HOOD Technical Group
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HOOD

An industrial approach to software design

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1. Preface

1.1 Introduction

HOOD (*Hierarchical Object Oriented Design*) is a design method, which is used after the requirements analysis activities and covers architectural design, detailed design and coding[1]. The method resulted from merging methods known as *abstract machines* and *object oriented design* and was further adapted to the needs of European software industry as an attempt to unify and integrate object orientation and advanced software engineering concepts and notations [Heitz92].

1.2 History of HOOD

The HOOD design method appeared in 1987, at the request of the European Space Agency (ESA) for a design method that would fit the needs of complex, real-time software, such as those encountered in space applications; the method had to fit the Ada programming language as its target language. The bid was won by a consortium consisting of CISI Ingénierie (France), Matra Marconi Space (France), and CRI (Denmark). HOOD resulted from merging Matra's experience with Abstract Machines [Mach85] and CISI's experience with Object Oriented Design [Booch86], while CRI provided its experience on the formal definition of the method. This resulted in the first version of the method, HOOD 1.

HOOD 1 was never really used for actual projects, but it served as a basis for an improved and more industrial version, HOOD 2. HOOD 2 was used industrially for the EFA (Euro Fighter Aircraft). The notion of a common representation of designs (the SIF, explained in section 19.3) allowed to freeze the interfaces between the subcontractors.

In September 1989, HOOD 3.0 was released by the HOOD Technical Group (HTG), a group of experts founded by ESA which is in charge of the maintenance and evolution of HOOD. In July 1992, HOOD 3.1 [HRM3.1] was adopted by the HOOD User's Group (HUG) as the official release of the method. It was an evolution from release 3.0 that incorporated feedback from over two years of experience on various projects.

After an evaluation phase on small pilot projects, the method was chosen for the COLUMBUS Manned Space and ARIANE-5 programs. Since, it has been adopted by

1. Chapter 2 will detail the precise definition of these terms.

EUROCOPTER, the French Navy and by several other large projects in aerospace, defence, transport, energy and nuclear applications.

However, the context of software development is a moving target. Object oriented method have gained wide acceptance in the meantime, extensive use of HOOD showed some difficulties, and there was a desire to support other programming languages. At the same time, C had moved to C++ [Stroustrup91] and Ada 83 [Ada83] had been replaced by Ada 95 [Ada]. For these reasons, an update of the method became necessary. This was achieved in 1995 as HOOD 4 [HRM4]. This is the current state of the method, and the one which is described in this book.

With thousands of engineers trained in Europe and the availability of several tool sets and companies providing support for using the method, HOOD is spreading continuously within the industry. The Hood User’s Group has been set-up as an international non profit organization and is in charge of controlling the evolution of the method.

1.3 Structure of the book

This book is organized in four parts that provide a gradual approach to the HOOD method.

Part 1 introduces the basic notions of HOOD; starting from general software engineering notions, it provides enough information to allow the reader to *understand* an existing HOOD design, at least at the level of the general structure. The part concludes with the presentation of a full HOOD design.

Part 2 then goes into deeper details, and a more formal presentation of the method; this corresponds to what the reader needs to know about the formalism to *write* a new HOOD design.

Part 3 discusses the methodological aspects, i.e. the process that brings from a white page to a full design.

Part 4 is a full scale example, that shows a full design from the early phases on down to actual code.

Annexes are included to provide the reader with supplemental information, such as bibliography, summary of acronyms and notations, and a full index.

As is common nowadays, we have used a `Courier` font to represent programs and names that appear in the textual formalism of HOOD.

> Paragraphs of this style provide additional information of less importance, or extra details on a particular point. They can be skipped at first reading.

1.4 About this book and other related materials

There is a number of publications and documents about HOOD. Apart from this book, two documents are of interest to the HOOD designer: the HOOD User Manual (HUM) and the HOOD Reference Manual (HRM).

This book is intended to give a first introduction to HOOD and to present a general overview of the method; it is *not* intended to cover all the details that are necessary before being able to start a full-scale project with HOOD, but rather present the main ideas that would allow a project manager to make a conscious decision when choosing a design method.

The HOOD User Manual [HUM96] aims at presenting more technical details for those who intend to use HOOD. It provides a thorough coverage of implementation details and covers examples on how to best use the method for various application domains.

The HOOD Reference Manual [HRM4] is the official definition of HOOD. It is very formal, and serves the need for a "standard" of HOOD, in order to insure interoperability of tools. An educated HOOD user may look at it in order to clarify some fine details, but it is not intended to serve as a pedagogical manual.

Information about HOOD can also be found on the Internet. Most tool vendors have their site, and there is a site dedicated to HOOD:
http://www.hood.be.
You'll find information about the HOOD User Group, the HOOD method itself and its tools. You can also download the reference manuals (HRM and HUM) and some relevant papers.

Let us finally stress that *no* book will ever allow one to become a HOOD designer (nor for any other method): actual training with hands-on exercises, availability of a HOOD tool, and assistance of an experienced tutor in the beginnings, are a must.

1.5 Acknowledgments

This book has been written on behalf and with the constant help and guidance of the HOOD Technical Group, which deserves collectively all my thanks. Of course, a group is mainly a collection of people, and some of them had a real outstanding influence on the form and content of this book. First, my deepest thanks and appreciation go to M. Heitz (CISI), the main designer of HOOD and head of the HOOD Technical Group, for his many advices, careful readings, and sometimes lively discussions on issues where we didn't necessarily agree, but where we were fortunately able to come to conclusions that were acceptable (and happily accepted) by all participants. I gratefully acknowledge the help of other members of the HOOD Technical Group who were able to devote some of their time to reviewing earlier versions of the book and

participating in the various coordination meetings: E. André (SEMA Group), P. Dissaux (TNI), C. Pinaud (Matra Marconi Space), and J-M Wallut (CNES). I would also like to thank people who provided me with some valuable inputs in the form of comments, reports, papers, and other documents. I was not always able to include directly their information, but their participation helped to shape the form of the book. This includes A. Burns (University of York), A. Canals (CISI), D. Minguillon (CNES), P. Panaroni (INTECS), and A. Wellings (University of York).

The help of companies that provided access to their tools for my experiments is gratefully acknowledged: TNI (Stood tool) and SEMA-Group (Concerto tool).

Finally, I'd like to thank my "naive" reviewer Jérémy Rosen. He was instrumental by knowing *nothing* about HOOD beforehand, and contributed a lot to making this book more understandable.

Part 1 :
Industrial software design issues

Software design is an integral part of the development of many industrial products; too often however does it rely more on *wizardry* than on industrial, fully mastered process.

What makes the approach we describe here unique, as supported by the HOOD method, is that it takes into consideration many industrial constraints within the design framework itself. Such constraints include working with subcontractors, hardware constraints, reuse, and long-term life cycle.

2. Hierarchical and object oriented design issues

In this chapter, we will recall the most basic notions of object oriented design and other software engineering principles, which form the basis of HOOD as well as many of other design methods. The goal is simply to explain how some basic terms are used in this book, since there are many diverging definitions of them.

2.1 Design: breaking software into modules

Before discussing about object oriented design, it is important to understand what *design* is about. A software product is generally too big to be dealt with as a single big chunk; it is therefore decomposed into *modules*. Design is the activity that starts after *requirements analysis* and whose goal is to *identify and define software modules*. Actual production of the modules is the task of the *coding* and *testing* phases.

The goal of analysis is to provide a high level description of the requirements, while design is oriented towards identifying and describing software solutions. Although traceability from analysis to design is of utmost importance, it does not mean that the design should be a mere rewriting of the analysis. On the contrary, design is a creative process that takes into account the constraints and paradigms of computer software. It must find a solution which is, at the same time, a satisfactory solution to the problems described by the analysis phase, while being efficient (in the broad sense) from a software point of view.

For example, the analysis often describes the problems by classifying the data in terms of "is a" relationships: a client "is a" person, a vibration detector "is a" sensor, etc. This can be sometimes translated at design level using the inheritance mechanism, but it is in no way mandatory, and alternative solutions (as always) should be investigated, and may well be more appropriate. Sharing properties at analysis level does not necessarily involve sharing implementation code!

2.2 Object orientation

We said that the goal of the design phase was to define modules. *How* to decompose a software piece into modules is what differentiates the various *methods*; it is therefore a central part of every design method.

Early design methods were functionally oriented: modules were defined according to the main functions of the program, and to the order in which they were performed. This approach was, and still is in many cases, very effective, but over time a number of drawbacks appeared, especially due to the strong temporal coupling between modules, difficulties in defining reusable modules, inability to deal with concurrency, etc.

A solution to a problem can normally be described using very common notions from the real-world. For example, it is quite natural to tell people to click on a button on the screen with the mouse. Of course, there is no *real* button on the screen, and even the fact that the pointer on the screen somehow follows the movements of the mouse is a pure artifact; however, these computer *objects* behave as if they were real objects, at least as far as their computer usage is concerned. They are *abstractions* of real world objects. *Object oriented design* consists in decomposing a program into modules that represent *objects*, as abstractions of real world objects. Since objects normally have both properties (colour, shape, etc.) and operations (being pressed for a button, etc.), computer objects embed both *data structures* and *program structures* that belong to a common entity of the problem domain. This is known as *encapsulation*, and is often used as a definition of a computer object.

2.3 Abstract state machines

An abstract state machine is the most elementary way of representing an object. It is a module that encapsulates the states of the object and provides operations to act on this state, or to direct the object to perform some actions. Since the object has states that can influence its behaviour, it is called a state machine, or automaton. Moreover, these states are normally hidden. In Ada, the machine would be implemented by a package, and the states would be encapsulated as variables of the package body. In C++, the variables would not appear in the ".h" file that defines the interface. Since the actual state variables are hidden to the external world, their internal structure can be quite different from what appears to be to the users of the object: the real state is *abstract*.

For example, a rail needle appears to have only two states: Left and Right. Actually, the object that deals with the needle has a much more complicated view: while it is moving, the needle is neither Left nor Right; moreover, the object must be able to deal with complicated cases, like when the needle is frozen, and several attempts must be made to move it from one position to the other one. But thanks to the encapsulation mechanism, such a complexity is hidden to the user.

2.4 Abstract data types

When an object is represented in a computer as an abstract state machine, there is only one occurrence, or to use the official term, only one *instance* of the object. One module equals one object. It is however often the case that data need to be exchanged between objects, or that similar objects must be created. There is a need to describe a common model for those data, from which many instances can be made.

Such a model that allows to declare several instances with the same properties is, in computer language terms, a *data type*. A data type is used to represent entities of the real world: a length, an employee's salary, a telemetry record, etc. The view of the data that makes sense for the user of the type is called the *abstract* view; but this abstract view has to be translated into the much simpler types that can be handled by the computer. This simpler view is called the *implementation* of the data type. For example, a printable character represents an element that can be read, but it is generally implemented as a byte in the machine.

Normally, the user should not depend on the representation of the abstraction. If the language (or the method) allows to define the data type in such a way that the actual representation is hidden and that the data type can be operated upon only through a well defined interface corresponding to the abstract view, then only this abstract view is accessible, and the data type is called an *abstract* data type.

2.5 Aggregation

Real world objects are generally made of *parts*, that are themselves objects that are assembled to build a higher level, *composite*, object. This is also true of software objects: a button is made of a frame and a label, a pixel includes X and Y coordinates as well as a colour, etc. The process and relationships by which an object is made of several sub-objects is called *aggregation*.

Note that the properties of an aggregating object are generally different from the properties of the aggregated parts. An aggregating object has its own properties, and the aggregated parts only serve to implement the global object.

Aggregation is a powerful mechanism for constructing objects, and some design methods do not require any other form of relationships between objects. To differentiate these methods from others that rely on the mechanism of inheritance (presented next), they are sometimes called *object based* methods.

2.6 Classes and inheritance

It is sometimes necessary to build a new type of object by extending the properties of an existing type. For example, a monitoring system to detect a current overload can be thought of as a normal amperemeter (which may already exist) with an extra feature that allows it to trigger an alarm when some predefined level is exceeded. In this case, it makes sense to define the monitoring system from the existing amperemeter, adding the new functionalities. Since the monitoring system will still have all the properties of the amperemeter, it *is*, from an abstraction point of view, an amperemeter. It is said to inherit from the amperemeter, and is considered to belong to the *class* of all amperemeters. A class is a kind of abstract data type which belongs to a set whose members are interconnected by inheritance relationships, allowing sharing of common properties.

Many people claim that inheritance is the most important feature of object orientation. It must be reminded here that often, the same effect can be obtained both by inheritance and aggregation. For example, an alternative solution to the previous example could have been to define the monitoring system as a stand-alone entity, that would include (*aggregation*) an amperemeter and an alarm system, but that would not have been considered as being an (belonging to the class of) amperemeter.

This is really a matter of different ways of modelling real world objects, and there is no absolute best way of doing it. In general, aggregation provides better encapsulation and information hiding, while inheritance allows for quicker development and code reuse. Which one to chose depends on the project's constraints.

2.7 Exceptions

Normally, an operation provides some kind of service. Sometimes, the required service can simply not be provided: either the parameters provided by the caller are inconsistent, or some external event prevents the operation from being able to do its business... Defining the semantics of an operation when problems are encountered is as important as defining the behaviour when all is well. Too often, this part of the semantic is undefined, and can lead to unexpected behaviour when such a condition is encountered: when what would happen is not specified, the caller presumes that it cannot happen.

Therefore, a complete description of the behaviour of an operation must include the conditions imposed on the caller for the operation to be able to perform its task (*preconditions*) and the definition of error conditions that can prevent the operation from succeeding. If such a condition is encountered, the operation must signal to the caller, in a non-ambiguous way, that the required service was not performed as specified (i.e. not fully completed or not performed at all). This kind of signal is called an exception.

Some programming languages (including Ada and C++) provide a built-in mechanism for signalling exceptions. Other languages (including C and FORTRAN) have no such device, and exceptions must be signalled using a return code, for example. However this does not change the principle: the caller has to know whether the requested service was performed according to its expectations/specifications or not, i.e. whether an exception has occurred or not.

2.8 Generics

Sometimes, it is discovered that a number of objects are made according to a given pattern, and differ only by some types or secondary operations. For example, the notion of a bounded list does not depend on the kind of data that is held into the list. It would not be cost-efficient to redesign as many lists as types being manipulated; it is better to gather this commonality in an object *template*. This corresponds to the notion of templates in C++ or generics in Ada.

A bounded list can therefore be seen as a parameterized object, whose parameters are the type of the data being manipulated and the maximum size of the list. Such a generic object cannot be used in itself: it can only be used to create *instances*, which are regular objects obtained from the generic by providing values to the parameters. For example, an instance of the bounded list could be a list of `Measure_Points` of maximum size 100.

Since instances are all derived from a common model, a change in the model will automatically update all instances, making maintenance much easier than by manual duplication of a "reference" object.

2.9 Concurrency

Most programs are defined as a list of *sequential actions*, i.e. a program is viewed as various statements that are performed by a computer one after the other. However, in real life, it is often necessary to deal with several things *at the same time*: in a tennis video game for example, it is necessary to control the movements of both paddles and of the ball simultaneously. When one (or several) computers have to handle different activities concurrently, it is called *concurrent* programming.

There are several ways to deal with concurrency; the most common one consists in separating the problem as several activities, called *threads* or *tasks*[1], each of them being purely sequential, but being executed in parallel with other threads. Note that many real-world objects do have a concurrent behaviour of their own; a microwave oven stops after the required time, without the cook having to stay in front of it with a watch! The same effect can be obtained for computer objects, if they include one or several threads. Such objects are called *active* objects.

1. In this book, we'll use the more general term "thread" to refer to the concept of "light weight process". We'll keep the term "task" for Ada tasks.

Concurrent programming induces a number of difficulties that have to be dealt with, that are not found in sequential programming. The most important of the issues are:

- *Implementability*. Although a convenient tool, concurrency may require support from the operating system or the underlying executive, which is sometimes not available.
- *Communication*. Sometimes, different threads need to exchange or share data. A special mechanism must be provided to that effect; examples of such mechanisms are *mailboxes* and *rendezvous*.
- *Synchronization*. Sometimes, a thread needs to know whether another thread has reached some point in its execution, or a thread must wait until it receives an indication from another thread that it can proceed. A special (and important) case of synchronization is needed when two threads can access some variable, or other shared element, at the same time. Special care must be taken to ensure that no chaos results.

  Note that communication and synchronization are *not* orthogonal issues. For example, the rendezvous is a synchronous communication, since both threads that communicate are in a well defined point in their execution. Threads can be desynchronized by introducing an intermediate agent thread. On the other hand, mailboxes provide asynchronous communication, since the sending thread knows nothing about the state of the receiving thread. Synchronization can be achieved by adding an extra message exchange.
- *Race conditions*. Sometimes, the correct behaviour of a program depends on the precise order in which threads perform a certain action, but it may be difficult to guarantee that the right order happens in every case, since threads may execute concurrently. When incorrect behaviour results from threads executing certain actions at inappropriate times, it is called a race condition. Race conditions are the cause of very hard-to-find bugs, since they may never happen under debugging conditions, but only on the real working system. Some common synchronization primitives used to avoid race conditions include *semaphores*, *monitors*, and *protected objects*.

2.10 The client-server model

A useful paradigm when dealing with complex systems is to use a *client-server* model. It consists in breaking the system into modules that act either as servers, defined by a number of services that can be requested from them, and clients that use these services. The principle is that a server provides the services to a number of clients, without having to know anything about the client; on the other hand, the client uses the services, as defined by the specifications of an *interface*, without having to know *how* the service is implemented. A real-life example of a client-server model is a post-office, where clerks provide services (sell stamps, accept parcels) to anyone who is in line, while the clients queue up at the booths without having to know about the mechanisms involved for sending a letter across the country.

2.11 Issues with distributed systems

A complex system rarely involves only one program running on one machine, but rather needs the cooperation of several programs, often distributed on a network of computers, or several computers connected by an industrial bus. This presents new challenges to design, since it is far from obvious to determine how to best split the parts of the system over the hardware configuration.

It is often tempting to account for distribution right from the start of the design. With this technique, a physical architecture is first defined, then it is decided which functions are to be implemented on which computers. Then, when a part of the system needs services from another part on another machine, it calls it through network services. The network is thus visible as a top element of the project. Many projects have used this approach, but experience has shown that it had severe drawbacks. The most important one is that the architecture of the software is driven by the hardware. If the hardware design evolves, or if it appears that the initial distribution of software modules over the hardware is unbalanced, it is often necessary to move some parts from a machine to another one. If the software is driven by the hardware, this implies a major redesign of the software architecture, sometimes very late in the project's life cycle.

Moreover, the precise hardware configuration may not even be fixed at the beginning of a project. Now that portable, standardized, middleware solutions (such as CORBA [OMG91]) are available, and that rapid evolution and changing prices of hardware makes economics forecasts difficult, it is increasingly the case that the supporting hardware is chosen late in the development process.

For these reasons, it is generally regarded as a better strategy to design the software independently from the distribution issues, and then deal with distribution as an independent step. On the other hand, a hardware architecture *has* to be designed, often quite early in the project. This means that both aspects must evolve concurrently, and that there must be a simple, versatile, and powerful way of mapping the software design over the hardware structure.

3. Overview of HOOD

HOOD is an architectural design method, helping a designer to partition the software into modules with well defined interfaces that can either be directly implemented or further partitioned into modules of lower complexity. It supports functional approaches as well as object based *and* object oriented design. It integrates both modular programming, centered on client-server and composition relationships, and inheritance programming.

HOOD was developed as a design method, with special consideration for other development activities that occur at the same time: smooth integration with requirements analysis, concurrent development of independent parts, automated code generation and testing, client-server and post-partitioning support. The integration of these aspects results from the return of experience gained from using previous issues of the method on industrial projects, thus making HOOD the architectural design method of choice.

3.1 Objectives of industrial software design

Complexity

There are several issues that make software development such a challenging endeavour. But encompassing all the others is the issue of *complexity*. It has long been observed that the human mind is limited in its ability to handle complexity [Miller56]; at the same time, software becomes increasingly complex. Therefore, as Booch points out [Booch91], "the fundamental task of the development team is to engineer the illusion of simplicity". But this does not happen through wishful thinking: design methods are intended to guide the developer into achieving this goal.

One of the issues that makes software complex is that there are several aspects to it: *what* to do, *when* to do it, and *how* to do it. A design method can help if it *separates concerns*, allowing the various aspects to be dealt with without introducing any coupling between them.

Reuse

Software is rarely entirely new; *reuse* of existing modules in new projects is often a concern. It is not something that happens by chance, and a structure is necessary in order to identify the pieces that can be reused, at design level as well as at code level.

Hardware vs. software

Most modern systems involve a network of computers, or at least several collaborating processes. The hardware architecture is often driven by external considerations, such as cost, power consumption, network bandwidth, etc., that do not necessarily map the software constraints; on the other hand, software is developed concurrently with hardware, and cannot rely on a definitive hardware architecture. Moreover, software changes and evolution should not have an adverse effect on the effectiveness of hardware usage. For these reasons, a design method should allow concurrent development of hardware and software, and provide for a late mapping of software upon hardware as well as for an easy remapping if necessary.

Traceability

It is a fact of life that requirements keep changing, long after design has started. Evaluating the impact of a change is difficult, but it can be eased if there are good *traceability* documents, that tell precisely which parts of the design are impacted.

Partitioning

Finally, large projects are seldom built as one piece. There is often a prime contractor who delegates part of the development to several subcontractors; the global design process is split into several concurrent activities. Even if the project is completed within a single company, it often requires several development teams. This implies that software must be partitioned between the various proponents, and that synchronization and consistency checks have to be done between loosely related participants. This aspect has a real impact on software design: what good is a software architecture if it is not feasible in time by the people in charge? It also implies that a design method must provide a common language for expressing strictly defined interfaces, allowing subcontractors to understand what they have to do, and allowing the prime contractor to check the resulting design against the specifications.

3.2 The HOOD approach to design

HOOD is a design *approach*, that uses standardized (textual and graphical) *formalisms* to express the results of the design. A number of *rules*, elaborated from industrial experience, apply to the design, and these rules can be checked by automated *tools*. The final goal is to achieve the best possible quality design.

3.2.1 The hierarchical approach

Since HOOD is a *design approach*, it provides a framework to guide the developer in the design activity, by describing and refining a software model from abstract structures and concepts towards machine code. Each step produces pieces of text reflecting the associated design activity, that can be reviewed and checked against quality criteria. Moreover, HOOD is a *hierarchical* approach: it defines high level structures that are refined into more detailed ones; the designer never has to cope with all the project's details at the same time. This dramatically reduces the complexity the designer has to deal with at any moment. The hierarchy can be organized according to management constraints, such as subcontracting or other organizational aspects.

An original aspect of the approach is the *separation of concerns*: each module includes separate descriptions for interfaces, functional aspects, data modeling, and behavioural aspects. The descriptions are kept independent, making it easy to apply dedicated development skills, and rigorous methods. For example, Rate Monotonic Analysis [Klein93], State-Transition or Petri nets [Reisig85] analysis, automated test scenario generation, can be applied to the behavioural part without relying on an implementation of the functions, while functional parts use abstract state machines, preconditions and post-assertions for functional proofs.

Separate hierarchies are defined for reusable software components. This allows for introducing a reuse policy as a natural step in design. Moreover, the notion of system configuration (see section 12.3) allows precise tracking of which components (design pieces as well as software components) are being used in each project.

Traceability with requirements as they are refined, followed by refined solutions, is still a problem in managing large projects. HOOD refinement properties support a development approach that encompasses the different design phases and helps ensuring consistency and traceability of a design solution, from requirements to implementation, even in the presence of unstable or evolving requirements.

Finally, the method includes an abstract model of distribution (the virtual nodes, see section 6.3) which is orthogonal to the structural design. A separate step is used to map the logical architecture into the physical one; this ensures independence and ease of relocation between software and hardware.

3.2.2 Balancing graphical and textual formalisms

HOOD includes the definition of a *graphical description* (i.e., boxes and arrows). It provides an abstraction of a solution with a clear, high level and easy-to-understand formalism. It offers a reduced, but consistent view of objects, and allows hierarchical refinement and easy understanding of the solution.

The notation is intended to *support* the approach, not to replace it. It is a convenient way to reason about software and to make a mental picture of its architecture, but not more. Therefore, the graphical description is complemented by a *textual description* which includes all details. It allows formal expression and refinement of the object's characteristics and properties by an Object Description Skeleton (ODS[1]). This con-

1. HOOD uses a number of abbreviations like this one. Annex A summarizes those that are used in this book.

cept helps structuring the descriptions into separate fields which support appropriate control and program description notations. Finally these descriptions are translated into a target programming language (Ada, C, C++, or FORTRAN, for example).

The textual notations leave provisions for both informal and formal texts, allowing the definition of a documentation skeleton which can serve as a framework for a step by step integration of advanced notations (like Petri nets for example). Tools can be used to capture and formally verify the characteristics of objects.

The graphical notation recalls the context of the design piece, but hides most implementation details, thus decreasing the design complexity, while the textual notation keeps all the details, including full traceability and control of dependencies between modules, with full consistency checking. These notations allow to use powerful structuring concepts for describing and organizing a system as a set of interconnected hierarchies of objects.

3.2.3 Design quality control: HOOD rules

Proper usage of HOOD requires obeying by a number of rules. Rules may appear as a nuisance to the stand-alone designer if they are perceived as arbitrary restrictions; on the other hand, they can be of great help when they are perceived as providing guidance, common guidelines, and thus forming the basis of quality assurance. The rules are summarized in section 16 of the HOOD Reference Manual. Each rule is assigned a number for easier reference, that includes a letter that classifies the rule, and an ordinal number. The keys for the rule letters are as follows:

C	*Consistency & completeness*	*P*	*Provided interface*
G	*General definitions*	*R*	*Required interface*
I	*Include relationship*	*U*	*Use & inheritance relationships*
O	*Operations*	*V*	*Visibility*

HOOD rules are of three kinds: *definitions*, *methodological rules* and *usage rules*. Definitions are simply statements of the main method elements. Methodological rules result from the very structure of the method’s entities . They must be enforced, or else the design would be inconsistent. Usage rules come from industrial experience. They are intended to help the designer and provide a basis for quality assurance, but there may be cases where an out-of-norm situation may lead to not obeying by the rule. Such exceptions must be documented and justified in the design documents.

In the book, we introduce rules as we encounter the corresponding situation. They are presented in a special box, to stress that they are formal rules, as follows:

Reference number		*Kind*
Text of the rule.		

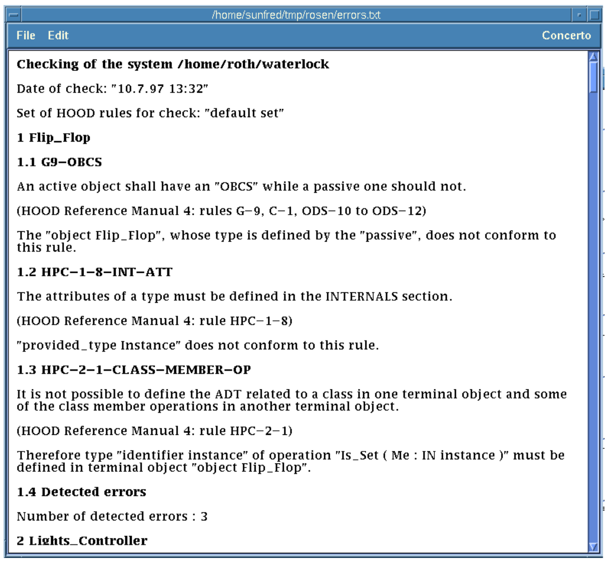
The reference number is as given in the reference manual, the *kind* is one of "Definition", "Methodological", or "Usage", and the text is the text of the rule as given in the reference manual. Note that "Usage" rules are not formal rules, and thus have no reference number.

There are also *code generation rules*, which define how to map HOOD concepts onto target languages. We will not address these here, since they are mainly a concern for the tool designers.

3.2.4 Supporting the method: HOOD tools

HOOD was designed right from the start with consideration for tools support. What this means is that tools were not added later, but that it was rather considered that tools were in any case necessary for any serious software development. The notations, the rules, and even the format of the design documents have been designed for being produced by tools and for being reviewable by tools.

What do the tools bring to the designer? First, they help with the design activity itself, by providing graphical and textual editors. They can generate documents according to various documenting standards (like DOD-2167A, DOD-198A or ESA PSS-05 [BSSC91]). They check and insure consistency between the representations. They can enforce HOOD rules, and provide various analysis of the design. For example, a typical output of such a tool is represented on figure 3-1.



```
Checking of the system /home/roth/waterlock

Date of check: "10.7.97 13:32"

Set of HOOD rules for check: "default set"

1 Flip_Flop

1.1 G9−OBCS

An active object shall have an "OBCS" while a passive one should not.

(HOOD Reference Manual 4: rules G−9, C−1, ODS−10 to ODS−12)

The "object Flip_Flop", whose type is defined by the "passive", does not conform to
this rule.

1.2 HPC−1−8−INT−ATT

The attributes of a type must be defined in the INTERNALS section.

(HOOD Reference Manual 4: rule HPC−1−8)

"provided_type Instance" does not conform to this rule.

1.3 HPC−2−1−CLASS−MEMBER−OP

It is not possible to define the ADT related to a class in one terminal object and some
of the class member operations in another terminal object.

(HOOD Reference Manual 4: rule HPC−2−1)

Therefore type "identifier instance" of operation "Is_Set ( Me : IN instance )" must be
defined in terminal object "object Flip_Flop".

1.4 Detected errors

Number of detected errors : 3

2 Lights_Controller
```

Figure 3-1 : A HOOD checking tool (Concerto, SEMA-Group)

Moreover, it is possible to extract parts of the design for processing by other tools, like proof making tools for example.

Several tools are currently available from various vendors, and this is a competitive market. HOOD defines a standard representation of designs (the Standard Interchange Format, or SIF, see section 19.3) that allows a design produced by a tool to be read by a different tool. This way, several subcontractors on a project need not use the same tool in order to exchange design documents.

3.3 From analysis to design: scope of HOOD

HOOD supports identification of a software architecture *after* requirements analysis activities and leads naturally into detailed design where operations of objects are further designed and implemented. This detailed design description may be further refined into target language descriptions up to a point where the target code can be generated. Figure 3-2 indicates HOOD applicability within a simplified life cycle model.

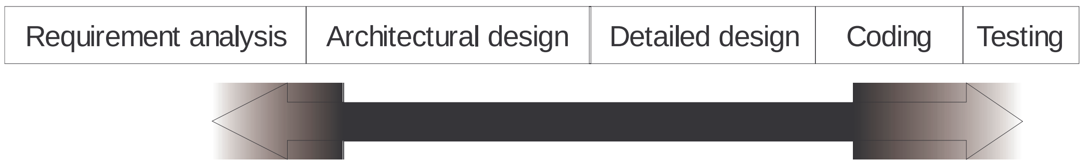


Figure 3-2 : HOOD in the development activities

Although HOOD is not a requirements analysis method, it handles "design requirements analysis" activities during the transition from requirements analysis to design. From this point on, it covers all phases of architectural design and detailed design down to coding, which can be greatly automated, and testing.

HOOD concepts are intended for easy integration of design with other development activities. More precisely, HOOD object properties have been defined in order to ease interface mastering, testing and integration in the context of parallel, multi-people team developments. This implies that HOOD is rather aiming at better filling the needs of the prime contractor and integrator than those of the low level programmer.

3.4 HOOD compared to other methods

As noted above, the challenge for a design method is to guide the developer in order to design complex software while giving it the look of simplicity. Many design methods fell into the pitfall of trying to accurately represent all of the complexity of the problem to be solved, while HOOD focuses on *hiding* the complexity by organizing the development in such a way that the designer, at any one moment, only has to cope with a well defined and bounded part of it that is within the reach of human understanding. This is the key concept that introduced the notion of *hierarchical* design.

Analysis methods, such as OMT [Rumbaugh91], are very efficient methods for representing the properties of system. As such, they are very fit as a requirements analysis method, and can actually be used as the input to a HOOD design. On the other hand, there is no clear module interface definition, so using it as a *design* method will badly lack context restriction, interface definition, testing and integration support.

The so-called object oriented methods (actually, inheritance based methods) provide excellent flexibility when in the exploratory stages of a project; but it is often at the cost of difficulties in traceability, testability and maintenance. By limiting inheritance to data structures in a very controlled way, HOOD achieves many of the benefits of these methods, without the drawbacks.

Finally, a special mention should be made to explain the relationships between HOOD and UML, the Unified Modelling Language [UML]. UML is a very general *language*, that can be used to describe various systems; it has been designed by merging concept and notations from OMT, Booch and OOSE methods. UML includes a graphical representation of the formal language. UML (purposely) does not include any *design process*; it is rather expected that various design processes be defined using this language. The general notation can be specialized, by identifying certain uses of the constructs as bearing some special semantics; such specializations are called *stereotypes*.

HOOD concepts can be described using UML, adorned with a number of ad-hoc stereotypes, and the HOOD method itself can be described using UML as a meta-model, the same way as UML is itself described using its own meta-model. In a sense, HOOD can be seen as one of the many possible design processes obtained by specializing UML. HOOD is not UML, but HOOD is compatible with UML.

HOOD notations differ in a number of places from UML notations. On one hand, when the same need arises in both approaches, it would make no sense to invent a different shape of arrow, and HOOD uses the same (or similar) notations as UML; on the other hand, when a stereotype is a cornerstone of the method, it does make sense to identify it by a special symbol to make it more easily recognizable than a simple annotation on a standard diagram. Deciding which level of concepts is worth a special symbol is a matter of judgement, but the apparent differences between the notations should not be taken to be more than what they are: various ways of representing the same underlying model, and it is absolutely possible to design a HOOD tool that would, at a user mouse click, present the design using either notation.

3.5 Summary

HOOD is a hierarchical design approach that incorporates the notions of object oriented design into an industrial process. It includes a notation and a design process. The formalism is supported by a set of rules which are enforced by tools.

4. HOOD objects

4.1 Objects and modules

Objects are the most basic entities manipulated by HOOD. There are various kinds of objects, that will be detailed all along this book; some represent "objects" in the sense of classical OO techniques, but others do not. To avoid ambiguity, we shall use the term *class instance* when we want to refer to an object as an instance of a class.

A HOOD object is a basic *module*, a conceptual unit of design and encapsulation. It may have an internal *state*, and is defined by the *services* it provides. These services are used by other objects, which act as *clients* for this *server* object. A fundamental aspect of HOOD is that interactions between objects always follow this client-server model: a server is an object that provides services, but does not know to whom the services are provided. On the other hand, a client is an object that uses the services, but does not know *how* the services are provided.

Every HOOD server object features a *provided* interface that defines the services that can be used by clients. Clients do not need to know (and, to be honest, *cannot* know) how these services are implemented. This enforces the software engineering principle of *encapsulation*. But of course, clients do know which services they need! Every HOOD client object must also include a *required* interface, to describe which services are being used.

A server may require other services in order to perform its tasks. In this case, it will act as a client to other servers; generally objects act both as clients and servers at the same time. They will thus exhibit both a provided interface *and* a required interface. Those interfaces should not be confused: the provided interface describes the services offered by the object to its clients, while the required interface represents the opposite view, i.e. the elements of the servers that the object needs to operate correctly.

4.2 Description of objects

An important aspect of a method is how to document the design pieces (objects, for HOOD). There is a tension between the need to give a simple view of the design, that will allow any person new on the project to rapidly understand the overall structure, and the need to have a thorough, complete and detailed documentation that will serve as a repository from which various pieces of information can be extracted at will.

HOOD solves this difficulty by providing two descriptions for each object: a graphical description and a textual description. The consistency between these descriptions is ensured by the tools; a tool that would simply allow for drawing arrows between boxes and provide a simple text editor could definitely *not* qualify as a HOOD tool! Fortunately, there is a competitive market for real HOOD tools that provide this logical link between textual and graphical descriptions.

4.2.1 Synthetic view: the graphical description

The graphical description provides a general view of the object and its main features, *without going into details*. Graphical views are in general easy to understand and help greatly in figuring the general picture, as long as they stay simple, are not too big, and do not become overloaded with symbols, arrows, etc. That's why a graphical view is appropriate for general pictures, but should not be used to give precise details.

The graphical symbol for a simple HOOD object is given on figure 4-1. More sophisticated forms will be given as we encounter them in the course of this book.

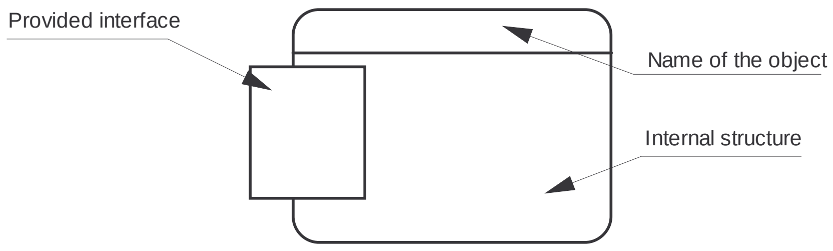


Figure 4-1 : Basic representation of a HOOD object

The object is represented as a container with its name on top, and a box containing the names of the provided services (the provided interface) on the left. As mentioned above, an object generally also requires services from other objects. These required objects are represented as small boxes, containing only the name of the required object, that appear on the border of the object, as represented on figure 4-2. Note that

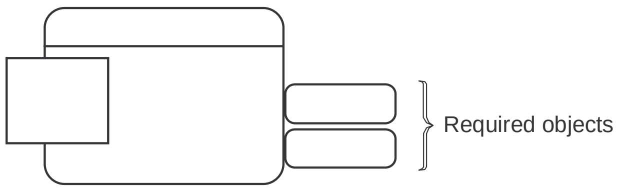


Figure 4-2 : Required objects

only the objects are represented at this level, *not* the precise required interface; these diagrams are intended to represent *the global framework of the object* for this level of decomposition, not the details of the dependencies.

Some object may have special properties that are of interest to the client; in this case, a distinctive letter appears in a box at the top left corner of the object. For example, some objects are *active*, i.e. they include their own thread(s) of control; this property is represented with an "A" in the upper left corner, as represented on figure 4-3.

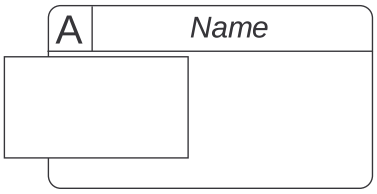
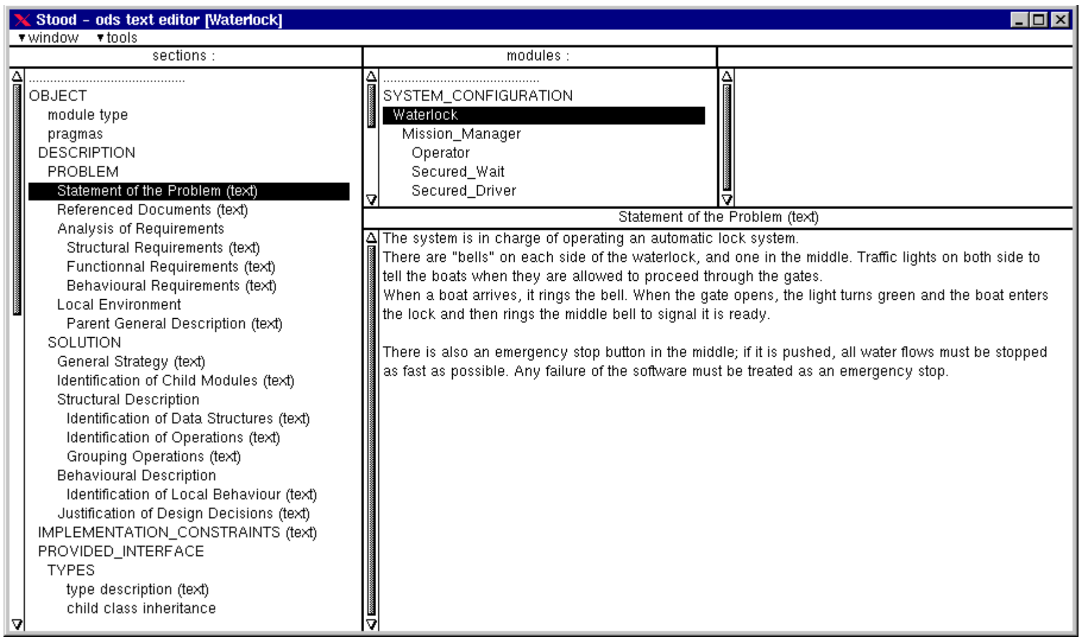


Figure 4-3 : An active object

When an object appears on a diagram as a server, no internal structure is displayed. It's only when design is focused on its *implementation* that the internal structure is shown. Otherwise, the strong solid line that surrounds the object is there to remind of its "black box" nature.

4.2.2 Detailed view: the textual description

The textual description is intended to keep as much information as possible about the object. It includes a lot of informations that were found relevant to *some* projects, but many are not useful for *every* project; actually, *no* project will need *all* the sections; that’s why it is allowed to leave some of them empty. The textual description is therefore long, detailed, and almost impossible to read from end to end. This is a deliberate choice: textual descriptions are easily processed by tools, allowing the designer to just view the interesting part for a particular task at hand. Figure 4-4 shows an example of such a tool.



```
OBJECT
  module type
  pragmas
 DESCRIPTION
  PROBLEM
   Statement of the Problem (text)
   Referenced Documents (text)
   Analysis of Requirements
    Structural Requirements (text)
    Functionnal Requirements (text)
    Behavioural Requirements (text)
   Local Environment
    Parent General Description (text)
  SOLUTION
   General Strategy (text)
   Identification of Child Modules (text)
   Structural Description
    Identification of Data Structures (text)
    Identification of Operations (text)
    Grouping Operations (text)
   Behavioural Description
    Identification of Local Behaviour (text)
   Justification of Design Decisions (text)
 IMPLEMENTATION_CONSTRAINTS (text)
 PROVIDED_INTERFACE
  TYPES
    type description (text)
    child class inheritance
```

```
SYSTEM_CONFIGURATION
 Waterlock
  Mission_Manager
   Operator
   Secured_Wait
   Secured_Driver
```

Statement of the Problem (text)

The system is in charge of operating an automatic lock system.
There are "bells" on each side of the waterlock, and one in the middle. Traffic lights on both side to tell the boats when they are allowed to proceed through the gates.
When a boat arrives, it rings the bell. When the gate opens, the light turns green and the boat enters the lock and then rings the middle bell to signal it is ready.

There is also an emergency stop button in the middle; if it is pushed, all water flows must be stopped as fast as possible. Any failure of the software must be treated as an emergency stop.

Figure 4-4 : An ODS editor (Stood, from TNI)

HOOD defines a fixed format for the textual description of objects. This format is called the *Object Description Skeleton*, or ODS. The ODS is organized as a (possibly quite long!) sequence of "sections", each starting with a keyword. For example, the provided interface of an object is described in the part of the ODS that starts after the key word `PROVIDED_INTERFACE`. A section may contain informal text, or formalized texts, depending on the section and how far the design has progressed.

