the inside of the diagram indicate synchronization. The open circle line from Release to Acquire indicates that the action of Release can release Acquire from a waiting condition. Buhr calls this event *opening*. The closed circle line from Acquire to itself indicates that Acquire's actions may impose a waiting condition; this is referred to as *closing*. Buhr points out that Ada performs opening and closing only through variable changes on guard expressions. He observes that in the design phase it is cleaner to explicitly draw the open and close operations.

Ada 9X specifies that when a function such as Release performs its actions, before it releases its lock it must re-evaluate the entry. This re-evaluation may cause the entry to execute. The convention of the open circle from Release to Acquire is a fitting representation for such a mechanism, as it suggests a more direct action than the changing of the current_count variable.

6.5. ASYNCHRONOUS TRANSFER OF CONTROL

This section proposes extensions to Buhr's notation to allow for the representation of asynchronous transfer of control.

6.5.1. Definition

Asynchronous transfer of control is defined in the Annotated Ada 9X Reference Manual (1993) in the following way (AARM 9.7.4.2;2.0):

```
ASYNCHRONOUS_SELECT ::=
                              select
                                   TRIGGERING ALTERNATIVE
                              then abort
                                   ABORTABLE PART
                              end select;

TRIGGERING_ALTERNATIVE ::=    TRIGGERING_STATEMENT
[SEQUENCE_OF_STATEMENTS]

TRIGGERING_STATEMENT ::=      ENTRY_CALL_STATEMENT | DELAY STATEMENT

ABORTABLE_PART ::=            SEQUENCE OF STATEMENTS
```

The transfer of control is accomplished through the use of an *abortable part* . If an entry call is completed while abortable part processing is taking place, the abortable part processing is aborted and control goes to the triggering alternative.

6.5.2. A Textual Example

A user command interpreter can be represented as a loop, in which commands are retrieved from a user's input on a terminal, and then invoked. At any point the user may wish to abort the program by pressing *escape, Control-C*, or some other special key combination. This can be written in the following manner (AARM 9.7.4.9;2.0):

```
loop
        select
                TERMINAL.WAIT_FOR_INTERRUPT;
                PUT_LINE("Interrupted");
        then abort
                PUT_LINE("-> ");
                GET_LINE(COMMAND, LAST);
                PROCESS_COMMAND(COMMAND(1..LAST));
        end select;
end loop;
```

Note that TERMINAL.WAIT_FOR_INTERRUPT is an entry call meaning that the triggering statement will wait until some event happens on the terminal that allows the accept statement on the terminal to complete.

6.5.3. Creating the Visual Convention

Early discussion of asynchronous transfer of control described it as being similar to an operating systems fork. More recent discussions have speculated on using a two-thread model to implement the feature. Therefore we first consider using Buhr notation features that deal with the creation and destruction of tasks.

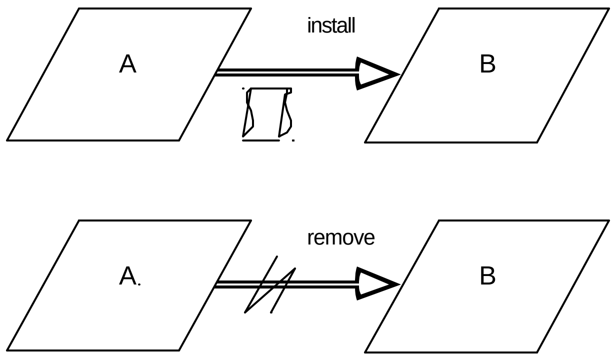


Figure 6.8. Installing and removing a robot.

Buhr(1984) contained the concept of abort - Buhr(1990) supersedes this with the paired concepts of installation and removal. The convention in the figure above shows a machine being installed based on a blueprint, represented as a scroll (we omit this scrolled icon from now on). The second part of the figure shows a machine being removed, which is equivalent conceptually to aborting a task.

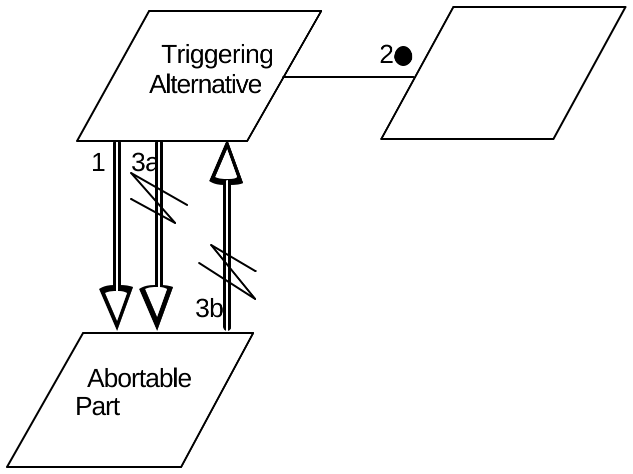


Figure 6.9. Using abort.

Above, the triggering alternative installs the abortable part, then makes an entry call (2) and blocks. (The dot at 2 is a Buhr convention indicating a potential waiting.) If the entry call completes, the triggering alternative removes the abortable part (3a). If the abortable part completes first, the abortable part aborts the triggering alternative (Ada 9X calls for the triggering statement to be aborted, and the sequence of statements of the triggering alternative not be executed) (3b).

This diagram makes explicit the two-sided nature of the asynchronous transfer of control - depending on whether the abortable part or the triggering statement complete first, either may end up aborting the sequence of statements or the triggering statement of the other.

However, the diagram implies concepts that do not exist in the language construct. In Ada 9X, there is no sense in which the triggering alternative creates the abortable part. In a more general sense, the triggering alternative is not intended to be an independent task. Also, the abortable part can only abort the triggering statement when the abortable part completes - the diagram implies more symmetry than exists in the language construct.

As an alternate way to model asynchronous transfer of control, Buhr's conventions for exception-handling can be used.

Buhr (1990) calls for a hooked line to be used to indicate propagation of exceptions and alarms. An alarm handler is represented as a rectangle:

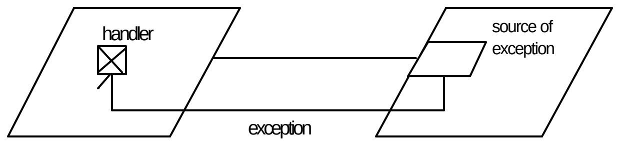


Figure 6.10. Using exceptions.

Using this convention, an asynchronous transfer of control can be shown:

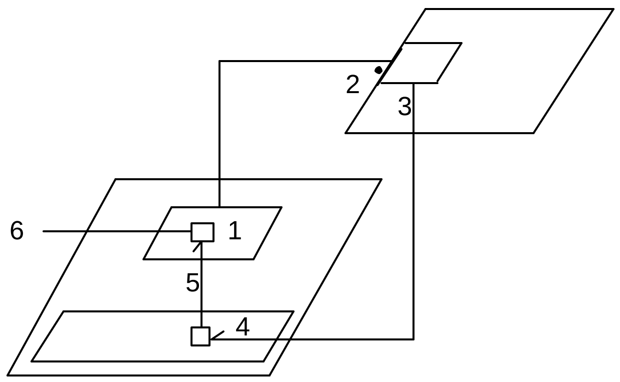


Figure 6.11. Asynchronous transfer using exceptions.

In the figure above, both the triggering alternative (1) and the abortable part (4) are shown as parallelograms inside a task. First, the triggering statement of the triggering alternative is made. In this case, an entry call is placed to another task (2). While the triggering statement waits, the abortable part is running. So when the accept statement completes, a signal is generated (3) that interrupts the abortable part (4). The abortable part immediately transfers control to the statements following the triggering statement in the triggering alternative (5). This is where the handling really takes place - the triggering alternative may make more calls outside the task (6).

This representation is a fairly complex and not very accurate portrayal of what is happening. A normal occurrence, the completion of an accept statement, is represented here as an exception, as it is necessary to suggest the interruption in the control of the abortable part. Yet this is deceptive, as the programmer cannot write a handler for an interrupt in the abortable part.

There is another issue with the above representation. The relation between the final part and the triggering alternatives is not made clear. There is no way to gather from the diagram that the two inner parallelograms are part of a single select statement. Nor is there a way to recognize the construction as being an asynchronous transfer of control as opposed to a normal exception propagation.

We propose the following convention:

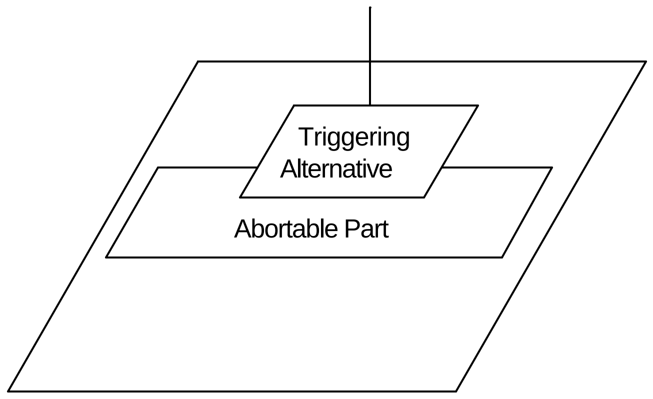


Figure 6.12 Proposed convention.

Note that overlap is used to indicate a form of precedence. The triggering alternative can interrupt and abort the abortable part. Overlap was chosen as it:

- suggests the triggering alternative as interrupting the abortable part
- establishes an association between the triggering alternative and the abortable part of the select statement.
- can be drawn easily.
- does not conflict with other Buhr conventions

The non-terminated vertical line is assumed to connect up to an entry call. In figure 6.13, the different stages of a task using an abortable part are shown.

In a), the triggering alternative places an entry call. In Figure b), the entry call has not returned, so the abortable part begins running. In c), the entry call has returned, and the abortable part is aborted. Control has gone to the triggering alternative.

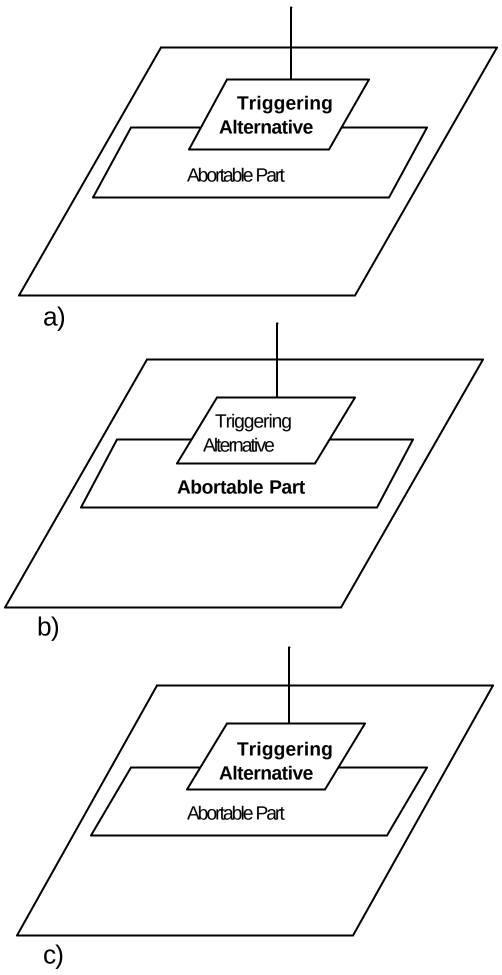


Figure 6.13. The sequence.

6.5.4. A Visual Example

Below, a textual and a graphic representation are compared:

```
loop
    select
        TERMINAL.WAIT_FOR_INTERRUPT;
        PUT_LINE("Interrupted");
    in
        PUT_LINE("-> ");
        GET_LINE(COMMAND, LAST);
        PROCESS_COMMAND(COMMAND(1..LAST));
    end select;
end loop;
```

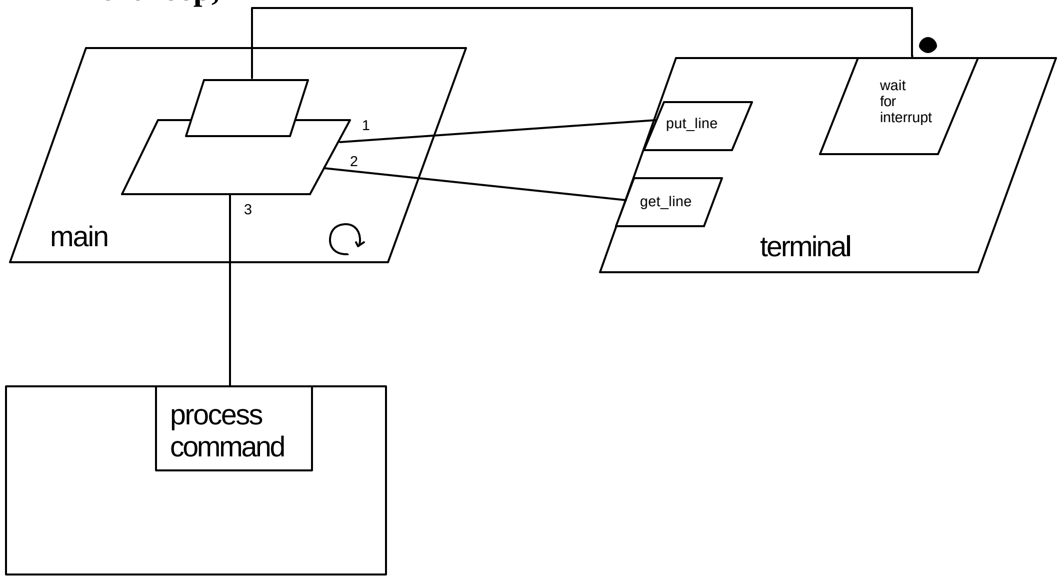


Figure 6.14. Shell example.