The main sections of the ODS are (see figure 4-5):

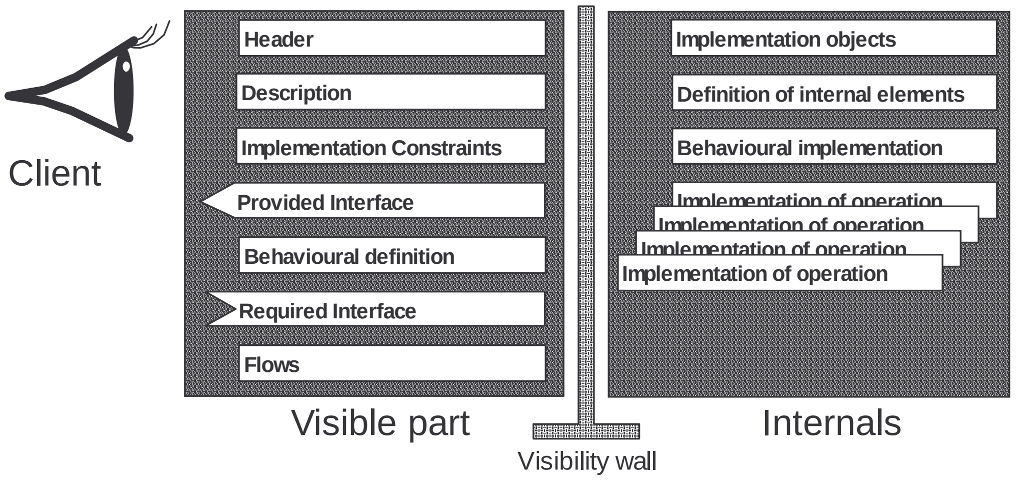

Client
Header
Description
Implementation Constraints
Provided Interface
Behavioural definition
Required Interface
Flows
Implementation objects
Definition of internal elements
Behavioural implementation
Implementation of operation
Implementation of operation
Implementation of operation
Implementation of operation
Visible part
Internals
Visibility wall

Figure 4-5 : Structure of the ODS

- A *header* that gives the name of the object and its kind (passive object, active class, etc.).
- A *description* section which includes only informal text for the "natural language" description of the purpose of the object.
- An *implementation constraints* section that describes particular conditions that must be met by the object due to the requirements of the implementation environment, like an upper bound to the memory used by the object, for example. This kind of constraints can be discovered at any stage of the development of the project, from requirements analysis to coding, and must immediately be documented in this section.
- A *provided interface* section that describes the various services that are made available by the object to its clients. Note that "services" may include things like types, constants, etc. and are not restricted to only subprograms.
- A *visible OBCS* section that describes the (observable) behavioural properties of the object
- A *required interface* section that describes the services used by this object acting as a client. Together, the provided interface and the required interface define the object as interfaces to the outer world.
- Several sections (*data flow, exception flow*) that give extra details about the services and the environment of the object; we will address these as we encounter them later in this book.

- An *internals* section that describes how the object is implemented. It includes also several subsections that will be described later. Everything described in the internals section is behind a "visibility wall": no external module can depend on the content of this section.

Most of these sections are mandatory. Sometimes however, a particular section may not apply: in this case, the section is filled with the word `NONE` or simply omitted.

> The description of the ODS given here corresponds to the latest version of HOOD (4.0). Earlier versions had slightly different headers or contents for some fields of the ODS, which are still accepted by tools for compatibility. The reader should therefore not be surprised if some forms not described here are found in actual, older, HOOD projects.

For example, the ODS for a simple object follows the following general structure:

```
OBJECT Object name is -- Header
  DESCRIPTION
    Informal description
  IMPLEMENTATION_CONSTRAINTS
    Informal description of implementation constraints (if any)
  PROVIDED_INTERFACE
    Formal description of the provided interface
  OBJECT_CONTROL_STRUCTURE
    Formal definition of behaviour
  REQUIRED_INTERFACE
    Formal description of the required interface
  DATA_FLOWS
    Formal description of data flows
  EXCEPTION_FLOWS
    Formal description of exception flows

  INTERNALS -- Visibility wall
    OBJECTS
      Declaration of objects that are necessary to the implementation

    (Several sections related to internal elements, not described here.)

    OBJECT_CONTROL_STRUCTURE
      Formal definition of the implementation of the behaviour
    OPERATION_CONTROL_STRUCTURES
      Formal definition of operations
END OBJECT Object name;
```

4.3 Design refinement: the "include" relationship

The "include" relationship, which defines objects as parents of other child objects, is the main originality that differentiates HOOD from all other object oriented methods, and gives the 'H' to its name - that's how the project is organized as *hierarchies* of objects.

4.3.1 An example

Let us consider a television set. A television is a kind of box which interacts with the external world: an On/Off button, channel selection buttons and a sound volume control. Moreover, it needs electricity in order to work.

For most users of the television, this is all they need to know about it. However, if you open the television, you discover that the television is no single big piece of electronics: it is assembled from various parts, each with a very precise function; and each of the controls of the television is actually a control of one of these parts. For example, the On/Off button is actually a switch on the power supply; the sound volume is a potentiometer which is logically part of the sound amplifier; etc. This situation is represented in figure 4-6.

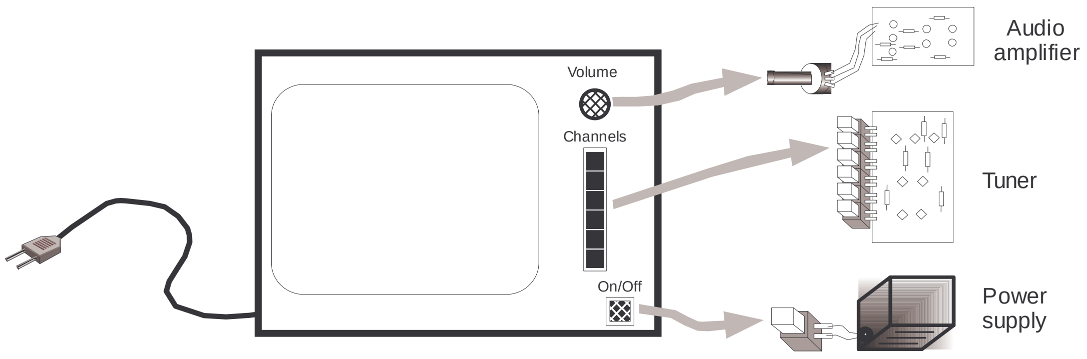


Figure 4-6 : Operations of a television set

In HOOD terms, we would say that the services of the television are *implemented by* services of the various boards; *externally*, the user sees the services as functionalities of the television, but *actually* they are services of the subparts. Once we see the internal structure, the television, as a whole object, disappears: it is just a convenient name that refers to a well organized set of subparts that do the actual work.

4.3.2 Parent and child objects

A high level object (i.e. the first objects to be defined in a design) may be decomposed into *child* objects; the initial object is called a *parent* object.

I-1		*Definition*
A parent is a module that includes at least one other module.		

I-2		*Definition*
A child is a module which is included by a parent.		

As any object, the parent object has an interface that defines the services it provides; however, it does not implement any service directly: they are all implemented by child objects. The goal of a parent is thus to *hide* the internal complexity of its implementation. This corresponds to the notion of *subsystem* found in other methods: a closed subset of a system that can be viewed externally as one single piece.

Graphically, a child object is represented inside its parent. An IMPLEMENTED_BY arrow connects each service provided by the parent to a service of a child that implements it. Figure 4-7 gives a representation of the television using this notation.

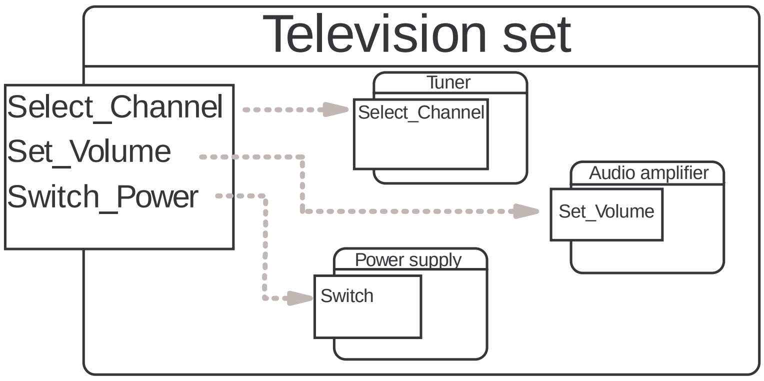


Figure 4-7 : HOOD representation of a television set

Note that the user sees, for example, a *volume button*, but the corresponding operation is called Set_Volume. This is because the names are chosen to show *services*: the button is the object, but *setting the volume* is the service provided by this button.

The IMPLEMENTED_BY arrow is the dotted arrow that goes from a provided operation of a parent to a provided operation of a child. For example, the Switch_Power operation is "implemented by" the Switch operation of the Power_Supply. In common words: the switch that appears on the television is actually a component of some hidden part inside - the power supply. Note that the operation that implements something may or may not have the same name as the operation being implemented.

I-6		*Methodological*
Each operation provided by a parent shall be implemented by one operation provided by one of its children.		

A parent is *required* (as opposed to simply allowed) to implement *every* property by a corresponding property of a child; a parent is an *empty shell* whose only purpose is to provide to clients a simplified view of the subsystem of all children. No code (nor data) is allowed directly within a parent. If it appears that some function could be implemented directly in a parent, a special child must be created to this purpose.

> This ensures that a parent is completely defined by the set of its children, with no "glue code" at parent level. It addresses the needs of a prime contractor, who must control the interface of the parent, but delegates the development of children to subcontractors; each child thus represents a well defined contract. This limits the integration effort by mastering the interfaces, while leaving full freedom to subcontractors for the implementation of their part.

How many children are allowed in a parent? There is no definite answer to this question. If there are too many children, relationships between them tend to be very complicated, but on the other hand, too few children will lead to spurious decomposition levels. In practice, the following rule of thumb can be used:

		Usage
A parent should be decomposed into 5 ± 2 children.		

Of course, the decomposition process is not limited to one level. During the design process, each child object will be further decomposed into more objects, and so on until the objects are deemed simple enough to be implementable in the target language. Objects that are not decomposed are called *terminal* objects and correspond to a module in the target language. Their description includes the associated code.

G-5		*Definition*
A terminal module is a module which has no child modules.		

Conversely, the object from where the design is started, i.e. the topmost object, is called the *root* object.

G-2		*Definition*
A module which does not have a parent is called a ROOT.		

Let us finally stress an important feature of the hierarchical mechanism of HOOD. It is often the case that a system has connections with the external world, and it is logical to show these dependencies at the top level of decomposition. For example, it is an important feature of the television that it features a sound volume control. However, *dealing* with these connections is often a low level implementation detail. The hierarchical mechanism allows the high level object to implement the functionality by some child, who will in turn implement it by some lower level child, and so on until the proper abstraction level is reached. In our example, the television would transmit `Set_Volume` to the electronic board, which will transmit it to the audio amplifier, as pictured in figure 4-8 below..

This figure is for explanatory purposes; on a real HOOD diagram, you *never* see several depths at the same time

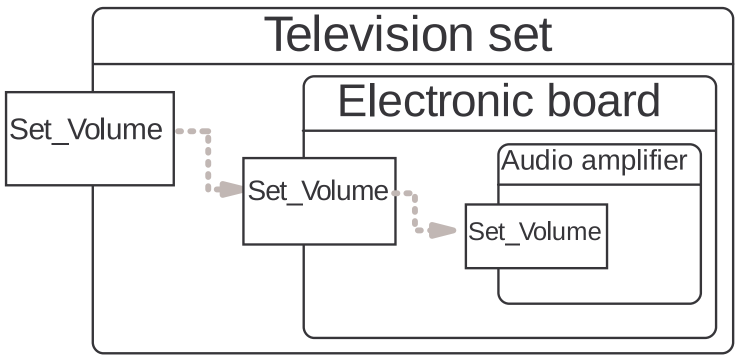


Figure 4-8 : Transmitting a connection to inner children

We see that the transmission of implementation solves the contradiction between a strong encapsulation mechanism and the need of having certain features appear in high level specifications, while being implemented by a low level module.

4.4 Client-server and the "use" relationship

The picture of the television given in figure 4-7 does not show all the parts in the television, nor the relations between these parts. For example, the various parts use power provided by the power supply; moreover, there is a device (not connected to the outside) that is used to amplify the video signals. In other words, some of the child objects provide services to others. We can even have child objects that implement *no* property of the parent's provided interface, but that are used only internally. Figure 4-9 shows a more complete representation of the television.

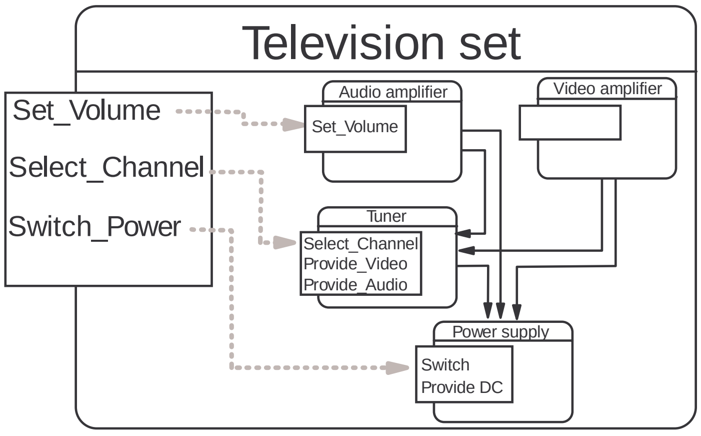


Figure 4-9 : The television set with "use" relationships

We see on this picture that the "use" relationship is represented by a bold arrow (the `USE` arrow). The arrow always goes *from client to server*, it is *not* related to the direction of the flow of data. It is a very rough information, only intended to show which objects act as servers for which clients; it does not show, for example, which *service* of the server is being used by the client. This more detailed information *is* managed by HOOD, but in the textual part: it would be too detailed for the graphical description. Once again, the idea is that the graphical description is only a simple, synthetic, and general view, while the textual description holds the full information.

Note that we have added more services to some child objects, that are only needed by their brothers, and also another child (`Video amplifier`) which corresponds to no operation from the outside (parent provided operation). This demonstrates a fundamental benefit of the HOOD approach: the outside view (as seen by clients of the `Television`) is *simplified* and *reduced* as compared to what actually happens inside. The parent object acts as the television box, whose purpose is to *hide* all the internal circuitry.

Finally, note that a client that uses a server does so through its provided interface, the only thing that is visible; the client knows nothing about the strategy used by the server to provide the services, and especially it does not know whether the server is a terminal object that implements the functions directly, or a parent whose services are implemented by children. This means that changing the strategy used by the server will never affect the clients. It is perfectly allowable (and actually recommended) to start with a prototype implementation of the server as a terminal object, and once the behaviour is validated, provide an actual implementation by further refining it into children.

4.5 Uncles: Combining the "use" and "include" relationships

4.5.1 Uncles

Consider the situation depicted on figure 4-10. This describes the first level of decomposition of a robot arm used for painting cars. We see that the robot includes two main parts, the physical arm and the driving device. Obviously, the driving device uses the physical arm.

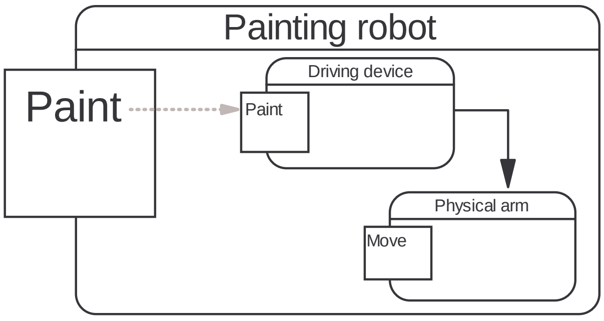


Figure 4-10 : A painting robot.

Consider now what happens at the next level of decomposition. If we analyse the driving device, we'll split it into a trajectory tracking system that will be in charge of computing and controlling the movements of the arm in space, a movement data base that will hold the data corresponding to basic movements, and a controller that will fetch the data from the data base and use them to drive the tracking system (figure 4-11). The interesting point in that example is that the driving device *as a whole* uses the physical arm, but *actually*, when decomposed, we see that only one of its children requires it: the tracking system. To summarize the situation:

- The driving device uses a brother, the physical arm. The physical arm is part of the required interface of the driving device.
- Since the driving device is not a terminal object, it is only an empty shell. There must be some child (the tracking system, see figure 4-11) that actually requires access to the physical arm.

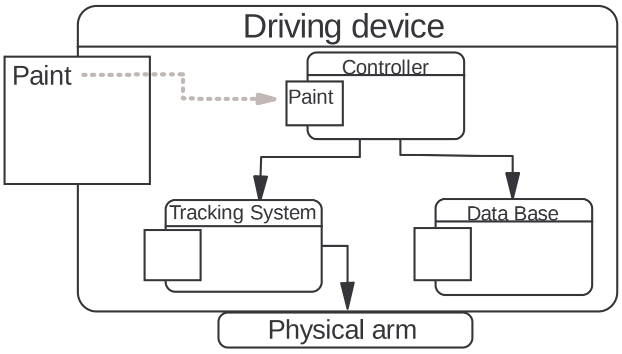


Figure 4-11 : The driving device.

- As viewed from this child, the physical arm is a brother of its parent. It is therefore called an *uncle*.

U-3		*Definition*
An uncle of a child module is a module used by its parent.		

This situation is very common, and results naturally from the decomposition mechanism of HOOD.

In the graphical description, we cannot have arrows pointing outside the current object (since we want to focus our view on the object itself). Therefore, uncles are represented by boxes at the edges of the object, and `USE` arrow can refer to them, as pictured for `Physical_Arm` on figure 4-11.

Let us stress now a very important aspect of this mechanism. Consider the situation exemplified on figure 4-12 below.

The following figure is just intended to explain the mechanism. On a real HOOD diagram, you never see global relationships *and* internals at the same time.

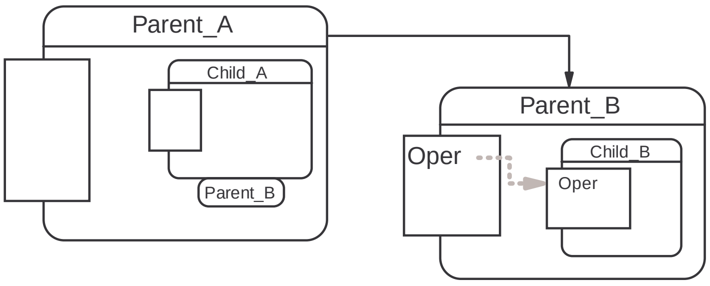


Figure 4-12 : Uncles and operations implemented by a child

At the upper level of design, we see that `Parent_A` uses `Parent_B`. But at the next level, we see that it is because `Child_A` needs it (it requires operation `Oper`); therefore, `Parent_B` appears as an uncle of `Child_A`. On the other side, we see that `Oper` is implemented by `Child_B`. Therefore, at execution time, `Child_A` will call the operation `Oper` of `Child_B`. This does not appear at design level, since the tools enforce the strict layered structure of the design, but the tools know it, and the generated code will result in a direct call to the actual eventual operation. In other words, the layered design structure does not end up in useless calls of subprograms that will just call other subprograms. There is no efficiency penalty in the generated code for the design structure. *The parent-child implementation model solves the contradiction between avoiding excessive nesting levels at run-time, and excessive complexity in the design.* This important property is not shared by many other design methods, and is a very positive effect of using HOOD, since the designers are not discouraged from a rigorous design by efficiency considerations.

If the target language is Ada, renaming declarations can be used to keep a code structure that matches the design structure for traceability reasons. If the target language is C++, the same effect can be achieved with macros or inlined functions. See the code generation rules in section 17 which describe implementation techniques.

4.5.2 Environment

Sometimes, a deep-level child needs the services of an object representing, for example, some reusable module, like a graphic or mathematical library. Since this library is not part of the current design, it should appear as a top-level, separate, hierarchy.

Normal HOOD rules require that a module used by a child be also marked as being used by its parent, since the child is part of the parent. If we follow strictly this rule, the library should be part of the required interface of every parent, up to the top-level one. This would clutter up the graphical description with a lot of uncles that are not really interesting from the point of view of the logical structure.

To avoid this, root objects from a different hierarchy are called *environment*, and are allowed to only appear at the decomposition level where they add significant information. In a sense, they are *implicitly* uncles of any object, without being part of the required interface of the parent. Because of this special property, they are marked with an "E" in the left part of the box.

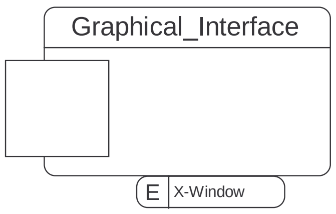


Figure 4-13 : Using an environment object

On the example of figure 4-13, objects inside `Graphical_Interface` may refer to object `X_Window` even if the parent object of `Graphical_Interface` does not refer to it.

Once introduced, environment are normally propagated to all lower levels. In other words, environment objects are allowed to enter the design tree by a "back door", at a level where they become significant. But once entered, they stay like any uncle. This avoids adding too much complexity to the diagram, for those objects which are not part of the software to be developed explicitly.

The notion of environment is very handy for representing the components that escape the normal hierarchical design, because they are used at any design levels. It is sometimes called "software buses" ([Rosen95-2]), by analogy with power buses in electronics, that can be used at any level irrespective of the logical structure. For example, the television requires power from the power plant. The power plant is therefore part of the required interface of the television, but it is clearly something "external" to the design of the television itself. It should appear as an environment object.

4.6 Other design issues

4.6.1 Splitting operations: OP_Controls

Sometimes, a provided operation of a parent does not match exactly one operation of one child, but rather a sequence of operations from one or several children. For example, an active object generally features a `Start` operation to initiate its activity. If the object is decomposed into several active children, its `Start` operation should call the `Start` operations of every child.

It would be tempting to have a procedure in the parent that simply calls the various operations, but this would break the principle that a parent object has no operation of its own. The operation could also be added to any child, but this would be a poor design, since it would not be logically related to the object that hosts it. Therefore, an intermediate module has to be introduced. However, it is not a full "object" in the sense that it does not correspond to any real-world object, nor has it the properties of an abstract state machine. It is rather an object reduced to a single functional abstraction, just here to express a sequence of actions. Since it is quite special, HOOD introduces a special kind of object for it: it is called an *OPeration control* (OP_Control).

G-7		*Definition*
An OP-Control is a terminal module without internal data dedicated to the implementation of one and only one operation.		

An OP_Control appears as a *child* of the parent, and *must* correspond to an `IMPLEMENTED_BY` arrow. It is represented as a simplified object, as on figure `4-14`. Note that there is no provided interface: only the operation name is significant.

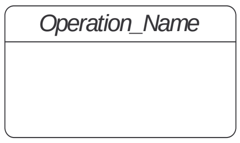


Figure 4-14 : Representation of an OP_Control

An OP_Control appears normally on the diagram, and `USE` arrows show which objects provide the operations being called. The example of the active object with `Start` operations would appear as on figure `4-15`.

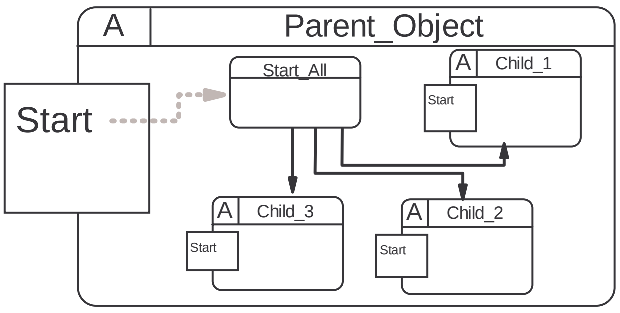


Figure 4-15 : Using an OP_Control

In practice, OP_Controls are seldom used; as soon as things get a bit complicated, it is better to provide a full-fledged object.

4.6.2 Grouping operations: operation sets

Sometimes, an object provides a set of operations that are logically related. For example, an iterator used to provide a walk through a data structure features an initialization operation, a way of getting an element and skipping to the next one, and an operation to check for the end of the structure. Applied to a file, this would correspond to the `Open`, `Get` and `End_Of_File` operations.

It would be possible to simply mention these operations in the provided interface of the object. However, this would not show the logical connection between the operations, and could lead to too many operations in the provided interface. For these reasons, such operations can be grouped into an *operation set*. An operation set has a name of its own and appears as only one element in the graphical description of the object. To differentiate it from an single operation, the name of the operation set appears within curly brackets, as shown on figure 4-16. Note that the object may provide other operations, not included in the operation set.

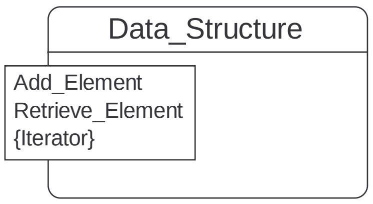


Figure 4-16 : An object with an operation set

An operation set may include other operation sets, but nothing else than operations and operation sets. This ensures that eventually only operations are provided; but the operation sets provide a convenient way of building a tree of operation groupings.

On most tools, it is possible to represent operation sets in "open" or "closed" representation. In the latter, only the name is displayed (as in figure 4-16) while in the former, the components of the operation sets are displayed. This allows the designer to see the level of details which is appropriate to his/her concerns at the moment. The same object in "open" representation appears on figure 4-17.

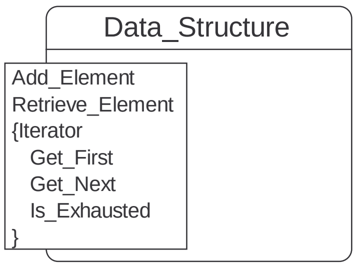


Figure 4-17 : An object with an open operation set

4.6.3 Sequential or concurrent execution: active objects

Normally, an operation is executed *sequentially* by the caller thread. Alternatively, the operation may be executed by another thread of control *on behalf* of the caller, allowing concurrent execution of the client and the service. This is an important property, since it requires a cooperation between the threads involved: a *protocol*.

HOOD offers various communication protocols that will be detailed in section 11.4.

For this reason, operations that are *not* executed sequentially are marked with a little "trigger" arrow, and an object that provides such operations is marked with an 'A' (for *active*). Other objects are said to be *passive*. It must be stressed that an active object is not simply the representation of a thread, but an object whose operations may influence the temporal behaviour (through scheduling, etc.) of the caller. At *implementation level*, active objects use tasks, processes, or threads, as provided by the language or operating system, but an active object is a higher level notion: for example, one HOOD object may correspond to *several* cooperating threads of control.

4.7 Summary

HOOD objects are basic design units, based on a client-server model. An object is either terminal or decomposed into *child* objects. A *parent* object is an empty shell whose purpose is to hide the implementation and lower the complexity of the design.

Objects use each others, and the "use" relationships is traced across all design level. An object that is used by the parent of a child is called an *uncle*, while a root object that can enter the design at any point is called an *environment* object.

Special objects used for functional modelling are called *OP_Controls*. Logically related operations can be grouped into *operation sets*. Objects may be *active* or *passive*.

5. Data modelling in HOOD

HOOD makes a clear difference between objects and data. Objects provide procedural services, while data are informations exchanged between objects by these services. Other design methods have taken the opposite view: everything is an object, as an instance of some defining class. This provides for a unification of concepts, a simplification from a theoretical point of view, but unification can easily lead to confusion. HOOD's choice is rather to separate concerns; separating data analysis from structural and functional analysis reduces the complexity that has to be dealt with .

5.1 Data flows

In the previous chapter, we saw that the graphical description tells which objects are clients of which servers. However, this is not sufficient to understand the relationships between client and server, because most of the time they exchange data (the parameters of the provided operations), which are part of the purpose of the server.

The flow of data is documented on the graphical description with *data flow* arrows, which are small arrows in the direction of the data flow: towards the server (in the direction of the `USE` arrow) if the data is consumed by the server, from the server if the data is produced by the server. A double arrow is used for data that transit both ways between the server and the client.

A double arrow may correspond to data that is modified by the server and returned to the client in one operation, or to data provided to the server in one operation and returned to the client in another one. It shows the flow of data between *objects*, not individual operations.

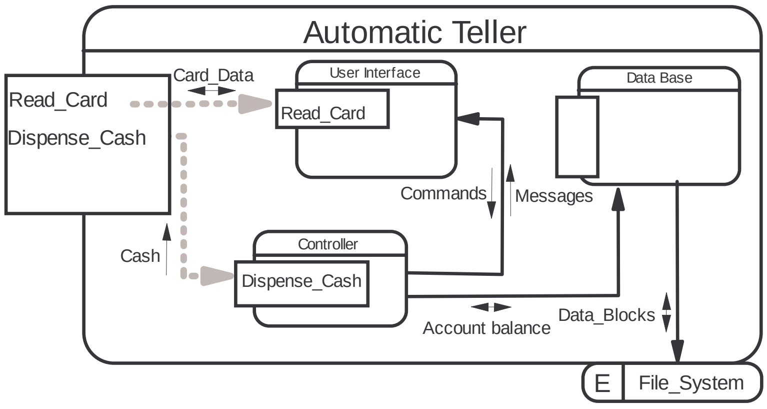


Figure 5-1 : Data flows

Each data flow arrow is documented with a name, an informal text which abstracts the information exchanged between the objects. Those arrows are put along the `USE` (or `IMPLEMENTED_BY`) arrow, as pictured on figure `5-1`.

This example shows the general organization of an automatic teller machine. The `Controller` sends messages to the `User_Interface`, and gets commands from it. It uses the customer `Data_Base` to update the account balance. The `Data_Base` exchanges informations in the form of data blocks with the `File_System`, an environment object.

Note that this figure does *not* show which operation of the user interface is used to send commands. It represents major data flows between *objects*, and is not intended to show the precise flows for each *operation*. Actually, it would be an error to try and show all parameters that are exchanged by the various provided operations. The graphical interface just shows flows that are useful for the understanding of the architecture. Of course, a complete description of all data flows is a very important documentation, but like any detailed description, it is kept in the textual description.

5.2 HOOD types

Every data in HOOD must be typed. A HOOD type defines the properties of data and parameters exchanged between objects, such as the set of values that belong to the type and the set of operations that can be applied to the data.

A type is recognized by its *name*, and data declared with different type names are different in nature, even if at machine level these types are represented identically, or with compatible machine types. This principle is called *strong typing*.

Although programming languages have various levels of typing, at design level, the focus is on the description of logical properties, not machine implementation. Therefore, strong typing must be applied, *even if the target language is not strongly typed*. In this case, the high level types of design will be implemented with the lower level types of the language, but the strong typing must be preserved at design level.

There is a hierarchy of types, according to their dependence to the target language and their degree of generality:

- Basic types.
- Abstract data types
- Classes

5.3 Basic types

Basic types are types whose value set and operations are entirely defined by the underlying language. Basic types can be *predefined* or *user defined*.

A predefined type is a type which is part of the definition of the language. They include predefined *integer types* (like Integer, Int, etc.), floating point types, fixed point types, boolean types... Such types vary not only with the language, but also with the machine, and sometimes with the compiler, even for the same language on the same machine. They suffer inherently from portability problems, but there is also a higher level issue: they do not belong to the *problem domain*. For example, it makes no sense to add a length to a voltage. If they are both represented as `FLOAT`, no consistency check can find such nonsense. So, it is generally better to avoid predefined types.

A user defined type is a type whose definition is provided by the user. It has at least a *name* that makes it different from other types. In the previous example, a `LENGTH` type can be defined that would be different from a `VOLTAGE` type. Both types can be *implemented* by a predefined type, but at design level, they are different types, thus improving possible consistency checks. Some languages (like Ada) can enforce that kind of strong typing for user defined types, while others (C, FORTRAN) cannot.

The properties of basic types (set of values, operations) are defined by the rules of the target language. For example, the following (Ada) definition:

```
type Counter is range 1..1000;
```

defines an integer type whose values are integer numbers in the range from 1 to 1000 (independently of any machine representation), with the usual arithmetical operations. On the other hand, the following (C) definition:

```
typedef int Counter;
```

defines an integer type of target-dependent range, with the usual arithmetical operations plus logical operations such as "shift", "and", "or", etc.

5.4 Abstract data types

Basic types are still very elementary. It is often useful to define more evolved data types, whose precise implementation is hidden and that can be accessed only by operations representing a well defined interface. Since the properties of these types are not linked to any concrete implementation, they are called abstract data types.

Abstract data types are convenient for describing entities of the problem domain. Since such types involve some structuring, as well as the definition of their behaviour, the data structure requires an analysis, and can be thought of as being made of various semantically important parts.

5.4.1 Introduction

HOOD provides a special construct to describe abstract data types, as a special kind of object, called a HOOD Abstract Data Type (HADT). It is represented like a regular object, but with square instead of rounded corners, as shown on figure 5-2. Abstract data type uncles (or environments) are represented as uncles with square corners.

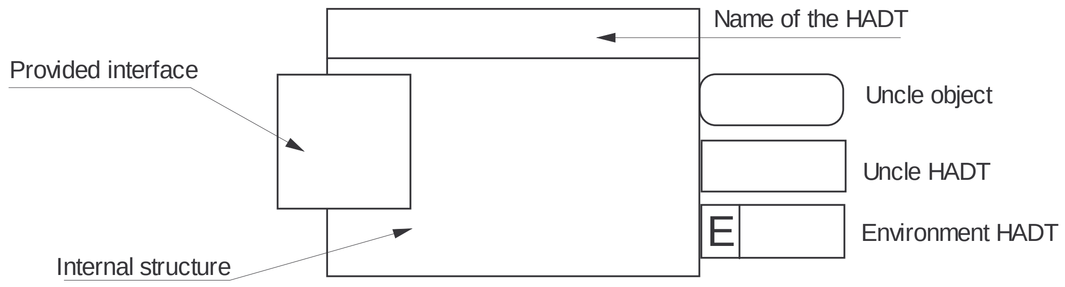


Figure 5-2 : Graphical representation of a HOOD abstract data type.

An HADT is an object whose provided interface exports a type, called the *main type*, and operations, all of which accept one or several parameters of the main type. The mandatory parameter of the type is called the *receiver*, and must have the name `me`.

Depending on the target programming language, there will be an explicit "me" parameter in the corresponding subprogram, or it will correspond to the implicit parameter called "self", "this" or "current".

G-8		*Definition*
An abstract data type is an object which provides one and only one main type and operations whose receiver is of type the main type.		

Only the type *name* is exported; the actual type structure is completely hidden, and is defined in the `INTERNALS` of the HADT. Since it is not possible to modify the structure directly, operations (called *constructors*) must be provided to construct values of the type.

From a client point of view, the HADT is assimilated to its main type, i.e. it is used like a type, but the object structure serves to encapsulate the type with its associated operations.

An HADT object is a regular object; it can be either terminal, or decomposed into other child objects that implement it. It can be a root (environment) object, or a child of some parent.

For example, figure 5-3 represents a fruit basket HADT. Since it is an HADT, the user may declare variables of type `Fruit_Basket`. It is possible to perform operations such as `Add_Apple`, `Remove_Melon`, or `Number_Of_Fruits`, to change or query the content of such a variable; *how* this variable is implemented is hidden.

5.4.2 Data refinement: the structure view

An HADT differs from other objects because its operations do not stand by themselves, but operate on data belonging to the main type. In order to use an HADT, the client must first declare one or several variables of the main type to which the various

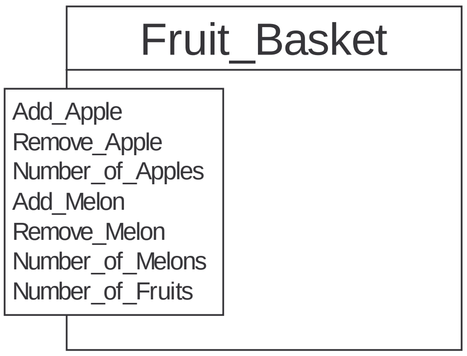


Figure 5-3 : A fruit basket HADT

operations are applied. The client therefore uses the HADT for its main type, *not* directly for its operations. This is still clearly a "use" relationship, but of a different nature than the one we have seen before: it is called a "type-use" relationship.

At this point, it is clear that there must be a way of representing graphically this new relationship. But putting new kinds of arrows on existing graphs would quickly lead to an excessive complexity. As usual, HOOD prefers to separate concerns. For this reason, relations between data structures are represented on a different kind of graph: the *structure view*. The graphical description that we used until now is called the *client-server view*. It is possible to display the structure view of every kind of object, but since it is used to describe the relationships between data structures, it is especially useful for HOOD abstract data types.

The structure view shows the parent and child objects like the client-server view, but the relations between the objects are different. A `USE` arrow in the structure view denotes a "type-use" relationship, which shows that the client uses a type defined in the provided interface of the server for one of its data. `IMPLEMENTED_BY` arrows are also possible on a structure view, but they always go from a provided *type* to another provided *type*. They mean that a provided abstract data type is actually implemented by another type provided by some child.

A full example of a structure view will be detailed in section 5.6.

The structure view does not replace the client-server view: both are necessary. The client-server view expresses the structure of the services (who uses what), while the structure view depicts the structure of the data that are exchanged along the relationships of the client-server view.

5.4.3 Aggregation

The "type-use" relationship is not the only way an abstract data type can be used: it is also possible to *aggregate* one or several abstract data types into another one. To state it simply, the *aggregating* type is made of several parts (components), and each part is of an *aggregated* type. The aggregating HADT is a client, since it includes elements provided by other (server) HADT. This relation is represented on the structure view with an AGGREGATION arrow, as represented on figure 5-4.

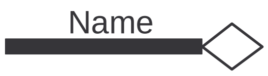


Figure 5-4 : Aggregation arrow

An AGGREGATION arrow joins the aggregating type to the aggregated type. The arrow is labelled with the name of the component in the aggregating type. Such components are called *attributes*, they are part of each instance of the type. Since an HADT can be non terminal, aggregated HADT may be children, as well as uncles, of the aggregating HADT.

Note that AGGREGATION arrows show the major aggregations, there is no obligation to have one for each component of the underlying structure. If components are basic types, there is no HADT to point to, and there cannot be any arrow to represent them.

The "aggregate" relationship should not be confused with the "type-use" relationship described before. A "type-use" relationship means that the client declares variables of a type provided by the server; it is a relation from *data (type instance) to type*. On the other hand, the "aggregate" relationship means that a type is built from other types: it is a relation from *type to type*. This is why it is necessary to provide a different kind of arrow for aggregation.

5.5 Classes

5.5.1 Introduction

Sometimes, different types share some common properties. In such cases, code sharing for common behaviours can be obtained through *inheritance*. Inheritance is a powerful tool, but it may increase the complexity of the design, and has to be controlled. Therefore, HOOD defines a special kind of HADT, called a *class*, for which inheritance is allowed. Only classes may use inheritance.

A class is represented like a regular HADT, with a "C" in the upper left corner. The same notation applies naturally to uncle classes also, as represented on figure 5-5.

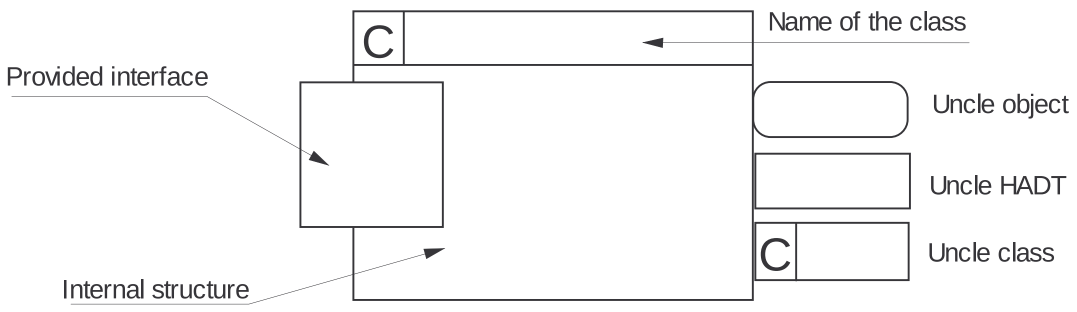


Figure 5-5 : Representation of a class.

5.5.2 Inheritance

As any abstract data type, a class may be defined and refined by *aggregation*, describing how they are assembled from other components; in addition, they can use *inheritance*, expressing that the new class is an extension of an existing class. Inheritance is represented on the structure view with an arrow whose form is given on figure 5-6. An inheritance arrow joins a *subclass* to its *superclass*.

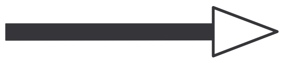


Figure 5-6 : Inheritance arrow

Inheritance in HOOD has its conventional meaning: the subclass gets the data structure and the operations of its superclass. Details of the inheritance mechanism (especially whether and how multiple inheritance is allowed) are left to the target language; the reasons for this are:

- Languages differ in their views of inheritance, and imposing a particular mechanism would lead either to not benefiting from all possibilities of the target language (if too restrictive), or inefficient implementations (if too liberal).
- Inheritance is *not* a driving aspect of HOOD; it appears only at the level of the leaves of the design tree, as a convenience when useful. There is therefore no *structural* issue involved when a design is used with different languages.

A class may inherit from one or several (if multiple inheritance is acceptable) classes, which may themselves inherit from other classes. Inheritance therefore defines, in itself, a tree structure (or to be mathematically correct, a lattice in the general case). Combining two independent tree structures would quickly lead to an excessive complexity. Therefore, when inheritance is used, it is necessary to forbid any further parent-child decomposition at the same time.

I-14		*Methodological*
A class shall be terminal.		

On the other hand, a class may be a root, or a child of another object. Whether a class should be a child or an environment is a design decision. A child appears naturally when a class is only used for the implementation of the enclosing object, while a reusable class appears as an environment that will be available to the whole project.

As a class is an HADT, it can also aggregate other HADT, or even classes. However, since a class is terminal, the aggregated HADT must be *external* to the class. It is important not to confuse aggregation, which describes (visibly) a data structure as gathering several other structures, with parent-child decomposition, which is an internal (and hidden) structuring.

5.6 Example

In this example[1], we show how we can model a company as an abstract data type. The object provides a number of services, some of which are related to the company itself (for example providing the gross income), while others are related to the employees, i.e. the people who work for the company (for example, whether a given employee previously worked for some other company). In a real project, there would be many such operations, but we'll show only one of each for the sake of the example.

The structure view of the company represented on figure 5-8 describes our model of the company, while the client-server view on figure 5-7 shows the provided services..

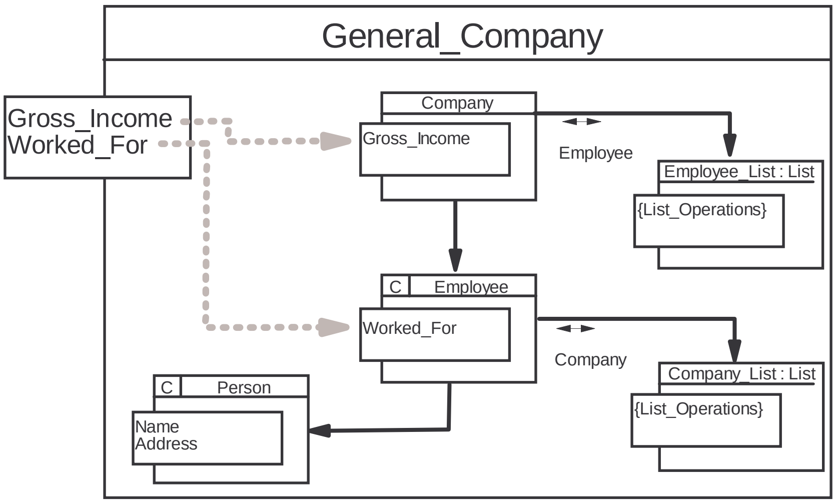


Figure 5-7 : Client-server view of the company

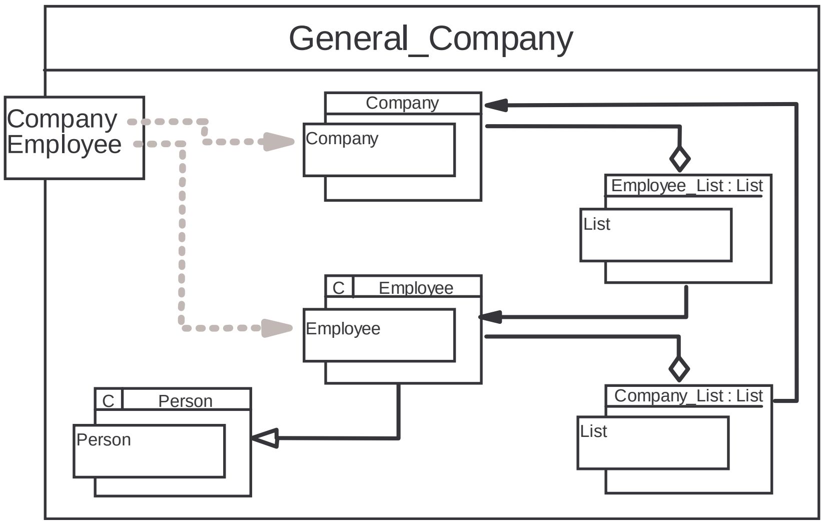


Figure 5-8 : Structure view of the company.