The triggering alternative waits for an interrupt from the terminal. At the same time, the abortable part puts and gets the command line to and from the terminal, and processes the command received. The circular arrow indicates that the main task is persistent and will continue to loop.

The example given in the AARM treats command processing as a procedure. In many multi-tasking systems, shells spawn tasks or processes to perform the work of the command. In Ada 9X, the textual code and its visual representation might be:

```
loop
```

```
        select
                TERMINAL.WAIT_FOR_INTERRUPT;
                PUT_LINE("Interrupted");
        in
                declare
                        SHELL: COMMAND_INTERPRETER;
                begin
                        PUT_LINE("-> ");
                        GET_LINE(COMMAND);
                        SHELL.EXEC(COMMAND);
                end
        end select
end loop
```

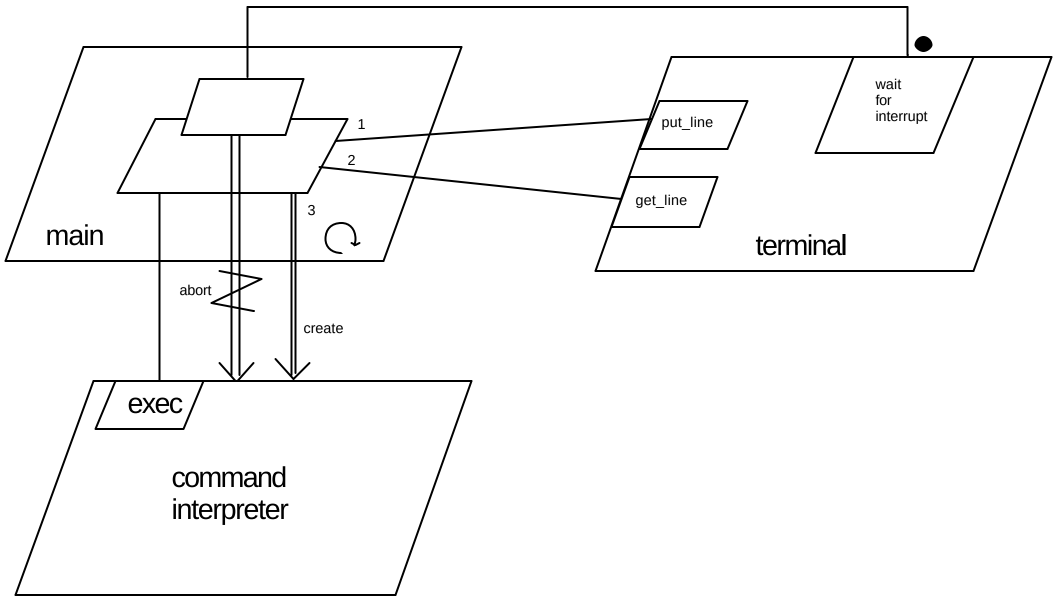


Figure 6.15. Shell using robots.

Above, note that a command task is created on every loop through the shell. In the event that the abortable part is interrupted, the command task will be aborted. This happens automatically as a result of the abort of the sequence of statements in the abortable part. We explicitly represent this as a removal arrow originating from the triggering alternative.

6.5.5. Delays

An abortable part can also be interrupted by a delay statement. This allows for code to be written that will be interrupted if it exceeds some time boundary, as in the example shown below (AARM 9.7.4.11;2.0) :

```
select
        delay 5.0
                PUT_LINE("Calculation doesn't converge");
        then abort
                HORRIBLY_COMPLICATED_RECURSIVE_FUNC(X,Y);
end select;
```

The visualization of this is analogous to the visualization shown before of an entry call statement. Instead of waiting for an accept statement to complete, the triggering statement is waiting for a timer to expire.

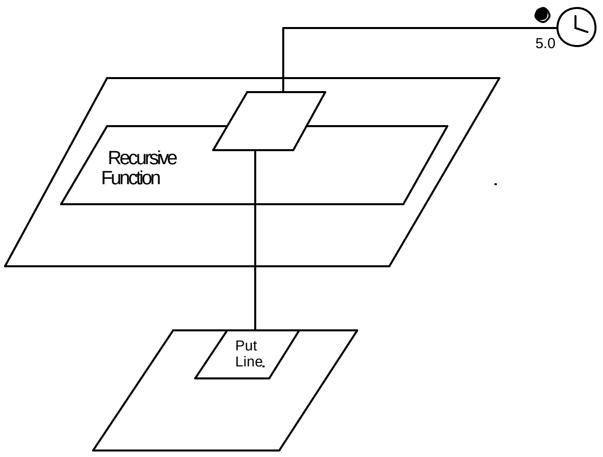


Figure 6.16. Delay visualization.

The clock symbol used here is consistent with Buhr (1990) notation. When the timer expires, control will transfer to the triggering statement, which in this case will put a message out to the terminal.

In systems with many time-outs, it is easy to imagine a short-hand emerging, in which the triggering statement itself contains the clock symbol:

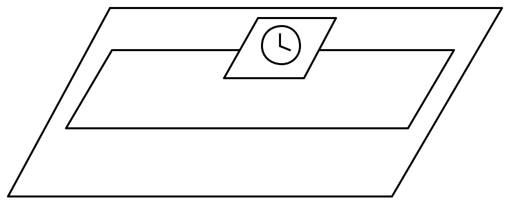


Figure 6.17. Delay shorthand.

The intended meaning is that of figure 6.16: when the timer runs out, if the abortable part is still running, abort the sequence of statements in the abortable part and transfer control to the triggering alternative.

6.5.6. Cascading Transfers

Given this new convention, it is worth considering how the visual representation of asynchronous transfer of control can contribute to the system design process. As Buhr (1990) points out, the visual can sometimes aid in capturing the essence of a problem that may be otherwise be represented as many lines of disparate code. One point of visual representation is to allow a concept to be represented in such a way that it can be taken in instantly. Another point specific to system design is to allow the multiple potential sequences of interaction to be walked through and discussed. Much of the utility of system design notations come from the work that a team can do with a shared convention and an interactive visual medium such as a whiteboard. This kind of conversation often involves using the diagram as a map, and sequentially stepping through an event and its implications on the process it directly touches, along with the ripple effect on other dependent or synchronized tasks. In a sense, in early design stages, the diagrams are used as the basis for informal simulations of the working system. Buhr proposes the use of graphic user interfaces as an alternate way of doing these simulations. With the proper design tools, and with the design diagrams linked with underlying code, the hope is that time-based systems design can benefit in the same way as other design fields have benefited from CAD tools.