1. This example is derived, with permission, from the example presented in [Canals97]

We see a module, `General_Company` which provides two types, `Company` which represents the company itself, and `Employee` which represents the employees working for the company. These types are implemented by corresponding child modules.

The company aggregates a list of its employees (the list itself is provided by a generic module, as described in the next chapter), and similarly an employee aggregates a list of the companies he/she worked for. Note that each of these lists "type-use" the type of their components (black arrows), i.e. a list of employees has to make use of the type `Employee` itself, and conversely for the list of companies.

`Employee` is represented as a class rather than a simple HADT, since we expect to have various kinds of employees that will share common properties. It inherits from the class `Person`, which represents the characteristics of a person in general (whether an employee or not). This shows that an employee *is a* kind of person.

The client-server view shows that the services offered are implemented by the corresponding child modules. We see also that the class `Employee` uses operations from `Person`, and that each of `Company` and `Employee` modules uses operations from the corresponding list types (`OP_USE` arrows).

5.7 Summary

HOOD clearly separates data analysis from functional analysis. The main concern is for data exchanged between objects, represented with *data flows*.

Every data is typed. HOOD recognizes *basic types*, which represent the elementary types of the programming languages; *abstract data types*, whose internals are hidden and that can be accessed only through their provided operations; and *classes*, which are abstract data types that can *inherit* from one another, but cannot be further decomposed into child objects.

6. Other HOOD features

6.1 Exceptions: designing for reliability

A reliable system is one that can produce an appropriate behaviour under any circumstances, including unexpected ones. An important principle for the design of reliable systems is *mutual distrust*: if a server requires some conditions to be obeyed by its callers (like not providing a negative argument to a `Log` function for example), it should not assume that the condition will always be met: it should rather check it, to avoid transforming a small error into a potentially huge problem.

However this principle immediately raises an issue: what to do if the condition is *not* met? It is not possible to return normally to the caller, since the required service has not been performed. There must be a mechanism to specify an *abnormal return*, which is clearly distinguishable from a normal return. The HOOD element that achieves this is called an *exception*.

An exception is an entity which has a name, and can be declared by objects (including HADTs and classes), in the same way that they declare types or operations. It specifies the potentiality of an abnormal return of control (to the client) during the execution of an operation. When the corresponding situation is detected, control flows back immediately to the client in order to notify it. The flow of exception is thus *opposite* to the normal control flow and this is shown by a line crossing the "use" or "implemented-by" relationships. This line is marked with the exception name(s). For example, figure 6-1 shows a diagram with exception flows on `USE` and `IMPLEMENTED_BY` arrows. It represents a temperature monitor that gets tempera-

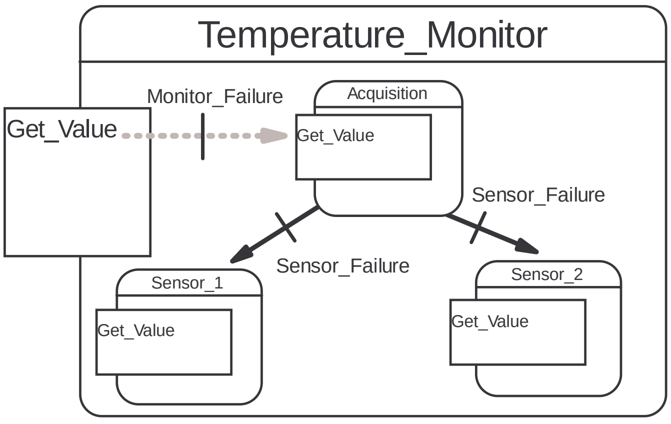


Figure 6-1 : Exception flows

ture from two sensors. If any sensor fails, it gets the value from the other one. If however both sensors fail, then the monitor as a whole reports failure

The last issue with exceptions is how to *handle* them: what should the client do in the case of such an abnormal return? It is up to the client to define it, but some response *must* be defined; otherwise, the exception may propagate to other levels that were not supposed to receive it, and the correct behaviour of the program will be at risk. This is why exceptions appear so prominently on the graphical description. Moreover, HOOD rules (that will be developed in section 9.3.2) ensure that when a client calls an operation that may raise an exception, it must define what happens to it.

6.2 Generics: designing for reuse

6.2.1 Generic definition

A generic object is a representation of a pattern of objects which can be reused and parameterized by types (including HADT and classes), constants and operations. These parameters define the *formal parameters* of the generic object.

R-9		*Methodological*
The formal parameters of a generic can only be types, constants or operations.		

Generics are only allowed as root objects (they cannot be children of another object); on the other hand, they may *use* freely siblings or other environment objects.

Generics cannot be child objects because they cannot actually provide services; they are just models. Only *instances* of generics (see below) can.

A generic appears on the graphical representation as an object (including HADT or class) with a special uncle named "Formal_Parameters", identified by an "F", which holds the definition of the formal parameters. Figure 6-2 represents a generic unit.

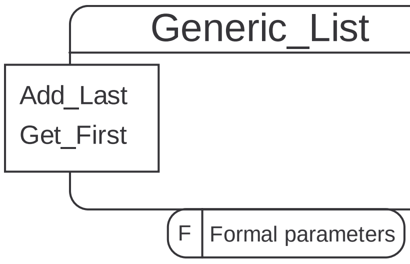


Figure 6-2 : A generic list

A generic is either terminal, or decomposed further into child objects, as usual. The formal parameters are really considered as an uncle; when a child of the generic requires a formal parameter, a `USE` arrow has to be drawn towards the formal parameters box. If the children of a generic are further decomposed, they must include the formal parameters of their parent in their required interface, as for any uncle.

> A generic object (or a non generic object) cannot have a generic child, since a generic is always a root object. Note that this rules is more restrictive than the rules for the equivalent structure (C++ templates or Ada generics) of the target languages. On the other hand, nothing prevents a generic from including a child that is an *instance* of a generic, i.e. a regular object built after the template.

6.2.2 Generic instantiation

An instance of a generic is a regular object, obtained from the generic by providing actual values to the generic formal parameters. These parameters must be provided by objects that are directly visible from the instantiation location; they may be supplied by environment objects, or siblings. As always, checks are performed to ensure that the actual parameters match the types of the formal ones.

Single instance

An instance can be either a child object inside some parent or a root (environment) object. Since an instance is a normal module, there is no special representation for it. However, its name must be followed by the generic name (in the header of the graphical description) to remind the reader that the object is an instance: the name is "typed" with the name of the generic object. For example, a list of measure points would be represented as on figure 6-3.

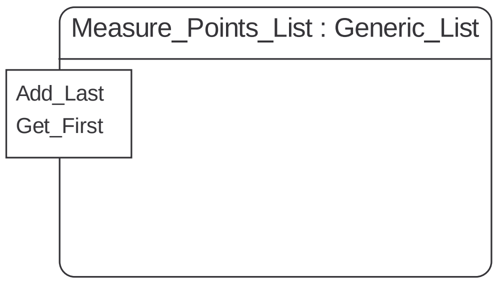


Figure 6-3 : Instance of a generic

Multiple instances

Sometimes, generics are used to provide a set of identical (modulo some parameterization) objects. For example, a plane with four engines requires one object to represent each of its engines; but since the engines are identical, it is better to design them only once as a generic, and then make four instantiations.

To show these similarities, the representation of several identical generic instances is a double shaped object or class with an indexed generic name "typed" with the name of the generic object. The names of the instances are generated as the generic name concatenated with the successive integer values of the index range. Figure 6-4 shows how the airplane's engines would be represented.

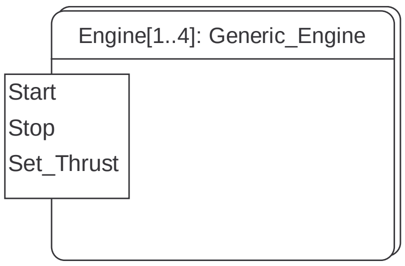


Figure 6-4 : Similar instantiations for the engines of an airplane

`Generic_Engine` is the name of a generic; the airplane has four similar engines, named `Engine[1]`, `Engine[2]`, etc. The objects (instances) are independent, but each has the same operations `Start`, `Stop` and `Set_Thrust`.

Since instances are made after a generic model, they have exactly the same interface as the model. The provided interface is a copy of the generic one (this is done automatically by the tool when an instance is declared) and is normally represented on the graphical description. On the other hand, although an instance inherits the full environment (required interface) of the generic, this imported interface is *not* shown in the graphical description. This is because the required interface is only a concern to the designers who deal with the generic, not to those who will use the instance.

> Dragging in the whole required interface of a generic would require including objects used by the generic into the required interface of the parent of the instantiation. It would clutter the design with irrelevant information, since the generic itself should be seen as a black box.

Note that multiple instances of a generic, whether obtained by several instantiations or by one multiple instantiation, are identical. Therefore it makes sense to have multiple instances only if there is some hidden internal state that can vary over time independently in each of the instances, either because there are global state variables, or because the object is active. Otherwise, calling a service provided by any instance would be strictly equivalent to calling the same service provided by another instance.

6.3 Virtual nodes: designing with distribution

HOOD has been designed with a great concern for distribution. This means that it allows the design of distributed systems without letting the distribution aspects clutter the whole design. It does it in the usual way: by separating concerns and isolating issues. Three independent views are important in a distributed system:

- the *logical space view*, consisting of a set of design trees. This is a set of software modules and is what we have been dealing with until now.
- a *distribution space view*, which deals with the definition of indivisible units of distribution, but still as logical entities. This will be the main object of this section.
- a *physical node space view*, which deals with the definition of physical nodes by configuration of distribution units. This is the available hardware.

The distribution space is modeled as a hierarchy of *virtual nodes*. They are called nodes because they *could* be units of distribution, but they are *virtual* nodes because they do not necessarily correspond to the physical nodes. Actually, several virtual nodes can be implemented on a single physical node.

A virtual node is represented as an object, with a "V" in the upper left corner, as represented on figure 6-5.

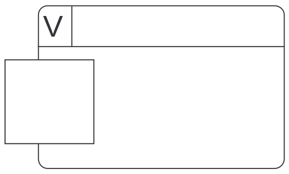


Figure 6-5 : representation of a virtual node

A virtual node is represented as an object with a provided interface, although it is generally empty. The reason is that this provided interface can be used to specify communication protocols, and other implementation details when they are not automatically taken in charge of by the tools. Similarly, virtual nodes can have `USE` arrows between them. Using these facilities is beyond the scope of this book.

A virtual node is either terminal (and corresponds to an executable if implemented by software), or decomposed into child virtual nodes (system level), therefore defining a tree of virtual nodes. In simple cases, this tree may be only two levels deep: level 1 represents the whole system, and level 2 the various servers. However, it may be more convenient to define more levels. For example, an airplane may be divided into a passenger subsystem, a control subsystem, and a flight subsystem. Each of these may (or not) be divided into more subsystems, as pictured on figure 6-6.

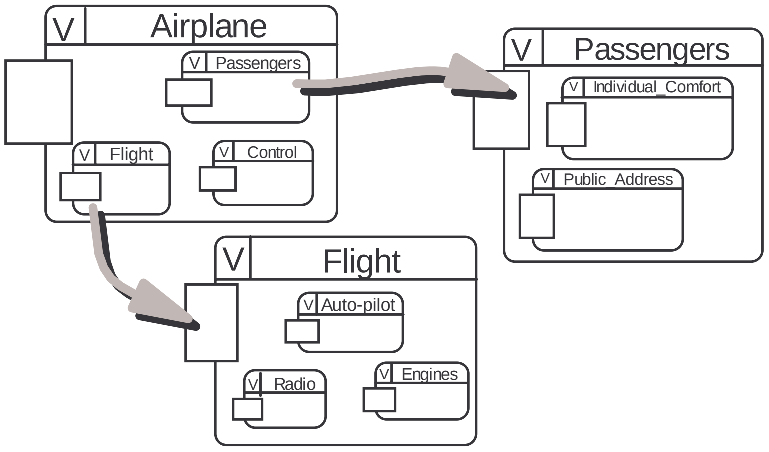


Figure 6-6 : VN description of an airplane

Note that this decomposition means that the passenger subsystem and the flight subsystem are considered independent enough to form different (but possibly still communicating) entities. It does *not* require them to be on different computers, they could all be implemented as subprocesses of a global centralized big computer (although this would obviously not be desirable!).

The previous partitioning was related to the logical structure of the project; it is not necessarily the case. For example, if it is expected that a system will involve several local networks, connected by a wide area network, it could be appropriate to describe the hierarchy of networks as a hierarchy of virtual nodes, as pictured on figure 6-7.

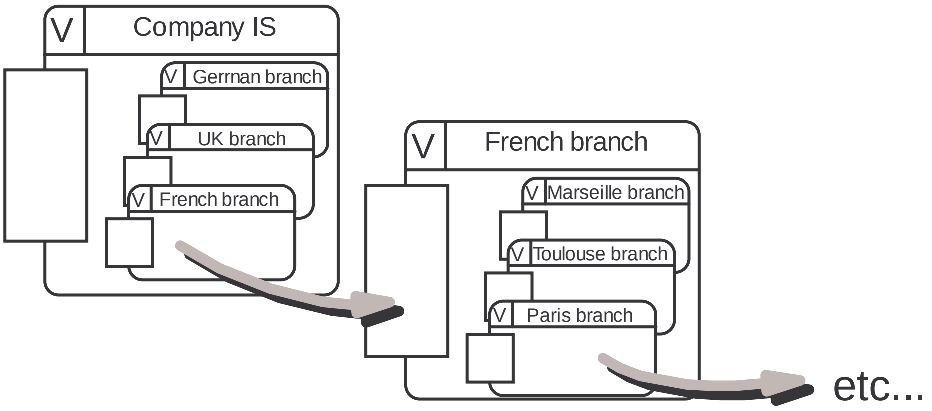


Figure 6-7 : A hierarchy of networks

Once again, this describes a *logical* structure of the system, there is no commitment to which parts of the software will run on which virtual node - and no commitment to a *physical* structure. For example, the Toulouse branch may run its programs on a machine which is physically in Paris, and also running the "Paris branch" virtual node.

A final note: the notion of virtual node is very handy to include in a design a representation of aspects that are not related to computers, like human operators, mechanical devices, etc.

6.4 Summary

Exceptions are the way to signal a client that the desired service could not be completed by the server.

Generics allow to make several similar objects (*generic instances*) from a common template. *Formal generic parameters* allow the instance to be parametered.

Virtual nodes provide a logical view of the distribution of a system that decouples it from any physical decomposition.

7. A design example

In this chapter, we show an example of a HOOD design. The reader is in the position of a project reviewer, i.e. we will present the structure of a project without explaining how it was obtained. The goal is to present how the HOOD "language" can be used to describe an existing project; the process that is used to design a project is of course extremely important, but it will be addressed later, in the third part of this book.

7.1 Introduction

This example shows the structure of an Electronic Mailing System (EMS). The system allows various people on a network to communicate by electronic mail. It is intended to work under a windowing environment, such as X-Window, with a nice user interface. Each user may send letters to other users, receive letters, reply, etc. There is a centralized data base of users, which is managed by an administrator. Only the administrator is allowed to add or remove users in the data base. Various parameters, such as window appearance, automatic text in messages, etc. can be configured.

7.2 General structure of the Electronic Mailing System

Figure 7-1 presents the client-server view of the first decomposition level of the EMS, and figure 7-2 presents its structure view. Note that at this point, it is really a *system* view: although it is designed as one HOOD object, it involves several *programs*.

The provided operations of the whole system are `Boot`, which represents the actions that are necessary to start the EMS when the computer is turned on, `ems` which represents the call by a user of the program that allows to send or receive messages, and a number of operations (represented here as an operation set, `GUI_Call_Backs`), that represent the *call-backs* issued by the OS following user interactions. Since the origin of the events (like mouse-clicks) is external to the system, we must represent the functions that are called in the provided interface. Note that this operation set is represented here in "open" state: we see that it includes three other operation sets, corresponding to various screens: the `Mail_Tool_Call_Backs` set for the regular mail tool screen, the `Administration_Call_Backs` for the administrator's screens, and the `Configuration_Call_Backs` for the screens dealing with personal customizing. These operations sets are *not* open here, since the precise defini-

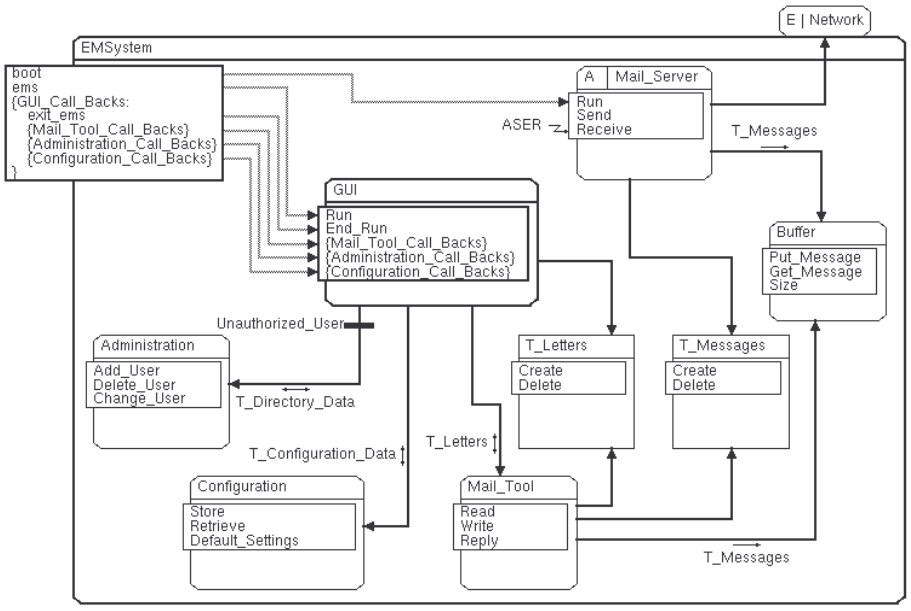


Figure 7-1 : Client-Server view of the EMS

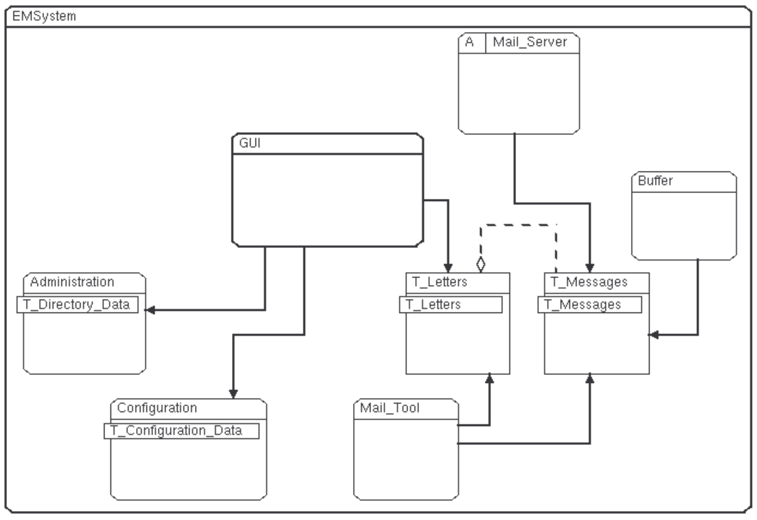


Figure 7-2 : Structure view of the EMS

tion of the call-backs is irrelevant for the current level of details. `GUI_Call_Backs` also includes an `exit_ems` operation which is the call-back to stop the program.

Internally, the system is decomposed into several children. We have decided here to separate the user interface from the various functions to be performed. We have therefore a `GUI` object which implements all user accessible functions, which constructs the various requests, and then uses the specialized objects to effectively execute the various functions. `Administration` is in charge of managing the user data base (with operations `Add_User`, `Delete_User`, and `Change_User`), `Configu-`

ration is in charge of managing user preferences (with operations Store, Retrieve, and Default_Settings), and Mail_Tool is in charge of actually sending and receiving the letters (with operations Read, Write, and Reply). We note the kind of data exchanged between the GUI and the various servers along the corresponding USE arrows (T_Directory_Data, T_Configuration_Data, and T_Letters), as well as the fact that Configuration may raise the Unauthorized_User exception if someone who has not the administrator's privileges is attempting some operation.

The Mail_Tool is the interesting part. It is in charge of transforming T_Letters (i.e. the high level notion, as viewed by the user) into T_Messages (i.e. the things that are exchanged over the network). This may involve adding headers, encoding the letter, etc. Those messages are put into a Buffer (with operations Put_Message, Get_Message, and Size) that serves as a temporary storage for the messages. A Mail_Server object is in charge of picking up the messages from the buffer and sending them to the Network (represented as an environment object that will include OS functions to access the network), and also getting the messages from the network and depositing them into the Buffer. Since Mail_Server implements the Boot operation, we see that it is started when the system is started.

The T_Messages play an important role; they are the basic data exchanged between the Mail_Tool and the network. They have to be created by an object, but are destroyed by another object. This calls for making them an independent module, but of course since T_Messages is actually a data exchanged through operations, this will be an HADT (with operations Create and Delete). If it is later discovered that there are actually several kinds of messages, the HADT may well evolve into a class. The same remark applies to the type T_Letters.

We note on the client-server view (figure 7-1) that there is *no* USE arrow from Buffer to the HADT T_Messages: this shows that Buffer does not create nor delete any message. On the other hand, since messages *are* parameters of Buffer operations, this arrow does appear on the structure view, as represented on figure 7-2.

We note also on this figure that T_Messages *aggregates* T_Letters, since messages contain (among other things) the letter itself.

7.3 Structure of the GUI

We won't detail here all the components of the EMS, but we'll go into more details for the GUI object to show an example of structural refinement. The client-server view of the GUI is represented on figure 7-3, and it structure view on figure 7-4.

Quite naturally, each of the operation sets is implemented by a dedicated child: Configuration_GUI, Administration_GUI, and Mail_GUI. Note that in general, most of the code for these modules will be generated with an User Interface

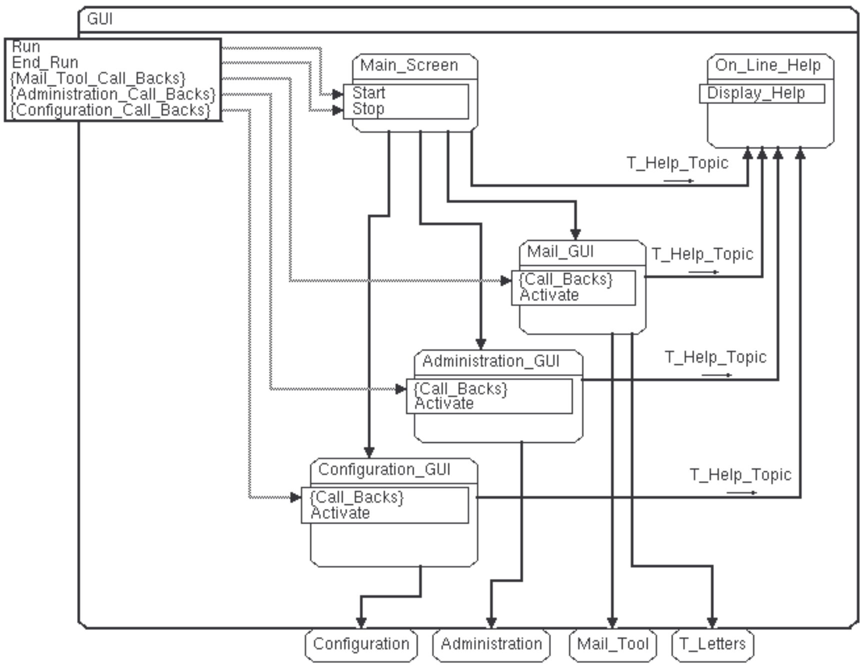


Figure 7-3 : Client-Server view of the GUI

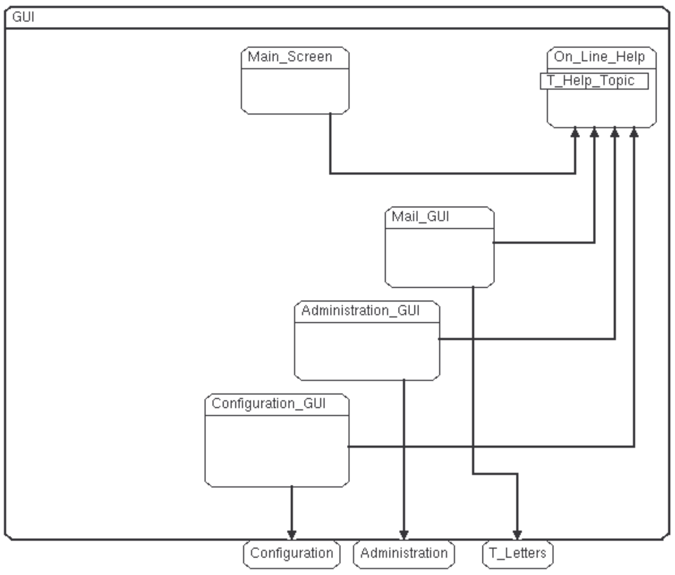


Figure 7-4 : Structure view of the GUI

Management System (UIMS). In addition, there must be a kind of "driver" to draw the initial screen and also terminate the system. This is done by the `Main_Screen` object, which implements the operations `Run` and `End_Run`. Each of the GUI objects also features a (non exported) `Activate` operation: when called, it will draw the corresponding screen and activate the associated call-back. On the other hand, there is no provided function to deactivate the screen, since this will happen from a user click on a "Quit" button in the corresponding screen, and is therefore internal to the object.

We also discover an object which is purely internal, the `On_Line_Help`. It is in charge of managing help windows. Help contexts are described as a data type which is exported by `On_Line_Help`, as can be seen on the structure view on figure 7-4.

7.4 Distribution

We can now decide how to split the various parts of the system over a network. Each user will reside on one node, while the `Mail_Server` will be on a dedicated server node. The administration system is a global resource that is not related to any special user, but must be shared by all users. For this reason, we may decide to map it to the server node. This can be defined using an allocation editor, like the one on figure 7-5 which shows which objects are allocated to the node `Server_Node`.

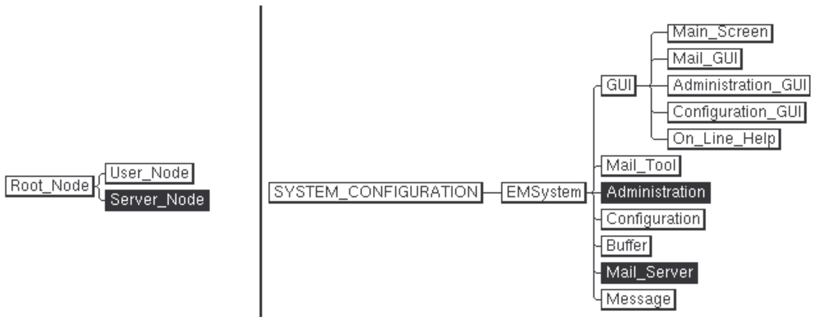


Figure 7-5 : Allocation of objects to VN.

7.5 Comments on the design

An important characteristic of this design is that we isolated into one object everything dealing with user interfacing. This solution has the benefit that everything related to the presentation layer is gathered in a single object, making it easier to change the appearance of the screens. Moreover, screens are often generated using GUI design tools, in which case it is more convenient to keep all presentation aspects together. However, an alternative design could have been to encapsulate all aspects of a function into a corresponding object, as represented on figure 7-6.

In this case, there is no `GUI` object at all (but the `Main_Screen` object needs to appear at the upper level), and each "problem domain" object implements its own callbacks. Note also that we had to add a `Stop` operation to each of the "domain" objects to allow the `Main_Screen` to stop them.

This alternative solution makes it easier to add new functions (everything to be added is concentrated in one object, including the user interface), but on the other hand

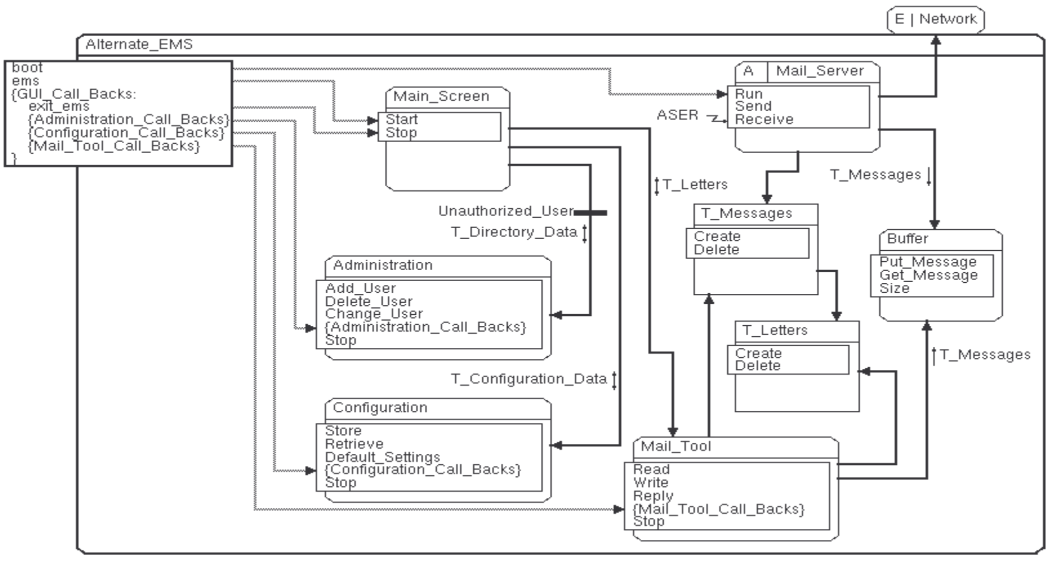


Figure 7-6 : An alternative design of the EMS.

changing the global appearance of all windows would necessitate changes in several objects, instead of only one in the previous solution.

Our goal is not to claim here that one solution is better than the other; they are both acceptable, and the trade-off is between various models of evolution of the system. However, the interesting point is that it is *very easy* to rearrange the design to transform one of the solutions into the other one. This involves just moving some objects and rearranging some arrows, an easy task with current tools. All external properties are preserved, and the designers can be assured that the system as a whole will still behave as before.

Part 2 : Formalization

In the first part, we have exposed the main notions involved in a HOOD design. However, a rigorous design process needs more than notions; precise definitions are needed, as well as standardized representations, in order for high level tools to be able to process and analyse the design, and to help the user to identify inconsistencies. This part will now take a more formal and detailed view at issues that are to be dealt when *writing* a complex system.

There are several important views of any project: structural (i.e. how the project is broken into modules), functional (i.e. the description of services to be performed), informational (i.e. the representation of data), and behavioural (i.e. the interactions between the various services). How to address them is a fundamental characteristic of any design method. A very important feature of HOOD is that these aspects are dealt with separately, therefore enforcing the principle of separation of concerns.

One chapter of this part will address the issues related to each of these aspects, while the last chapter will address how the project itself is modeled as a whole. Each chapter concludes with a "practical tips" section that gives tips, advices, or experience resulting from industrial usage.

8. Formalization and refinement of the structural decomposition

8.1 "Include" relationship

The decomposition into child objects is part of the implementation of the object. As a consequence, the "include" relationship is formally described in the `INTERNALS` part of the ODS. The `INTERNALS` include a section named `OBJECTS` giving the name of included children, plus, for each provided element, a description of how it is implemented, according to the following structure:

```
INTERNALS
   OBJECTS
      Child name
      ...
   TYPES
      provided_type IMPLEMENTED_BY Child_Name.Type_Name
      ...
   CONSTANTS
      provided_constant IMPLEMENTED_BY Child_Name.Constant_Name
      ...
   OPERATIONS
      provided_operation IMPLEMENTED_BY Child_Name.Operation_Name
```

Note that here, as well as everywhere in HOOD, an element that belongs to a module is referred to by giving the module name together with the element's name.

Of course, a child name given in the `IMPLEMENTED_BY` clause must be one declared in the `OBJECTS` section! Note that with HOOD tools, these sections are filled automatically, since the information can be inferred from the graphical description.

We have seen that a parent is only an empty shell. This is formally enforced by the following rules:

C-21		*Methodological*
A parent has no internal operations.		

C-23		*Methodological*
A parent has no data.		

This implies that the only way for a parent to provide operations is to have them implemented by children.

Some common sense rules ensure that the "include" relationship defines a proper tree:

I-4		*Methodological*
A child shall not have more than one parent.		

I-5		*Methodological*
A module shall not include itself.		

8.2 Provided interface

The provided interface is the most important part of an object, since it defines the services provided by this server object. Within the ODS, the `PROVIDED_INTERFACE` section has the following structure:

```
PROVIDED_INTERFACE
   TYPES
      Declaration (and potentially definition) of provided types
   CONSTANTS
      Declaration of provided constants
   OPERATIONS
      Declaration of provided operations
   OPERATION_SETS
      Declaration of provided operation_sets
   EXCEPTIONS
      Declaration of provided exceptions
```

Elements defined in the provided interface, and only those, are accessible from outside the object; elements defined elsewhere are completely hidden. The designer of an object knows exactly what can be accessed by clients, and what is completely under his/her responsibility.

V-11		*Methodological*
An entity (operation, type, constant, exception) not declared in the provided interface of a module can not be referenced (i.e. is not visible) outside this module.		

This rule is strictly enforced by the tools: a client cannot use anything from a server object unless it has been declared in the provided interface of the server.

Since a parent must implement its services by the provided services of its children, it must have access to them:

V-16		*Methodological*
The provided interface of a parent has visibility on the provided interface of its children for implementation.		

8.3 Required interface

On the client's side, a client object must declare in its `REQUIRED_INTERFACE` the services (and server objects) that it uses.

V-10		*Methodological*
A module has visibility on outside world only through its required interface.		

The required interface lists the subset of the services provided by the server which is actually used by the client. This provides traceability (knowing what is being used by a module), but is also a great help to testing and maintenance, which are primary concerns of HOOD: a precise specification of the required interface defines the test environment for unit testing.

Within the ODS, the `REQUIRED_INTERFACE` section. has the following structure:

```
REQUIRED_INTERFACE
   OBJECT Object_name
      TYPES
         Names of required types
      CONSTANTS
         Names of required constants
      OPERATIONS
         Names of required operations
      OPERATION_SETS
         Names of required operation_sets
      EXCEPTIONS
         Names of required exceptions

   OBJECT ...
```

There is one `OBJECT` subsection for each required object, which gives the object name, and lists which operation, type, or other service from the object is being used.

R-1		*Definition*
OBJECT fields shall list all of (and only) actual modules (i.e. siblings and uncles) required by the module.		

R-3		*Methodological*
For each actual module, the list of all required resources (types, constants, operation sets, operations, exceptions) shall be given.		

These rules imply that there is no other way for an object to access something than to declare it in the required interface; each object must accurately document which elements, from which object, are used. Tools even check that an external entity used in *the code* of an object has actually been declared in the required interface; the required interface is not pure documentation, it is kept true and accurate under tool's control.

Of course, the tools check also that the name of a service in a required interface matches the corresponding declaration in the provided interface of the server:

C-28		*Methodological*
The reference to an entity in the required interface of a client module shall be consistent with the declaration of that entity in the provided interface of the server module.		

In other words, all client-server relationships are traced and checked on both sides of the relation. The required interface tells what services are necessary to a client, while the `USE` arrows clearly show which clients use a given service.

8.4 "Use" relationship

A child may use the services provided by other child objects of its parent:

V-15		*Methodological*
A child has visibility on the provided interface of its siblings.		

On the other hand, a child *cannot use its own parent as a server*:

V-14		*Methodological*
A child has no visibility on the provided interface of its parent.		

In the television example, various boards need power from the power supply; but the internal parts are not allowed to consider the television *as a whole* as something they can use.

To permit a child to use its uncles, we need the following rule:

V-13		*Methodological*
A child has visibility on the required interface of its parent.		

As always, HOOD tools will check the consistency of the design, and especially that an uncle can appear in a child's description if, and only if, it is actually a brother or an uncle of some parent (the process can extend several levels down). This is formally stated by the rule:

U-4		*Methodological*
If a child module OP_uses an uncle, then it shall also be OP_used by its parent.		

The term *OP_uses* in the previous rule refers to the "use" relationship described here. This special term is needed in the formal rule to differentiate it from the other form of "use" relationship ("type-use").

Conversely, if a parent requires some brother (or uncle), it must be the case that some child also requires it, since the parent is an empty shell with no properties of its own:

U-5	*Methodological*
If a parent OP_uses another module, then at least one of its children shall also OP_use it.	

8.5 OP_Controls

Since an OP_Control is restricted to a single procedure, it has a simplified ODS:

```
OP_CONTROL OP_Control_Name IS
  INTERNALS
    OPERATION_CONTROL_STRUCTURES
      Only one (regular) OPCS allowed here (see page 84)
END OP_Control_Name
```

There is no provided interface since it is a simple procedure, and the `IMPLEMENTED_BY` arrow that points to it (there must be one) tells what it is doing.

C-24	*Methodological*
An OP-Control has no provided interface.	

If processing requires the use of internal data, it creates dependencies on the corresponding data types: a full object must be used.. The following rule enforces that an OP_Control is only an "adaptor ring" between a provided operation of a parent and several children, and cannot be used to provide higher level functionalities:

C-25	*Methodological*
An OP-Control has no data.	

8.6 Generics

8.6.1 Generic module

A generic object has the same ODS as a regular one, with the addition of a `FORMAL_PARAMETERS` part immediately after the header of the ODS:

```
FORMAL_PARAMETERS
  TYPES
    Names of required types
  CONSTANTS
    Names of required constants
  OPERATIONS
    Names and signature of required operations
```

Note that the `FORMAL_PARAMETERS` is similar to an `OBJECT` section, since the formal parameters are considered an uncle. The formal parameters are given in the target language syntax.

R-10		*Methodological*
FORMAL_PARAMETERS field in a generic definition shall list all formal parameters, i.e. types, constants and operations required by the generic itself or any of its descendants.		

In the client-server view, a "use" relationship toward the "Formal_Parameters" uncle is represented if, and only if, a child requires execution of a service provided by the object's formal parameters. Conversely, in the structure view, a "type-use", an "inherit" or an "aggregate" relationship toward the "Formal_Parameters" uncle is represented if, and only if, a child of the generic requires a type, inherits or aggregates one.

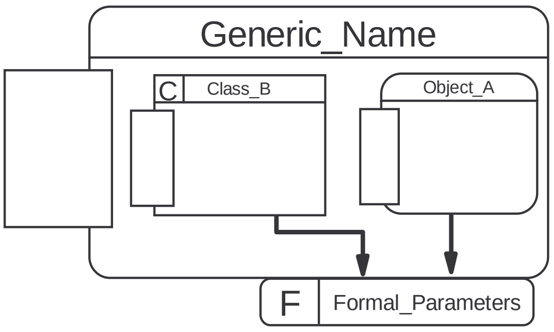


Figure 8-1 : Client-server view of a generic

On figure 8-1, we see that `Object_A` and `Class_B` use some operation that is provided by the formal parameters. On the other hand, figure 8-2 shows the structure view of the same object.

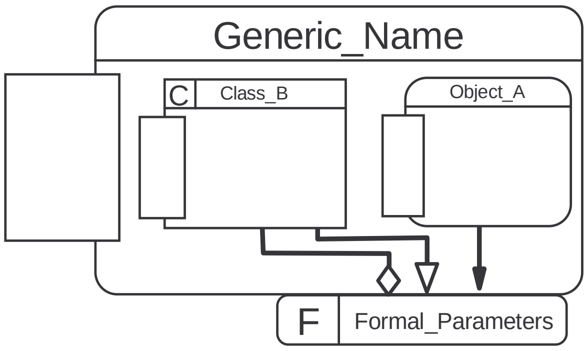


Figure 8-2 : Structure view of a generic

Here, we see that `Object_A` "type-uses" a formal parameter, i.e. it declares an element whose type is provided by a formal parameter. On the other hand, `Class_B` aggregates a type, and inherits from a type, that are both provided by the formal parameters.

8.6.2 Generic instance

The only things that must be defined for an instance of a generic are the actual parameters. Of course, these parameters may be provided by other objects, therefore there is also a `REQUIRED_INTERFACE` section, but only objects (and the corresponding services) needed by the `PARAMETERS` part may be mentioned. The full ODS for a generic instance has the following structure:

```
OBJECT |CLASS Generic_Instance_Name IS INSTANCE_OF Generic_Name
   [ INSTANCE_RANGE lower_bound..upper_bound ]
PARAMETERS
    TYPES
      Formal_Type_Name=> Object_Name.Actual_Type_Name
      ...
    CONSTANTS
      Formal_Constant_Name=> Object_Name.Actual_Constant_Name
      ...
    OPERATIONS
      Formal_Operation_Name=> Object_Name.Actual_Operation_Name
      ...
DESCRIPTION
  Standard fields
IMPLEMENTATION_CONSTRAINTS
  Standard fields
PROVIDED _INTERFACE
  Copy of the generic's provided interface
REQUIRED _INTERFACE
  Standard fields
DATAFLOWS
  Standard fields
EXCEPTION_FLOWS
  Standard fields
END Generic_Instance_Name;
```

Note that if a formal parameter is an operation, an actual operation has to be provided for the instantiation, and this operation will be called from the instance; therefore, a `USE` arrow must be drawn between the instance and the server (brother, uncle or environment object) that provides the operation. On figure 8-3, we see an example of a

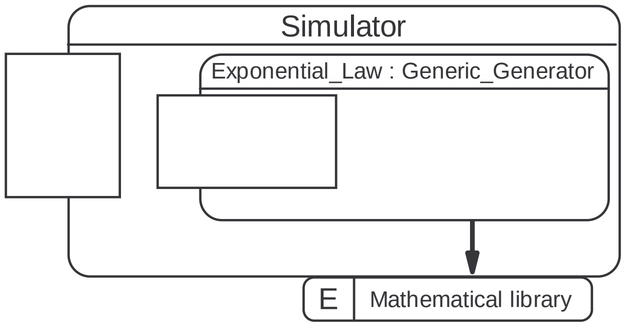


Figure 8-3 : Dependencies of an instance

generic random number generator that can be parametered by a function, in order to provide various probability laws. It has been instantiated as an exponential generator, by using the exponential function provided by the mathematical library. There is therefore a dependence from the instance to the library.

8.7 Practical tips

8.7.1 Provided interface

The provided interface is extremely important, since it is what allows the object to be used by clients. In practice, not all aspects can be described formally. It is a good practice to add to each element of the provided interface a free-text textual description of the semantics of the element, including boundary cases, error cases, etc.

In some cases, it may be appropriate to duplicate this information in places where it is convenient to have the documentation readily available.

8.7.2 "Use" relationship

Some usage rules are intended to enforce software engineering principles:

		Usage
The "use" interconnection graph of a set of objects should not be cyclic.		

This means that objects should not use each other circularly, like objects `A`, `B`, and `C` on figure 8-4. Such a circular relationship would raise structural issues, since each ob-

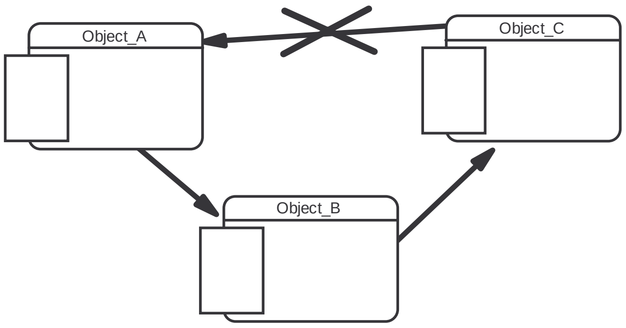


Figure 8-4 : Circular "use" between objects.

ject is at the same time a client and a server; it is strongly coupled, since no object can be made independent of the others; and it would also hinder the test process. Practice shows that such a structure often results from an incorrect decomposition of objects: either from operations that have been allocated to the wrong object, or entities that have been split in two different objects when they shouldn't have been.

If the circularity comes from a service being allocated to the wrong object, the solution is to move the service to the proper object (from `Object_A` to `Object_C` in the example).This means that `Object_A` would call `Object_C`, rather than the other way round; note that this has no influence on the direction of data flows. An example where the direction of the call was similarly reversed can be found in the final example, see section 20.3.5

		Usage
The "use" interconnection graph should be of as low complexity as possible, i.e. objects should use as few other objects as possible, but they should be used as much as possible.		