With this in mind, we consider a more complicated instance of asynchronous transfer of control. In the example of figure 6.15, a new task is created by an abortable part. It is certainly possible that a task that is created may itself include an asynchronous transfer of control. It may not be immediately obvious in a system with many lines of code how deep this cascading of asynchronous transfers of control goes. Yet the end effect is a set of tasks that are closely linked together - the completion of an accept statement on any of the blocked entry calls will affect all the tasks at a deeper level of the cascade.

This sort of cascade can be represented in the following way:

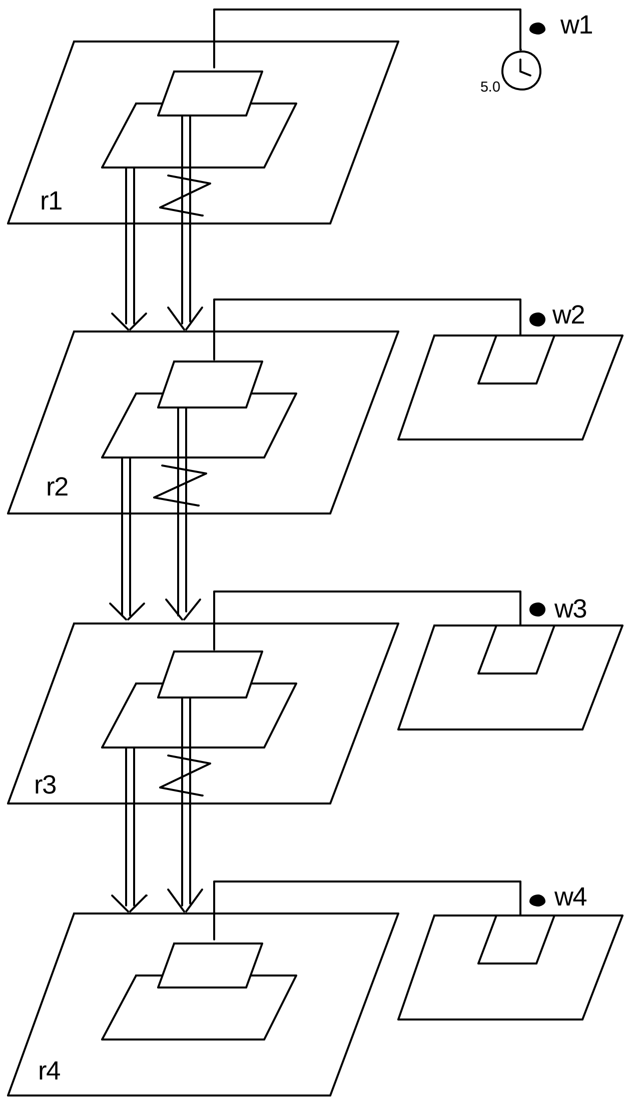


Figure 6.18. Cascading transfer of control.

The first robot (r1) creates r2, which in turn creates r3, which in turn creates r4. Each robot contains an asynchronous transfer of control with a corresponding waiting place (w1, w2, w3, w4). In the event that any triggering statement completes, the task dependent on the abortable part will be aborted. This is shown through a set of abort arrows from the triggering alternative to the created tasks.

In the event that a task is aborted, all tasks dependent on it are also aborted. If, say, the accept completes at w2, then not only will the abortable part of r2 be aborted, but r3 will also be aborted. The abort of r3 will in turn cause the abort of r4.

So, from this diagram it becomes clear that, depending on which triggering statement completes first, a chain reaction of aborts is possible. It is also clear, that no matter what else happens, r2, r3, and r4 will be aborted when the timer at w1 expires after 5 seconds.

For the system designer, the extension to MachineChart notation shown here makes it possible to visually trace the ramifications of a design that uses asynchronous transfer of control.

6.6. REQUEUE

While a protected record is a well-understood concept in operating system design, the requeue of Ada 9X is not so universal.

The requeue is allowed only in an entry body or an accept statement. It can be used to complete the execution of the entry or accept statement, by redirecting the original entry call to a new entry.

This is very different from calling another entry from within the body of an entry. Buhr notation allows for a button, the equivalent of an entry, to fire off another externally visible button. The diagram must show the line coming out of the interior of the task and invoking the entry from the outside, as in the following diagram:

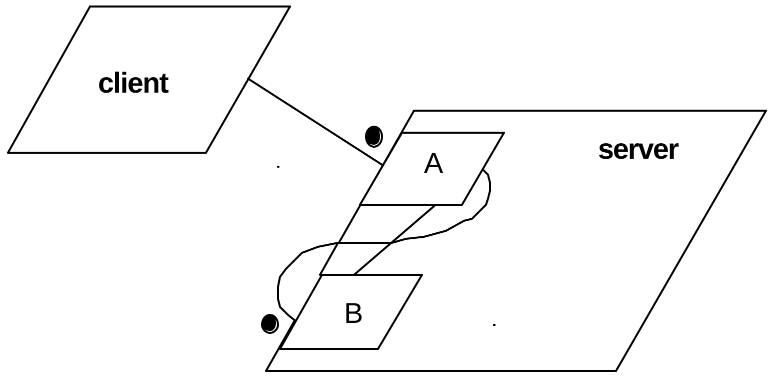


Figure 6.19. A invokes B and deadlocks.

Note that the client is waiting on A, and A is waiting on B. Since, in this example, A and B are part of the same task, a deadlock will occur. This is visually apparent - there is an obvious cycle in what amounts to a resource dependency graph.

There exists no convention for requeue in Buhr notation, but it is obvious we must differentiate it from the above situation. Since the call from the client is essentially being redirected, we show the call bouncing from one entry to another entry. In this case it bounces to another entry in the same task.

While Buhr's convention calls for lines to be undirected, with flow indicated by additional dataflow arrows, we propose that Requeue be shown with a directed arrow to emphasize the redirection aspect of the command. Requeue either has no parameters or passes through the existing parameters, so dataflow arrows are unnecessary.

In analyzing a diagram for resource loops, the Requeue command should, in the example shown, translate to the client waiting on B, not A waiting on B. From a resource management perspective, this is the correct way to look at the problem. From an implementation perspective, a lock may still be held on A if B is in another task or another protected record.

But A is not waiting on B. Since a requeue is probably part of some conditional logic, deadlock detection algorithms will have to traverse alternate paths from this diagram, one for the case of a normal execution of A, another for the case of a requeue.