The graph of "use" relationships is the highest level description of the solution. It is therefore important to keep it as simple as possible. If too many objects are using each other, it might be better to isolate sub-graphs. Figure 8-5 shows a graph of objects which can be interpreted as three strongly coupled objects (`B`, `C`, `D`) used by object `A`.

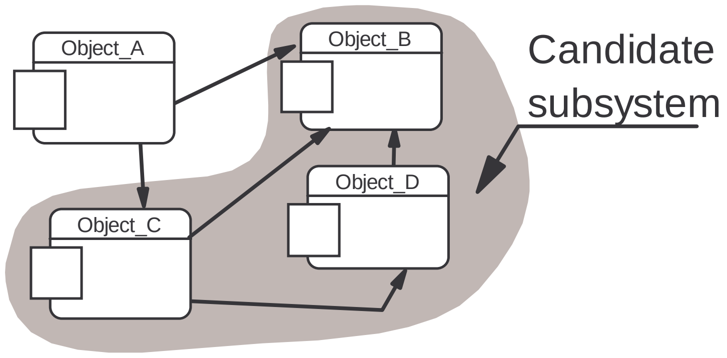


Figure 8-5 : A complex "use" structure

The graph can be simplified by considering that `B`, `C` and `D` make up a subsystem, and encapsulating them into an object, as represented on figure 8-6. This way, the extra complexity that results from the coupling between objects is *hidden* to `A`.

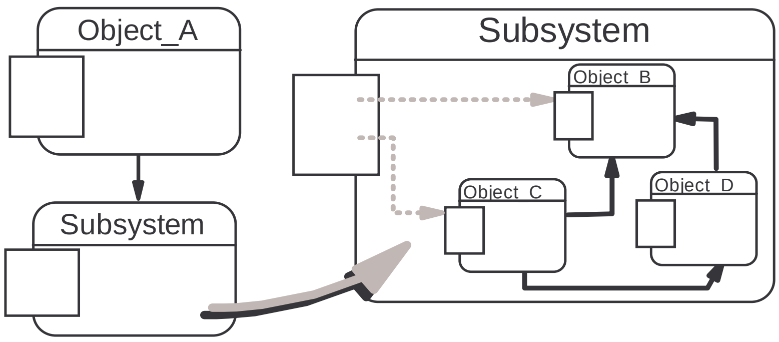


Figure 8-6 : Reducing "use" complexity

Note that operations of objects `B` and `C` that were previously used directly by `A` are now operations of the single object `Subsystem`, which are implemented by the corresponding operations of `B` and `C`. The structure is more understandable and simpler.

8.7.3 Environment or child object?

It is not obvious whether a required object should be made a child or an environment object. Making it a child means that it is included in the parent, and not directly usable outside. But, making it an environment means that it becomes a top level object, that can be used everywhere, therefore weakening the strict hierarchical design. There is no simple, general answer to this issue, and it must be dealt with on a case-by-case basis. Here are some hints that can be helpful to the designer.

- If the object is implementing some operations of its parent, HOOD rules require that it be made a child (operations can be implemented only by children).

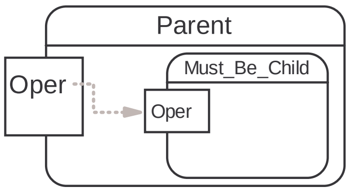


Figure 8-7 : Implementing some parent operation

- If the object requires some other child which cannot itself be an environment, then it must be also be a child.

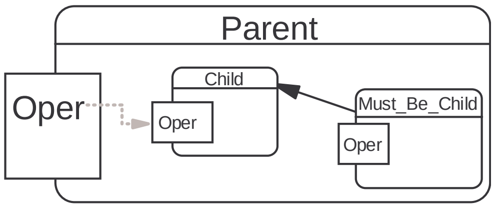


Figure 8-8 : Using another child

- If the object represents a library of software components, and especially some off-the-shelf library not designed by the current project, it has to be an environment.
- If a child has all or most of its provided interface re-exported by its parent, it is likely that it has to be moved up or put as an environment (unless it requires some brother objects, in which case the previous rule would apply). There is no benefit in having an (internal, hidden, independent) child, if it is used from the outside.
- If a child object is heavily used by several brothers (and deep nephews), it may be a reusable entity that should rather be an environment. Otherwise, too many "use" relationships through several levels of decomposition would clutter the design.

8.7.4 Starting active objects

Since an active object has a life of its own, it must be started at some time. In Ada, tasks start automatically. In other languages, there may be a "start" operation.

		Usage
An active object must have a "start" operation		

HOOD recommends to provide a "start" operation for each active object, to make sure that the point of activation is perfectly deterministic and controlled; this applies also to full designs, since they must have a starting point. If an active object uses an Ada task for its implementation, this task must provide a synchronization point for the beginning of its actions, like an entry or a call to a protected object. Moreover, it could be useful to add a `Stop` operation to correctly stop the activity of the object.

8.7.5 Redundant systems

A redundant system is one where some functionalities are handled in parallel by two independent computers; in case of a hardware failure in one of them, the other one can be used to provide a back up and ensure continuous operation.

Of course, the redundancy should be hidden to clients, and both systems are similar. It is therefore natural to make the server generic, and to have two instances. A dispatcher will direct the requests to the servers, as pictured on figure 8-9.

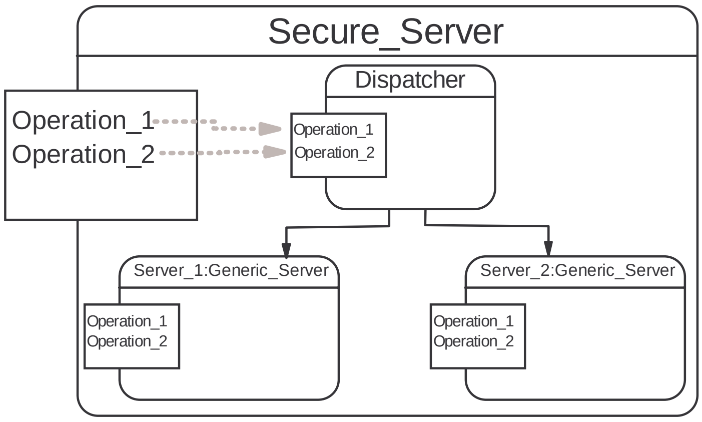


Figure 8-9 : Model of a redundant system.

Of course, the duplicated servers will normally be allocated to different virtual nodes, in order to allow for a distributed implementation which is necessary if redundancy is intended to allow to recover from hardware failures.

8.8 Summary

The ODS of an object includes a `PROVIDED_INTERFACE` section that formalizes all the provided properties, and an extensive `REQUIRED_INTERFACE` that formalizes every required property from any object used. In addition, generics have a FORMAL_PARAMETERS section to describe their parameters. In an instance of a generic, there is a matching `PARAMETERS` section to provide actual parameters.

Visibility rules, which are checked by the tools, ensure that only operations declared as being used are actually used by the code.

9. Formalization and refinement of functional aspects

9.1 Operations

9.1.1 Specification of operations

Each provided operation is described in the provided interface of the module that provides it. The formal description includes the operation's name, the names and types of all parameters, and if the operation returns a value, the type of the returned value. This is called the *signature* of the operation. Each parameter is further qualified as "`IN`" (a parameter which is not changed by the operation), "`OUT`" (a parameter whose value is provided by the operation, the previous value being irrelevant) and "`IN OUT`" (a parameter whose value is modified by the operation).

The syntax of the description is inspired by Ada, but is actually independent from the target language. The tool will transform this description into the appropriate syntax for the language. For example, imagine an object that provides an operation called `Safe_Add` that adds `Value` to `Variable`, and tells in a boolean `Success` if the operation was performed or if it overflowed. There is also a function `Negate` that returns the opposite of its argument. The description of these operations would be:

```
PROVIDED_INTERFACE
  OPERATIONS
    Safe_Add
      (Value    : IN      Integer;
       Variable : IN OUT  Integer;
       Success  : OUT     Boolean);

    Negate (Value : IN Integer) return Integer;
```

Note that the difference between a procedure and a function (in Ada terms) is the presence or absence of a `return` in the declaration. In C/C++ terms, if there is no `return`, it corresponds to a function that returns `void`.

Internal operations

In addition to provided operations, a terminal module may need *internal* operations that are local subprograms, only used within the object itself, and not provided to the outside. Since they are not visible, they are declared in the `INTERNALS` part of the ODS, in the `OPERATIONS` subsection, with the same syntax as provided operations.

9.1.2 Implementation of operations

A terminal object (whether a regular object, an HADT or a class) actually implements its provided operations in code. The implementation of each operation is described in the ODS by a structure called the *OPeration Control Structure* (OPCS). *How* an operation is implemented is, of course, not visible from the outside. Therefore, the description of the implementation of operations is part of the `INTERNALS` section of the ODS. Every operation, even internal ones, *must* be described by an OPCS.

C-18		*Methodological*
Each provided and internal operation of a terminal module shall have an OPCS.		

Note that we are talking here about *terminal* objects; non-terminal (parent) objects have no OPCS, since they implement their operations by child objects.

C-22		*Methodological*
A parent has no OPCS		

All operations are described in the `OPERATION_CONTROL_STRUCTURES` section of the ODS, each with an `OPERATION` subsection. The structure of this section is as follows:

```
OPERATION_CONTROL_STRUCTURES
   OPERATION operation_name
      DESCRIPTION
         Informal description of HOW the service is implemented
      USED_OPERATIONS
         Operation_Name
         ...
      PROPAGATED_EXCEPTIONS
         Exception_Name
         ...
      HANDLED_EXCEPTIONS
         Exception_Name
         ...
      PSEUDO_CODE
         Operation main algorithm
      CODE
         Actual code in target language
   END_OPERATION operation_name;

   ... -- Description of other operations
```

Of course, irrelevant subsection can be omitted. Here are some more details on the meaning of the subsections:

- `USED_OPERATIONS` lists every operation called by this operation. It must be consistent with the `REQUIRED_INTERFACE`!

- `PROPAGATED_EXCEPTIONS` lists every exception that is raised within this operation and *not* handled locally (and thus returned to the caller).
- `HANDLED_EXCEPTIONS` lists every exception that is raised *and* handled within this operation (and thus, not known to the caller).

  Note that when an operation raises an exception, the exception must appear on the client side either as a `PROPAGATED_EXCEPTION` or as a `HANDLED_EXCEPTION`: The designer cannot inadvertently forget the exception.

- `PSEUDO_CODE` gives a pseudo-code structure for the operation. This is generally very important if the code is in a low-level language (i.e. assembler), but generally useless and best avoided when the implementation language is (almost) at the same level as the pseudo-language (Ada). In this case, a simple outline of the algorithm can be given in the `DESCRIPTION` section.
- `CODE` gives the actual code of the operation in the target language, including possible local declarations (local variables, local types, etc.).

Depending on the tool and the target language, it may or may not be possible to check the consistency of the `CODE` section with regard to the other sections, i.e. that only `USED_OPERATIONS` are actually used, etc. Even if such an automated control is not possible, it is generally quite easy to check consistency manually, since the granularity of operations is such that the amount of code involved is quite small.

C-16		*Methodological*
An operation listed in the USED_OPERATIONS field of an OPCS shall be either a required operation, an internal or a provided one.		

This rule explicitly forbids using operations that are not officially declared in one of the relevant sections of the ODS, ensuring in turn that they have an OPCS. The principle is that *no code*, even for very little things, should be without at least *some* formal declaration at design level, and that there must be an explicit link to each operation being used: once again, total traceability is guaranteed.

9.2 Operation sets

Operations that are members of an operation set are declared normally (individually) in the textual description, but their name is followed by the keyword `MEMBER_OF` and the name of the operation set to which they belong. Similarly, `MEMBER_OF` is used to declare an operation set which is itself a member of another operation set. Of course, an operation set can be part of the provided interface of a non-terminal object, but then the full set has to be implemented by some child.

O-4		*Methodological*
An operation set of a parent can only have operations and/or operation sets as MEMBER_OF elements.		

This rule shows that an operation set can only provide operations (i.e., no data, exceptions, etc.). An operation set *can* include another operation set, but it does not contradict the previous statement, since everything will end up being operations.

When an operation set is provided by a non-terminal object, the `INTERNALS` of the parent object include an `IMPLEMENTED_BY` link to the child's operation set, and a corresponding arrow joins the two operation sets, as represented on figure `9-1`.

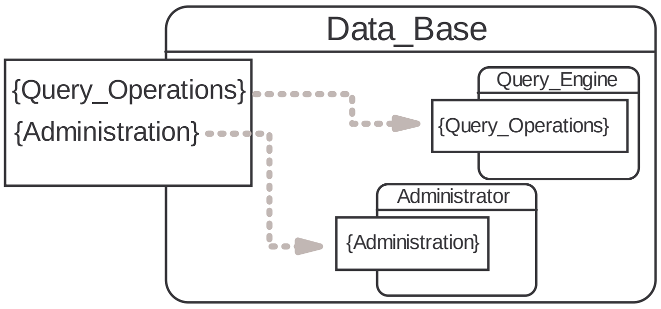


Figure 9-1 : Operation sets implemented by children

Here we see the most general view of a data base system. There are two very different kinds of operations: *queries*, and *administration functions*. Since each kind includes many operations, we simply represent them as operation sets. At the next level, we see that the queries are implemented by a `Query_Engine` object, while administration functions are implemented in an `Administrator` object. The operations are still described as operation sets in the children.

9.3 Exceptions

Exceptions are used for dealing with abnormal situations; they are by nature linked to critical events, and it is very easy to overlook that an exception can be raised at some point. For these reasons, HOOD requires a very precise description when exceptions are involved.

9.3.1 Server side

In the `PROVIDED_INTERFACE` of the ODS, a section named `EXCEPTIONS` describes exceptions raised by the object. The structure of this section is as follows:

```
PROVIDED_INTERFACE
   ...
   EXCEPTIONS
      Exception name RAISED_BY Operation name;
      ...
```

This tells precisely not only which exceptions can be raised by the object, but also which operation(s) raises a given exception.

As other elements, the `INTERNALS` section describes the implementation of exceptions in the `EXCEPTIONS` subsection. If the object is terminal, it simply includes the list of all internal exceptions:

```
INTERNALS
   ...
   EXCEPTIONS
      Exception_name;
      ...
```

This section may seem redundant with the `EXCEPTIONS` section of the `PROVIDED_INTERFACE`, but it is not. It lists exceptions defined by the current module, while the section in the `PROVIDED_INTERFACE` lists all exceptions that can be raised by the module, including exceptions declared by another module and propagated by this one.

If the object is not terminal, the exception has to be implemented by some child. In this case, the `EXCEPTIONS` section tells who is implementing the exception:

```
INTERNALS
   ...
   EXCEPTIONS
      Exception_name IMPLEMENTED_BY Child_name.Exception_Name;
      ...
```

9.3.2 Client side

Exceptions raised by a server propagate to its clients, and it is important to make sure that the client is aware of the possibility of an exception being raised.

Firstly, the exception flows from the graphical description are described in the textual description in the `EXCEPTION_FLOWS` section. It has the following structure:

```
EXCEPTION_FLOWS
   Exception_name <= Object_Name;
   ...
```

This describes exceptions at *object* level, i.e. "this exception can be transmitted from this server to the current object". Note that an exception may be raised by several operations.

Then, since the exception has to be dealt with by the current object, it must also be stated in the `REQUIRED_INTERFACE` under the corresponding `OBJECT` subsection, as any other entity (see 8.3).

Finally, in a terminal object, each operation must describe what it does with raised exceptions. In the OPCS, a `PROPAGATED_EXCEPTIONS` subsection lists the exceptions propagated by the operation, and a `HANDLED_EXCEPTIONS` lists all exceptions that are handled within the operation, and thus not propagated further.

C-17		*Methodological*
The propagated exception list in the OPCS shall be a subset of the provided exception list in the provided interface.		

This rules means that only exceptions that are declared in the provided interface can be raised in an operation; or taken the other way round, it means that all exceptions raised by an operation must be declared in the object's provided interface. This rule is intended to make sure that the client is aware of all potentially raised exceptions.

Conversely, the set of exceptions appearing in the `EXCEPTIONS` section of the `PROVIDED_INTERFACE` is the union of all exceptions appearing in the `PROPAGATED_EXCEPTIONS` of the various OPCS. This can appear as redundant, but it means that it is easy to find the information by looking in the right place, depending on the granularity of the information needed. It does not involve extra work for the designer, since the tools make sure that consistency is enforced, and fill automatically most of the sections.

9.3.3 Internal exceptions

Terminal objects are allowed to have internal exceptions, i.e. exceptions declared in the `INTERNALS` part of the ODS. Such exceptions may be raised only by internal operations, and are *not* allowed to propagate through provided operations: they *must* be handled before control is returned to the client. This ensures that only exceptions that actually appear in the `PROVIDED_INTERFACE` can be raised in the client.

C-11		*Methodological*
Only exceptions listed in the PROVIDED_INTERFACE EXCEPTIONS field of a module shall be propagated by operations provided by the module.		

Note that this rule is more restrictive than the way exceptions work in most languages that provide a built-in exception mechanism.

9.4 Practical tips

9.4.1 Naming conventions

Giving proper names to operations is *not* a secondary issue, since it will have an outstanding influence on the understandability of the design. Like most rules, there are exceptions, but in general the following guidelines can be observed:

- Name procedures (operations that do not return a value) with action verbs that express what is being performed. For example, `Read_Keyboard` is a better name for a *procedure* than `User_Input`.
- Name functions (operations that return a value) with a noun describing the value returned. For example, `User_Input` is a better name for a *function* than `Read_Keyboard`.

- Name the operations according to the client's point of view. For example, if a server provides samples of some physical parameter, the operation should be called `Get_Sample` rather than `Provide_Sample`, since the client is actually *getting* the samples.

9.4.2 Error managers

Exceptions are a powerful tool, but it does not mean that any error encountered in a program must be turned into an exception. In general, it is a good practice to define a policy for dealing with errors. Often, there will be an environment object that will be in charge of managing errors; with such a centralized error manager, it is easy to make sure, for example, that all errors are logged in an error history file. The error manager may or may not, depending on the project's policy, raise an exception.

Note also that a HOOD exception does not necessary map to a language exception. It is perfectly allowable to map HOOD exceptions to a return code, provided that care is taken that the error codes are always checked on operations return.

9.5 Summary

Each operation is described in details in the ODS by a section called the `OPCS` (OPeration Control Structure). The `OPCS` provides all details for the operation, from informal description down to actual code. Every element used by the operation is documented.

Exceptions are documented in such a way that it is easy to check (and difficult to forget to define) what happens when an exception is raised by used operations.

10. Formalization and refinement of data structures

As mentioned before, the properties of every data in HOOD is defined by its (mandatory) type. Variables can be defined only in terminal objects, since parent objects are empty shells. On the other hand, parent objects can (and often do) define types.

10.1 Description of types

The syntax for declaring types and data (even the very notion of type) varies considerably depending on the programming language. This raises an issue, since at *design* level, we want a high-level, language-independent, view of the types, while automatic code generation implies that the types must be declared *somewhere* according to the rules of the target language.

This issue is solved by separating the *declaration* of types, constants and data, which is basically announcing the existence and meaning of the entity in a language independent manner, from its *definition*, which gives the details of the entity using the target language syntax.

The most important types, from a design point of view, are those that are declared in the provided interface of some object. Since types are used to define data exchanged by operations, they must be related to parameters of the provided operations:

		Usage
An object should not provide any type which is not used as the type of some parameter of an operation.		

Sometimes, types are really abstract: clients do not know how they are implemented. In some other cases, the type needs to be fully known to the client, for example if it is used to return some data to the client. Therefore, two cases may occur:

- it is possible to *declare* (but not *define*) the type in the provided interface; only its name is accessible by clients (it is called a *private* type). Its structure (*definition*) is hidden to clients and will be described in the `INTERNALS`, as a full description if the object is terminal, or as `IMPLEMENTED_BY` a provided type of a child object if it is a parent object.
- it is also possible to declare *and* define the type in the provided interface; the structure is then fully accessible to clients (it is called a *visible* type). For a terminal ob-

ject, the type structure is fully described in the `PROVIDED_INTERFACE`, and for a non-terminal object, the type structure is `IMPLEMENTED_BY` a provided type of a child object.

Types of internal data (which can only appear in terminal objects) can be either internal types declared and fully defined in the `INTERNALS`, or types provided by another object (HADT or class, either as local objects or environments). In the latter case, the dependence to the external object requires a "type-use" relationship. Of course, "type-use" relationships follow the same rules as regular ("OP-use") relationships:

U-6		*Methodological*
If a child module TYPE_USES an uncle, then it shall also be TYPE_USED by its parent. This rule is implicit for environments.		

U-7		*Methodological*
If a parent TYPE_USES another module, then at least one of its children shall also TYPE_USE it.		

10.2 HADT and classes

10.2.1 Global and instance attributes and operations

HADT and classes encapsulate attributes which are part of the main type definition: each instance (variable) includes its own set of attributes. Such attributes can only be accessed as members of a specific instance of the HADT or class. They are often called *instance variables* in OO languages. Attributes may be *visible* (they can be modified directly) if they are declared in the provided interface of the HADT or class. Access to the attributes may also be restricted by declaring them as *private* in the `INTERNALS` of the ODS.

HADT and classes may also include data that are declared within the object itself and are thus accessible from all operations. Such data play the role of what is called *class variables* in OO languages: they are unique and conceptually shared by all instances of the class. Such data appear in the `INTERNALS` data field of the ODS. Similarly, operations may be global to the HADT or class, and play the role of *class methods*; such operations are specially useful to access values of class variables. By analogy with the receiver parameter "`me`" of instance methods, such class methods must have a parameter of name "`myClass`".

Note that the "`me`" and "`myClass`" parameters may disappear at code generation, since they constitute the implicit parameter in languages such as C++.

10.2.2 Aggregation and inheritance formalization

The main type of an HADT or class appears as a regular type in the provided interface of the object, but the syntax is extended to reflect the aggregation and inheritance arrows. The ODS for a main type has thus the following structure:

```
TYPES
    Main type name
        INHERITANCE
            class name
            ...
        ATTRIBUTES
            HADT or class name
            ...
```

Of course, the `INHERITANCE` subsection is only allowed for a class (not an HADT). On the other hand, for a non terminal HADT, this description will be replaced with an `IMPLEMENTED_BY` clause that designates the child that implements the type.

10.2.3 Abstract classes

Some classes are intended to serve as a common notion gathering more specific subclasses, but a direct instance would make no sense. For example, it is useful to gather in a class all the properties that are common to all widgets[1], but it is not possible to create a data that would be a pure widget, without being something more specific (a window, a button, etc.) at the same time. Such classes are called *abstract classes*.

P-3		*Methodological*
If a class is abstract, then its main type cannot be instantiated.		

This rule enforces that the only purpose of an abstract class is to be inherited by other classes. A class is defined to be abstract by putting the word `ABSTRACT` behind the name of the corresponding type declaration in the ODS.

Similarly, it may be necessary to express that some operations are provided by all subclasses of the abstract class, but no implementation can be given; implementations must be provided by the subclasses. Such operations are declared as *abstract operations*, and are defined by putting the word `ABSTRACT` behind the name of the corresponding operation declaration in the ODS. The folling rule ensures that an abstract operation can never be called, since it has no implementation:

O-7		*Methodological*
An abstract operation shall only be defined in an abstract class.		

1. A widget (*window gadget*) is a common term to designate buttons, windows, menus, etc. that appear on a screen.

10.3 Constants, variables and parameters

10.3.1 Constants

A provided constant is declared in the provided interface and only its name is accessible by the clients (*not* its value). This is because the name describes the *logical* meaning of the constant, while the value is only an implementation detail. For example, a file system may export a variable named `End_Of_Line_Mark` which defines a special character used to mark the end of the line. Which character is used (the ASCII character Line_Feed for example) is not important to the client.

The structure and value of the constant is given in the `INTERNALS` of the ODS, unless the object is not terminal, in which case the constant is `IMPLEMENTED_BY` a provided constant of a child object, as usual.

10.3.2 Data

HOOD objects exchange data via parameters of operations. Data can only be declared in terminal objects, in the `INTERNALS` of the object. They can be of any accessible type (including, of course, a type provided by an HADT or class).

> No data can be declared into the `PROVIDED_INTERFACE` of an object: it is recognized that such "public" variables would be error-prone. If an object logically exports some data, it must provide procedures to query or change its value. See practical tips in section 10.4.2.

Note that data are not represented on the graphical description (except for data flows). This is because data can only appear in the `INTERNALS` of an object, and the details of `INTERNALS` are never represented on the graphical description. In the textual description, data appear in the `DATA` field of the `INTERNALS` part of the ODS:

```
DATA
    Variable declarations
```

10.3.3 Data flows

In the visible part of the ODS, a section named `DATA_FLOWS` describes the flow of data between the current object and the server objects that are used. The structure of this section is as follows:

```
DATA_FLOWS
    Data name   =>  Server object name
    Data name   <=  Server object name
    Data name  <=>  Server object name
    . . .
```

The little arrow symbol indicates the direction of the flow: it is "`=>`" for an "in" parameter (provided to the object), "`=>`" for an "out" parameter (provided by the object), and "<=>" for an "in out" parameter (exchanged both ways with the object). This section is filled automatically by the tool from the graphical description.

10.4 Practical tips

10.4.1 Naming conventions

As for naming operations, it makes sense to have uniform conventions for naming data. Variables should be named with a simple noun expressing the use of their content, while types should have a name that starts with "`T_`", and is a plural of the designated entities. For example, the type of messages in the example in section 7.2 is called `T_Messages`; A variable of that type could be called `Current_Message`.

10.4.2 The "good" data

In practice, data encountered in a HOOD design are of three kinds: parameters, attributes and internal data (internal to a full object, or only to an operation). There is one kind of data that does *not* belong to HOOD: global (shared) data. HOOD rules do not allow an object to provide directly variables; they have to be encapsulated and accessed or modified through provided operations. For example, if an object provides some kind of counter, it is not allowed to let the corresponding variable directly accessible; operations, such as procedures `Increment` and `Decrement`, and a function `Current_Value,` must be provided to change or get the value of the counter.

There is of course a reason for this: global data are widely recognized as poorly reliable and maintainable. By forcing access to variables through a procedural interface, one ensures that all modifications are made through a single well defined access point. It makes tracking changes to the data much easier, and is especially important in the presence of concurrent accesses.

> Uncontrolled concurrent access to shared variables would result in race conditions. Concurrency constraints can be put on operations to prevent this; see section 11.4.

10.4.2.1 Parameters

Parameters are data that are being exchanged between a client and a server object through operations. Since a client can only call a server that it has declared to use, data can only be exchanged between objects which are related by a "use" relationship, or along an `IMPLEMENTED_BY` arrow.

Except for the simplest cases, parameters are instances of HADT or classes. They are documented on the graphical description as data flows along the `USE` or `IMPLEMENTED_BY` arrows.

10.4.2.2 Attributes

Attributes are data members that are conceptually part of the definition of an object. In the `Company` example on page 56, we have seen that an employee had a list of companies as an aggregation attribute, and inherited the attributes of a person. Such attributes appear on the graphical description as aggregation or inheritance arrows.

Like for global data, HOOD requires all access to attributes to be performed through provided operations of the object, or functions having the same name as the attribute and returning its value (i.e. read-only access to the attribute). This provides complete control of access to the attributes.

10.4.2.3 Internal data

Internal data are variables that are used as temporaries for the execution of an operation, or as hidden storage to keep some information between calls. Such data do *not* appear on the graphical description, since they are only implementation details. Data that are local to an operation are described in the `DATA` field of the OPCS, and data shared by several operations are described in the `DATA` field of the `INTERNALS`.

10.4.3 HADT or class?

When designing and HADT, it is often an issue to decide whether to make it a class or not. The commonalities and differences between a plain HADT and a class are the following:

- Both HADT and classes are structured data types, and can refine their structure by aggregating other data types.
- An HADT can be decomposed into child objects, possibly defining other (sub) HADTs, while a class is always a terminal object.
- Classes may extend existing properties through inheritance, but not HADTs.

In short, the main difference is that a plain HADT is refined through the parent-child decomposition mechanism, while the class is refined through inheritance.

HADT are therefore more appropriate for high level constructs that need to be refined into several participating types that do not share common behaviours. Classes are more appropriate for final data types that belong to a set of types with common, shared code. Classes are also appropriate to describe off-the-shelf software components that are provided as class libraries.

10.4.4 Avoiding too many root classes: class libraries

It is often the case that several classes are closely related (often through "inherit" relationships). In order to avoid having too many root classes, and to show this coupling, it is usually better to define related classes as children of a parent "class library object". This provides the OO designer with the necessary encapsulating facility which is lacking in many other popular methods.

A class library is just a usual object, which re-exports the types and operations of included HADT and classes, as pictured on figure 10-1.

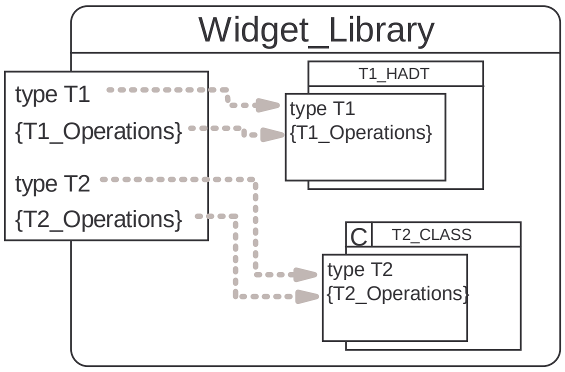


Figure 10-1 : A class and HADT library

For a client, the whole library would appear as an uncle, as on figure 10-2.

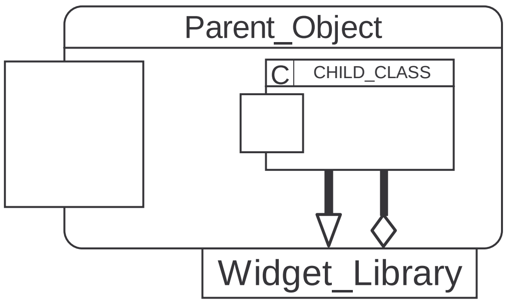


Figure 10-2 : A client of the library, structure view

This figure tells that the CHILD_CLASS inherits and aggregates from types defined in the Widget_Library; it doesn't tell which types are aggregated or inherited, and there is no reason to believe that both arrows relate to the same type. The real information content of the picture is: "CHILD_CLASS requires the Widget_Library for aggregation and inheritance purposes". Once again, the graphical description only shows the main dependencies that build the logical structure. Of course, all the details about what is aggregated or inherited can be found in the textual description.

10.4.5 Controlling instances: object factories

Regular (non HADT) objects are often abstract state machines; for one object in the diagram, there is only one instance. On the other hand, an HADT defines only a model; there is an unknown number of instances in each of the objects that use the HADT (i.e. each object may declare variables of the type at will).

Between these extremes, there is some time the need for an intermediate paradigm: when several instances are necessary, but nevertheless there must be some control on the management and number of instances. This can be obtained by using an *object factory*. An object factory is a regular object that resembles an HADT in that it provides a main type, and associated operations. However, the main type is simply a reference type[1] to the real (and hidden) abstract data type. In addition, there is a *create* operation that is used to obtain a reference to a new object. Typically, a call to `Create` would allocate the new object from the heap, or from an array local to the factory... The important point is that the factory manages all the objects, and that only references to the actual objects are exchanged between clients.

This is a common situation: for examples, when opening a file, the operating system often returns a *file handle*, which designates the actual file description table. For security reasons, the file description table is entirely managed by the operating system, and not accessible to the user.

Since the object factory is an object *manager*, it is an abstract state machine, and as such is represented with rounded corners, although its provided interface looks like an HADT. The difference in the notation allows to show the difference. A typical structure of an file manager would be as on figure 10-3.

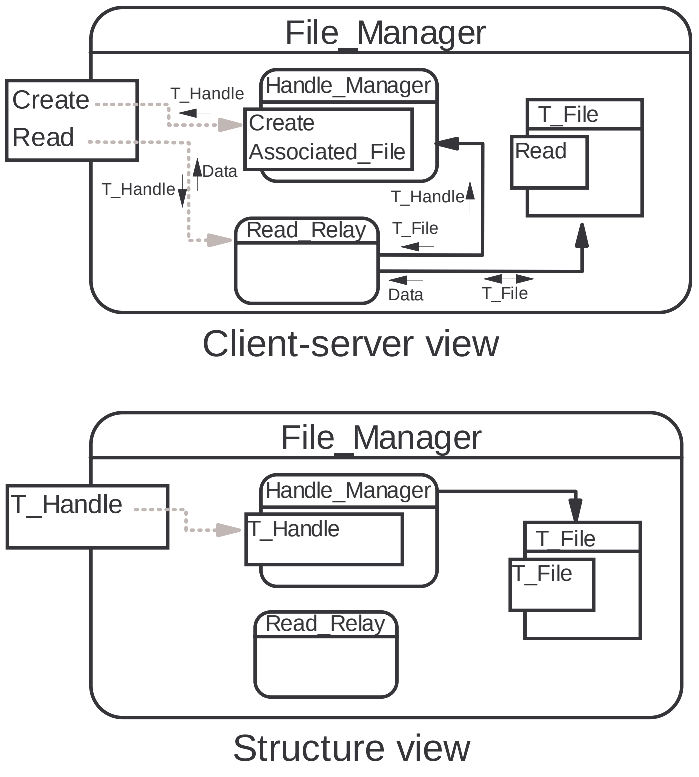


Figure 10-3 : An object factory

1. i.e. a pointer, or an index into an array of actual data.

On this picture, we see an object factory, `File_Manager`, whose purpose is to encapsulate the type `T_File` (defined in the HADT object `T_File`). This type has an operation associated to it, `Read` (for simplification, we did not represent all file operations). Clients of the file system only have access to a *reference* to `T_File` objects, through the provided type `T_Handle`. They must first create objects through calls to the `Create` operation, which is implemented in the child `Handle_Manager`.

Operations on files, such as `Read`, are implemented by an OP_Control whose role is simply to get the actual `T_File` associated to a `T_Handle` (thanks to the operation `Associated_File` of `Handle_Manager`) and then call the actual `Read` provided by `T_File`.

Since the real `T_File` type is inside the object factory, it is *guaranteed* that no instance of type `T_File` can be created except by calling the `Create` operation, and therefore that all instances are managed and controlled by `Handle_Manager`.

10.5 Summary

Data manipulated by HOOD are either elementary types of the target language, abstract data types (HADT) or classes. Abstract data types are refined through parent-child decomposition, while classes are refined through inheritance.

Data instances are either parameters of operations, attributes that are part of the logical description of an object, or local (hidden) data. Fields of the ODS allow precise tracking of all properties of the data.

11. Formalization and refinement of behavioural aspects

The behaviour of an object is the description of the various conditions that govern how the object *behaves*, as opposed to what it does (the functional formalization). This "behaviour" covers such various issues as whether some conditions have to be met before a given service can be called, whether a request will time-out if not serviced within a given time frame, etc. This includes all the dynamic aspects of the design, as opposed to the static description provided by the OPCS.

11.1 Defining execution conditions: operation constraints

Given the client-server model of HOOD, the behaviour of an object is defined by the conditions that allow operations provided by a server to be (successfully) called by clients. These conditions are called *constraints*, since they restrict the way the provided services can be used. Many provided operations may be called without special care: computing a sine function, for example, can be done at any time. Such operations are said to be *unconstrained*, i.e. no special constraint applies to them, and they are insensible to external events. On the other hand, the service provided by some other operations can be granted only if certain conditions are met. For example, you can push data on a stack only if it is not full, and you can pop data only if it is not empty. Such operations are said to be *constrained*. Many kinds of constraints can be invented, but HOOD limits those that can be used to a small number of basic ones, because:

- They are sufficient to describe systems and to implement higher levels protocols.
- They can be easily modeled and allow tools to perform proofs such as absence of deadlocks, schedulability, etc.
- They provide a common language allowing designers to easily understand the properties of objects defined by other people.

HOOD defines three, orthogonal, kinds of constraints: *state* constraints, *concurrency* constraints, and *protocol* constraints. *Orthogonal* means that each kind of constraint describes a different aspect of the behaviour; it is thus possible to attach one (but only one) constraint of each kind to any operation. The various constraints will be described in full details later in this chapter.

Constrained operations are represented with a *trigger arrow*, as on figure 11-1. The arrow may be labelled with the constraint's *kind*, but the precise constraint is not represented: as usual, the graphical description only warns the reader that the operation has some constraint; the precise description can be found in the textual description.

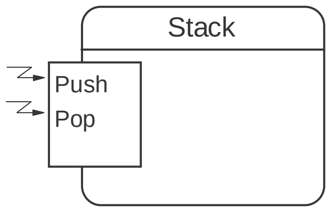


Figure 11-1 : A stack with constrained operations

11.2 HOOD execution model

When an object provides constrained operations, there is a special structure, the *OBject Control Structure* (OBCS), which is in charge of providing the correct behaviour for constrained operations. Since constraints are not particular to a single operation, but generally depend on the state of the object as a whole, there is one OBCS in the object for all provided constrained operations.

From a designer point of view, the OBCS is primarily a description of the conditions that allow (or not) a service to be provided; however, at code generation time, the OBCS is generated as a special module that actually checks and enforces the various constraints. Since the functional part may rely on the constraints being met, the checks must happen *before the service can actually be provided.* The OBCS acts as a kind of child unit, inserted between the interface of a provided operation and the actual functional code as described by the OPCS for the operation. The way the OBCS interacts with the execution of operations is pictured on figure 11-2.

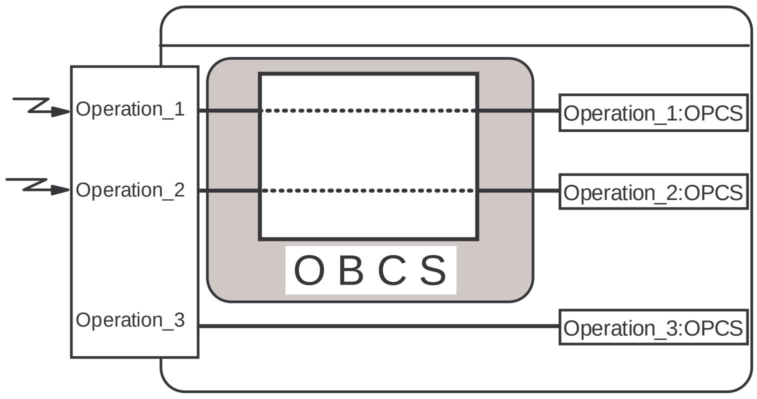


Figure 11-2 : Object execution model

This figure is for explanatory purposes; in practice, the OBCS is never represented explicitly on a graphical description.

We see that an execution request for a constrained operation is performed *through* the OBCS. In other words, when a client calls `Operation_1` or `Operation_2`, it calls a special operation of the OBCS that will check that all applicable constraints are met; only after this check has been performed will the OBCS call the actual operation, i.e. the one that is described by the OPCS (the service itself). Since there is one OBCS for all constrained operations of the object, it can account for interactions between the various operations. On the other hand, when the client calls an *unconstrained* operation such as `Operation_3`, the OPCS code is called directly.

This picture shows how the concept of OBCS is used to separate concerns: all the behavioural parts are described in the OBCS, while the OPCS describes the actions to be performed, assuming that all constraints applicable to the operation are met. This means that when the designer is working on the functional part, he/she does not have to care about the behavioural aspects; conversely, when studying the behavioural aspects, it is not necessary to care about the functional aspects.

> Or to state it differently: in the OBCS, you deal with constraints and assume that services are performed OK. In the OPCS, you deal with services, and assume that all applicable constraints are met.

This separation has many other benefits: during development, it is possible to check the behaviour by replacing the functional parts with prototypes; during maintenance, the kind of bug (behavioural or functional) immediately determines which part should be investigated; etc. Note that there is a number of methods (Rate Monotonic Analysis [Klein93], Petri Nets [Reisig85], SDL [CCITT89], ROOM) that are specialized in formalizing or proving behavioural aspects of a system. Since the behavioural properties are physically separated from the functional ones, it is easy to extract them in order to process them with proof making tools.

11.3 State constraints

In the stack example, the constraints simply allowed (or not) operations to be performed according to some internal state (whether the stack is full, empty, or in between). Such constraints are called *state* constraints. Note that some conditions may be known *after* an operation has been performed; for example, after a push, a stack cannot be empty. These conditions are known as preconditions and post-assertions [Meyer88]. State constraints are the HOOD way of representing the same notion.

Object State Transition Diagram

As said before, an object can be in one of several states. In each state, only a subset of the provided operations can be performed, and the current state changes according to the operations being called. HOOD provides *Object State Transition Diagrams* (OSTD) as an easy way to describe the states of an object and the transitions between them. The OSTD is therefore the part of the OBCS that formalizes state constraints. Although it is represented graphically, it is part of the textual description, since it is a detailed description of the behaviour of the object. It can be found as a subsection of the OBCS section of the ODS.

There is a text equivalent to the graph, but we will not describe it here, as only the graphical description is of interest to the user.

An OSTD is represented as a box with rounded corners, with its name at the top left corner, as pictured on figure 11-3.

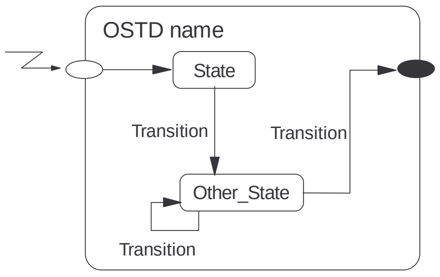


Figure 11-3 : Representation of an OSTD

- A state is a box with rounded corners, with the name of the state in it. It is assumed to be stable (it does not change except through execution of provided operations).
- A transition is represented as an arrow, labelled with a constrained operation name. Several transitions with the same label are allowed from a state to another one (including cycles). The transition is assumed to be executed in a null delay.
- Initial and final states are represented with ovals on the edges of the box (a white oval for the initial state, a black one for the final state). The *initial state* corresponds to the state of the object when the object is created; since the operation is always constrained, it is marked with a trigger arrow.

It should be stressed at this point that the OSTD serves as a description *for the client* of the conditions that allow the operations to be performed (it is part of the *visible* OBCS); it is *not* a description of the internal algorithm. For this reason, transitions can be triggered only by the execution of provided operations. If an operation is called while the object is in a state that does not allow it, the service cannot be provided, and the exception `X_Bad_Execution_Request` is automatically raised.

Example

Consider the microwave oven represented on figure 11-4. It has a keyboard to enter cooking time, a clear ("C") button to clear it, a "Start" button to start cooking, and a "Stop" button (that can be pressed at any time) to stop it immediately.

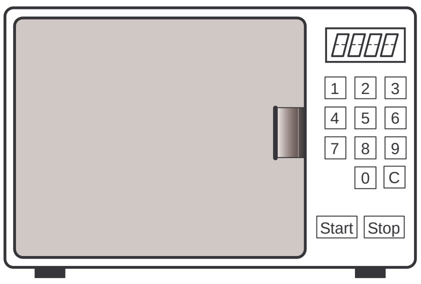


Figure 11-4 : A microwave oven

A first decomposition of the software to control this object is pictured on figure 11-5.

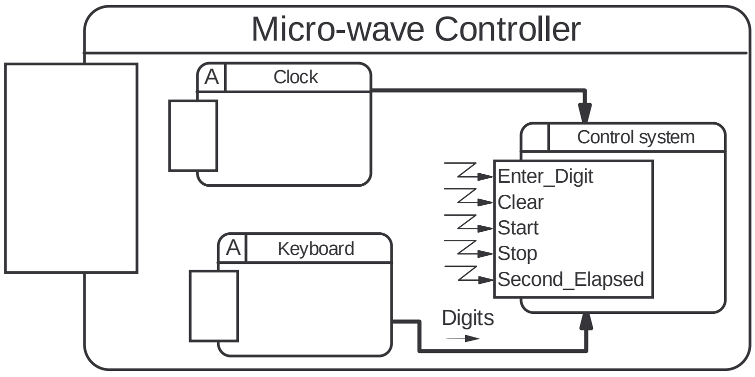


Figure 11-5 : Decomposition of the microwave oven

The keyboard sends the digits to the control system as they are entered, while a clock provides a basic time reference by calling `Second_Elapsed` each second. It is not possible to enter digits while the oven is cooking, nor can the clock have any action when the oven is stopped. This logic is represented with the OSTD on figure `11-6`.