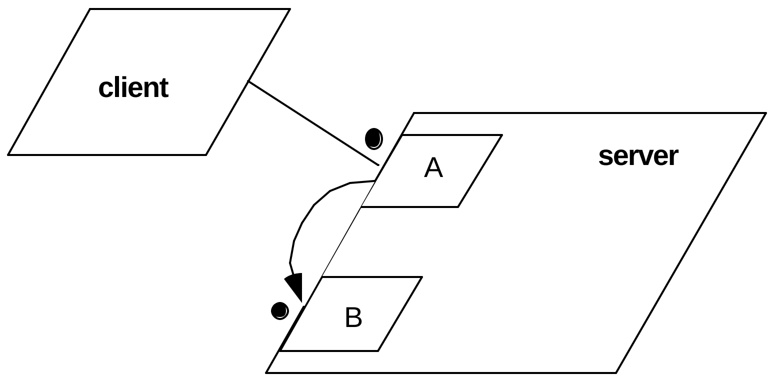


Figure 6.20. Requeueing from A to B.

Requeue can be used to suspend a caller from within the server task. The following is an Ada outline from the Map Specification (S9.7.1) which demonstrates the use of requeue to allocate print jobs to multiple printers.

```
package PRINTER_PKG is
   task PRINTER_SERVER is
      entry PRINT(FILE_NAME : STRING);
   end PRINTER_SERVER;
end PRINTER_PKG;

package BODY PRINTER_PKG is
   type PRINTER_INFO is record ...;
   protected type PRINTER is
      procedure START(FILE_NAME : STRING);
      entry DONE;
      procedure INITIALIZE(INFO : PRINTER_INFO);
   private
      procedure HANDLE_INTERRUPT;
   record
      INFO : PRINTER_INFO;
      PRINTER_BUSY : BOOLEAN := FALSE;
      CURRENT_FILE : SRING(1..MAX_FILE_NAME);
      POSITION_IN_FILE : NATURAL := 0;
      BUFFER : STRING(1..4096);
   end PRINTER;

   type PRINTER_ID is range 1..NUM_PRINTERS;
   PRINTER_ARRAY : array (PRINTER_ID) of PRINTER;
   PRINTER_INFO : constant array (PRINTER_ID)
      of PRINTER_INFO :=
         6.6.1. => ...);
   task body PRINTER_SERVER is
      PRT : PRINTER_ID;
   begin
      for I in PRINTER_ID loop
         PRINTER_ARRAY(I).INTIALIZE(PRINTER_INFO(I));
      end loop
      loop
         select
            for I in PRINTER_ARRAY'RANGE
               PRINTER_ARRAY(I).DONE;
               PRT := 1;
         end select;
         select
            accept PRINT(FILE_NAME : STRING) do
               PRINTER_ARRAY(PRT).START(FILE_NAME);
            requeue PRINTER_ARRAY(PRT).DONE with abort;
            end PRINT
         or
            terminate
         end select;
      end loop;
```

```
         end PRINTER_SERVER;
      end PRINTER_PKG;
```

This can be represented with MachineChart notation extended with the requeue arrow:

Figure 6.21. Requeue as a load balancing mechanism for a print server.

First the client calls the only visible routine to him, PRINT. PRINT calls the START procedure of the protected type of an available printer, and then puts the caller onto DONE queue of the protected type using requeue. When the print job is done, the barrier on the DONE entry will be true, and the client will resume. Requeue in this case is being used to load balance.

Note that the physical printer can be represented on the diagram. Most probably, the printer will raise a signal on completion of printer or detection of an error; this is shown here as a link from the hardware device to the interrupt handler.

A file name is passed to the protected type PRINTER. The procedure START will be responsible for reading from the file and formatting the data. The file is represented as a protected record.

The first reaction to figure 6.21 is one of disbelief at the complexity of it. Yet there is nothing extraneous on the diagram. By creating an alternate description of the problem from that of source code, the hope is that programmers and testers can gain a better understanding of the intricacies of time-domain problems.

6.7. GENERICS

Reuse in Ada is accomplished through generics. We look at how generics can be represented visually,

Buhr (1990) invents a template icon, that is to be thought of as a partially unrolled blueprint. It represents a set of building plans. A line from a template to a box represents installation. Customization parameters are shown as dataflow arrows along the install arrow. In the example below, a template STACK is used to construct a stack package. The type of the element in the stack, ITEM, can be customized, as can the upper limit on the size of the stack.

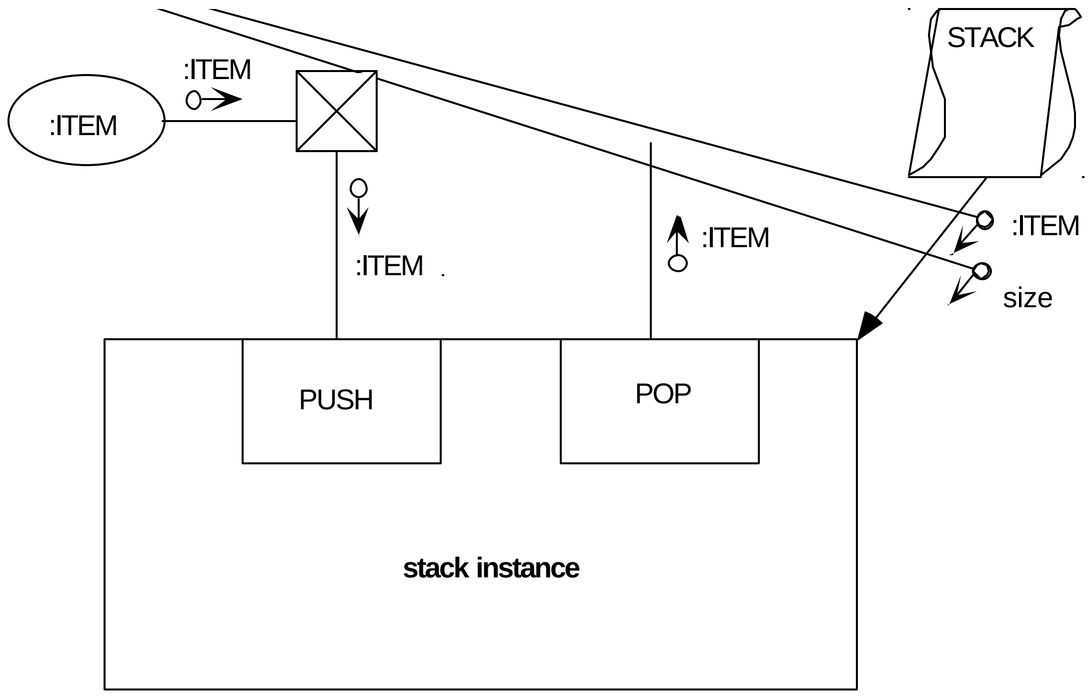


Figure 6.22. Stack instantiation from a template. The diagram is not complete; there would normally be exception conditions raised by PUSH and POP after comparison of an internal stack size counter with either 0 or the customized size.

Ada 9X allows the ability to pass instantiated packages into generics as parameters. This adds a lot of power to the Generics, and makes the diagramming of Generic relations more challenging. Here is a textual example from the Ada 9X mapping specification.

```
generic
   type FLOAT_TYPE is digits <>;
package GENERIC_COMPLEX_FUNCTIONS is
   type COMPLEX is
      record
         REAL : FLOAT_TYPE;
         IMAG : FLOAT_TYPE;
      end record;

   function "-" (RIGHT : COMPLEX) return COMPLEX;
   function "+" (LEFT, RIGHT : COMPLEX) return COMPLEX;
   ...
end GENERIC_COMPLEX_FUNCTIONS;

generic
   with PACKAGE COMPLEX FUNCTIONS is
      new GENERIC_COMPLEX_FUNCTIONS(<>);
package GENERIC_COMPLEX_MATRIX_OPERATIONS is
   type COMPLEX_MATRIX is
      array(positive range <>, positive range <>)
         of COMPLEX FUNCTIONS.COMPLEX;
   function "*" (LEFT : COMPLEX_FUNCTIONS.COMPLEX;
             RIGHT : COMPLEX_MATRIX)
     return COMPLEX_MATRIX;
end GENERIC_COMPLEX_MATRIX_OPERATIONS;

package SHORT_COMPLEX_PKG is
   NEW GENERIC_COMPLEX_FUNCTIONS(SHORT_FLOAT);
...
package SHORT_COMPLEX_MATRIX_PKG is
   new GENERIC_COMPLEX_MATRIX_OPERATIONS(SHORT_COMPLEX_PKG);
```

The Matrix package takes a complex function package as a parameter. This means that first GENERIC_COMPLEX_FUNCTIONS is instantiated, and then the Matrix package is built with this as a parameter. Within the Matrix package the types and functions of the package that has been passed in can be accessed.

In order to visualize this, we go through a few different representations, before settling on a notation that is different from Buhr's generic notation.

In the following diagram, Buhr notation is used. Since the typing and binding of parameters in Buhr diagrams take place in small arrows with circular tails, there is no obvious way to bind the result of an operation to the formal parameter of another. Shown below is an attempt at this by drawing an arrow from a package instance of GENERIC_COMPLEX_FUNCTIONS to the formal package parameter of generic complex matrix operations.

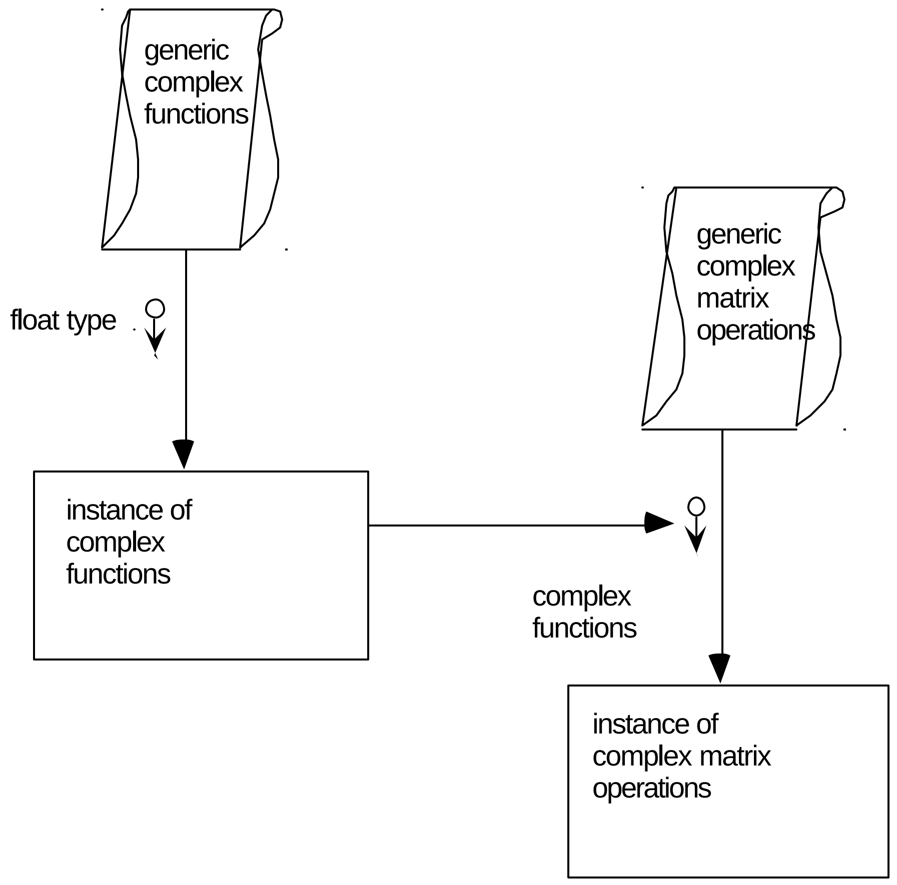

generic complex functions
float type
generic complex matrix operations
instance of complex functions
complex functions
instance of complex matrix operations

Figure 6.23. Generics using existing conventions.

In the following diagram, a convention is set up to explicitly bind actual parameters to formal parameters by drawing arrows that meet at a diamond-shaped node. The binding arrow is shown as a dotted line.