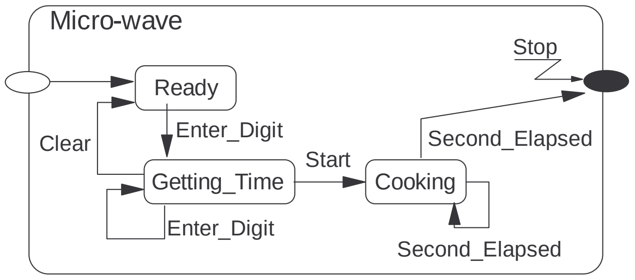


Figure 11-6 : OSTD of the control system of the microwave oven

Note the transitions which cycle on a state: it means that the current state is not changed by the operation, as when a second has elapsed, but the cooking time has not yet been reached. The annotated trigger is a short hand to specify triggers that apply to every state and make return from the current OSTD, as for the `Stop` button, since it immediately cancels any current operation.

11.4 Concurrency constraints

Concurrency constraints define the conditions that govern access to a service by several clients at the same time. By default, such access is unconstrained, meaning that several clients can call the service simultaneously without causing any problem. This is the case, for example, with pure functions: there is no problem if two threads are computing a sine at the same time. However, it is often the case that such unrestricted access could lead to inconsistent states, for example if the service modifies the state of the server. It is then necessary to limit and control the access. This is indicated on the graphical description by putting predefined texts next to the trigger arrows.

11.4.1 Mutual EXclusion Execution Request (MTEX)

`MTEX` means that the operation is executed in mutual exclusion: if a client thread calls an `MTEX` operation while some other client thread is currently executing it, it is held until the other thread exits the service. It is therefore guaranteed that no two client threads can be executing the operation simultaneously; the operation is protected against race conditions.

Note that the MTEX constraint involves only one operation, irrespective of other operations that may be executing at the same time in the same object.

11.4.2 Read Write Execution Request (RWER)

`RWER` means that the operation is defined as possibly modifying the state of the object to which it belongs, and that protection against concurrent accesses is granted. This implies that while a client thread is executing an `RWER` constrained operation, no other client thread can execute an `RWER` or `ROER` (described next) constrained operation from the same object. Note that here, mutual exclusion is at *object* level, not at *operation* level as it was the case with an `MTEX` constraint. It corresponds to what [Burns96] calls a *writer operation,* controlled by a *reader-writer monitor*.

11.4.3 Read Only Execution Request (ROER)

`ROER` means that the operation may access the state of the object, but performs no modification of global variables that would require mutual exclusion. As a consequence, several client threads *may* execute simultaneously `ROER` constrained operations, provided that no client thread is currently executing an `RWER` constrained operation. It corresponds to what [Burns96] calls a *reader operation* controlled by a *reader-writer monitor*.

11.5 Protocol constraints

Protocol constraints define the conditions that govern the interaction between a client thread calling a provided operation, and a server thread in charge of providing the corresponding service.

In a normal operation call, the client is in a sense "blocked" while the service is executed. However, it is sometimes not necessary (nor desirable) to block client activities while the service is being performed. A typical example is sending a line to a printer; it would make no sense for the client to wait until the line is printed before being allowed to go on with processing. This typically requires "someone else" to perform the operation, a *server thread*. An operation which is performed by a server thread is *pro-*

tocol-constrained. Conversely, a protocol-constrained operation requires a server thread to execute it, and therefore can only be part of an active object.

O-1		*Methodological*
If an operation is protocol-constrained, then it shall be provided by an active module.		

Protocol constraints are indicated on the graphical description by putting predefined texts next to the trigger arrow, like concurrency constraints. There are various forms of protocol constraints, which are described in the next sections.

Since protocol-constrained operations are executed by a dedicated server thread, it is easy to distribute them on a network with remote servers.

Protocol-unconstrained operations

Operations to which no special protocol constraint apply are simply executed by the client thread, there is no server thread at all. This is the usual "subprogram call protocol", and it is the only allowable protocol for a passive object. Note that if an active object has (by definition) protocol-constrained operations, it may *also* provide protocol-unconstrained operations at the same time. Imagine for example an object used to communicate on a network. It has of course `Send_Message` and `Receive_Message` operations, but also operations to query the statistics of the transmission. The situation is represented on figure `11-7`.

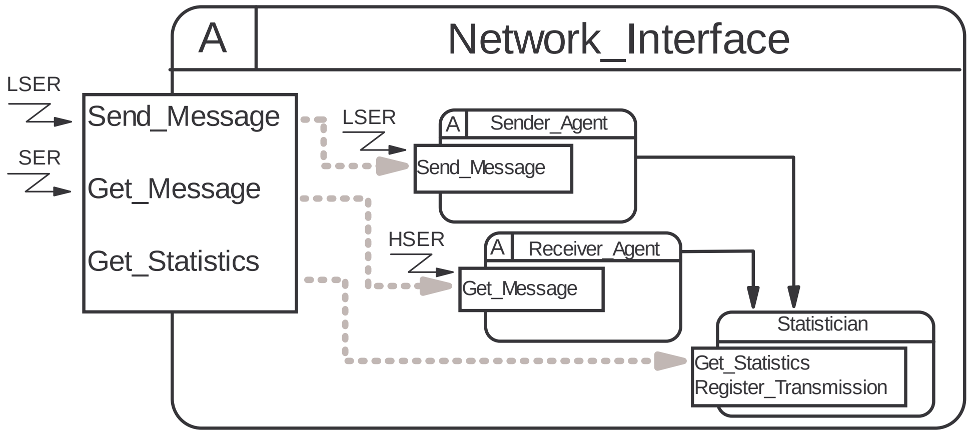


Figure 11-7 : A network interface

The `Send_Message` and `Receive_Message` operations are implemented by active children, but the `Statistician` object is passive, and the `Get_Statistics` operation is typically unconstrained.

11.5.1 Highly Synchronous Execution Request (HSER)

In this protocol, the client thread is suspended until the required service has been entirely performed. From a client point of view, it behaves almost like an unconstrained request, except for an important issue: timing. The server may not be available at the time the client issues the request, in which case the client thread will have to wait until the server is ready. This is sometimes called a WAIT_REPLY communication protocol in the literature. The protocol of an `HSER` is represented on figure 11-8.

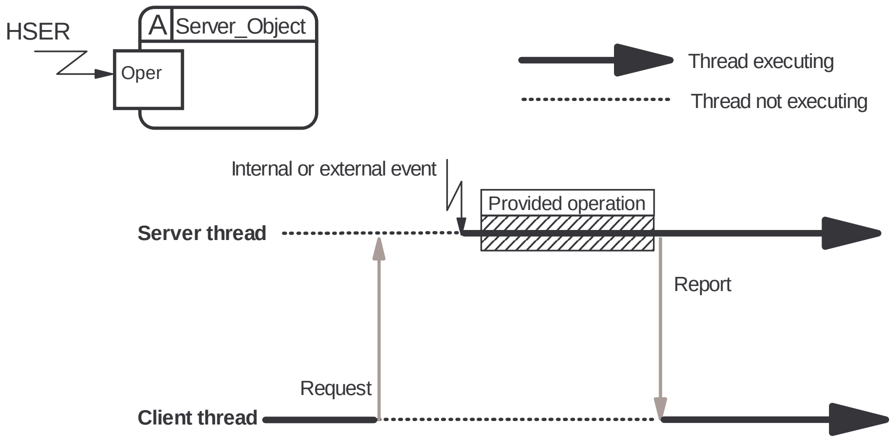


Figure 11-8 : HSER protocol

That the server thread may have to wait for some event before servicing the request should not be confused with state constraints: when a state constraint applies, and the server is not in a state that allows it to serve the request, any attempt to call the service will result in an exception being raised *immediately*. With an `HSER`, if the server is not in a position to accept the request *at the time it is issued*; the request is put on hold and will be accepted later.

11.5.2 Loosely Synchronous Execution Request (LSER)

In this protocol, the client thread is suspended until the required service has been accepted (i.e. the server arrived to "take the orders"), but not necessarily entirely performed; the client thread is released while the service is being performed in parallel. This is sometimes called an ACKNOWLEDGE communication protocol in the literature. The protocol of a `LSER` is represented on figure 11-9.

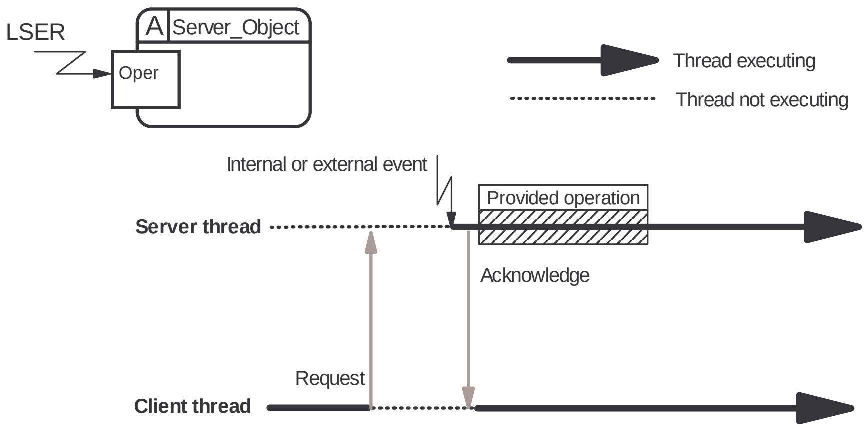


Figure 11-9 : LSER protocol

11.5.3 Asynchronous Execution Request (ASER)

In this protocol, the client thread is not suspended at all. It just sends a signal to the server to trigger execution of the operation, and proceeds without any suspension.The protocol of an ASER is represented on figure 11-10. Interrupt handler routines are rep-

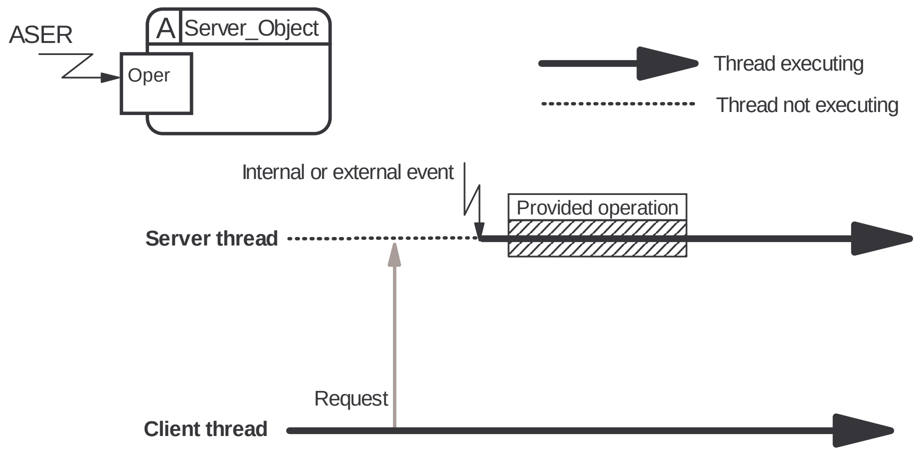


Figure 11-10 : ASER protocol

resented as special ASER-constrained operations that are "called" by the hardware interrupt; they are documented with a label ASER_BY_IT next to the trigger arrow.

A client thread calling an ASER constrained operation is not suspended; from its point of view, calling an ASER is not different from calling a protocol-unconstrained operation

11.5.4 Reporting Loosely Synchronous Execution Request (RLSER)

In this protocol, the client thread is suspended until the required service has been accepted, like for a regular LSER. However, the client needs the results of the processing at a later time. An RLSER is equivalent to submitting a request as an LSER, and then waiting for the output with an HSER. However, these actions *together* describe the interaction, and cannot be separated. Hence the need for as special label for this communication protocol. The protocol of a RLSER is represented on figure 11-11.

11.5.5 Reporting Asynchronous Execution Request (RASER)

This protocol is similar to an RLSER, except that the request is submitted to the server as an ASER rather than as a LSER: the client does not wait until the server accepts the request, but goes on immediately. It fetches the result at a later time with an HSER.

The protocol of a RASER is represented on figure 11-12.

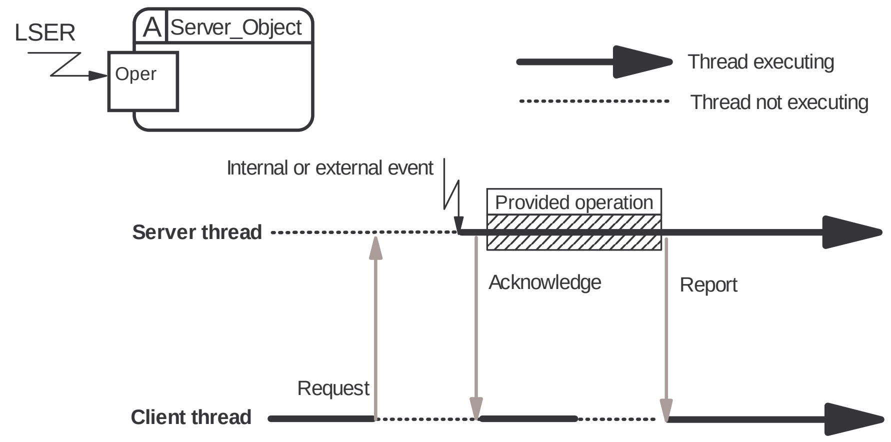


Figure 11-11 : RLSER protocol

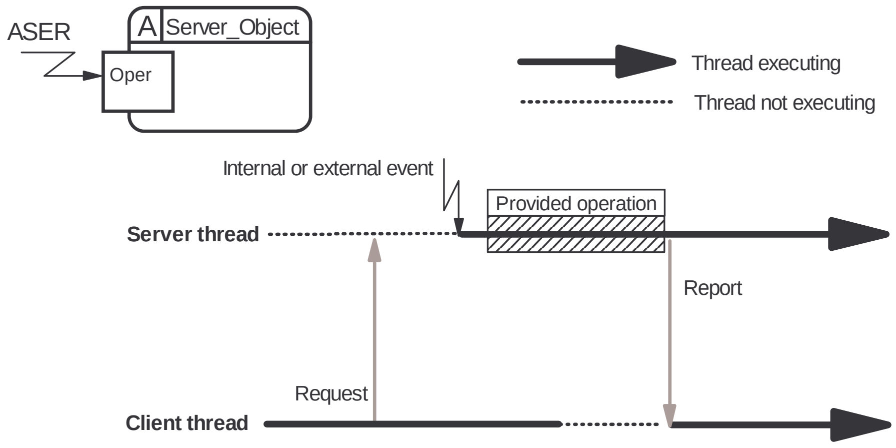


Figure 11-12 : RASER protocol

11.6 Time-out constraint

In the description of previous protocols (`HSER`, `LSER`, `RLSER`, `RASER`), we said that the client had to wait for the server to be ready to accept the request, or to get a report from the server. However, in many real-time systems it is unacceptable for a client to be blocked for an unknown amount of time; in a fail-safe system, it is necessary to provide some escape mechanism for the case where the server is down and never accepts the request.

For these reasons, the time-out constraint (`TO`) allows a client to request and check that an operation is executed within a given period of time. The time-out is the maximum elapsed time before the request is taken into account or executed by the server. `TO` can only be combined with the above protocol constraints. A default time-out value is attached to the operation, but the client may override it at request time.

It would not make sense to add `TO` to an `ASER`, since the client is never suspended.

When a TO constraint is added to a request, the client control flow will resume either:

- when the time-out has occurred or
- when the service has been acknowledged (LSER_TOER) or completed (HSER_TOER, RLSER_TOER, RASER_TOER).

A TO-constrained operation has a default "out" boolean parameter to tell the client which of these reasons terminated the execution request. On the other side, the *server* thread continues its execution (until the nominal end of the operation or until an exception occurs), whether the time-out occurred or not. This is because the *requests* times out, not the *service*. If the service has some "out" data, they are discarded.

For example, the protocol of a HSER_TOER is represented on figure 11-13.

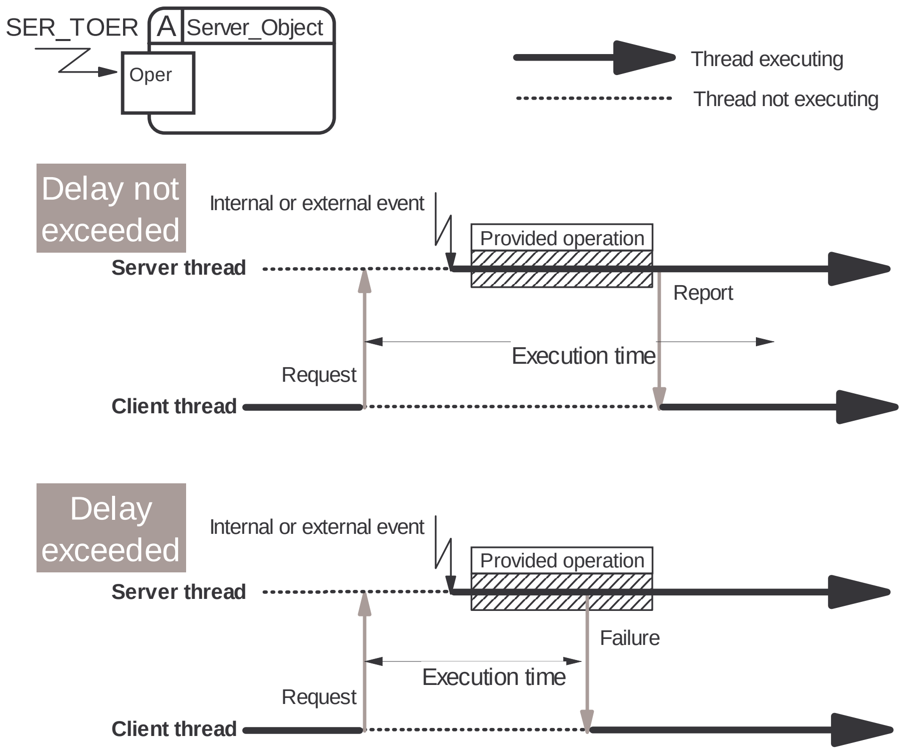


Figure 11-13 : HSER_TOER protocol

11.7 Practical tips

11.7.1 State constraints

State-constrained operations should be entirely described by the OSTD. As a consequence, every state-constrained operation should appear at least once in the OSTD. Conversely, every operation used in the OSTD must be state-constrained (this last condition can be checked by the tool).

In highly critical systems, it is common to mention every provided constrained operation as an exit from every state. This ensures that there is a well defined behaviour under any circumstance, rather than relying on the exception mechanism for unexpected service requests.

11.7.2 Consistency of protocol constraints

There are some incompatibilities between constraints, and appropriate rules are used (and enforced) to avoid them. For example, a protocol-unconstrained operation is one that cannot "block" (i.e., it is always running). This would not hold if the operation called another operation that could block; the "unconstrainedness" must be transitive. This is enforced by the following rule:

		Usage
Unconstrained operations should not use protocol-constrained operations, except for ASER constraints.		

The rule does not extend to `ASER` constraints, since `ASER`-constrained operations are just signals that do not block the caller.

11.8 Summary

The behaviour of an object is the description of the various conditions, or *constraints*, allowing a service to be provided. There are *state* constraints describing the states of the object that allow operations to be performed, *concurrency* constraints that define if and how concurrent calls to operation are allowed, and *protocol* constraints that define interactions between the client thread and the server thread.

Constrained operations are performed through the *Object Control Structure* (OBCS) which enforces and regulates the various kinds of constraints. This enforces the separation between the behavioural and functional description of operations.

12. A model of the global project organization

HOOD provides not only a well formalized model for its various entities, but also a very convenient model of the organization of the whole project.

12.1 The HOOD design tree

We have seen that a HOOD design started from a root object, that was decomposed into child objects, as represented on figure 12-1. The whole system can be represented

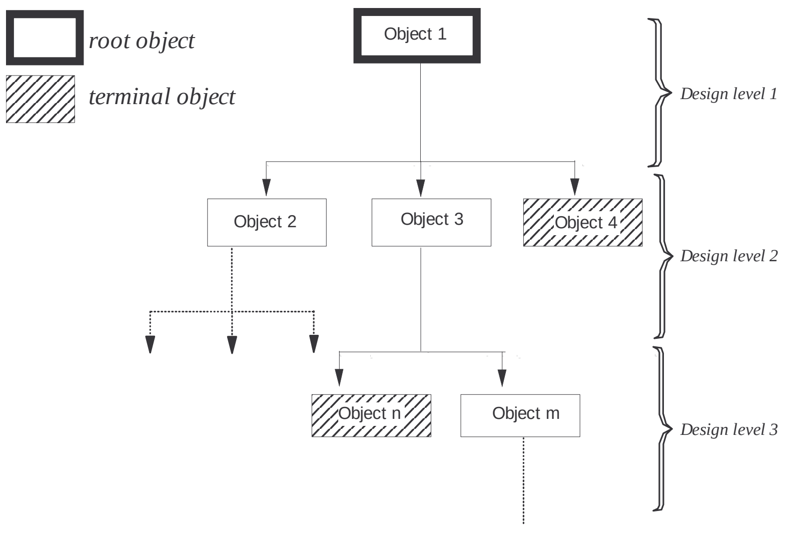


Figure 12-1 : the HOOD design tree

as a tree where branches are parent objects broken into children, and leaves represent terminal objects. This tree is called the *HOOD design tree* (HDT).

Although we represented only a single tree here, it must be remembered that, but for the simplest designs, a full system involves several subsystems, each with its own design tree. So in general, a complete HOOD design consists in a set of design trees.

12.2 The global project picture

In the various HOOD design trees that make up a project, some are actually designed by the project, while others are environment objects representing parts that have been reused from other projects, commercial components, etc. Since a project includes various kinds of trees, it is convenient to group them into "spaces".

12.2.1 Object space

This space comprises all "regular" design trees, i.e. all non generic, non virtual-node root objects and their descendants. It is the only place where actual, executed, code can be found.

The complete object space includes all roots; however, a design team which is a subcontractor to some prime will be concerned only by its own system to design, plus other HDT that are *used* by it and appear as environment objects. Other objects, not viewed by the current system to design, are irrelevant. In general, each designer will only have a partial view of the complete object space of the project.

12.2.2 Generic space

The generic space includes all the generics that are part of the project. Generics are considered as a different space, because they are always root objects (this is required by the method), and they do not constitute objects by themselves; they are just models, not actual code. A generic itself is not part of the eventual program (although *instantiations* of the generic are).

Like for the object space, only a part of the whole generic space is viewed by the subcontractors.

12.2.3 Virtual node space

If the system is distributed, it will include a virtual node tree. For similar reasons, the virtual node hierarchies are defined in a separated virtual node space. This is the space where executables are defined. In general, the virtual node space is only a concern for the prime contractor and the integrator.

12.2.4 Physical node space

Although physical machines are not really part of the software design, the software designer will have to map the virtual nodes onto a physical architecture. It is therefore important to have a picture of the physical architecture in the design. This picture constitutes the physical node space.

12.2.5 The global picture

A whole project is organized as a set of spaces and hierarchies, as represented on figure 12-2. On this figure, we see the various HDTs as "planes" which are "plugged"

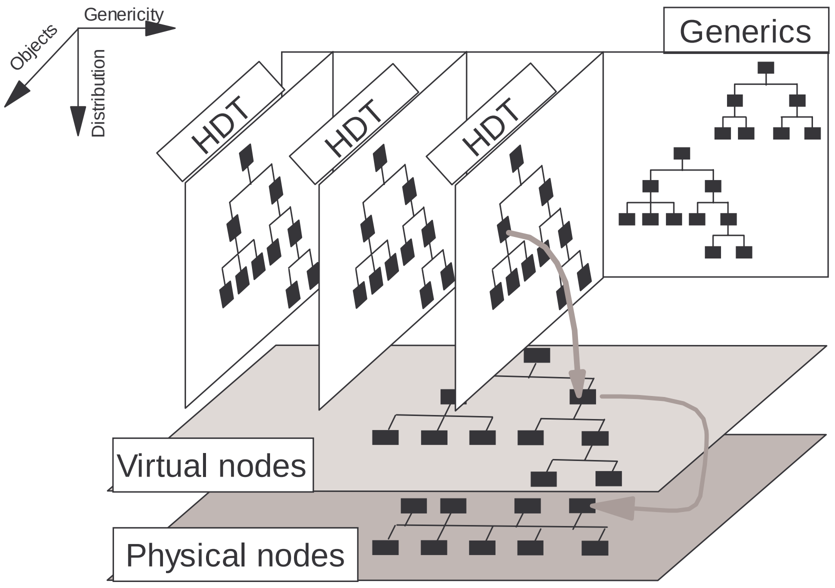


Figure 12-2 : The HOOD Design Model as a set of spaces and hierarchies

into the generic space, the space of reusable modules. If the application is distributed, the various nodes are projected onto the virtual node space, which itself is projected on the physical node space. Note that the physical node space is hidden below the virtual node space, and as such not visible from the object space.

12.3 System Configuration

A system to design is defined as a set of root objects. There will be of course *the* system to design, the one that includes the whole project, but each subcontractor will also have its own partial view. A set of root objects that describes a partial or global system to design is called a *system configuration.* There will be therefore two kinds of system configurations:

- the global system configuration of the project. If the project involves several subcontractors, this global configuration is maintained by the prime contractor. It defines the configuration of the whole project by integrating all hierarchies.
- the local system configuration of a subcontractor. Such a configuration is at least the one defining the context of the hierarchy associated to the local development. The subcontractor will enrich it with new environment objects and classes, as he progresses in the refinement of his object/subsystem hierarchies.

Of course, the global configuration is defined as the union of all local configurations. It is the duty of the prime contractor to ensure that all new elements defined by a subcontractor are included in the global configuration, in order to ensure consistency of the global HOOD model.

V-17		*Methodological*
A module has visibility on environments and other roots declared in the system configuration.		

Note that there could be a contradiction between the notion of environment (reusable components that are available to everybody), and the strict control required by HOOD about who uses what in the system. The above rule states that a module cannot use another (environment) module unless the other module has been mentioned in the system configuration; in a sense, the system configuration plays the role of a required interface for the whole system. Given several systems sharing some environment libraries, the system configuration traces which components are used in which system.

As everything else, the system configuration is formally described with an ODS of its own. Its structure is:

```
SYSTEM_CONFIGURATION
   ROOT_OBJECTS
      Root_Object_Name;
      ...
   ROOT_GENERICS
      Generic_Name;
      ...
   ROOT_VN
      Virtual_Node_Name;
      ...
END
```

12.4 Summary

A whole project includes several hierarchies of objects, generics and virtual nodes. It is split into partial views that include only the hierarchies that are meaningful from each subcontractor's point of view.

Each view is described by a system configuration. There is a global system configuration at prime contractor level which is the union of all local system configurations.

The consistency between the global view and all partial views is enforced.

Part 3 :
The design process

In the previous parts, we have seen how a HOOD design was represented. We will now focus on the *process* that will lead to a well structured design.

Design is a creative activity, that involves a lot of personal skill and knowledge. As Booch pointed out, "the [software] professional [...] must have a dual nature as a scientist/artist" [Booch87]. But, as a *product*, software is subject to industrial constraints, and should not rely on *wizardry*. It is therefore important that, although creative, the design process be driven, conducted in a systematic way, following industrial considerations such as readability, traceability, and ease of evolution.

HOOD proposes a process that helps the designer in creating designs of any size and complexity. There are actually, two aspects to it, that correspond to two different views of the design:

- a basic decomposition process defines the activities necessary to break down a given object into children, from a root object down to terminal objects. This is the view which is important to the individual designers.
- a general process for driving the whole project development process describes the approach and activities to perform along the architectural design phase in order to organize the system according to the development constraints of the project. This is the view which is important to prime contractors and project managers.

13. The basic decomposition process

HOOD diagrams may be used in many ways, and it is possible to use them without any method at all. Experience has shown that it is error-prone and not cost efficient. It must be understood that the notations are there just to support a design *method* and capture its results; they do not replace a rigorous process.

It is therefore necessary to provide guidance on how to go from a blank page to a full design, in a way that is consistent with the goals of HOOD. On the other hand, it is impossible to define a design process that would fit everyone's needs. When a method attempts to define too precisely a step-by-step design process, each project in practice defines its own variations, and nobody applies the method as defined in the reference book. To tell the truth, this is what happened with previous issues of HOOD.

For these reasons, HOOD does not impose a precise design process, but provides guidelines that are to be followed in order to get the expected benefits from the method; it is the job of the method director to define precisely how the method is to be applied in practice. An example of this is described in section 13.4; it fits the spirit of HOOD, and provides a sound basis for defining a custom process that will account for the habits of the company and the constraints of the particular project.

13.1 The iterative process

HOOD is a top-down design method. A top-down design method is one that starts with general modules (*objects* for HOOD), which are then broken into more refined ones (*children* for HOOD). Although this idea is widely accepted, it is sometimes argued that the opposite way (bottom-up design) can also be used. While quite effective for rapid prototyping, building an application starting from elementary bricks does not allow for an organized, global picture of the design process and as such does not meet the requirements for big, long lived, and safe industrial projects.

Therefore, the design of a software piece should start with the definition of a *system to design* which is extracted from a set of requirements, possibly detailed after requirements analysis. It is initially defined as a *root* object, which is then broken down into several lower level objects, that are similarly refined until they reach a terminal level. A terminal level is achieved when the complexity is low enough to allow direct implementation in a target language, or when it corresponds to designs, components or environment services that already exist and can be reused.

The process of breaking down an object into children is called the *basic design step*. If an object is terminal, it has to be *implemented*, including coding in the target language. Building a full design will consist in performing a succession of basic design steps and implementations in an iterative manner, until the system is fully implemented. We address in this chapter only the issues of developing a single design tree; how roots are identified, and how the whole process is started is addressed in section 14.2.

In practice, design is not an easy task. It is not performed as a single step, but rather as a succession of steps, going from an informal description of the solution that may still miss many important aspects, to a completely defined ODS. Errors, inconsistencies and missing features are often discovered long after an object has been initially defined, requiring some reworks. Design is best viewed as a set of converging cycles, rather than as a straight, top-down line.

13.2 The refinement process

The previous description of the iterative process should not be understood as meaning that each object should be completely defined before lower level objects can be designed; actually, it is a goal of HOOD to replace the classical waterfall model with a progressive refinements process. However, there are two kinds of refinements, and HOOD allows them to be managed simultaneously without interference:

- Refinement by adding more details to object descriptions. At the time an object is identified, its properties are generally not precisely known. The activity proceeds by enriching the descriptions of an object with more and more details, as the features of the object are more precisely understood.
- Refinement by decomposition. An object is initially defined as an interface, without regard for its implementation. It is then refined by decomposing it into child objects, that will be later decomposed, etc.

How can these processes be managed independently? Each refinement leaves the initial model (the view of an object provided to clients) invariant. In the first steps of design, the services are only vaguely defined and incompletely implemented. As the refinements progresses, the definition gets firmer and firmer, and the implementation moves toward a complete implementation; but from an external point of view, *the object stays the same*. For example, a first level of description is composed of three objects and represented by the design tree on figure 13-1.

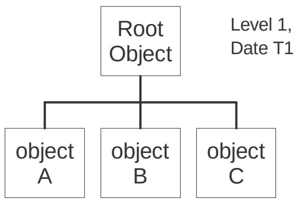


Figure 13-1 : A HOOD initial model

Later, a second level of description is refined by further decomposing some objects. The level 1 view is kept unchanged, but a level 2 of refinement has been added. The design now includes 9 objects, as described by the design tree on figure 13-2.

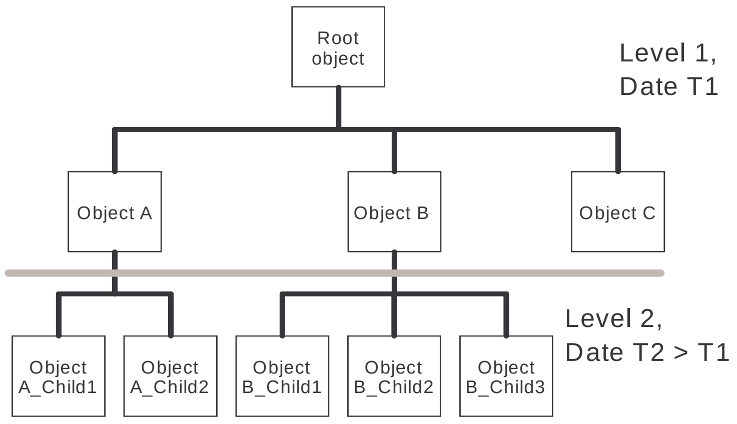


Figure 13-2 : A refinement of the initial model

This concept of initial invariant model development is fundamental and specific to HOOD: a development step will thus allow to freeze, prototype and validate a new model refinement, that is still consistent and equivalent to the initial one.

13.3 The basic design step

As mentioned above, the basic design step is the process that allows to break an object into child objects. It is therefore the *body of the basic loop* in the iterative design process. It is recommended to decompose the basic design step into a sequence of *activities,* i.e. something that has to be performed, and produces some recognizable *output* to preserve the results of the activity and to allow formal (or informal) verification. This is not intended to hamper the creativity of the designer, but to provide a common background to all designs within a company, for example; it makes maintenance by people other than the initial designer much easier, since there is a common language, and a common design framework to all designers.

HOOD does not mandate a precise set of activities to perform a basic design step (an *implementation* of the basic design step); this should be defined by the method director. However, there are important aspects that should be addressed by any implementation of the basic design step, and we'll present them in the following sections.

13.3.1 Understand the problem

The first activity of a design should always be to understand what *really* has to be designed. The goal of this phase is to integrate all facets of the problem, before devising a solution. This is where requirements can be reworked and clarified from a designer’s point of view.

It cannot be stressed enough that this is *very difficult*, and that many inconsistencies, that often appear much later in the design process, originate in an incorrect understanding of the problem. This is not restricted to HOOD nor even to software design; taking the habit of analyzing the very nature of problems before trying to solve them can prove very effective in everyday's life!

The difficulty comes from the fact that most people see the problems only through the way to solve them. For example, consider the driving device for the robot arm from section 4.5.1. An incorrect formulation of the problem would be:

> *Send a sequence of orders to the physical arm as required by the defined sequence of movements.*

This is however the description of a *solution*. The *problem* it is intended to solve should rather be formulated as:

> *Let the robot arm follow the path defined by the current painting trajectory.*

A word of caution: generally, designers do not fully understand the importance of this step. They tend to jump directly to drawing boxes and arrows (making a sketch of a *solution*), then fill in the required document parts just to please the quality assurance people. They often accomplish this by simply "cutting and pasting" from other parts of the design. The designer has a feeling of doing useless stuff, and the actual information in the document is redundant with other parts. Designers must be aware, and project leaders should enforce, that this first step be performed, and if possible reviewed, before any attempt to implementing is started.

This activity is by nature informal; its output is necessarily some free text that must be kept as part of the project's documentation. At the least, a summary of the definition of the problem, and constraints imposed by the outside world, should be put into the informal fields of the ODS (`DESCRIPTION` and `IMPLEMENTATION_CONSTRAINTS`).

13.3.2 Refinement lines

Once the *problem* to be solved is defined and understood, a *solution* has to be found. This involves three main activities, also called *refinement lines*:

- The *modular decomposition refinement line*. This refinement line expresses a solution by decomposing the system to design into child objects (or deciding that the object is terminal). Standard decomposition criteria are applied, based on allocation of functions to objects with a concern of defining loosely coupled objects, with minimized provided interfaces.

- The *abstract data type refinement line*. Objects previously identified exchange *data*: this refinement line identifies and refines the data being exchanged, leading to the definition of HADT objects and classes. Each data flow identified in the previous line can be implemented as a basic type of the target language, as an instance of an abstract data type, or as an instance of a class. The operations on the data are identified as the client objects are further refined, therefore this refinement is performed in parallel with the modular refinement. Since HADT and classes are just special kinds of objects, they will in turn be designed through modular decomposition *and* abstract data type refinement.
- The *logical to physical refinement line*. When a system is distributed, there is no reason to believe that the physical architecture (where objects do actually execute) match the logical architecture, as results from the decomposition. This refinement line maps objects into virtual nodes that fit the targets' constraints.

Each refinement line is eventually translated into an update (or creation) of ODSs and associated documentation. Actually, the whole development process can be seen as a succession of improvement to the formal view of the system that the various ODSs for the current design tree provide.

13.3.3 Design activities

According to the principles summarized above, the following activities should be part of any implementation of the basic design step:

- The starting point of the step should be to define the system to design as an interface (a set of provided and required services) to its environment. Graphically, this corresponds to creating a new box, with the provided interface and the uncles that appear to be necessary at this point.
- Identify the key child objects. These are the objects used to implement provided operations, as well as objects that appear to be necessary to allow them to communicate. Graphically, this corresponds to drawing child objects, `IMPLEMENTED_BY` arrows, and `USE` arrows.
- Define the implementation of the communications and data flows. Graphically, this means decorating `IMPLEMENTED_BY` arrows and `USE` arrows with the most important data flows, and adding exception flow marks where appropriate. Of course, this applies to arrows drawn towards uncles as well as to arrows connecting child objects.

  > At this point, note that there is a fundamental difference between HOOD and other design methods. Whereas several methods identify classes on the basis of analysis techniques that are mainly derived from the Entity-Relationship model extended with inheritance, the HOOD design approach leads naturally to the identification of classes, from the definition of logical interfaces, as abstract data types used for communications between objects.

- Design the data types. At this point, it is necessary to decide whether the data types that were identified are basic data types, or higher level data types that will be im-

plemented with HADT or class objects. In the latter case, add the corresponding objects to the current design, with the corresponding arrows in the client-server view and in the structure view.
- Document ODS fields that were not automatically filled by the tool from the graphical description.

Of course, the main output of these activities will be the identification of new objects, whether regular objects, HADTs or classes. A basic design step will have to be performed on each of them, and this is where the method will iterate.

13.3.4 Justification of the solution

The last activity of a design should always be to justify the adopted solution, (when not obvious). Once a solution is accepted, the reasons that lead to that solution have to be kept. Preventing the return of previous errors, and insuring that every design decision resulted from a conscious choice where alternative solutions were considered, are the goals of this activity.

The issue is that a design activity involves *always* balancing trade-offs between possible solutions[1]. Often, there were conflicting requirements, several solutions were investigated, and there were sound reasons for choosing one solution over possible alternatives: a solution that looked appealing at first sight eventually showed unimplementable, or unacceptable for various reasons, and some alternative solution was preferred. Later in the process, the original designer will have moved, and someone else will look at the design and say "Hey, those guys were really stupid, they didn't use the obvious solution!".

The design choices (solutions that have *not* been adopted) are an important part of the solution, and the knowledge that has been acquired through the design process has to be kept. It is therefore important to document the *justification of the adopted solution*. This piece of documentation will serve for the review process, and also, if some external constraints change, in order to be able to decide whether the chosen solution is still the appropriate one, or if some other alternative has now to be preferred.

For example, a solution can be preferred, because a more elegant (or more reusable, or safer) one would have exceeded the available computing power. If the project later decides to move to a more powerful computer, this design decision may be reversed.

13.3.5 Ordering of activities

Let us finally stress that although we had to enumerate the activities sequentially, they are *not* to be followed in a linear order; it is recognized that design involves moving

1. If you see only one solution to a problem, it does not mean that it is the only one; it means that you didn't see the other ones.

forward and backward as the solution is refined. Problem understanding has to be performed first, but the creative activities involved in finding child objects are iterative (by successive refinements), and overlap with similar activities for the children. It is also often the case that the better understanding of a child's properties developed during its design leads to some adjustments in the parent.

13.4 A typical workout of the basic design step

We said that the precise definition of the basic design step should be adapted to each development's context. We'll present now an example of what such an implementation would look like. This example is derived from the (more formal) process that used to be mandatory with previous issues of the method; it reflects the experience of years of development with HOOD, and can serve as a sound basis for a custom implementation of the basic design step.

> In previous issues of the method, the activities of the basic design step were rigidly defined, and design documents had to follow exactly the basic design steps. These documents were organized in chapters that corresponded to the activities; they were numbered H1 for the first one (with subdivisions H1.1 and H1.2), H2 for the second activity, etc. Although this proposed implementation is based on this older structure, we have not kept the numbering scheme, since evolution of the method would have not allowed to keep it consistent.

13.4.1 Activity 1: problem definition

13.4.1.1 Activity: Understand the problem to solve

This activity includes two parts: first, the designer states the problem, and then analyses and restructures the requirements with respect to his own designer's perception.

a) Statement of the problem
The designer states the problem in one correct sentence, giving a clear and precise definition of the problem as well as the context of the system to design. At this level, it is of utmost importance to really state the *problem* without being "polluted" by any possible implementation.

We'll illustrate the design process with the example of an airline reservation system. The problem to solve can be stated as follows:

> *This system is the basic workstation for all on-ground commercial staff. It is in charge of all commercial transactions, such as selling tickets, making reservations, moving people between flights, attributing seats in the plane, etc.*
>
> *Although the system itself is unique, not all staff have access to all functions; the system must thus include some kind of authorization procedure. It must be*

> *highly available and reliable. Under normal conditions (i.e. 80% of the time), a transaction must respond within one second; in no case should a transaction take more than 20 seconds.*

b) Analysis and restructuring of requirement data
Once what the problem *is* has been clearly stated, it is important to understand the *parameters, requirements*, or other *constraints* that affect the problem. We are not talking about constraints on the implementation at this point, only those that belong to the problem domain. Part of the understanding of the requirements is to state how the piece under design is to integrate with the others. At this stage, the designer will also define the software environment of the system to design.

The designer gathers, analyses and organizes all the information relevant to his problem, clarifying all points which are not yet clear. There are two reasons why some points might not be clear:

- The designer did not fully understand the requirements
- The requirements are incorrect, incomplete, self-contradictory, or otherwise flawed.

Note that these reasons are not exclusive! In any case, the important point at this stage is to identify any such points, and to discuss the issue with the originator of the requirement. When the object to design is a root of a design tree, the requirements will come from the client (a real client, or some system design team of a higher level). This process is actually the transition between requirements analysis (description of the WHAT), and the design (description of the HOW). When the object to design is a child, the requirements have been set by the design of the parent; the designer should go to the author of the parent object to discuss the issue.

> *For example, our airline client has stated a desired response time, but not the number of workstations, nor the maximum number of transactions that can occur simultaneously! It may well be the case that the client intends the solution to be extensible, i.e. that hardware be improved as the number of workstations increases, but it has an impact on design, since the solution in that case must make sure that there is no bottleneck that would prevent such an extension from providing the desired increase in transactions power. These points must be clarified right from the start.*

It may seem logical that a same person designs the parent and all the children; however, in this case, there will be no critical review of the requirements (as long as the designer understands his own requirements!). Therefore it may be very productive to systematically mix-up objects among a team in such a way that the implementors of an object are never those who have set the requirements for it.

There are various forms of requirements. Since HOOD will implement each kind of requirement in a separate, well defined entity, it is important to classify the requirements into functional, behavioural and non-functional ones, and to perform design sensitive analysis upon them.

> *For example, the functions provided by the airline system (make a reservation, attribute seats, handle authorizations, etc.) are functional constraints. The mandatory response time is a behavioural constraint. Availability and reliability are "other" constraints.*

Finally, it may be useful for some applications to produce a *user manual* outline of the system to design at this point. This ensures that the provided features are not influenced by the underlying implementation.