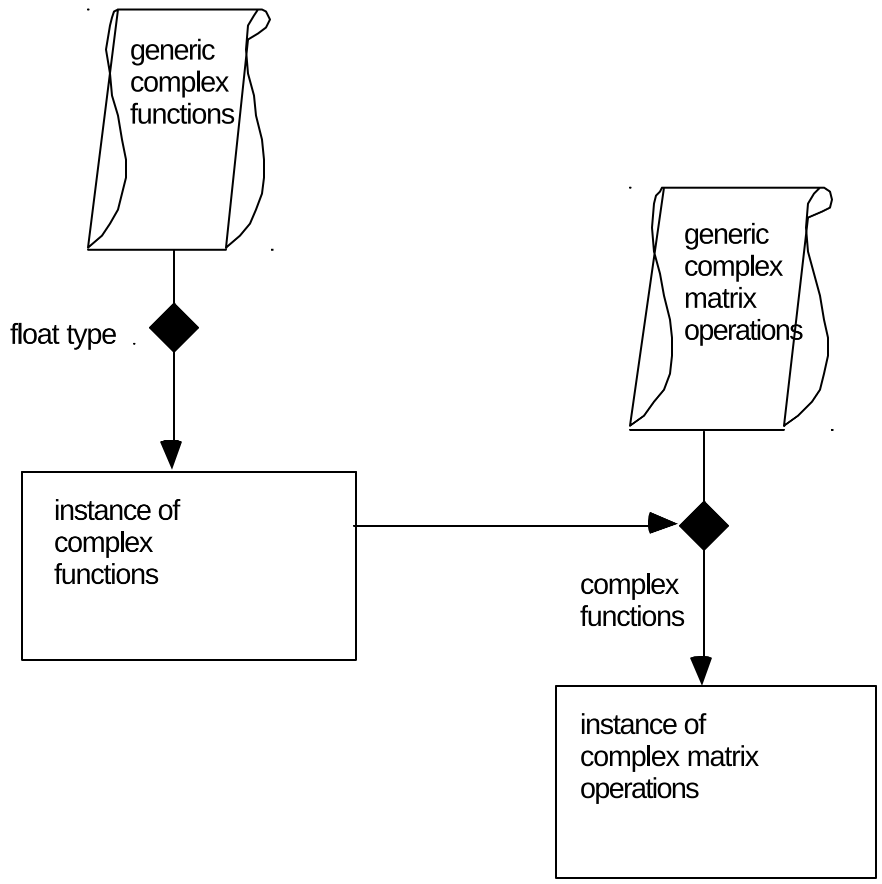
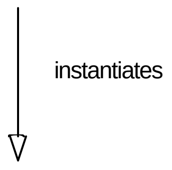

generic complex functions
float type
instance of complex functions
generic complex matrix operations
complex functions
instance of complex matrix operations

Figure 6.24. An alternative way of representing generics.

In looking at the above diagram, it is bothersome that it does not represent the syntax of Ada. In Ada, the generic takes a parameter very much like a function takes a parameter. Then the generic is instantiated with the **new** keyword. As one step toward this kind of representation, we create a new convention for instantiation, using an arrow with an unfilled head as below:



The next step is to redraw the previous diagram using the instantiation arrow, and feed generic parameters into the templates for binding before instantiation:

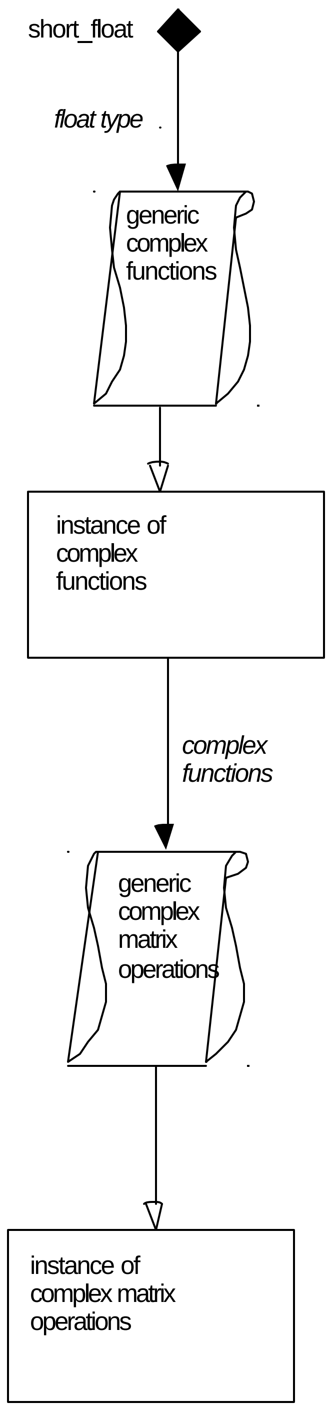

short_float
float type
generic complex functions
instance of complex functions
complex functions
generic complex matrix operations
instance of complex matrix operations

Figure 6.25. A new convention for generics.

The above is more like a data flow diagram than a MachineChart diagram. However, it seems to model better what is happening in the Ada language. If this convention is used as part of a

Case tool, a series of templates with their corresponding formal parameters might be arranged as part of a graphic menu. By combining these templates with instances and primitive types, it would be possible to fully specify a set of instantiations. Such a menu might look like this:

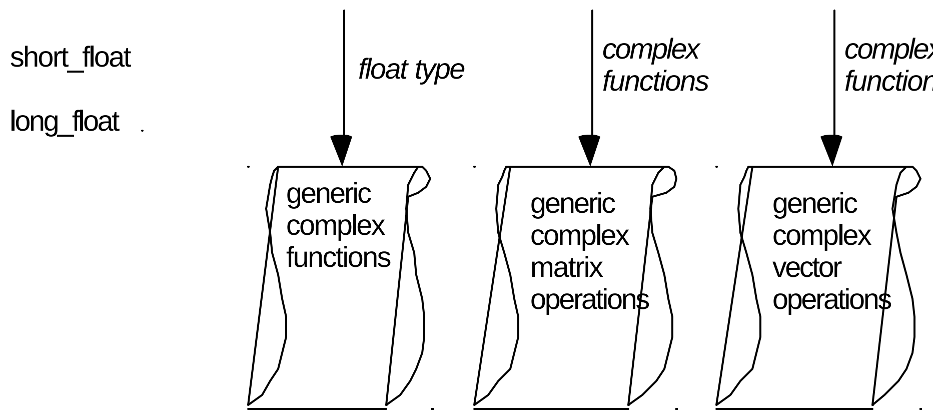

short_float
long_float
float type
complex functions
complex functions
generic complex functions
generic complex matrix operations
generic complex vector operations

Figure 6.26. Icons for generics.

The following is a continuation of the textual example above, also taken from the Ada 9X Mapping Specification:

```
generic
      type GROUP_ELEMENT is private;
      IDENTITY : CONSTANT GROUP_ELEMENT;
      with function OP(LEFT, RIGHT : GROUP_ELEMENT)
            return GROUP_ELEMENT;
      with function INVERSE(RIGHT : GROUP_ELEMENT)
            return GROUP_ELEMENT;
package GROUP_SIGNATURE is end;

generic
      with package GROUP is new GROUP_SIGNATURE(<>);
function POWER(LEFT : GROUP.GROUP_ELEMENT; RIGHT : INTEGER)
      return GROUP.GROUP_ELEMENT;

function POWER(LEFT : GROUP. GROUP_ELEMENT; RIGHT : INTEGER)
      return GROUP.GROUP_ELEMENT is
      result : GROUP.GROUP_ELEMENT := IDENTITY;
begin
      for I in 1 .. abs RIGHT loop
            result := GROUP.OP(RESULT, LEFT);
      end loop;
      if RIGHT < 0 then
            return GROUP.INVERSE(RESULT);
      else
            return RESULT;
      end if;
end POWER;

package SHORT_COMPLEX_ADDITION_GROUP is
      new GROUP_SIGNATURE(SHORT_COMPLEX_PKG.COMPLEX,  IDENTITY =>
(0.0, 0.0),
      OP => SHORT_COMPLEX_PKG."+",
      INVERSE => SHORT_COMPLEX_PKG."-");

function COMPLEX_MULTIPLICATION is
      new POWER(SHORT_COMPLEX_ADDITION_GROUP);
```