13.4.1.2 Outputs

Since analysis of the problem is such a crucial step, it is extremely important to keep the outcome of it, and especially for traceability. At this stage, it can only be informal texts. The output is organized in two sections:

a) Statement of the problem
A description of the problem and its context in a few sentences. This section can be put into the `DESCRIPTION` section of the ODS.

b) Analysis and restructuring of requirement data
An analysis of the constraints and requirements that apply to the object. This section may either be put into the `DESCRIPTION` section of the ODS, or in a dedicated document that parallels the ODS. It is mainly an update of the requirements which should include, as needed, the following subsections:

- analysis and definition of the object environment
- analysis of functional constraints
- analysis of behavioural constraints
- analysis of data model constraints
- analysis of non-functional constraints
- user manual outline

13.4.2 Activity 2: elaboration of an informal solution strategy

We are entering now what we called the "creative part" of design. Activities 2 to 4 are presented in a "normal" order, i.e. the one that would happen if everything was perfectly foreseen and specified right from the start. In practice, those steps will be conducted more or less in parallel. For example, an informal solution can be sketched (activity 2), from which children are identified (activity 3) and formalized (activity 4). At this point, it can be realized that the solution exhibits some inconsistency, or can be improved. In such a case, the designer *must* iterate, i.e. rework activity 2 to state the new solution, then adjust outputs from activities 3 and 4 accordingly. The big "Not-To-Do" would be to update the formalized solution that results from activity 4, without reworking the output of the previous activities. Not only would the documents be inconsistent, but this would be equivalent to jumping directly to a solution without performing the necessary analysis.

13.4.2.1 Activity: Refine and work out a solution

This phase has as goal the expression of a solution. This is the most creative part of design: once the problem is described and understood, a solution has to be found. At this stage, the designer describes only an *informal* solution: he/she identifies the main abstractions involved in the solution, the various actions that happen between them, and gives a *scenario* of how the solution works accordingly (including, if necessary degraded modes). The description is informal because it is expressed in natural language, and tries to avoid any computational detail, as well as forward references (e.g. how a child object will do its work).

13.4.2.2 Output: Elaboration of an informal strategy

The output of this activity should be a clear text explaining the solution in natural language. As the design evolves, it must be kept consistent with the graphical and textual descriptions elaborated during the following activities.

For example, a possible solution for the airline reservation system can be expressed as follows:

> *The system is split according to the various domains involved. A screen manager is in charge of formatting the screens and getting orders from the operator. A data base is in charge of all information storing and retrieval. In between, a controller is in charge of doing all the "intelligent" work.*
>
> *Typically, the controller will get orders from the screen manager, translate them into one or several requests to the data base, get the response from the data base, format the response into logical screens that are sent back to the screen manager. Dealing with physical screens (i.e. actual presentation) is purely the job of the screen manager.*

13.4.3 Activity 3: formalization of the strategy

13.4.3.1 Activity: Refine and work out the selected solution outline

This phase has as goal the extraction of the major concepts of the informal strategy, in order to achieve smoothly a formalized description of the solution. *Concepts* include the objects involved, their relationships, and the actions they perform on data.

The designer refines the strategy by producing textual descriptions of all relevant objects and operations, and a graphical description that summarizes the architecture. The idea is that a solution which can be expressed clearly in natural language is an already mastered solution. Let us stress again at this point that identifying "good" objects is not easy, and that it is often necessary to rework this step.

13.4.3.2 Outputs

The output of this activity is a graphical description representing the breaking of the parent object into children, with a set of textual descriptions of the children.

Since this is a difficult step, it is better to clearly separate the issues, and to organize these descriptions according to the following subsections.

a) Identification of objects
The designer expresses, from the strategy text, how each child objects works with the others and what they do, which functions they embed. The output is a textual description of the child objects required by the solution. These descriptions will later serve as Activity 1 for the children: define the problem that they solve.

Here is the identification of the objects from the informal description of the airline reservation system:

> *There are three top-level objects: the SCREEN_MANAGER, the DATA_BASE and the CONTROLLER.*
>
> *Data exchanged between these objects are ORDERS, LOGICAL_SCREENS, and REQUESTS to the data base, that trigger REPLIES from the data base.*

b) Identification of operations
The designer identifies all operations, to which object they belong, which objects can use them, and gives for each one a textual description. It is often beneficial to first identify the operations (i.e. what has to be done), then associate the operation to a child (i.e. which object is in charge of performing the operation). The designer may point out all attributes relative to concurrency, synchronism, periodic execution. The result of this phase is for each child object, a textual description of the operations it provides to its users.

The description of operations for our example would look like:

> *An operation GET_ORDER to get the next order from the keyboard. This operation belongs to the SCREEN_MANAGER.*
>
> *An operation SEND_SCREEN to display a logical screen on the terminal. This operation belongs to the SCREEN_MANAGER.*

There will certainly be various kinds of requests to the DATA_BASE. It is too early at this stage to define them precisely, so we'll just define an operation set DATA_BASE_REQUESTS that belongs to the DATA_BASE.

c) Graphical description

Now that the breaking into objects is defined, the designer will capture the main relationships between the children, and the features of the parent they implement, in the graphical description.

This description will include all the "use" and "implemented-by" relationships, together with the most relevant data and exception flows.

It is appropriate to stress at that point that the graphical description is only an abstraction of the textual descriptions: as a result not everything should be shown in the diagram, but only the most relevant information easing the understanding of the architecture. Of course, the consistency with the textual description must be ensured; but generally the tool will take care of it.

The structure of the airline reservation system can now be pictured as on figure 13-3.

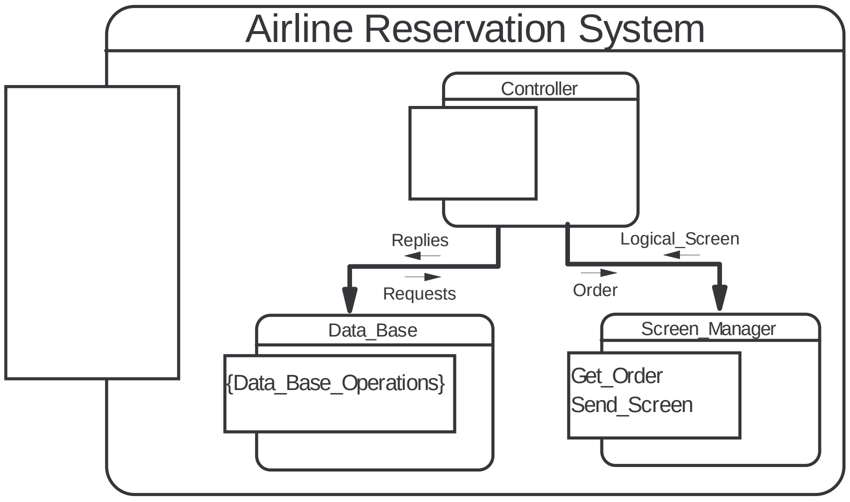


Figure 13-3 : Graphical description of the airline reservation system.

13.4.4 Activity 4: formalization of the solution

13.4.4.1 Activity: Formalize the reviewed solution in the ODS

The goal of this phase is to obtain a detailed description of the solution with all the characteristics of the object formally stated. Therefore, this steps consists in filling all the fields of the ODS. Note however that a number of fields can be deduced from the graphical description, and are generally automatically filled by the tool.

13.4.4.2 Outputs

The formal output of this activity is naturally a set of completed ODSs. Actually, this activity involves two kinds of formalization:

- Since child objects have been defined, their ODS must be created. It will include their informal definition, to serve as a starting point when they will be further designed, and some other information that can be deduced from the graphical description (like "use" relationships as well as some operations...)
- The complete definition of the parent object's ODS. From then on, it is completely and formally described, and will remain the unique reliable piece of documentation for detailed design and code generation.

13.4.5 Activity 5: analysis of the solution

13.4.5.1 Activity: review and justify all design decisions

Different activities can be performed in order to check the correctness of the solution:

- Justification of the design solution
- Consistency and completeness validation
- Identification of reusable objects
- Identification of potentially generic objects
- Analysis of the dynamic behaviour, which may include state transition modelling.
- Post-analysis design update. If necessary, update the design steps N and N-1 according to the requirements discovered in this step.
- Traceability entries: this is the right time to define which requirement the current design is fulfilling. The designer can thus define entries in a traceability matrix or directly within the ODS.
- Risk analysis, in order to identify critical issues in the solution in terms of technical and management risks. For technical risks concerning failure management, detection means and recovery actions have to be studied and the solution has to be updated if necessary.

13.4.5.2 Output: Analysis of the solution

A document should gather the results of the various checks that have been performed. It can be a "stand-alone" document, or it may be attached to the ODS of the parent object under decomposition within the `DESCRIPTION` field. In that case this valuable information is immediately available in case of later reuse of this object/solution.

For example it is not as obvious as it may seem that the operation GET_ORDER belongs to the SCREEN_MANAGER. A justification for this decision could be:

An alternative solution would be to make SCREEN_MANAGER an independent entity that would send orders to the controller. In this case, we would rather have a RECEIVE_ORDER operation in the controller.

This would provide for a better solution if we wanted to process several requests simultaneously, while the adopted solution only allows for a basic Get_Order - Process - Display result cycle. However, we have no requirement for concurrent processing of requests. On the other hand, the adopted solution provides for a better encapsulation, since the SCREEN_MANAGER is in charge of user interaction, and nothing but user interaction, without any knowledge of the other modules in the system (i.e. it is a pure server).

13.5 Terminal implementation

When considering an object identified by a previous step, it has to be decided whether the object is further broken down or not. If not, then the object is terminal, and has to be implemented.

This activity corresponds to what is often called *detailed design*. What remains to be done at this point is filling the `INTERNALS` part of the ODS of the object. Note that it involves more than mere coding: for example, the `OPCS` sections include descriptive subsections that have to be properly documented.

13.6 Summary

The basic decomposition process is the methodological approach that leads the designer from a set of requirements to a completed design, organized as a hierarchical structure called the HOOD Design Tree.

This process involves iterating over a basic design step, which summarizes the activities to be performed for breaking parent objects into children. There is a recommended, but not mandatory basic design step defined by HOOD. When an object is not further broken down, it is implemented in the target language.

HOOD acknowledges that no strictly top-down model of design can be effective; therefore, the approach favours progressive refinements of the initial design.

14. Designing in the large

14.1 Prime contractor's activities

The development of a system involves a *general process*, whose responsibility belongs to the project manager, or when subcontractors are involved, to the prime contractor. These activities are supported by HOOD in a way that enforces the independence between them.

14.1.1 Activity 1: Define the logical architecture

This is the definition of the logical (as opposed to "physical") decomposition: a HOOD design is first produced, ignoring all physical and implementation details and constraints. The principle is to produce a "clean" solution, ignoring all non-functional-constraints, as if an ideal target with unlimited power were available, and then rework it to add more features dedicated to the implementation of non-functional constraints such as performance, reliability, distribution.

This activity is achieved by iterating over basic design steps. Note that the same design pattern is applied in the same way throughout the design, from the start down to the final phases. This provides a unique systematic approach for designs of any size and complexity, and helps unifying management procedures, distributing the design and development, and defining milestones to provide visibility over work in progress.

14.1.2 Activity 2: Select reusable components

Before starting designing pieces anew, it should be investigated which existing components may be reused. The infrastructure includes all the pieces that are necessary to the project, like communication services, operating system, archiving system, etc.

14.1.3 Activity 3: Decide the distribution strategy

We have seen the importance of the virtual node concept to maintain a logical architecture that is not driven by the physical architecture. This does not mean that the physical architecture can be totally ignored: at some point, a mapping from logical to physical must be defined. Similarly, the virtual nodes are intended to host the actual objects of the system. This also requires a mapping activity. This activity consists in building a logical view of distribution, or partitioning, and describing it as a virtual node tree. Therefore, the following steps have to be performed:

- Make an architectural design without accounting for distribution.
- Define a model of distribution as a tree of virtual node.
- Define the physical architecture (unless it is defined by the requirements)
- Partition the software by deciding which objects from the architectural design are associated to which virtual node.

The important aspect of HOOD is that each of these steps is independent, and that it is possible to change the various mappings at any point in time. Of course, it may happen that two communicating objects that used to be on the same node are moved to different nodes; in such a case, the local calls will change to remote procedure calls, a modification that can be dealt with by the tools. But this will have *no effect* on the logical structure of the project.

Why is it so important to maintain such an independence? Imagine, for example, a system distributed over two processors. Allocation of objects to processors should be consistent with the logical structure, while minimizing network communication bottlenecks that can be induced by too many data exchanges between objects allocated to different nodes. Although these exchanges can be simulated to a certain extent, some trial-and-error can be necessary to determine the best allocation scheme. Moreover, an evolution of the functionalities, or the addition of a processor, can reverse some previously optimal allocation strategy. By keeping the logical structure independent from the physical structure, the allocation strategy can be changed at any time in order to provide an optimal throughput over the network.

14.1.4 Activity 4: Physical architecture

This activity involves describing the actual underlying physical architecture, and mapping the logical partitioning onto it (i.e. deciding on which physical node each virtual node will be implemented).

14.2 Initiating the design

The basic design step describes how a parent object is decomposed into children. However, when a new project is started, there is no parent object to start from! On the other hand, it is beneficial to initiate a design in a way that is consistent with the rest of the method, although the project manager must take into account special constraints such as subcontracting, parallel development, reuse, system design, etc.

Initiating a design thus consists in moving from *requirements* to a first HOOD representation of the system. An analysis of the requirements is performed, and translated into a *design* by performing the following steps:

- define the system to design (at this point: the whole project) as an interface to its environment.
  - Represent the system to design as a single HOOD object. Like any object, it has a required interface which, in this case, represents the "external world" to which the system is connected. This external world is represented as environment objects. It may also be obvious (or required) to reuse some existing objects: for example, an existing data base management system.
  - Define a first version of the system configuration, which includes the system to design itself, and any required objects known at that point.
  - Define the services that are provided to the environment.
  - Define the dataflows between the system and its environment.
- Perform the first basic design step (decompose the root system to design into child objects)
  - Perform a basic design step on the root object, in order to achieve a first decomposition. Like for any child object, it has to be decided whether they are to be kept as children, or promoted to environments. At this stage, it is generally the case that most if not all the children are promoted to environments, since they are normally, weakly coupled, and likely reusable. This almost always happens if they correspond to parts of the projects that are subcontracted, since the subcontractors will get (partial) system configurations corresponding to their parts.
  - Update the system configuration to include the new root objects that have been identified.

From then on, it is possible to iterate basic design steps down to a level of detail which allows for direct implementation and coding.

14.3 Subcontracting

In a big project, it is often the case that the development is given to a *prime contractor* who will partition the work and delegate parts of it to *subcontractors.* Splitting the work and managing the subcontractors is a difficult task for the prime contractor; the HOOD approach has been designed in order to ease that task.

Defining the work breakdown and allocation to subcontractors is a complex process that depends on multiple factors, including the industrial organization defined to support the project. The task definition work generally includes the following activities:

- *Elaboration of a HOOD initial model.* The top-level system is split into as many objects as can be developed in parallel. In general, many of these objects are environments to enforce independence, but it is also possible to have child objects. This elaboration of the initial model may constitute in itself a sub-project and is certainly not an easy task: depending on the validation effort, it may take up 30% to 40% of the project resources.

- *Definition of HOOD system configurations associated to subcontracted objects*. The bounds of the developments given to each subcontractor are defined by partitioning the global system configuration into local system configurations that include only the parts of the system that are either used or to be developed by a given subcontractor. If necessary, confidentiality constraints are enforced by *not* including unnecessary sensitive modules in a subcontractor's system configuration.
- *Definition of the virtual nodes architecture*. This task is performed either in parallel with the elaboration of the initial model, or later. The architecture which is set-up (and possibly prototyped) should be compliant in terms of performances, target system, and possibly to a domain application generic model (extracted through capitalization of the know-how in the domain).
- *Allocation of objects onto VNs*. This task allows grouping objects of the initial model according to physical and/or organizational constraints. Note that depending on the project's structure, sharing of the responsibilities between the prime and the subcontractors, etc., this allocation task can be performed either by the designers as part of the basic design step, or by the prime at the time of integration.
- *Elaboration of associated Technical Requirement Specifications*. This document defines, for each subcontracted object, its precise behaviour and properties. Normally, most of the required information has been put in the description fields of the associated objects; most of the document can thus be produced by extracting information from the various ODS associated to the initial model
- *Contractual allocation of development tasks to subcontractors*. According to the work breakdown established above, the prime contractor must choose the subcontractors and define the contractual conditions.

A main difficulty in subcontracting is finding the "right" granularity of breakdown. It must be fine enough to provide the subcontractors with a well defined, bounded task, but if it is too fine, there is a serious risk of doing the work of the subcontractors.

The work of the prime contractor is not over as soon as the subcontracted parts have been assigned to subcontractors. His duties include the follow-up of the work, integration and validation. There are several levels of validation that are easily dealt with in the HOOD model:

- *Level validation*. The prime contractor may participate to formal reviews performed by the subcontractor when major design steps are reached. It is useful for detecting early deviations from the requirements, for synchronizing the parallel developments by several subcontractors, and for factorizing developments across teams, since the prime may discover objects that are used by several teams.
- *Update of system configuration*. The system configuration of subcontractors is updated at the time of these reviews, since root objects of each local system configuration are likely to be common resources at global system configuration level.
- *Pre-integration of subcontracted object/subsystems*. Subcontractors can be provided with (at least) prototype implementations of used modules that they didn't develop themselves. The HOOD contractual model enforces that these prototypes

will match the actual components, therefore providing a *test harness* to the subcontractor, who will be able to start pre-integration on its own site.
- *Final Integration and validation*. This task must be performed on the prime contractor's site. The prime will take all the various subcontracted parts and put them together to check the global behaviour of the system. Once again, the HOOD contractual model enforces the consistency of the various views, so any discrepancies should have been found earlier, and the final integration should proceed smoothly.

14.4 HOOD and development standards

We have seen that the HOOD modular decomposition proceeds by successive refinements in two directions: consolidating objects and refining the decomposition structure (see section 13.2). This is beneficial for the designer's activity, but raises some concerns from a manager's point of view.

Most management activities have been organized according to the classical waterfall model, also called the "V" life cycle. This is a comfortable model for the management, since it defines planed steps that are easily tracked against a software development plan: architectural design, detailed design, coding, unit testing, integration, etc.

The definition of these activities, especially architectural and detailed design, do not fit very well with the model of progressive refinement of HOOD. In a sense, it is beneficial, since HOOD is precisely intended to break the classical waterfall model with its well-know drawbacks; however, a bridge is to be found with management techniques, if simple questions like "how is the project doing?" are to be answered.

The best way to address this issue is to map HOOD activities into classical activities. This can be achieved by considering the object as a unit of configuration, thus:

- architectural design corresponds to a set of refinements by decomposition.
- detailed design corresponds to a set of refinement activities by enrichment of descriptions of terminal objects using stepwise refinement on pseudo-code and/or code descriptions. (A parent object is fully defined by its children. If all children are specified, then the parent is also defined).

However, an architectural design review has to apply to a model where the architectural choices have been made and validated. Architectural design reviews should only be applied to significant models, where some validation has been performed.

14.5 Configuration management

Configuration management is the process used to master the definition of the components of a project. It involves archiving the various elements, and keeping track of which version of which module is part of a given version of the product.

Configuration management is not limited to code; the state of all design documents must be kept as well, in order to be able to reconstruct the complete and exact state of the project. All the elements that must be kept under configuration control are called *configuration items*.

The configuration of a HOOD development is defined at any moment by the system configuration and associated ODSs. Therefore, the system configuration and the ODSs corresponding to all the elements in the various trees included in the system configuration are configuration items.

With a HOOD tool, *all* the code can be generated automatically from the ODS; in this case it is *not* necessary to keep the code at all, since the precise state of the project can be regenerated from the ODS. The code *can* be archived, but it will serve as a short-hand or as a mean of verification: if the code regenerated by the tool is not strictly equal to the archived one, the configuration is inconsistent. Note however that this implies that the HOOD tool itself has not changed in-between! Serious configuration managers archive also the old version of the tools whenever a new one is installed.

In practice, it may happen that the code, as generated by the tool, must be reworked before being used. For example, it may be necessary to modify the generated code for adjustments that are beyond the scope of automated code generation, like those that are necessary to adapt it to particular target constraints (addition of Ada pragmas such as pragma IN_LINE, SUPPRESS_CHECKS, representation clauses, etc.).

> To be honest, this can also happen because of an insufficiency (or bug) in the code generator of the HOOD tool.

In such cases, it is tempting to make the eventual code a configuration item, together with the ODSs. Feedback from early HOOD projects shows however that it is better to keep ODSs as the basic configuration item, and to use scripts (batch editor commands such as Shell procedures, SED, or MAKE under Unix environments) that make the necessary transformations upon the generated code. Other good reasons for using such scripts will be detailed later as we address the issues of target language generation, but for now let us simply note that this allows to automatically generate code from the ODS, therefore bringing the designer back to the situation of the perfect HOOD tool. Of course, such scripts are also configuration items in order to be able to reconstruct the complete project.

Some tools may allow items of finer granularity than the ODS to be extracted. If the ODS is the coarsest configuration item that makes sense, some projects may feel the need to define such finer elements as configuration items. This will depend on the constraints of the project and available tools.

How often should a new configuration be created? It depends obviously on project constraints, but there are some major milestones that *require* a new configuration. These are the end of the architectural design phase, the end of the detailed design phase, and the end of the coding phase.

The first configuration of a project defined at the end of the architectural design phase corresponds to the definition (and optionally to the prototyping) of an initial HOOD model defining a contractual reference state. The test specification and test plan will be derived from this configuration, as well as traceability activities.

Note that creating a configuration at the end of detailed design is *not* useful: the HOOD model is a smooth evolution by successive refinements from the initial HOOD model down to code. There is therefore no identifiable point that would mark the end of a detailed design phase, and it is generally better to *not* have a formal detailed design review. Such a review point can be artificially defined, but experience has shown that the state is often not quite stable, and therefore not really meaningful.

It is rather better to proceed to a second configuration at the end of the coding and unit testing phase. Such a configuration may be thoroughly reviewed (inspections, authors-reader cycles) and will form the first stable version of the project. From that point only, the design will be put under change control and every code modification will lead to a change within an ODS, and a regeneration using automated tools, that will require a rerun of the unit tests and regression tests to validate the modification.

14.6 Human factors and HOOD management

Human factors are as important with HOOD designs as with any other team effort. HOOD is a proven effective method, provided it is correctly used and applied. Proper training is therefore of utmost importance, and analysis of difficulties that have arisen in some HOOD developments showed that very often, improper training was the root of the problem. The main issues where lack of understanding of the method has lead to difficulties are:

- *Insufficient training in object oriented thinking*. People trained to other design methods tend to carry over their usual way of thinking, and call "objects" things that are merely functional modules, for example. Sometimes, an audit discovers that, although the design uses OO terminology, it is actually a functional or data flow model. This leads often to inconsistencies that are difficult to resolve.

  > Assuming, that an OO structure is intended. HOOD modules *can* be used to represent a functional decomposition, if this is the way the project works. There is a problem only when the project is assuming OO decomposition, but the programmers do not apply it correctly.

- *Producing documentation for the documentation*. Documenting the fields of the ODS is intended to guide the developer in the design process. However, tools are very efficient to producing a lot of paper. If the designers confuse quantity with quality (or if they are judged on the quantity of produced paper!), they can give the illusion of a huge amount of work, while the actual progresses are rather slow.
- *Using the method and the tools backward*. Some designers tend to jump into coding, then fill the documentation fields of the ODS because quality assurance would not accept it otherwise. The recommended approach leads to filling the various

documentation fields gradually, going from informal to more and more formal descriptions, eventually to code. If taken backwards, it makes no sense to make descriptions more and more informal, so the designer will repeat the same information in the various fields. He will be frustrated by useless repetitions, and will not benefit from the gradual refinements approach of the method.
- *Decomposing the project according to available people*. The development team is often in place before the start of the project, and it is tempting to define a first decomposition that maps the split of work between participants. Although it might seem to simplify the work of the program manager, it will rarely correspond to a logical, maintainable solution. Moreover, it is extremely susceptible to a change in people. If one of the team members leaves, the whole project may be at risks.

A practice which is highly beneficial for teams that are new to HOOD is tutoring. Tutoring consists in having an experienced tutor in charge of supporting "on-line" a project team that has been recently trained in a new technology. His main tasks are:

- looking over the shoulders of the designers to check that the new technology is correctly used and applied;
- providing additional support and training when needed.

Tutoring is very beneficial to HOOD projects, especially when the team is new or has very few HOOD practice. When a new HOOD project is started, a recognized HOOD tutor should be allocated to the team: experience has shown that the cost of correcting errors increases dramatically as the design is more advanced. A tutor whose experience avoids mistakes in the beginning generally proves to be very cost efficient.

It is therefore important that the tutor be available right at the elaboration of the top-level design, and that he injects back all his experience to the new team. Areas of expertise where the tutor may be especially useful include:

- launching the project, configuring the HOOD tool set, and the development environment
- defining the project approach
- author-reader cycles on the first informal strategies
- etc...

14.7 Summary

Large projects are under the responsibility of a prime contractor, whose duties include the management of the project, the general architectural decisions, and the breaking of the project into units submitted to subcontractors. The hierarchical structure of HOOD has been designed to ease these tasks.

The prime contractor is also in charge of maintaining the configuration and integrating the various pieces. Human factors such as proper training play an important role in the success (or failure) of a project.

15. Design documentation

In this chapter, we give a description of the design documentation suitable for describing and checking HOOD designs. We are talking here about *design* documentation, that should not to be confused with a full *project* documentation which may need additional items depending on the documentation standard used by the project.

The method gives recommendations about *what* is to be documented, but imposes no particular *form* of documentation. The important issue is for the information to be here, not how it is presented: each project has its own standard for documentation, and it is impossible to fit everyone's needs with one single model.

The last issue with documentation is *where* to store it. Documentation is more easily updated and retrieved if it is kept in a place that is easily accessible to the designer. For this reason, the ODS allows all documentation associated to an object to be kept together with the object, including informal texts (especially in the `DESCRIPTION` field). Most HOOD tools are able to extract this information in order to form various design documents, meeting the project or company-wide documentation standards.

15.1 Why is documentation important?

Everybody tells that documentation is important, but why? The answer is not obvious, since it is so difficult to get proper documentation from software engineers... The main issue is that in an industrial project, no knowledge or understanding gained by a designer should be lost to the team. Moreover, a design is rarely reread by the person who wrote it. The difficulty is that documentation must be written with this "unknown reader" in mind, with the goal of transmitting all the knowledge gained by the designer while studying various solutions to a problem. Formalizing documentation is at least a way of ensuring that no mandatory or important part has been forgotten.

The HOOD documentation is intended to favour communication and explanation of a solution within a development team. It describes the software at different levels of details and abstraction. It allows quality assurance teams to check that both the HOOD approach and description standards have been enforced during the development. Documentation also serves to supporting author-reader cycles.

15.2 Relations between documentation and design fragments

One of the benefits of object oriented design is that all the properties (data structures, program structures) that belong to a real world object are encapsulated in a single design object. This should extend to documentation as well: all the aspects of an object should be found in a single place.

This is achieved in HOOD by gathering in the ODS both high-level, informal documentation (like a free text describing the general purpose of the object), and detailed elements (such as the code in a terminal object). Therefore, the ODS is the main documentation unit.

Of course, the ODS is only a logical concept; a physical representation of an ODS is a piece of text grouping the contents of the fields of an ODS into a human readable form. This latter may take different layouts according to the documentation features of the HOOD tool set and the purpose of the documentation. It is often the case that documentation matching certain contractual requirements is extracted from the ODS. The associated notations and formalisms can in fact be used for:

- informal verification (through author-reader cycles) of textual descriptions
- design verification (designs checks, pseudo-code)
- code generation for prototyping
- code generation for final products.

In practice, there are two kind of documentation:

- the *running documentation*, a set of ODSs maintained by the HOOD tools, that acts as the fundamental design data base, gathering in a structured form as much information as possible
- *external documentation*, that serve a very special purpose: peer reviews, traceability matrices, architectural document, formal parts for automatic verifications, etc. These documents can be automatically produced from the running documentation.

A special mention should be given to the separation, in the ODS, of the OPCSs and the OBCS, which allows concurrent analysis of real-time behaviour together with the development of sequential code.

It must be understood that the goal of HOOD is *not* to produce huge amounts of documentation. It is true that this "central design data base" concept *allows* to produce almost any kind of documentation, and can be easily abused of. But the idea is to be able to issue, at any time, any form of document that can be desired.

15.3 Generating standard documents

Sometimes, the eventual client requires a documentation in some standard formats, like the DOD-2167A, DOD-198A, ESA PSS-05, etc. These documents are generally organized following a waterfall model, while HOOD documentation follows the decomposition into objects. However, this is more a difference in presentation than in content: the necessary information is present in the ODS.

Providing a documentation to some standard format is more an issue of extracting and reorganizing paragraphs extracted from the ODS rather than an extra documentation effort. Actually, many tools are able to do this extraction automatically, and recreate documents in the format of various standards from a HOOD documentation.

15.4 Trends in documentation

Most documentation is eventually produced as paper; however, the raw amount of paper, and the difficulty to make sure that the document at hand is effectively the most recent issue call for exchanging documents as computer files. This was long hampered by the difficulty in finding an appropriate, portable, common document format that could be viewed and processed on various platforms.

Such a format now exists: HTML[1]. It is sufficiently well defined for the purpose of documentation, there are browsers to view it on virtually any machine, and it provides hypertext facilities that are very convenient to relate various parts of the document. Current HOOD tools are able to produce the documentation as HTML files; as a consequence, it can be expected that in the future paper will be dramatically reduced, and that deliverables to customers will include only SIF and HTML files.

1.Hypertext Markup Language, the format of documents exchanged over the Internet.

16. Design reviews

HOOD is intended to serve the needs of large scale industrial projects. In this context, a designer's work has to go through several review steps in order to be accepted. These review are intended to improve quality and make sure that one person's error cannot put a whole project at risk. HOOD provides support not only for the designer, but also to all the people in charge of reviewing and accepting the designs.

16.1 Authoring reviews and quality assurance

Several kinds of reviews are involved during designs. We distinguish here the two most important ones: *author-readers cycles*, and *quality assurance*. Other kinds of reviews exist, like the final control by the customer, or audits by experts... when something goes wrong and the origin of the problem has to be investigated.

Reviews are intended to increase the quality of software, but can easily turn into a heavy bureaucratic process. It must be stressed that insisting on too much formal paperwork gives the illusion of quality, but may also seriously hamper the productivity of designers without an increase in actual quality.

16.1.1 Author-readers cycles

Author-readers cycles happen *during* design, and are relatively informal. When an *author* designs a piece, he sends it for review to a *reader* whose role is to review it, trying to find flaws, inconsistencies, better solutions, etc. The reader should check the main ideas (informal strategy and operations descriptions) rather than pinpoint every subsection of the ODS. In a team, it is often the case that each member acts simultaneously as an author *and* as a reader for other members.

The risk with author-readers cycles is that they can have a negative effect on schedule, if the author is blocked waiting for the reader to return his comments... that may well be simply "everything's OK". A good basis is that any document submitted to a reader should be returned within a week, or be assumed to be OK. Otherwise delays become too important and the process hinders the design elaboration.

Author-readers cycles can be made more efficient by careful planning. If the readers know *when* they are to receive reviews, they can plan their schedule for shortest response times. Alternatively, they can receive information almost continuously and read the designs as they evolve. This practically requires that the author and the reader share the same tool, allowing simultaneous creation and review.

16.1.2 Quality assurance

Quality assurance is a much more formal process, that takes place *after* initial design, to check that the design meets the quality criteria of the project and can be incorporated. It focuses on completeness of documentation, consistency, traceability, etc.

The first task of a quality assurance team is to define a set of precisely outlined *quality criteria*, to be used later as a yard stick for the evaluation of projects. Such criteria should allow, as far as possible, for objective assessments. For example, rather than stating that "a procedure should not be too long", it is better to state that "a procedure should not be more than 50 lines long". This kind of criteria should not be taken too strongly: it is often the case that *not* obeying by a rule is necessary to a higher quality code. However, any deviation from a rule should be *justified*. The criteria serve as an objective mean of identifying *potential* problems, but the final decision about whether it is actually a quality fault or not has to be taken after careful inspection.

As far as possible, criteria that are measurable by tools should be defined. There is always a risk of overlooking something in a manual inspection, that can be lessened with the help of automated tools. For example, inspection tools can be run over the code, with a result presented as a "star diagram" as on figure 16-1.

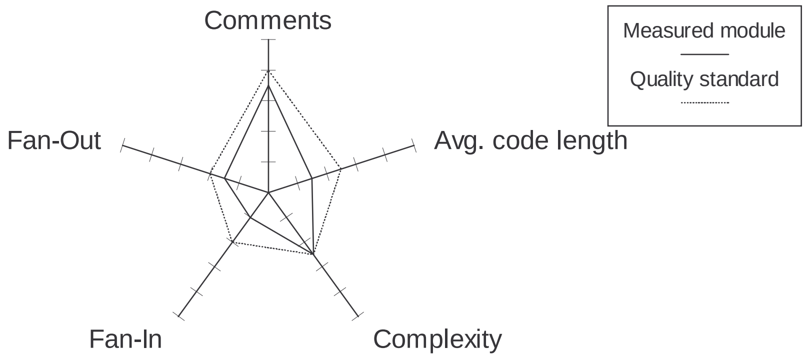


Figure 16-1 : A star diagram

Such a diagram should not be interpreted as an absolute quality measure; however, experience shows that when a diagram significantly differs from the usual shape of other modules in the project, there is often a quality problem that is worth looking at.

16.2 Preparing reviews

A HOOD design is a set of documents. Ideally, when dealing with a complete check of a design, the following documents (or document parts) should be available:

- a description of the system configuration;
- for each hierarchy of the system configuration, the design tree;
- for each object or class its ODS, and especially the most important parts: description, interfaces, and behaviour;
- a validation report about the verifications (if any) that have been performed during the design process.

Of course, the world is not perfect, and some elements may be missing or incomplete, especially during author-reader cycles that happen before the design is complete.

ODS provided for review can be computer files or paper documents. In the latter case, the documents should be structured in in a way that eases reading and understanding of the design.

Organization

A full design is a linear document of a tree architecture. It can thus be organized as "depth first" (taking the first object at the first level, then its first child, then the first child of this child, etc.) or "breadth first" (taking all first level objects first, then all second leve objectsl, etc.) Experience has shown that "breadth first" organization is easier to manage, since top level objects are not diluted in a sea of low level objects, and since it follows the natural path from high level concepts to low-level details.

Although a HOOD documentation tends to produce auto-sufficient documents, references to required objects may force the reader to navigate between several related ODS. Hence it is always necessary to have a "map" of the object organization: the system configuration allows to define the context and the scope of that verification.

Furthermore it is important that in a document submitted to a review, an ODS appears only *once*, even if it used in multiple places, otherwise confusion will result. But even so, there may be some time redundant parts between the descriptions appearing in the parent ODS and the ones appearing in child ODSs.

Such redundancy adds volume to the documentation to read, without any real benefit. An acceptable compromise consists in allowing child ODS fields to *refer* to (rather than copy) a parent ODS field. However such referencing should not be systematic, but only be allowed for the parent information which is not distributed among several children. Moreover it should not be used across several level of decomposition since this would make the reading of a deeply nested child very uncomfortable.

16.3 What to check in a HOOD design

16.3.1 Looking for the "good" design

The idea of a "good" design is very subjective: every designer describes his production as "clean", "elegant", "understandable", even if he is the only one able to understand it... Moreover, there are often several ways of achieving the same goal. Some people tend to think naturally in functional terms, while other favour a compositive OO approach, or a classification approach.

Therefore, the review process should also be guided in order to know what to check in a HOOD design. The main issue is to make sure the design is *consistent*. It is perfectly possible to use HOOD with a functional approach, as well as with OO decomposition; but a functional approach *in a project that made the decision to follow an OO approach* is a design flaw.

Following is a list of some common errors that are found in HOOD designs, and that should be looked for in the review process.

- Objects not linked to proper abstractions. In an OO design, an object should clearly map a real-world object, or at least a well identified entity that implements every aspect of one notion.
- Operations improperly attributed. Often, an operation involves two or more objects. It is a common error to attribute the operation to the wrong object.
- Functional deviations in OO projects. People often think according to their previous habits, and if not sufficiently trained in "OO thinking", tend to analyse the problem in terms of functionalities, not objects. The modules tend to be purely functional. A good clue of this happening is when many objects have names like "manager of...", "handler for...".
- Data flow deviations. This is the symmetrical problem for people accustomed to data flow oriented methods.
- Design after coding. Sometimes people rush to drawing boxes and arrows, then fill the problem analysis sections. A clue of this happening is when the various levels of descriptions repeat each other, instead of going from informal to more formal.

16.3.2 Design evaluation process

The general evaluation process involves three major directions:

- consistency of decomposition (i.e. are parent-child descriptions consistent?),
- traceability (i.e. have all requirements been taken into account and where?),
- software engineering quality criteria (i.e. do we have a "good design"?).

Depending on the kind of review, emphasis on the various aspects will vary. A methodological review will primarily check for errors in understanding the method and in applying software engineering principles. Quality assurance review will mainly check the consistency of parent-child descriptions, while the final customer will check out requirements implementation and testability. But more emphasis on some aspects does not mean that other ones should be ignored; it is clear that a customer should *also* validate the quality of the design which is being delivered to him.

A general outline of a review process can be sketched as follows:

- Evaluate the design through "successive validation steps", by checking one by one the decompositions of parent objects into children, level bylevel. This process mimics the "successive design steps".
- For each level, and before going to the next level of decomposition, check the traceability analyses.
- Finally evaluate the decompositions through quality criteria (reuse, testability, software engineering quality, HOOD rules, etc.)

These activities may be done in a collaborative way by people having different backgrounds. But they all must have knowledge of the HOOD method (rather high for people evaluating design quality), as well as a good knowledge of the requirements and its environment (rather high for people checking traceability).

16.3.3 Reviewing the tree structure

A complete review should start from the more general information: the system configuration. It allows a first understanding of the partitioning of the system and of its environment. The system to design is itself described through several hierarchies of HDT. The analysis of the tree structure gives a global view point on the architecture.

A design reviewer should always keep the design tree in mind, in order to follow its own navigation philosophy. We recommend to navigate "horizontally", level by level down to a level close to terminal objects. At that time, it may be appropriate to conclude with "vertical navigation", since low level objects have very little to do one with another if they belong to distinct hierarchies. Moreover it may be interesting to look globally at subsystems: in certain designs, subsystems are highly related and it may useful to shift to vertical navigation.

The analysis of the design tree may highlight problems related to the quality of design. One may observe for example that similar objects have been developed several times: they could be promoted to an upper level as common objects, or defined as environments. Some errors in understanding the method can be also detected, such as useless objects or decomposition levels (decomposition of an object into a single object, or into only OP_Control ones). Finally, examining the structure of a design tree may highlight apparently strange partitioning. These may result from good reasons or from design flaws; a well justified design decision must be provided.

16.3.4 Reviewing ODSs

After checking the global tree structure, each element (i.e. individual ODSs) has to be inspected. Some simple rules insure a better efficiency of this process:

- ODS analysis should be done tree by tree.
- the evaluation should start at level 0.

- an evaluation should first check the implementation of a parent specifications into child objects.
- an evaluation should then trace requirement support child by child

It is also recommended to check the `REQUIRED_INTERFACE` since this allows also the detection of inconsistencies in the use of the HOOD method, such as the call by a parent object of an operation provided by a child.

Knowing that the information contained in the fields of a parent ODS is generally distributed in some child ODS fields (such type of redundancy is unavoidable), it is necessary to check its consistency:

- If the text elaborated in the parent ODS fields is refined in the child ODS fields and is no more consistent/compatible with the parent ones, it has to be pointed out, and the information in the parent ODS corrected.
- if the text elaborated in the parent ODS fields refers to the child ODS, this may indicate that the documentation of the parent object was produced after the child's. This in turn may be a clue of the method not being applied top-down, and should be investigated.

Part 4 :
From design to code

Eventually, every design must be turned into target language code. HOOD is committed to making this last step as automated as possible, therefore raising the level of abstraction that the designer has to deal with.

How this is achieved is the purpose of this part.

17. Mapping HOOD to programming languages

As a *design* method, HOOD is independent from programming languages. However, the design must eventually be translated into code. In a program text, the various notions, such as data modelling, functional or behavioural aspects, etc. are completely mixed. It is where the method makes the difference, by keeping theses aspects *separated*, although they use the target language itself to describe algorithms and data structures in terminal objects. In short, the design includes all necessary pieces of code, but organized in a way which is appropriate to design and does not form a proper program: description of actions are in the OPCS, code dealing with protocol constraints is in the OBCS, and possible state transitions are described in the OSTD.

17.1 Tool support issues

The tool is in charge of automatically generating the code by gathering the various pieces from the design to build a correct, complete program in the target language. Ideally, the designer would always work in the design tool, and regenerate the code after any change. This may prove impractical for various reasons:

- Some tools are not able to generate a complete code from the design; some manual adjustments are required. It is not a big concern if it is done only once, but can prove very painful and error-prone if it has to be done every time a small change is done into the code. As mentioned before, this can be mitigated if the adjustments are automated by external tools, like *shell scripts*. If these scripts are considered part of the code of the project, the result is the same as with a "perfect" tool.
- In some projects, the design has to be frozen at some point, and from then on the development is not allowed to change it any more.
- The generated code may not meet coding quality criteria or coding styles.

In such cases, the programmer will generate a first draft of the code, and then work on the generated code. This entails a risk of design documents not corresponding to the code any more. The designer must make sure that any change to the code is reflected into the design. Some tools now include a *reverse coding* feature, that allows the design to be updated automatically from the code in case it was changed.

In any case, traceability between design and code needs to know how code is generated from design. Some uniformity in this area is desirable, to ensure that this traceability does not depend too much on the particular tool being used. For this reason, HOOD defines *code generation rules* that outline how the various HOOD features are mapped onto language constructs. It is not the purpose of this book to describe all such rules; they are mainly a concern for tool builders. We willonly describe the most important ones to show how the gap is bridged between design and code, and to allow the user to check the generated code.

17.2 Principles of target language mapping

General principles

The target language features should be used as far as possible to express HOOD concepts, unless there are some good reasons to choose an alternate solution. For example, target language encapsulation facilities should be used to match HOOD modules and visibility rules as closely as possible; if the language provides exceptions, they should be used to implement HOOD exceptions, unless project rules forbid them; if the language offers concurrency, it should be used to implement active objects, unless the use of some commercial real-time executive is mandated; etc. The main idea here is to try to narrow the gap between design and implementation, in order to ease traceability from design to implementation. Of course, this will be more easily achieved as the implementation language is of a higher level.

Note that the previous statement should not be reversed: the language is here to implement the method, not the other way round. For example, languages often allow structures that are forbidden by the method (like direct access to global variables for example). If a programmer complains that "the method does not allow to express what he/she wants to code", it is a clear indication of code-before-design!

HOOD run-time library

The implementation requires a set of specialized services, provided by a *HOOD Run-Time Library* (HRTL) which is a set of software modules used for the mapping of HOOD concepts. The precise content of the HRTL depends on the tool, but it is not a problem since it is used only from automatically generated code.

However, since code is intrinsically at a lower level of abstraction than design, code generation will inevitably loose some high level information. It is beneficial to keep as much information as possible in the code, since it is what the designer will first look at. Therefore, high level information that cannot be translated into language features should at least stay as comments in the generated code. Note that such comments can adopt a standardized format that will ease the job for reverse coding tools.

Identifiers

Target language identifiers should be kept identical to HOOD identifiers. This may not always be possible (for example, some languages have restrictions on the maximum length of identifiers; C does not allow several (global) operations with the same name; etc.). Sometimes, a HOOD entity has to be mapped into *several* target language constructs; in this case, automatically generated identifiers should take the form of the

HOOD identifier, with some additional name appended. For example, an operation (`OPER` for example) of an object is normally generated as a procedure with the same name; however, if the operation is constrained, the plain name `OPER` should be reserved for the operation called by clients, in this case the entry point in the OBCS that controls access to the procedure. A different name must be used for the actual operation, as described in the OPCS. A good name would be `OPCS_OPER`.

OBCS

A special mention should be made for the implementation of the OBCS. Since it has to deal with many aspects, going from state constraints to distribution, the implementation of the OBCS is organized as several layers. There are various implementation techniques, depending on the capabilities of the programming language. In the general case, a call to a constrained operation follows the model pictured on figure 17-1.

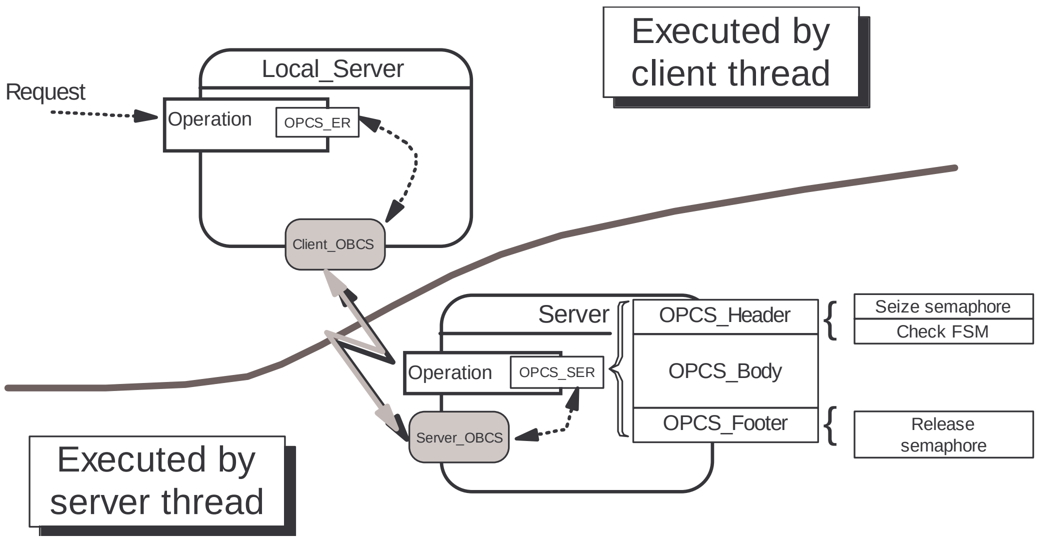


Figure 17-1 : General structure of a call to a constrained operation.

In this example, the server is not located on the same physical node as the client. When the client issues a request to an operation provided by the server, it actually calls an operation (`OPCS_ER`, for *OPCS execution request*) provided by a local "image" of the actual server. This `OPCS_ER` (there is one for each operation) will transmit the request to a special module, the `Client_OBCS` (one for each object) which is in charge of routing the request to the actual server. On the receiving node the request is transmitted to the `OPCS_SER` (for *OPCS server execution request*) that will perform the actual operation. This is in turn made of three parts:

- A header part, that seizes the semaphore that ensures the proper concurrency constraint, and then checks the Object State Transition Machine (OSTM) and raises an exception if the state of the object does not allow the operation to be performed.
- A body part, which is the actual code for the operation. This is what the designer has actually put in the OPCS for the operation.
- A footer part, that releases the semaphore.

The return status will then be transmitted back to the caller through the network by the `Server_OBCS` to the `Client_OBCS`.

Depending on the tool and on the kind of constraint, the various parts of the code for the OBCS (Client_OBCS, OPCS_Header, etc.) may be automatically generated (with the help of some environments or OS libraries), or not. Even when the code can be automatically generated, the tool may *allow* the user to provide the associated code manually, if closer control over the communications is desired. To that effect, there is a `CODE` section in the OBCS that allows the designer to provide an actual implementation for the OBCS. Often, this code involves (global) data that are part of the *state* of the object, and as such participate in the constraints associated to some operations. They should be declared as local variables within the OBCS to ensures that the OPCSs of various operations cannot access them, and that the separation between constraint management, which belong to the OBCS, and functional behaviour, which belongs to the OPCS, is enforced. As an example, here is the generated code for an `OPCS_SER` in Ada:

```
-- OPCS Header
begin
    HRTS_Semaphores.P;
    HRTS_FSM.Fire (...);
exception
    when X_Bad_Execution_Request =>
      HRTS_Semaphores.V;
      raise;
end;

-- OPCS body
Actual code of operation

-- OPCS footer
HRTS_Semaphores.V;
```

And here is the same code in C++:

```
// OPCS Header
    HRTS_Sema.P;
    EXCEPTIONS_SET("X_NONE");
    OSTM.fsm->FIRE(...);
    P_FSM_EXCEPTIONS_HANDLE();

//OPCS body
Actual code of operation

// OPCS footer
    HRTS_Sema.V
```

Of course, the previous general description is for the most general case, and it does not mean that all those layers are generated for each constrained operation! Only those that are relevant to the particular constraint do actually produce code.

17.3 Ada mapping

17.3.1 Objects

Objects are mapped into packages, whose visible part corresponds to the provided interface of the object. Child modules are mapped to private children of their parent, therefore enforcing HOOD structure and visibility rules. For terminal modules, the implementation corresponds to variables, constants, and bodies of subprograms in the corresponding package body.

17.3.2 "Implemented-by" relationship

Operations of non-terminal modules use a renaming declaration to reflect the `IMPLEMENTED_BY` clause. For example, a structure is represented on figure `17-2`:

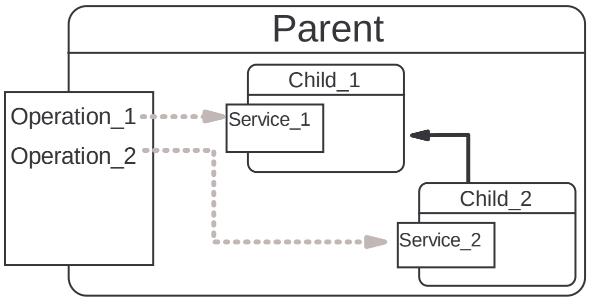


Figure 17-2 : A HOOD structure

It would translate into the following Ada structure:

```
package Parent is
   procedure Operation_1;
   procedure Operation_2;
end Parent;

private package Parent.Child_1 is
   procedure Service_1;
end Parent.Child_1;

with Parent.Child_1;
private package Parent.Child_2 is
   procedure Service_2;
end Parent.Child_2;

with Parent.Child_1, Parent.Child2;
package body Parent is
   procedure Operation_1 renames Parent.Child_1.Service_1;
   procedure Operation_2 renames Parent.Child_2.Service_2;
end Parent;
```

Note that (private) child packages and the renaming-as-body are new features of Ada 95. Ada 83 code generation rules would require the renaming to appear in the package specifi-

> cation, therefore requiring more recompilations when the package `Parent` evolves from a terminal to a non-terminal object.

Since HOOD objects map to packages, the required objects correspond to **`with`** clauses, and the same dotted notation is used to refer to the provided services and to the corresponding Ada elements.

17.3.3 HADT and Classes

HADT and classes are mapped to packages that define a "controlling" type whose name is `Instance`, as suggested in [Rosen95-1]. It is a regular type for an HADT, and a tagged type for a class. The formal controlling parameter of the provided operations has the name "`Me`".

> In the method, the controlling type has the same name as the HADT. However, a direct translation would provide a type with the same name as the package that contains it. This would be allowed by Ada, but would be quite confusing. This is an example of automatic name translation performed by the tool.

17.3.4 Exceptions

Exceptions are normally mapped directly into Ada exceptions, or to special services of the HRTL if the use of exceptions is disallowed.

17.3.5 Generics

A generic is mapped into the corresponding Ada generic unit.

17.3.6 Concurrency

Although a HOOD active object is not a direct image of an Ada task, the implementation of active objects generally uses Ada tasks in a straightforward manner. Similarly, protected objects can be used to provide `MTEX`, `RWER` and `ROER` constraints. Alternatively, as for any language, implementation of concurrency may rely on services of the HRTL or of an underlying OS.

17.3.7 Distribution

Ada provides various levels of support for distribution, from lightweight tasks to a fully distributed execution model and a standardized interface to CORBA. There are therefore various implementation strategies for HOOD virtual nodes. It is worth noting that the virtual nodes concept maps nicely to the distributed annex of Ada 95, but an implementation over CORBA is also feasible.

17.4 C and C++ mapping

A number of HOOD notions have no direct mapping into the C/C++ languages. The mapping thus relies on HOOD run-time libraries provided with the tool.

17.4.1 Objects

In general, a HOOD object is mapped into a C/C++ module, defined through two files: a *header file* (the ".h" file) and a *body file* (the ".c" file). The file is named as the object it implements. The provided and required interfaces are translated into declarations of the header file, while the internals are translated into comments, pre-processor directives and declarations in the body file.

17.4.2 "Implemented-by" relationship

C/C++ have no scoping rules for global functions: every exported subprogram is visible. Therefore, if an operation of a parent is implemented by an operation of a child *with the same name*, nothing needs to be generated: simply calling the function will resolve at link time to the appropriate implementation. If the provided operation is implemented by an operation with a *different* name, a C/C++ function is generated with the provided name, whose (inlined) body only contains a call to the implementation function. Since the function is inlined, it will eventually resolve to a simple call to the implementation function, and no overhead will be incurred.

17.4.3 HADT and Classes

A HOOD class can be mapped into a C++ class or into a C++ module.

17.4.4 Exceptions

Exception may be mapped to C++ exceptions, or to a set of services provided by the HOOD run-time library.

17.4.5 Generics

A generic class is mapped into a C++ class template. Other kinds of generics may use macros, or the generic substitution may be performed directly by the HOOD tool. Some additional generation rule make sure that the full HOOD semantic is preserved.

17.4.6 Concurrency

Neither C nor C++ provides, at language level, any support for concurrency. It is thus necessary to use the services of an underlying executive or operating system. Depending on the tool's capabilities, this may require extra design steps, since the concurrency notions of HOOD are of a higher semantic level than most OS primitives.

17.4.7 Distribution

Distribution is treated the same way as concurrency, through services provided by the OS. Implementations may use the services of a CORBA broker, or any other facility available for the target system.

17.5 Other languages

There are no formal rules defined by HOOD for other languages. It is expected however that code generation for other languages will follow the spirit of the rules for Ada and C/C++. The object oriented architecture should be preserved and the HOOD structure echoed in the generated code as much as possible. As done for C/C++, a HOOD run-time library may have to be defined. Modularity and visibility mechanisms of the language should be used, or simulated by whatever device is available. Some tools on the market are able to generate code for FORTRAN 90, and even Java.

17.6 Adjusting mapping rules: HOOD Pragmas

Pragmas are directives included in the ODS fields to add information directed to the HOOD tool (as opposed to the human reader). They are used to give the designer a better control over documentation and code generation. Some pragmas are defined by HOOD , but tools can have pragmas of their own.The syntax of a pragma is:

```
    PRAGMA Pragma_Identifier Optional_Parameters
```

Many pragmas defined in the HRM are provided to improve tools interoperability. They can appear only in SIF files (see section 19.3), and are of no interest to the user. We will just describe here those that can be used directly by the designer.

17.6.1 Target language

This pragma may be added at the top of the ODS to identify the target language for the implementation of the design. It tells the tool how to generate the associated code. The form of the pragma is:

```
    PRAGMA Target_Language (Name => language)
```

The default for *language* is Ada.

17.6.2 Mutex code generation control

This pragma may be added to the OPCS_HEADER section of the ODS to inform the code generator that the logic of the program is such that no race conditions can appear when accessing the OSTD, and that it is not necessary to generate code for mutual exclusion at that point. This increases the efficiency of the generated code, but should be used only when it is absolutely certain that the condition is met. The syntax is:

```
PRAGMA Nomutex
```

17.6.3 Testing support

It is important, when designing a module, or even a single operation, to define how it can be unit-tested. On the other hand, test code does not belong to the project, at least in its final delivered form. Two pragmas are defined, that help in automatically building test harnesses: pragma OTS at the object level, and pragma OP_TEST at the operation level. They allow the code generation tool to include (or not) the associated code used for debugging or testing purposes.

Pragma OP_TEST is used to specify preconditions (conditions that must be true when the operation is called), post-assertions (conditions that must be true when the operation is complete), etc. For example, a precondition could be:

```
PRAGMA OP_TEST(
    OPERATION        => Pop,
    TestName         => Stack_Consistency,
    DescriptionField=> PreCondition,
    Code             => --|Length(Stack)>0|--)
```

The meaning of this pragma is that it applies to operation Pop, it is called (for tracing purposes) Stack_Consistency, it is to be checked *before* calling the operation (PreCondition), and it checks that the length of the stack is greater than zero.

Pragma OTS may be added before the END of the ODS to add a number of information fields to support the assembling of unit test software for the object. It features fields that are similar to those of pragma OP_TEST.

17.7 Summary

HOOD permits code to be generated automatically from the design. Every HOOD tool provides code generation facilities. The generation strategy makes the best use of target language features to keep the structure of the code as close as possible to the structure of the design.

18. Hard real-time systems

There are several levels of real-time systems, depending on how tight timing constraints are. It is common to distinguish *soft* and *hard real-time* systems; while with the former, it is acceptable to miss some deadlines, the latter must absolutely process every event within the required framework. Failing to do so might be at risks for costly systems, like a rocket ship, or for human life.

Quite understandably, software that is part of a hard real-time system must meet much more stringent requirements than other kinds of systems. Studies have been conducted in order to formally *prove* the real-time behaviour of such systems. HOOD provides a convenient framework for organizing and developing all sorts of systems, including hard real-time ones; however it does not provide direct support for the special demands of hard real-time analysis.

For this reason, the European Space Agency ordered a study that was conducted by British Aerospace and the University of York, and which produced a variant of HOOD called HRT-HOOD[1]. HRT-HOOD is based on the version 3.1 of HOOD with special features for analyzing the real-time behaviour of systems. A set of tools has been developed to support this method, and some results of the study were incorporated into HOOD 4.

18.1 Hard real-time specific issues

HRT-HOOD is fully conform to the spirit and main principles of HOOD, it is just more specialized for hard real-time systems, with a special emphasis on provability of real-time behaviour. This of course requires more information about real-time properties of objects than what is provided in HOOD.

The timing analysis is based on the notion of *worst case execution time*, that must be measured for each terminal operation. In the case of objects that behave (more or less) randomly, an upper frequency of requests must also be defined. Finally, *budget* time may be allocated to operations, and it is possible to stop an operation that has exhausted its budget. In this case, a rescue process can be defined in case the budget is exhausted. Of course, for schedulability analysis, the total time of the operation *plus* its possible rescue operation must be taken into consideration.

1. HRT stands for "Hard Real-Time".

18.2 Additional features of HRT-HOOD

We will just summarize in this part the features that distinguish HRT-HOOD. For more information, the reader is referred to [Burns94], or to [Burns95] for a complete description of the method.

18.2.1 Sporadic, cyclic and protected objects

In addition to regular passive and active objects, HRT-HOOD defines *sporadic, cyclic* and *protected* objects. The precise definition of these objects is as follows:

- `PASSIVE` objects have no control over when invocations of their operations are executed, and do not spontaneously invoke operations in other objects.
- `ACTIVE` objects may control when invocations of their operations are executed, and may spontaneously invoke operations in other objects. They are equivalent to HOOD active objects, and suffer no special constraint.
- `PROTECTED` objects may control when invocations of their operations are executed, but do not spontaneously invoke operations in other objects. They are used to control access to shared resources, and behave somehow like monitors or Ada's protected objects. Since their operations are constrained, they have an OBCS, but they do not include any thread.
- `CYCLIC` objects represent periodic activities, and may spontaneously invoke operations in other objects, but the only operations they provide are requests which demand immediate attention (they represent asynchronous transfers of control). They include a thread, and may have an OBCS if they provide operations.
- `SPORADIC` objects represent sporadic activities, and may spontaneously invoke operations in other objects, but they can have only a single provided operation which is called to invoke the SPORADIC object, plus extra operations which are requests which demand immediate attention (they represent asynchronous transfers of control). They have a thread and an OBCS.

18.2.2 HRT rules

Analysis of real-time constraints cannot be performed in the general case. It is thus necessary to impose additional rules that will constrain the design to those forms that are amenable to analysis.

18.2.2.1 Decomposition rules

As in HOOD, objects are decomposed using the parent-child model. The terminal objects should all be `CYCLIC`, `SPORADIC`, `PROTECTED` or `PASSIVE`, because these are the objects on which schedulability analysis can be performed. `ACTIVE` objects are used at higher level, to represent activities that will be decomposed into children with different properties, that can therefore not be transmitted to their parent. Otherwise, `ACTIVE` objects are allowed as terminal objects only to model background activities for which timing is unimportant.

All forms of objects are allowed to be non-terminal, however the new ones have constraints on allowable forms. These constraints are:

- `ACTIVE` objects: no constraint
- `PASSIVE` objects: may not contain any active object

  Note that this is not the case in HOOD: a passive object may include active ones, as long as the passive nature of the parent is not violated (i.e. the provided operations are not protocol-constrained).

- `PROTECTED` objects: may include `PASSIVE` ones, and one `PROTECTED` object.

  It is not possible to implement the operations of a non-terminal `PROTECTED` object through several children, since it would break the inherent atomicity of `PROTECTED` objects.

- `SPORADIC` objects: may include at least one `SPORADIC` object, along with one or more `PASSIVE` and `PROTECTED` objects.
- `CYCLIC` objects: may include at least one `CYCLIC` object along with one or more `PASSIVE`, `PROTECTED` and `SPORADIC` objects.

18.2.2.2 Usage rules

The common background to these rules is that an object that is declared as belonging to a certain kind should not use operations that would violate the properties for that kind. Therefore:

- `CYCLIC` and `SPORADIC` objects may not call arbitrary blocking operations in other `CYCLIC` or `SPORADIC` objects.
- `PROTECTED` objects may not call blocking operations in any other objects.
- `PASSIVE` objects may not call any synchronization operation.

18.2.3 HRT execution model

We have mentioned that some operations perform *asynchronous transfers of control* (ATC). It means that when the operation is invoked, the object immediately leaves its current activity to process the request. It is *not* like an interrupt, since the object will not return to its previous activity. Examples of ATC include notifying an object that its maximum run-time for an operation has elapsed, or mode changes in a system.

On the client side, the operation is triggered without waiting for completion, as in an `ASER`. It is therefore called an *asynchronous ATC* or `ASATC`. Other forms are defined, in forms similar to an `LSER` (`LSATC`) or to an `HSER` (`HSATC`).

Operations on a PROTECTED object are always constrained, and can be synchronous or asynchronous. Therefore, operations of a `PROTECTED` object are labelled as

PSER (*protected synchronous execution request*) or as PAER (*protected asynchronous execution request*). A PSER can also have a time-out condition (TOER_PSER).

18.2.4 Real-time attributes

In regular HOOD, real-time constraints are more or less informally defined in the IMPLEMENTATION_CONSTRAINTS part of the ODS. Since real-time analysis is the goal of HRT-HOOD, a more refined structure is needed. A new section, called REAL-TIME_ATTRIBUTES, is introduced in the ODS. It defines the timing properties of the object, such as for example:

- DEADLINE: Deadline execution time for the execution of a thread of a CYCLIC or SPORADIC object.
- THREAD_WCET: worst case execution time for the execution of a thread of a CYCLIC or SPORADIC object.
- PERIOD: period of execution for a CYCLIC object.
- MAXIMAL_ARRIVAL_FREQUENCY: maximum arrival frequency of events for a SPORADIC object.
- IMPORTANCE: describes whether the object represents a hard or soft real-time thread
- etc...

18.3 HRT execution model theory

The execution model can be tailored to different forms of analysis. For example it can be based on the Fixed Priority Scheduling theory, a preemptive priority based model that assigns priorities according to deadlines, with a blocking policy called Immediate Priority Ceiling Inheritance. A precise description of these theories would go far beyond the scope of this book, but it is enough to state here that they allow to prove the real-time behaviour of a system. This means that, knowing the worst case execution time of each sequence of code, it is possible to state whether a hard real-time system will meet all its deadlines or not. Note that the precise separation of functional code (OPCS) versus reactive code (OBCS) is a great help for analysing real-time systems.

18.4 Tool support of HRT-HOOD

Two tools have been developed, not counting the adaptation of existing HOOD tools for HRT-HOOD: a schedulability analyzer, and a scheduler simulator. The former is in charge of analyzing a design and estimating worst case execution times, while the latter is in charge of performing a run-time simulation of the system behaviour in terms of predicted scheduling events and their associated time of occurrence.

19. Preserving design investment: the HOOD "standard"

19.1 The HOOD Reference Manual

HOOD is not a *standard* in the official sense, since it has not been adopted by any standardization body. It is however defined by an official document, the HOOD Reference Manual [HRM4]. The HOOD Technical Group (HTG), which includes the initial designers of the method, representatives of HOOD tools vendors, and representatives of main users, is in charge of the maintenance and evolution of the method. This is done under supervision of a larger group, the HOOD User's Group (HUG), whose purpose is to gather all the people using, or interested into, HOOD.

The HOOD Reference Manual contains the complete definition of the formalisms, and constitutes the official definition of the method. Like any reference manual, it is intended to serve as unique, formal, definition and not as a text book; reading it is not recommended to beginners, but it helps tools designers and quality reviewers to ascertain what is, or is not, HOOD.

19.2 Formal definition of the ODS

The ODS is the core of the method, since every information about a design, including the graphical description, can be deduced from the ODS. The HOOD Reference Manual provides a complete description of the ODS in BNF[1] format, together with a description in YACC[2] syntax, in order to make sure that all tools process the same ODS.

This syntactic description is complemented with a number of semantic rules whose purpose is to enforce the rules of the method. A complete description of the formal ODS would go beyond the scope of this book, but the interested reader is directed to annex H of the reference manual that provides all necessary details.

1. Backus-Naur Form, the standard way of describing the syntax of a language.
2. YACC is a tool commonly found on Unix systems that serves to automatically generate language analyzers. It stands for "Yet Another Compiler Compiler".

19.3 Exchanging designs between tools: the Standard Interchange Format

The ODS defines only a logical view of a HOOD design. The Standard Interchange Format (SIF) is a file format standard that defines a concrete form. Hence a SIF representation of an ODS is a valid one, but may not be a very readable document. SIF is basically a text file that conforms to the formal definition of the ODS, with a full ASCII representation. SIF is an important feature of HOOD: this notion has been present from the earliest issues of the method on.

The goal of SIF is to provide a common language that allows for exchanging designs across HOOD tools, as well as for allowing HOOD designs to be analyzed, checked or otherwise processed by external tools. Moreover, since SIF defines a representation of the design as a regular file, it is possible to manage designs the same way as documents or code; they can be for example baselined, or put under configuration control (see section 14.5). It is thus a key feature for integrating HOOD tool sets into software development environments.

In order to define a minimum base for interoperability, it is expected that each tool should be able to import or export SIF files corresponding to (at least):

- A system configuration
- A complete design tree
- One module (object, generic or virtual node)
- One module and all its descendants.

These goals have been met: every tool currently on the market accepts and generates SIF files. This means that in the case of projects involving several subcontractors, possibly from different companies even in different countries, it is *not* necessary that all participants use the same tools. Each may use the tool it is most familiar with, and exchange designs with other partners.

Part 5 :
A full design example

We'll conclude the book with a full, realistic, example of the use of the method. The constraints for a book like this one will not allow the full SIF and generated code to be given here (and this would be quite boring to read linearly anyway), but they can be downloaded from the HOOD web site. Similarly, it is not possible to show the cyclic aspects of design, which involve errors, corrections and various iterations before a satisfactory design is achieved.

The design is presented in the order a designer would encounter the problems, *which is not necessarily the order in which they are to be documented*. For example, we may discuss issues in the phase "elaboration of an informal strategy", because it is during that phase that the designer will consider them. On the other hand, the corresponding design documentation may have to be placed in the chapter "Justification of the solution".

Some relevant parts of the ODS that correspond to the steps that are fully described in the following chapters are given in annex E.

20. Starting the project

20.1 Requirements

A water lock is a device found on canals and rivers that allow boats to go past waterfalls or other differences in the flow level. Our goal is to define an automated lock system, i.e. one which is fully operated by a computer without a human operator. Figure 20-1 shows a picture of the lock.

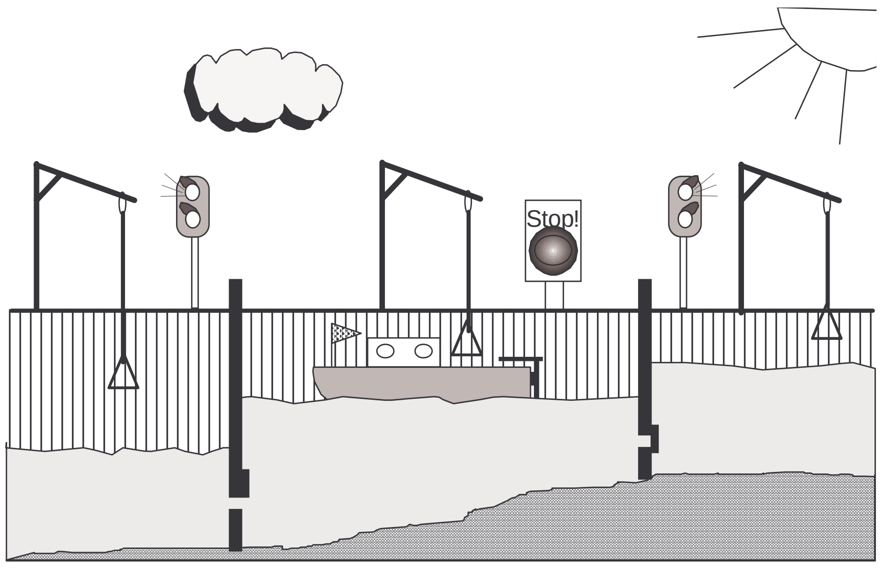


Figure 20-1 : The water-lock system.

There are three poles hanging over water: one on each side of the lock, and one in the middle, and traffic lights to indicate when boats are allowed to proceed. There is also an emergency button, used to stop the whole system in the case of an emergency. When a boat wants to enter the lock, it rings the system by pulling the pole, waits for the green light, and enters the system. It then rings the middle pole to tell the system that it is in. All the rest is automatic.

20.2 Initiating the design

To initiate the design, we have to translate the requirements into a single HOOD object that will form the basis of the design. This object represents the whole system and is defined as an *interface to its environment*.

Here, the way the environment interacts with the system is simple: the three poles, and the emergency button. HOOD reminds us to add another interaction: the start of the system.

Note that we just made a very important decision, that is far from being obvious: we included all the hardware (the gates and the traffic lights) *inside* the system. We could have considered that the system included only the computer part, and that all hardware control was external interactions. This would have certainly be the case if we had been provided with some existing hardware, with already well defined interfaces, and which could be viewed as reused components. However, in the present case, our work involves defining the interactions with these hardware pieces, so it seems logical to include the modelling of the hardware interactions into the design.

At this point, we can picture the system as the object represented on figure 20-2.

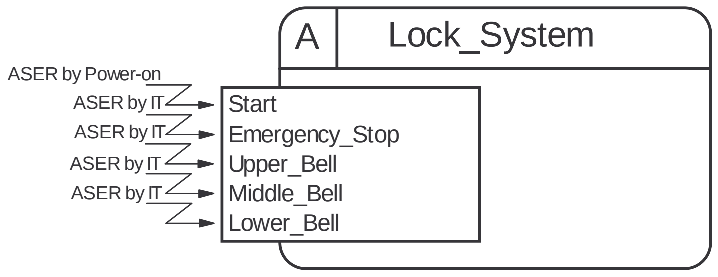


Figure 20-2 : Global view of the lock system.

20.3 The first basic design step

20.3.1 Problem definition

Here we state our understanding of the problem. It may seem to replicate a part of the requirements, but it should be remembered that we are here in a *design* document, and it is normal to recall what has to be done. It is also more precise, because we have to add information which will be important to the design although it may not have been stated by our client.

20.3.1.1 Statement of the Problem

The system is in charge of operating an automatic lock system.

There are "bells" on each side of the lock, and one in the middle. Traffic lights on both side tell the boats when they are allowed to proceed through the gates.

When a boat arrives, it rings the bell. When the gate opens, the light turns green and the boat enters the lock, and then rings the middle bell to signal it is ready.

There is also an emergency stop button in the middle; if it is pushed, all water flows must be stopped as fast as possible, and if the gates are moving, they must stop immediately. Any failure of the software must be treated as an emergency stop.

20.3.1.2 Behavioural Requirements

The system is intended to be operated without human assistance.

Boats can arrive at any time, so requests have to be queued.

When the emergency button is pushed, the system must return to a stable state, defined as closing all flows and stopping the gates at their current position.

Extreme care must be taken to not perform an hazardous operation (such as opening the lower gate while the system is full of water).

20.3.2 Elaboration of an informal strategy

In an object oriented design, we model our solution according to real-world objects. The best way to design a solution is therefore to observe how a man-operated lock system would function.

The system includes two main gates that can be opened or closed, and also provide small underwater doors that allow water to flow in or out. The two gates are identical. The system also includes traffic lights that can be set to red or green. The person in charge (let's call him the manager) waits for boats to arrive, and then operates the devices accordingly.

In the real world, the manager can always look at both ends of the lock and see whether boats are waiting. However, this information is only important when the system returns to the idle state (after a boat has exited the system). At this point, the manager must make a decision about which action to perform, like letting the next boat in, or returning the system to the other level without any boat (which is necessary if, for example, two boats want to go down in a row without any boat going up). Let's call such an action a *mission*. Missions have to be queued and optimized (don't make a mission without a boat if a boat is waiting that could be let in). So we'll consider that there is some kind of controller who tells the manager the next mission to be performed.

20.3.3 Formalization of the strategy

From the informal strategy, we can identify several objects and data. The description we give is actually the "statement of the problem" for each of the identified objects.

> In this example, we use Courier fonts to refer to HOOD objects, to differentiate them from informal descriptions. For example, the request controller is represented as the HOOD object `Request_Controller`.

20.3.3.1 Identification of objects

a) The request controller
The request controller accepts requests from boats through bell signals. It provides the next mission to the gate manager. Requests are optimized.

We note here the notion of "mission". It is clearly a data type that is provided by the `Request_Controller`.

b) The mission manager
The mission manager is in charge of executing a mission, controlling all operations to move a boat up or down. There are also missions with no boat (the manager should then not wait for the "boat inside" signal).

It is OK to request a null mission, i.e. go down when the water is already down. This can be useful to ensure a proper state at start-up, for example, and is harmless.

c) Lights_Controller
The lights controller is in charge of turning the lights red or green.

d) Gates
We said that there were to identical gates. We really need two objects since we have two real world objects, but on the other hand we do not want to duplicate designs. This calls for making the gates instantiations of a common generic model `Generic_Gate`. Of course, there must be some difference between the gates, since they do not operate on the same physical gates! Let’s assume that they have a generic parameter that tells the physical address of the devices they operate on. And since we want to be able to change the hardware configuration easily, let’s put everything related to hardware in a separate environment object called `Hard_Configuration`.

20.3.3.2 Identification of operations

We'll start the identification of operations from the provided operations of the lock system. `Upper_Bell` and `Lower_Bell` operations are, from the point of view of the system, mission requests. They are dealt with by the `Request_Controller`, but we will call them `Up_Request` and `Down_Request` since it is the appropriate meaning, as viewed from the `Request_Controller`.

The `Middle_Bell`, on the contrary, has nothing to do with missions; it is just a signal that the boat has entered the water lock, and is of concern only to the `Mission_Manager`. We will therefore implement it by a `Boat_Inside` operation of the `Mission_Manager`. Note that the three bells appeared identical at the upper view, but that we discover here that they actually play different roles. The encapsulation mechanism of HOOD allows us to keep the views that are most appropriate to each level.

The `Emergency_Stop` operation is intended to immediately stop all ongoing operations. Since these operations are controlled by the `Mission_Manager`, the operation must be implemented by an operation of the `Mission_Manager`.

We said that the role of the `Request_Controller` was to accept requests and provide missions to the `Mission_Manager`. This implies that the `Request_Controller` must provide a `Next_Mission` operation that returns the next mission to be performed.

The lights controller must have operations to set the upper light and the lower light. These operations must have a parameter, the colour to set the light to.

Finally, we didn't yet decide how the global `Start` operation would be implemented. Since it appears the `Mission_Manager` is the real central part of the system that drives all other objects, it makes sense to implement it by a `Start` operation of the `Mission_Manager`. It is understood that this operation has to call the possible `Start` operations of all other objects.

> In this case, it is consistent to keep the `Mission_Manager` in charge of all supervision; that's why we preferred to delegate the `Stop` operation to it, rather than use an OP_Control.

Note that we didn't define at this point the operations of the (generic) gates. We certainly do know that the gates will be managed by the `Mission_Manager`, but it is hard to tell at this point *how* the gates will be managed, and therefore what are the correct provided operations. Moreover, we decided that the gates would be generic, and a generic is always a different root of the system. For these reasons, we'll *delay* the definition of gates operations until later, when we understand better what is really needed.

20.3.3.3 Graphical description

At this stage, we can represent our design as pictured on figure 20-3.

> Of course, the gates should provide operations; but we see here just an intermediate state, until the gates are further refined.

20.3.4 Formalization of the solution

The formalization of the solution involves filling the various fields of the ODS. Although it is an important step, it is essentially an activity with the tool. The reader is referred to annex E, section 2. for the listing of the resulting ODS.

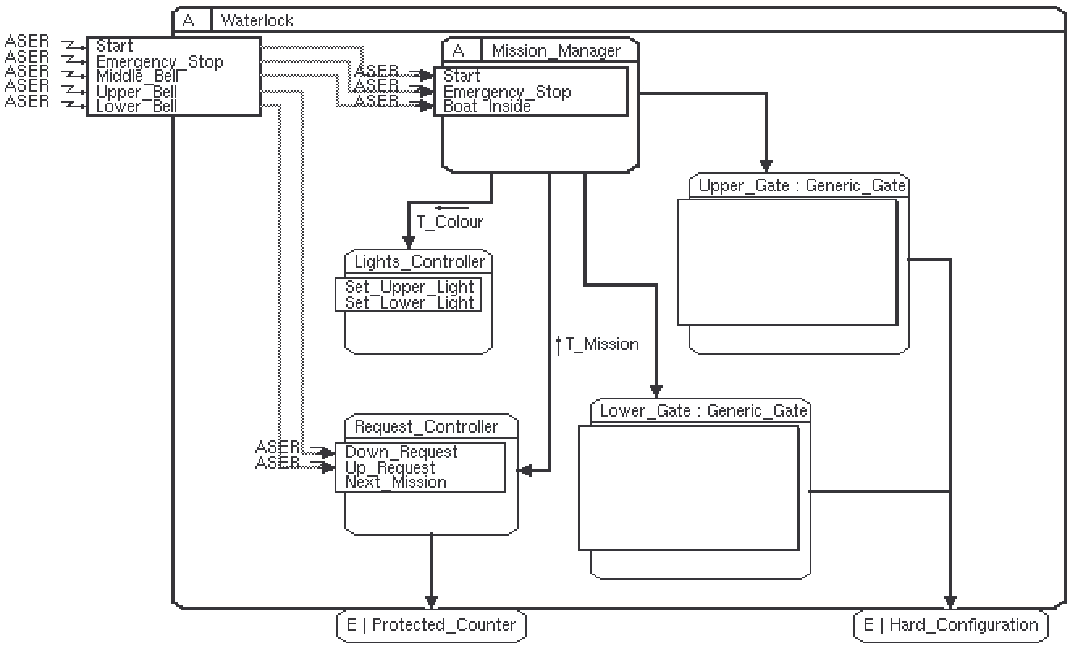


Figure 20-3 : Breakdown of the lock system

20.3.5 Analysis of the solution

There are some issues that need justification in our solution.

First, `Next_Mission` is an operation called by `Mission_Manager`. An alternative design could have been to make the `Request_Controller` an active object that sends orders to the `Mission_Manager`. Historically, we first designed it this way, but it raised difficult issues since it makes sense to send new missions only when the `Mission_Manager` is idle, and it implied that the `Request_Controller` had to be aware of the internal state of the `Mission_Manager`. By having the `Mission_Manager` call the `Request_Controller`, the problem disappears since the `Mission_Manager` requests a new mission only when it is ready to accept it. On the other hand, this implies that the `Request_Controller` has to memorize outstanding missions.

Then, we chose to have only one object to manage both traffic lights. We could as well have had two objects, but since they are really simple there is no need to have several objects, and this solution has the added benefit that we may add some consistency checks, like making it impossible to have both lights green at the same time.

21. First level objects

Now that we have broken the global project into the main objects, we can go on with the next level. In the real world, these objects could be subcontracted to different partners.

21.1 The Mission_Manager

21.1.1 Problem definition

As stated before, the mission manager is in charge of executing a mission, controlling all operations to move a boat up or down. It operates the gates as needed.

There is a requirement that a mission can be stopped at any time, and the doors returned to a "safe" state. A safe state is defined as closing all flows, and if the gates are moving, immediately stop them at their current position.

21.1.2 Elaboration of an informal strategy

Apparently, managing a mission simply involves a very linear succession of steps. However, two requirements make this more complicated:

- The requirement to be able to interrupt the action at any time
- The requirement of protecting operations to make sure that no software error can lead to a dangerous situation.

The problem with the first requirement is that the `Emergency_Stop` operation is a kind of interrupt (an ASER in HOOD terms). The simplest way to deal with it is to simply set some kind of boolean flag to state that an emergency stop has been requested. But we want to avoid having to test that flag in many places, since it would increase the risk of inadvertently *not* testing it. We can now note that although it is important to check it, there is no hard real-time constraint associated with it. When an emergency stop is requested, it will take several seconds to stop the gates motors... Therefore it is sufficient to check for an emergency stop at places where the system needs to wait. We will therefore need a single `Wait` procedures, with the following important design decisions:

- Every time the mission manager needs to wait for some event, it will do so by polling the state of an object, and the loop must include a call to the `Wait` procedure.
- When the `Emergency_Stop` is triggered, the `Wait` operation will return with an exception.
- There must be no unbounded loop outside the mission manager.

To satisfy the second requirement (make sure that not hazardous operation is performed), we decide to not operate the gates directly, but through a dedicated "driver" that will act as an abstract state machine that will prevent any inconsistent operation.

21.1.3 Formalization of the strategy

21.1.3.1 Identification of objects

From the informal strategy above, we see that we'll need an `Operator` object that will do the actual work, a `Secured_Wait` object to manage the `Wait` operation as described, and a `Secured_Driver` object to access the actual gates operations.

We also noted the presence of a "flag". This flag may be set and tested asynchronously, therefore some concurrency constraints will apply to it. This is clearly an abstract data type. The real-life object whose behaviour maps best our requirements is a hardware flip-flop, so we will call this object a `Flip-Flop`.

21.1.3.2 Identification of operations

As discussed before, the `Emergency_Stop` operation must be implemented by an `Emergency_Stop` operation of the `Secured_Wait` object. This object must also provide the `Wait` operation, and an `Init` operation whose main purpose will be to make sure that the internal flip-flop is initially reset.

The `Boat_Inside` operation must be implemented by a similar operation from the `Operator`. We note here that we don't know precisely when that operation will be called, and we require the `Operator` to test for the arrival of the event. This is very similar to the `Emergency_Stop`, and we'll take advantage of our Flip-Flop data type to memorize it the same way.

Operations on the `Flip-Flop` are taken from our hardware model: `Set`, `Reset`, and a query function `Is_Set`. Since we mentioned that these operations must be protected against concurrent accesses, we'll define `Set` and `Reset` as RWER operations, and `Is_Set` as a ROER operation (it does not change the state of the flip-flop).

The operations on the `Gates_Secured_Driver` are all operations that act on the physical state of the gate: `Open_Upper_Gate`, `Close_Upper_Gate`, `Open_Lower_Gate`, `Close_Lower_Gate`, `Open_Upper_Flow`, `Close_Upper_Flow`, `Open_Lower_Flow`, and `Close_Lower_Flow`.

21.1.3.3 Graphical description

We can now summarize our design decisions in the graphical description. Figure 21-1 represents the client-server view of the mission manager, while figure 21-2 represents the structure view.

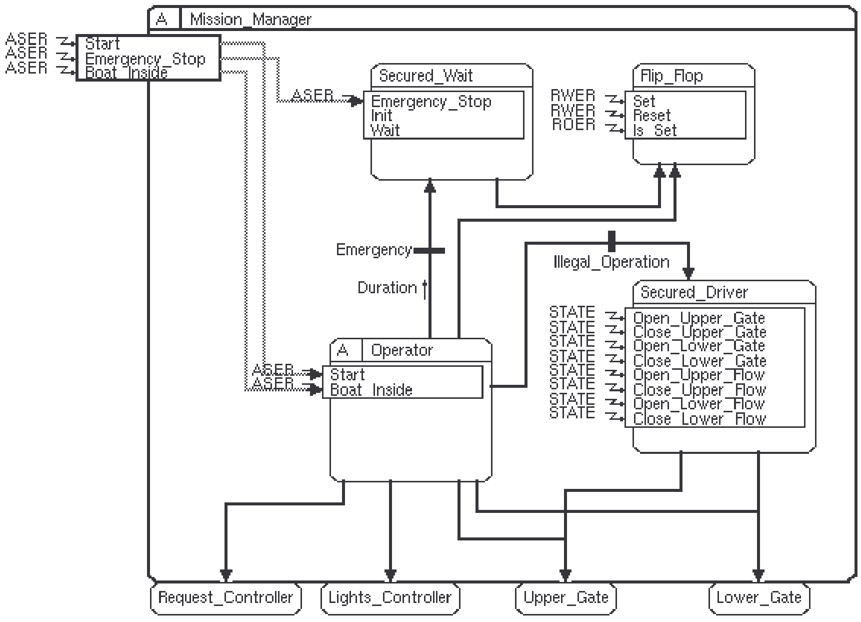


Figure 21-1 : Mission manager, client-server view

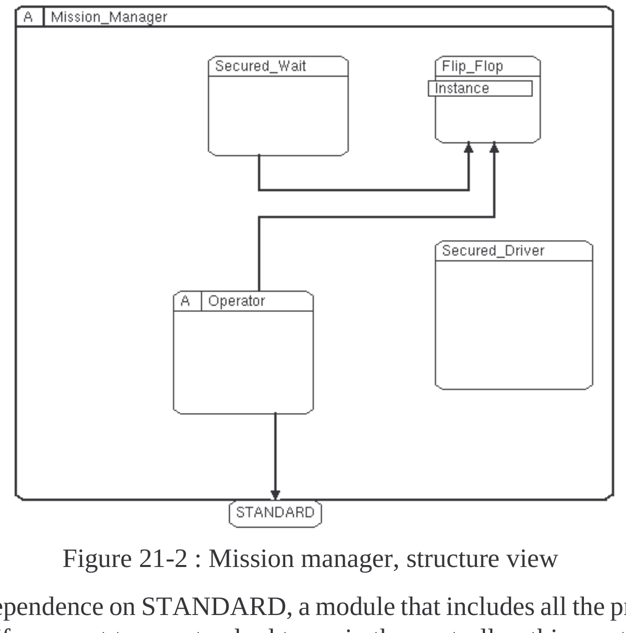


Figure 21-2 : Mission manager, structure view

Note the dependence on STANDARD, a module that includes all the predefined types of the language. If we want to use standard types in the controller, this must be described as anything else!

21.1.4 Formalization of the solution

The `Secured_Driver` serves to provide constrained access to the gates operations. Since the conditions that allow its operations to be called are part of its interface, they have to be formalized at this point; see the OSTD on figure 21-3.