In order to visualize the above program, it is necessary to create representations for the group signature package as well as for the power generic function:

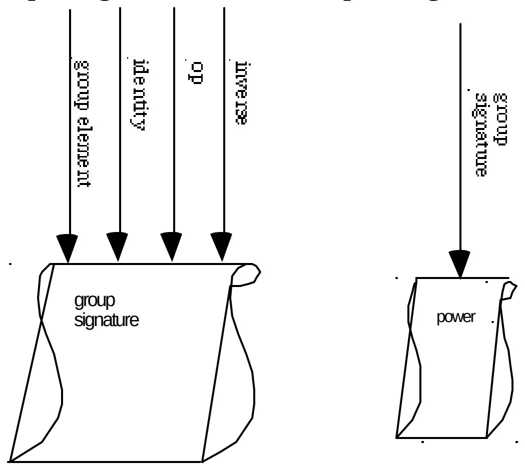


Figure 6.27. Group signature representation.

It is also necessary to show more detail on the contents of the instantiation of the short complex package. We choose to use a notation most similar to Rumbaugh's (1991) notation, which has the advantage of making the COMPLEX type visible for connections.

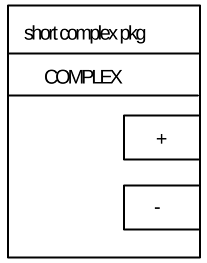


Figure 6.28. Using an OMT-like convention.

The following represents the instantiation of the power function:

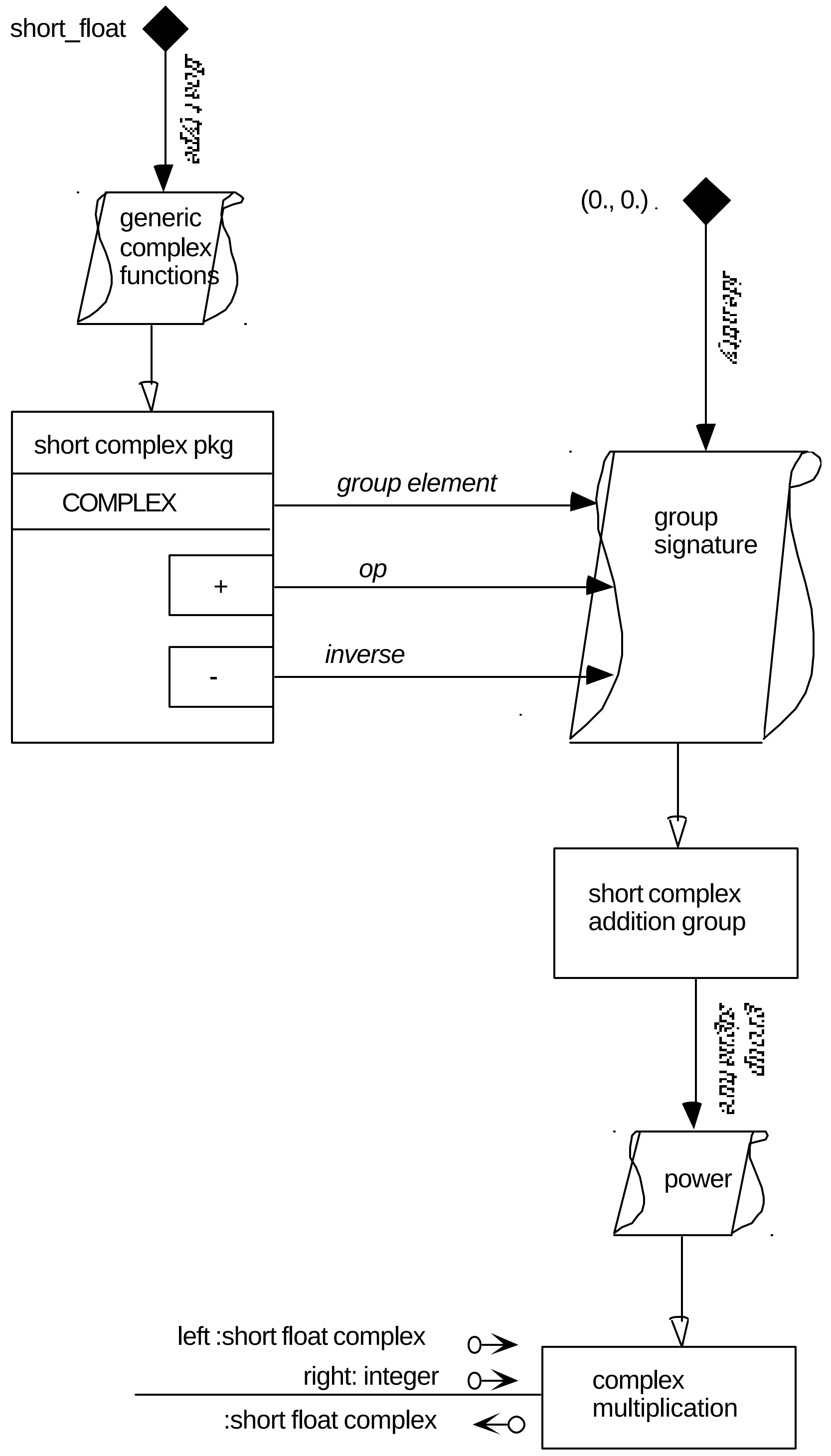


Figure 6.29. An example with the new convention.

6.8. CONCLUSIONS

System design is often done collectively on white boards. The results of this design process are often lost in the translation to textual code. Buhr's MachineChart notation is a rigorous way of capturing system diagrams. It also has the potential to be used in generating code from diagrams. And it certainly helps in the detection of common system problems such as deadlock, because cycle detection from a visual graph is easier than cycle detection from text.

Buhr's concept of a reactor works as a representation of Protected Records in Ada 9X. A simple extension to the notation allows requeueing to be modeled. Asynchronous transfer of control also can be successfully grafted on to the notation. The 9X extensions to Generics, however, suggest the possibility Buhr notation for generic instantiation needs a revamp in order to handle the bindings of packages to generic formal parameters. Or, in a deeper way, it suggests that perhaps Generics are best represented textually - that Generics are based on a naming convention, while most other components of system design deal with places.

System design seems to go with graphic representation. The place-like nature of processes lends itself to something akin to architecture in a topological domain. It is something to keep in mind as we now turn to understanding the limits of the visual.