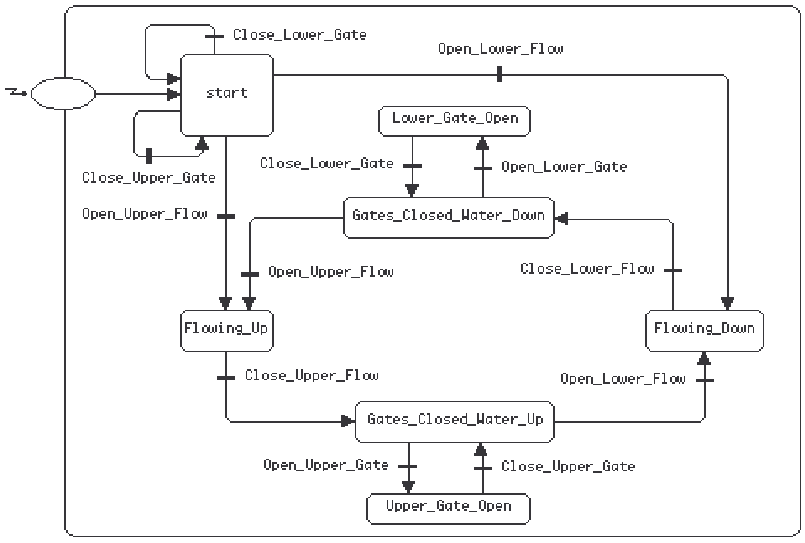


Figure 21-3 : OSTD for the secured driver

The complete ODS for the Mission_Manager can be found in annex E, section 3.

21.1.5 Analysis of the solution

The `Gates_Secured_Driver` object is really here for security reasons, i.e. make sure no dangerous operation is performed. Some security could have been put in the gates themselves, for example that the flow opens only when the gate is closed. However, the most important checks involve both gates at the same time (for example that both gates are not open at the same time). Therefore, the control had to be put at a level that controls both gates simultaneously.

For example, we note on the OSTD that the two most dangerous operations (`Open_Lower_Gate` and `Open_Upper_Gate`) are never triggered by transitions that originate from the same state; moreover, the only way to exit the states where a gate is open is through the corresponding `Close` operation. This proves formally that the doors cannot be open at the same time.

21.2 The secured driver

This is a terminal object, therefore no further design steps are needed. The implementation of provided operations is very straightforward, since each of them simply calls the corresponding operations on the appropriate gate.The real added-value of this object is the state constraints; in a sense, this object is there essentially for its OBCS!

See annex E, section 5. for the ODS.

21.3 Request controller

21.3.1 Problem definition

The request controller accepts requests from boats through bell signals. It provides the next mission to the gate manager. Missions can be either to go up or down, with or without a boat inside. There are therefore four possible missions.

Requests are optimized: a mission with no boat inside should be provided only when no boat is waiting to go that direction.

21.3.2 Elaboration of an informal strategy

At first sight it could seem necessary to keep a queue of pending requests, sorted in some clever way. Actually, it is sufficient to maintain two counters of unsatisfied "up" and "down" requests. If no counter is 0, the request controller alternates the missions. Of course, the counter should be decremented after a mission is issued. It may happen that two "up" requests, for example, are to be served in a row if the "down" counter is zero. In that case, a "Down_Empty" mission must be sent to the `Mission_Controller`.

If no mission is waiting, it would seem logical for `Next_Mission` to wait until one is requested. But this would violate our decision that there should be no wait outside the `Mission_Controller`. Therefore, we will return `No_Mission` in that case. The `Mission_Controller` can enter a wait, and re-request a mission later.

21.3.3 Formalization of the strategy

21.3.3.1 Identification of objects

The `Request_Controller` is a terminal object. The only issue is whether the counters are simple variables, or instances of a more sophisticated data type. Since requests can arrive at any time, protection against concurrent access to the counters is necessary. We identify therefore the need for an abstract data type, the `Protected_Counter`. Although we identify it at this level, there is nothing specific to the lock system in this object. It seems more appropriate to turn it into an environment HADT to make it reusable.

21.3.3.2 Identification of operations

The `Protected_Counter` data type must feature `Increment` and `Decrement` operations, and a `Current_Value` function that returns its current value.

21.3.3.3 Graphical description

There is no graphical description for a terminal object (since it is not decomposed).

21.3.4 Formalization of the solution

See the ODS in annex annex E, section 7.

21.3.5 Analysis of the solution

We don't need the current value of the counter, only to know whether it is null or not. But this kind of object is very general, so providing the general `Current_Value` (rather than a simple `Is_Null` function) makes it more reusable.

21.4 Generic_Gate

Now that we have analyzed how the system works, we can return to the definition of the generic gates.

21.4.1 Problem definition

The generic gate abstracts all services to operate the gates. The gate includes two main devices: the gates themselves, and the underwater door that controls the flows.

Because of our constraint of not having any wait outside the mission manager, no operation should be blocking for a long time.

21.4.2 Elaboration of an informal strategy

We did not decide previously of the *provided* operations of the gates. We need to do it now. This can be seen as a refinement of the previous view of the gate.

Obvious operations are opening and closing the gates, and opening and closing the flows through the doors at the bottom of the gates. Since these operations are quite long, and no blocking is allowed, we must provide some way of knowing whether the operation is still going on or terminated. We could have one interrogation function for each operation (something like `Is_Gate_Opening`, `Is_Gate_Closing`, etc.);

however, we note that not two such operations are allowed at the same time. Therefore, a single `Operation_Completed` function is sufficient. And since we rely on not allowing two operations at the same time, we note that we need an exception (`Illegal_Operation`) if ever a request were issued while the previous operation is still going on.

> It is of course a safety feature due to the principle of mutual distrust; the exception should never be raised in practice.

Finally, we need to know when it is safe to open a gate, i.e. when the water is level on both sides. The simplest way is to have a device which senses the pressure difference across the gate, and provide an `Equal_Pressures` operation.

Now that we have refined the definition of the gates, we need to actually design an implementation strategy. At this level, driving the gates really means operating the various motors; much of the work will be done by the hardware. It seems appropriate to have some data that represents the motors. Actually, we can view a gate as the aggregation of two motors (for the gates and the flows) and one differential pressure meter. We can therefore decide to make the generic gate a terminal object that will aggregate the abstractions of the various hardware devices.

21.4.3 Formalization of the strategy

21.4.3.1 Identification of objects

From the previous informal strategy, we have clearly identified two abstract data types: the motors and the pressure-meter. However, these modules are abstractions of hardware devices; they will be reused if the same hardware is reused. It makes sense then to define them as root objects.

As for the motors, we have two of them: one for the gate, and one for the flow. Nothing tells us that they are the same, or that they are commanded the same way. It seems more careful at this point to consider that we have two different ADTs. To avoid a multiplication of root objects, we will gather the motors (and possibly others that may be designed later) in a *motors library*, that will act as class library (see section 10.4.4).

21.4.3.2 Identification of operations

The `Pressure_Meter` just needs an `Equal_Pressures` function.

The motors can operate both ways. We need a `Set_Motion` operation which will take an argument telling the direction (a provided data type with two values, `Opening` and `Closing`). The motor will automatically stop when it reaches the end of its run (this is done by a hardware switch), but we need to know when this state is attained, so there is an `Is_Stopped` function. Finally, we need to stop the motor at any time, in the case of an emergency. We add therefore a `Stop_Motion` operation.

21.4.3.3 Graphical description

We can now represent the client-server view of the generic gate as on figure 21-4, and the structure view as on figure 21-5.

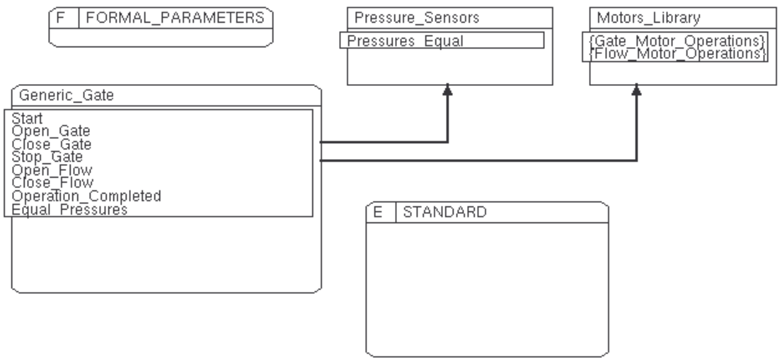


Figure 21-4 : Client-server view of the Generic_Gate

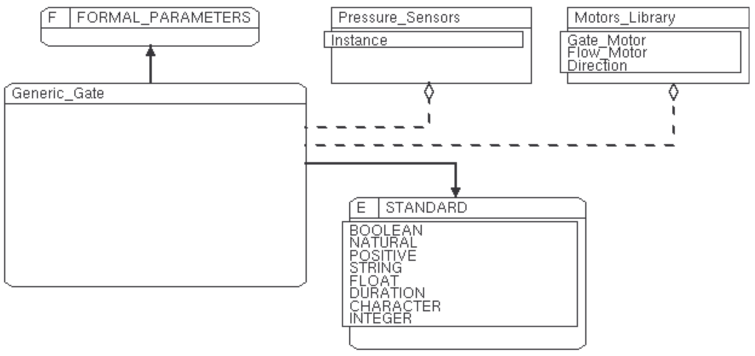


Figure 21-5 : Structure view of the Generic_Gate

21.4.4 Formalization of the solution

The ODS for the Generic_Gate is given in annex E, section 8.

21.4.5 Analysis of the solution

It may not seem necessary to have a separate operation for `Stop_Motion`, since an alternate solution would be to add a third value to the parameter of `Set_Motion`, like `Idle`. However, stopping the motor can be done at any time (it is an ASER), while the hardware may require that `Set_Motion` be called only when the motors are stopped. By providing two different operations, we may enforce this behaviour with state constraints.

22. Other objects

We won't describe in details all the other objects, since they are terminal and include mainly code. Here are however some remarks of interest about their implementations.

22.1 Motors library

We have seen that this object gathered the various kinds of motors. But of course, we don't want to duplicate code if by any chance the motors are compatible! This calls for making the motors classes that inherit from a common model, that we'll call the `Root_Motor`. Since this class is intended to serve only as a common root to all possible motors, it should be abstract.

The client-server view of the motors library is represented on figure 22-1, while the structure view is represented on figure 22-2.

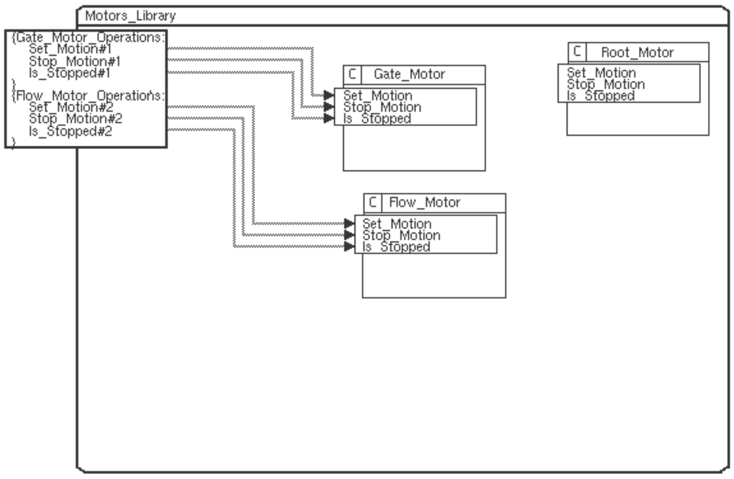


Figure 22-1 : Client-server view of the motors library

22.2 Lights_Controller and Pressure_Sensor

These are very simple objects, that just sense or activate some hardware devices. We made them environment objects because they are direct images of the corresponding hardware devices.

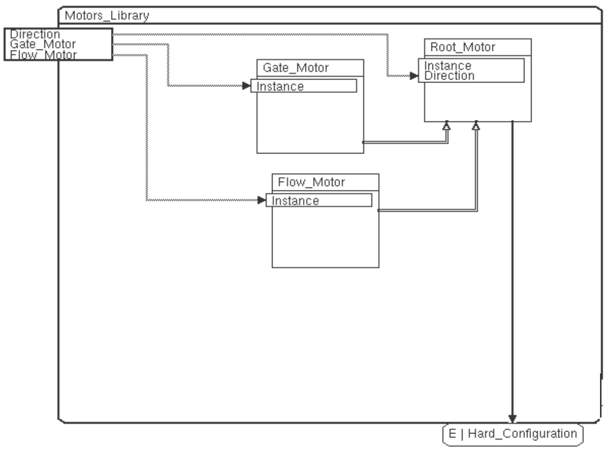


Figure 22-2 : Structure view of the motors library

22.3 Protected counter and Flip_Flop

These are very simple terminal objects, except for their concurrency constraints. In Ada, they can be implemented in a straightforward manner with protected objects. In C++, they would be protected by an `OPCS_HEADER` that would seize a semaphore (and of course, an `OPCS_FOOTER` to release it), as explained in section 17.2.

22.4 Gates instantiations

There is nothing to be done at *design* level for an instantiation; however, it is described, as anything else, by an ODS. However, it is entirely automatically generated. As an example, the ODS for Lower_Gate is given in annex E, section 9.

22.5 Hard_Configuration

This module is intended to allow a simple reconfiguration of the system. We assume that there is some kind of "address" which allows to identify any piece of hardware. The module exports a type `Device_Address` and two constants of that type, `UG_Address` and `LG_Address`, corresponding to the base addresses of the upper and the lower gates. By "base address", we assume that other addresses, like the physical address of the motors, can be deduced from this base address.

22.6 System configuration

As an example, the ODS for the system configuration is given in annex E, section 1.

Annexes

These annexes are taken in part (with permission) from the HRM and HUM.

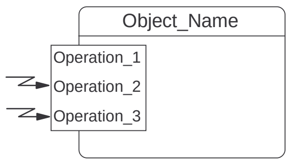
A. Abbreviations

HOOD uses a number of abbreviations. All those used in this book, as well as some others commonly used, are defined in the following list.

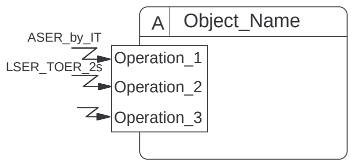
ADT	Abstract Data Type
ASM	Abstract State Machine
ASATC	Asynchronous ATC
ASER	Asynchronous Execution Request
ASCII	American Standard Code for Interchange of Information
ATC	Asynchronous transfer of control
BNF	Backus Naur Form
FSM	Finite State Machine
ER	Execution Request
ESA	European Space Agency
HDT	HOOD Design Tree
HOOD	Hierarchical Object Oriented Design
HRM	HOOD Reference Manual
HRTL	HOOD Run Time Library
HSATC	Highly Synchronous ATC
HSER	Highly Synchronous Execution Request
HTG	HOOD Technical Group
HUM	HOOD User Manual
HUG	HOOD User Group
LSATC	Loosely Synchronous ATC
LSER	Loosely Synchronous Execution Request
MTEX	Mutual Exclusion constraint
OBCS	OBject Control Structure
ODS	Object Description Skeleton
OOD	Object Oriented Design
OPCS	OPeration Control Structure
OS	Operating System
OSTD	Object State Transition Diagram
OSTM	Object State Transition Machine
PAER	Protected asynchronous execution request
PSER	Protected synchronous execution request
PDL	Program Design Language
RASER	Reporting Asynchronous Execution Request
RLSER	Reporting Loosely Synchronous Execution Request
SIF	Standard Interchange Format
TOER	Timed Out Execution Request
TOER_PAER	Timed Out Execution Request-Protected asynchronous execution request
TOER_PSER	Timed Out Execution Request-Protected synchronous execution request
VN	Virtual Node
VNT	Virtual Node Tree

B. Summary of graphical notation

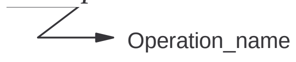
Passive object



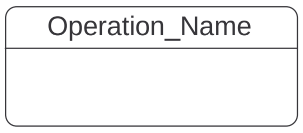
Active object



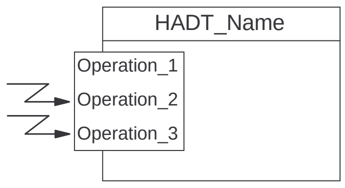
Constrained operation



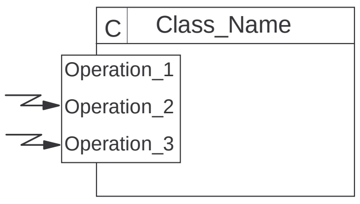
OP_Control



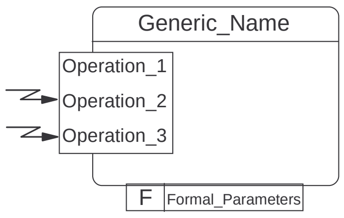
HADT



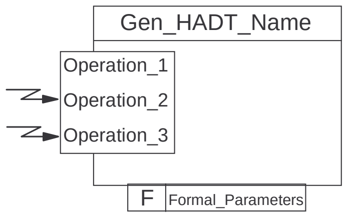
Class



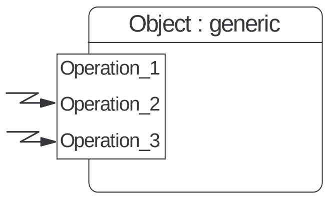
Generic object



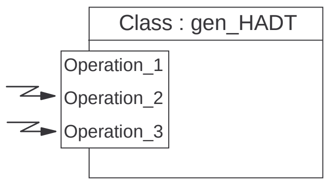
Generic HADT



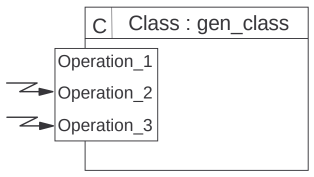
Object instance



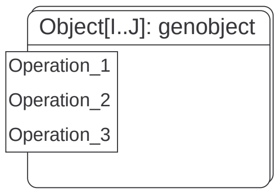
HADT instance



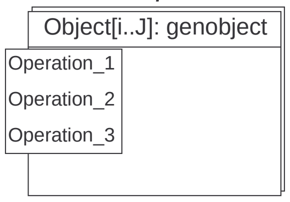
Class instance



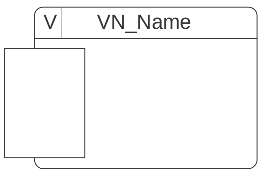
Multiple instances



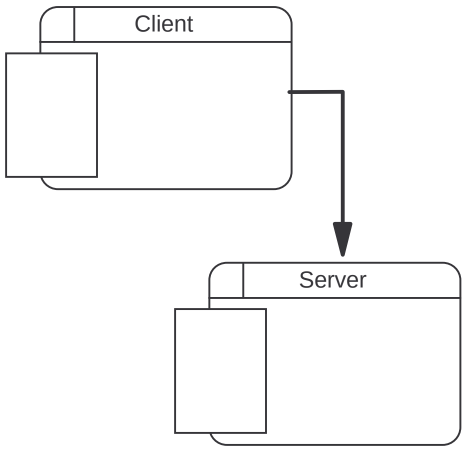
Multiple instances of HADT



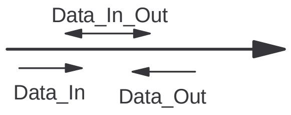
Virtual node



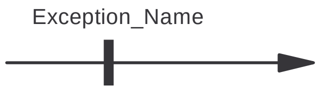
Use relationship



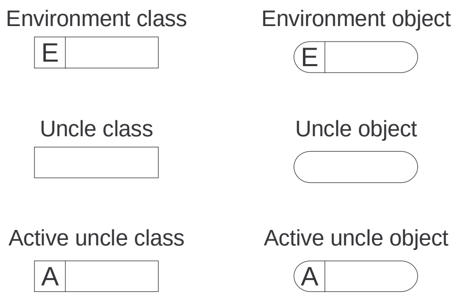
Dataflow



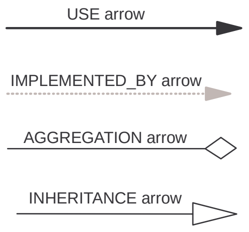
Exception flow



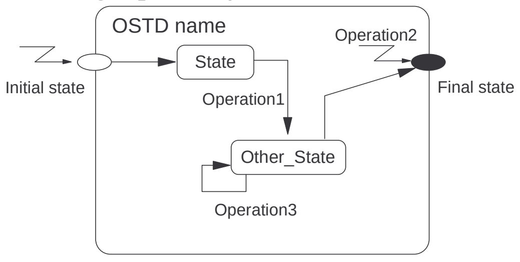
Uncles



Relationship arrows



OSTD graphical formalism



C. Glossary

Abstract class

A class specified with the keyword `abstract`. An abstract class cannot be instantiated (it can only be inherited). See section 2.6.

Active object

An object which provides some protocol-constrained operations. See section 4.6.3.

Actual parameter

A parameters provided to an instantiation of a generic in order to parameterize the instance. See section 6.2.2.

Aggregation

The property of an *aggregating type* that includes several components belonging to an *aggregated type*. See section 5.4.3

Class

A special form of HADT that allows inheritance. A class must be terminal. See section 5.5.

Constrained operation

An operation that is constrained in its execution either by the internal state of the object, by concurrency requirements, or by a communication protocol. See section 11.1.

Control flow

Direction where the execution of a thread goes when executing an operation of a server. Indicated by the `USE` relationship. See section 4.4

Data flow

Flow of data exchanged between client and server objects. See section 10.3.3.

Design process

Successive break-down of a system to design from the root object until terminal objects are reached. See section 13.

Environment

A root object which is not part of the current design and serves for black-box reuse. See section 4.5.2.

Exception flow

Flow of exceptions propagated from a server to a client along the `USE` relationship. See section 6.1.

Formal parameters

Types, constants and operations parameters of a generic. See section 8.6.1

Generic

An object pattern to represent a reusable object that can be parametered with types, data and operations as formal parameters. See section 6.2.

HOOD abstract data type - HADT

An object exporting a type named as the object, and whose provided operations all have a receiver parameter of this type with name `me`. See section 5.4.

HOOD design tree - HDT

The hierarchy of objects resulting from a design process applied on a root and consisting of the successive decompositions of parent objects into child objects. See section 12.1.

Include relationship

Relationship expressing that an object is decomposed into a set of child objects that collectively provide the same functionality as the parent. See section 4.3.

Inheritance

The property of a *subclass* of being defined as a specialization of a *superclass*, from which properties (attributes, operations) are inherited. See section 5.5.2

Instance

A data that represents the instance of an HADT or class. See 5.
An object that is instantiated from a generic and customized through actual parameters. See section 8.6.2

Internal operation

An operation that is defined in a terminal object to support the step-wise refinement of an OPCS and implementation of provided operations. Internal operations are not shown on the graphical representation. See section 9.1.1.

Non-terminal object

An object which is decomposed into child objects. See section 4.3.2.

Object Control Structure - OBCS

Part of the ODS of an object that defines the various constraints that apply to provided operations. See section 11.2.

Object Description Skeleton - ODS

The formal textual description of an object. See section 4.2.2.

Object State Transition Diagram - OSTD

Graphical representation of the state constraints that apply to an object, as a set of states, and transitions triggered by provided operations . See section 11.3.

OP_Control

An object that implements the mapping between one parent operation and several child object operations. See section 4.6.1.

Operation Control Structure - OPCS

Part of the ODS of a terminal object that defines the control structure / logic of an operation. See section 9.1.2.

Operation set

A set of operations represented as a single provided entity in order to ease the representation of long lists of operations. See section 4.6.2.

Passive object

An object which is not active. See section 4.6.3.

Physical node

The physical processor or computer on which virtual nodes can be configured. See section 6.3.

Provided interface

Property of an object which defines which services are available to other objects. See section 4.1.

Required interface

Property of an object which defines servers and associated items required for the implementation of that object. See section 4.1.

Root object

A top level object which has no parent. See section 4.3.2.

System configuration

The set of root objects defining the scope of a design. See section 12.3.

Terminal object

An object which is not decomposed into child objects. See section 4.3.2

Use relationship

Relationship expressing that an object requires one or more services provided by another object. See section 4.4.

Virtual node

A unit of distribution defined by allocation of HOOD objects, and used to define distributed systems. See section 6.3.

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E. ODS of the water-lock system

We give here the ODS for the main objects of the water-cool system. They are *not* presented in raw SIF format, but as they result from a design documentation extraction tool.

1. System configuration

SYSTEM_CONFIGURATION IS

ROOT_OBJECTS

```
--|Hard_Configuration|--,
--|Motors_Library|--,
--|Pressure_Sensors|--,
--|Protected_Counter|--,
--|STANDARD|--,
--|Waterlock|--
```

GENERIC

```
--|Generic_Gate|--
```

END

2. Waterlock

OBJECT Waterlock IS

DESCRIPTION

PROBLEM

Statement of the Problem (text)

The system is in charge of operating an automatic lock system.
There are "bells" on each side of the water-cool, and one in the middle. Traffic lights on both side to tell the boats when they are allowed to proceed through the gates.
When a boat arrives, it rings the bell. When the gate opens, the light turns green and the boat enters the lock and then rings the middle bell to signal it is ready.

There is also an emergency stop button in the middle; if it is pushed, all water flows must be stopped as fast as possible. Any failure of the software must be treated as an emergency stop.

Analysis of Requirements

Behavioural Requirements (text)

The system is intended to be operated without human assistance.

Boats can arrive at any time, so requests have to be queued.

When the emergency button is pushed, the system must return to a stable state, defined as closing all flows and stopping the gates at their current position.

Extreme care must be taken to not perform an hazardous operation (such as opening the lower gate while the system is full of water).

SOLUTION

General Strategy (text)

The system includes two main gates that can be opened or closed, and small underwater doors that allow the water to flow in or out. It also includes traffic lights that can be set red or green.

A mission consists in moving the water up or down, with or without a boat, at the request of boats arriving. Since requests for missions from the boats have to be queued, there must be a request controller that provides missions to a mission manager in charge of controlling execution of the missions.

The precise hardware interface is not defined; however, there must be some kind of "address" to identify the various hardware devices.

Identification of Child Modules (text)

Gates:
abstraction of the hardware gates. Control all operations on the physical gates. The two gates are identical, therefore they will be instantiations of a Generic_Gate model.

Lights_Controller:
abstraction of the hardware lights. Control the setting of both lights.

Request_Controller:
receives requests from the boats, and provides them to the Mission_Manager, in an optimized order.

Mission_Manager:
Processes a mission by operating the gates.

Hard_Configuration:
A simple data repository that provides the "address" of devices.

Identification of Data Structures (text)

T_Mission:
The kind of mission. Can be either No_Mission, Up_With_Boat,

Down_With_Boat, Up_Empty, or Down_Empty.

T_Colour:
The colour to set the lights to (Red or Green).

Identification of Operations (text)

Mission_Manager:
Start: Start of the system.
Emergency_Stop: Interrupt when the emergency button is pushed.
Boat_Inside: Interrupt received from the middle bell to signal that the boat is inside.

Lights_Controller:
Set_Upper_Light, Set_Lower_Light: To turn the corresponding light Red or Green.

Request_Controller:
Up_Request, Down_Requets: interrupts received to signal that a boat is ringing the lower bell or the upper bell, respectively.

Identification of Local Behaviour (text)

Mission_Manager is the only active object. No operation is allowed to block outside the Mission_Manager.

Justification of Design Decisions (text)

Interfaces to the real hardware devices are embedded in the corresponding abstractions, rather than being part of the system interface. This is possible because the definition of the interfaces is not imposed, and avoids a global dependency to any hardware implementation.

We chose to have only one object to control both lights to avoid too many small objects, and to add the possibility of cross-controls of the lights (like not having both lights Green at the same time).

The No_Mission value is necessary because we decided that no operation should block outside the Mission_Manager (see analysis of the Mission_Manager).

PROVIDED_INTERFACE

OPERATIONS

Start

operation spec. description (text)

initialization of the system, performed when the power is set on (called by hardware).

operation declaration (hood)

```
Start;
```

Emergency_Stop

operation spec. description (text)

interrupt handler called when the emergency button is pushed. called by hardware interrupt.

operation declaration (hood)

```
Emergency_Stop;
```

Middle_Bell

operation spec. description (text)

interrupt handler called when the middle bell is rung. called by hardware interrupt.

operation declaration (hood)

```
Middle_Bell;
```

Upper_Bell

operation spec. description (text)

interrupt handler called when the upper bell is rung. called by hardware interrupt.

operation declaration (hood)

```
Upper_Bell;
```

Lower_Bell

operation spec. description (text)

interrupt handler called when the lower bell is rung. called by hardware interrupt.

operation declaration (hood)

```
Lower_Bell;
```

OBJECT_CONTROL_STRUCTURE

constrained operations

```
Start CONSTRAINED_BY ASER --|By_OS|--;
Emergency_Stop CONSTRAINED_BY ASER --|by_IT|--;
Middle_Bell CONSTRAINED_BY ASER --|by_IT|--;
Upper_Bell CONSTRAINED_BY ASER --|by_IT|--;
Lower_Bell CONSTRAINED_BY ASER --|by_IT|--;
```

REQUIRED_INTERFACE

OBJECT Hard_Configuration;

CONSTANTS

```
LG_Address; UG_Address;
```

OBJECT Protected_Counter;

TYPES

```
Instance;
```

OPERATIONS

```
            Increment; Decrement;
```

OBJECT STANDARD;

TYPES

```
BOOLEAN; DURATION;
```

INTERNALS

OBJECTS

```
Mission_Manager;
Request_Controller;
Lower_Gate;
Upper_Gate;
Lights_Controller;
```

OPERATIONS

Start

```
implemented_by Mission_Manager.Start
```

Emergency_Stop

```
implemented_by Mission_Manager.Emergency_Stop
```

Middle_Bell

```
implemented_by Mission_Manager.Boat_Inside
```

Upper_Bell

```
implemented_by Request_Controller.Down_Request
```

Lower_Bell

```
implemented_by Request_Controller.Up_Request
```

END Waterlock

3. Mission manager

OBJECT Mission_Manager IS

DESCRIPTION

PROBLEM

Statement of the Problem (text)

The mission manager is in charge of executing a mission, controlling all operations to move a boat up or down. It operates the gates as needed. There are also missions with no boat (the manager should then not wait for the "boat inside" signal).

It is OK to request a null mission, i.e. go down when the water is already down. This can be useful to ensure a proper state at start-up, for example, and is harmless.

Analysis of Requirements

Functional Requirements (text)

There is a requirement that a mission can be stopped at any time, and the doors returned to a "safe" state. A safe state is defined as closing all flows, and if the gates are moving, immediately stop them at their current position.

Behavioural Requirements (text)

There is a requirement that a mission can be stopped at any time, and the doors returned to a safe state. See "Behavioural requirements" of the water-lock.

The system should be designed in such a way that it can formally be proved that dangerous operations, like opening both gates at the same time, are impossible.

SOLUTION

General Strategy (text)

The actual actions to operate the gates a performed by an operator (abstraction of a human operator in a manually operated gate). However, the requirement of provability implies that we need some specialized object through which all critical operations are performed, which will prevent any dangerous operation.
At some points, the operator will have to wait for movements to be completed. This is the right time to detect emergency stops (the time to perform computer operations in negligible). All waiting will be done through a dedicated operation of an object, which will sense the emergency stop. Since the button might be pressed at a time when no wait is being called, it needs a flip-flop to memorize the condition.

Identification of Child Modules (text)

Operator:
The module that provides the logic for controlling the gates.

Secured_Driver:
an abstract state machine that prevents every dangerous operation from happening.

Secured_Wait:
An object providing the wait operation.

Flip_Flop:
a simple object to memorize a condition.

Functional Description

Identification of Operations (text)

Operator:
Start, Boat_Inside: implementation of the parent's provided operations.

Secured_Driver:
Open_Upper_Gate, Close_Upper_Gate, Open_Lower_Gate, Close_Lower_Gate, Open_Upper_Flow, Close_Upper_Flow, Open_Lower_Flow, Close_Lower_Flow: the various operations that can be requested from the gates.

Secured_Wait:
Wait: the basic Wait operation. Raises "Emergency" if the emergency button is pressed.
Emergency_Stop: handle the interrupt from the emergency button
Init: initialization.

Flip_Flop:
Set, Reset: change the state of the Flip_Flop.
Is_Set: returns the state of the Flip_Flop.

Justification of Design Decisions (text)

The Secured_Wait object may not seem necessary, since it would be easy to wait directly in the Operator object. However, having a single wait point ensures that every time a wait happens, an emergency stop will be detected.

PROVIDED_INTERFACE

OPERATIONS

Start

operation spec. description (text)
Initialization of the Mission_Manager.

operation declaration (hood)
```
Start;
```

Emergency_Stop

operation spec. description (text)
interrupt handler called when the emergency button is pushed. called by hardware interrupt.

operation declaration (hood)
```
Emergency_Stop;
```

Boat_Inside

operation spec. description (text)
interrupt handler called when the middle bell is rung, meaning that the boat is inside the lock. called by hardware interrupt.

operation declaration (hood)
```
Boat_Inside;
```

OBJECT_CONTROL_STRUCTURE

constrained operations

```
Start CONSTRAINED_BY ASER --|By_OS|--;
Emergency_Stop CONSTRAINED_BY ASER --|by_IT|--;
Boat_Inside CONSTRAINED_BY ASER --|by_IT|--;
```

REQUIRED_INTERFACE

OBJECT Lights_Controller;

OPERATIONS

```
Set_Lower_Light; Set_Upper_Light;
```

OBJECT Lower_Gate;

OPERATIONS

```
Close_Flow; Stop_Gate; Operation_Completed;
Equal_Pressures; Open_Gate; Close_Gate; Open_Flow;
```

OBJECT Request_Controller;

OPERATIONS

```
Next_Mission;
```

OBJECT STANDARD;

TYPES

```
BOOLEAN; DURATION;
```

OBJECT Upper_Gate;

OPERATIONS

```
Close_Flow; Stop_Gate; Equal_Pressures;
Operation_Completed; Open_Gate; Close_Gate; Open_Flow;
```

DATAFLOWS

```
T_Mission <= Request_Controller;
T_Colour => Lights_Controller;
```

INTERNALS

OBJECTS

```
Operator;
Secured_Wait;
Secured_Driver;
Flip_Flop;
```

OPERATIONS

Start

```
implemented_by Operator.Start
```

Emergency_Stop

```
implemented_by Secured_Wait.Emergency_Stop
```

Boat_Inside

```
implemented_by Operator.Boat_Inside
```

END Mission_Manager

4. Operator

OBJECT Operator IS

DESCRIPTION

PROBLEM

Statement of the Problem (text)

The controller is in charge of acquiring missions from the request controller and executing them.

Analysis of Requirements

Behavioural Requirements (text)

All waits must be performed through the Secured_Wait object.

IMPLEMENTATION_CONSTRAINTS (text)

The controller must respond to an emergency stop as soon as possible.

PROVIDED_INTERFACE

OPERATIONS

Start

operation spec. description (text)

Initialization of the Operator

operation declaration (hood)

```
Start;
```

Boat_Inside

operation spec. description (text)

interrupt handler called when the middle bell is rung, meaning that the boat is inside the lock. called by hardware interrupt.

operation declaration (hood)

```
Boat_Inside;
```

OBJECT_CONTROL_STRUCTURE

constrained operations

```
Start CONSTRAINED_BY ASER --|By_OS|--;
Boat_Inside CONSTRAINED_BY ASER --|by_IT|--;
```

REQUIRED_INTERFACE

OBJECT Flip_Flop;

TYPES

```
Instance;
```

OPERATIONS

```
Set; Is_Set; Reset;
```

OBJECT Lights_Controller;

OPERATIONS

```
Set_Lower_Light; Set_Upper_Light;
```

OBJECT Lower_Gate;

OPERATIONS

```
Close_Flow; Stop_Gate; Operation_Completed;
Equal_Pressures;
```

OBJECT Request_Controller;

OPERATIONS

```
Next_Mission;
```

OBJECT Secured_Driver;

OPERATIONS

```
Close_Lower_Gate; Close_Upper_Flow; Open_Upper_Flow;
Open_Upper_Gate; Close_Lower_Flow; Close_Upper_Gate;
Open_Lower_Flow; Open_Lower_Gate;
```

OBJECT Secured_Wait;

OPERATIONS

```
Init; Wait;
```

EXCEPTIONS

```
Emergency;
```

OBJECT STANDARD;

TYPES

```
BOOLEAN;
```

OBJECT Upper_Gate;

OPERATIONS

```
Close_Flow; Stop_Gate; Equal_Pressures;
Operation_Completed;
```

DATAFLOWS

```
Duration => Secured_Wait;
```

EXCEPTION_FLOWS

```
Illegal_Operation <= Secured_Driver;
Emergency <= Secured_Wait;
```

INTERNALS

OPERATIONS

Stop_Everything

operation declaration (hood)

```
Stop_Everything;
```

Go_Up

operation declaration (hood)

```
Go_Up(with_Boat : in BOOLEAN);
```

Go_Down

operation declaration (hood)

```
Go_Down(With_Boat : in BOOLEAN);
```

Main_Loop

operation declaration (hood)

```
Main_Loop;
```

Report_Error

operation declaration (hood)

```
Report_Error;
```

DATA

Boat_Signal

data declaration (ada)

```
Boat_Signal : Flip_Flop.Instance;
```

OBCS CODE (ada)

```
begin
  accept Start;
  Main_Loop;
end OBCS;
```

OPERATION_CONTROL_STRUCTURES

OPERATION Start IS

used operations

```
Operator.Go_Down
Secured_Wait.Init
Lights_Controller.Set_Lower_Light
Lights_Controller.Set_Upper_Light
```

operation code (ada)

```
begin
  Secured_Wait.Init;
  Set_Upper_Light(Red);
  Set_Lower_Light(Red);
  Go_Down(False);
```

END Start

OPERATION Boat_Inside IS

operation body description (text)

Memorize the signal into the corresponding Flip_Flop

used operations

```
Flip_Flop.Set
```

operation code (ada)

```
begin
  set (Boat_Signal);
```

END Boat_Inside

OPERATION Stop_Everything IS

operation body description (text)

This operation should return the system to the most secure state possible.
All flows are closed.
Gates are stopped as they are (including, possibly, half open).

used operations

```
Lower_Gate.Close_Flow
Upper_Gate.Close_Flow
Lights_Controller.Set_Lower_Light
Lights_Controller.Set_Upper_Light
Lower_Gate.Stop_Gate
Upper_Gate.Stop_Gate
```

operation code (ada)

```
begin
  Set_Upper_Light(Red);
  Set_Lower_Light(Red);
  Upper_Gate.Close_Flow;
  Lower_Gate.Close_Flow;
  Upper_Gate.Stop_Gate;
  Lower_Gate.Stop_Gate;
```

END Stop_Everything

OPERATION Go_Up IS

operation body description (text)

Sequence of operations to move the water from the lower level to the upper level.

used operations

```
Operator.Boat_Inside
Secured_Driver.Close_Lower_Gate
Secured_Driver.Close_Upper_Flow
Upper_Gate.Equal_Pressures
Flip_Flop.Is_Set
Secured_Driver.Open_Upper_Flow
Secured_Driver.Open_Upper_Gate
Lower_Gate.Operation_Completed
Upper_Gate.Operation_Completed
Flip_Flop.Reset
Lights_Controller.Set_Lower_Light
Secured_Wait.Wait
```

operation code (ada)

```
begin
  if With_Boat then
    Reset (Boat_Inside);
    Set_Lower_Light (Green);
    while not Is_Set (Boat_Inside) loop
      wait (1.0);
    end loop;
    Set_Lower_Light (Red);
  end if;

  Close_Lower_Gate;
  while not Lower_Gate.Operation_Completed loop
    wait (1.0);
  end loop;

  Open_Upper_Flow;
  while not Upper_Gate.Equal_Pressures loop
    wait (1.0);
  end loop;

  Close_Upper_Flow;
  while not Upper_Gate.Operation_Completed loop
    wait (1.0);
  end loop;

  Open_Upper_Gate;
  while not Upper_Gate.Operation_Completed loop
    wait (1.0);
  end loop;
```

END Go_Up

OPERATION Go_Down IS

operation body description (text)

Sequence of operations to move the water from the upper level to the lower level.

used operations

```
Operator.Boat_Inside
Secured_Driver.Close_Lower_Flow
Secured_Driver.Close_Upper_Gate
Lower_Gate.Equal_Pressures
Flip_Flop.Is_Set
Secured_Driver.Open_Lower_Flow
Secured_Driver.Open_Lower_Gate
Lower_Gate.Operation_Completed
Upper_Gate.Operation_Completed
Flip_Flop.Reset
Lights_Controller.Set_Upper_Light
Secured_Wait.Wait
```

operation code (ada)

```
begin
  if With_Boat then
    Reset (Boat_Inside);
    Set_Upper_Light (Green);
    while not Is_Set (Boat_Inside) loop
      wait (1.0);
    end loop;
    Set_Upper_Light (Red);
  end if;

  Close_Upper_Gate;
  while not Upper_Gate.Operation_Completed loop
    wait (1.0);
  end loop;

  Open_Lower_Flow;
  while not Lower_Gate.Equal_Pressures loop
    wait (1.0);
  end loop;

  Close_Lower_Flow;
  while not Lower_Gate.Operation_Completed loop
    wait (1.0);
  end loop;

  Open_Lower_Gate;
  while not Lower_Gate.Operation_Completed loop
    wait (1.0);
  end loop;
```

END Go_Down

OPERATION Main_Loop IS

operation body description (text)

Main processing loop of the system. Wait for missions and execute them. Provides the safety exception handlers catch all exceptions.

used operations

```
Operator.Go_Down
Operator.Go_Up
Request_Controller.Next_Mission
Operator.Report_Error
Operator.Stop_Everything
```

handled exceptions (hood)

```
Emergency
```

operation code (ada)

```
begin
  loop
    case Next_Mission is
    when Up_With_Boat =>
      Go_Up (True);
    when Down_With_Boat =>
      Go_Down (True);
    when Up_Empty =>
      Go_Up (False);
    when Down_Empty =>
      Go_Down (False);
    end case;
  end loop;
exception
  when Emergency =>
    Stop_Everything;
  when others =>
    Stop_Everything;
    Report_Error;
```

END Main_Loop

OPERATION Report_Error IS

operation body description (text)

Called when an unexpected exception happens, signals a software error.

operation code (ada)

```
begin
  Text_IO.Put_Line("Bug in software");
```

END Report_Error

END Operator

5. Secured_Wait

OBJECT Secured_Wait IS

DESCRIPTION

PROBLEM

Statement of the Problem (text)

Provides the single wait point for the system, and handles the emergency stop request.

Analysis of Requirements

Behavioural Requirements (text)

In no case should an emergency stop request be lost.

PROVIDED_INTERFACE

OPERATIONS

Emergency_Stop

operation spec. description (text)

Interrupt routine for the emergency stop request.

operation declaration (hood)

```
Emergency_Stop;
```

Init

operation spec. description (text)
Initialization of the Secured_Wait.

operation declaration (hood)
```
Init;
```

Wait

operation spec. description (text)
Actual wait routine

operation declaration (hood)
```
Wait(How_Long : in Duration);
```

EXCEPTIONS

Emergency

exception description (text)
Raised during a wait if an emergency stop has been received during the wait, or before Wait was called.

exception definition (hood)
```
Emergency RAISED_BY Wait;
```

OBJECT_CONTROL_STRUCTURE

constrained operations
```
Emergency_Stop CONSTRAINED_BY ASER --|by_IT|--;
```

REQUIRED_INTERFACE

OBJECT Flip_Flop;

TYPES
```
Instance;
```

OPERATIONS
```
Set; Reset; Is_Set;
```

OBJECT STANDARD;

TYPES
```
DURATION;
```

INTERNALS

DATA

Emergency_Signal

data declaration (ada)
```
Emergency_Signal : Flip_Flop.Instance;
```

OPERATION_CONTROL_STRUCTURES

OPERATION Emergency_Stop IS

used operations

```
Flip_Flop.Set
```

operation code (ada)

```
begin
  Set (Emergency_Signal);
```

END Emergency_Stop

OPERATION Init IS

used operations

```
Flip_Flop.Reset
```

operation code (ada)

```
begin
  Reset (Emergency_Signal);
```

END Init

OPERATION Wait IS

used operations

```
Flip_Flop.Is_Set
```

propagated exceptions

```
Emergency;
```

operation code (ada)

```
  End_Time : Calendar.Time := Clock + How_Long;
begin
  while Clock < End_Time loop
    if Is_Set (Emergency_Signal) then
      raise Emergency;
    end if;
    delay 0.1;
  end loop;
```

END Wait

END Secured_Wait

6. Request_Controller

OBJECT Request_Controller IS

DESCRIPTION

PROBLEM

Statement of the Problem (text)

The request controller accepts requests from boats through bell signals. It provides the next mission to the gate manager.

Requests are optimized. A mission with no boat inside should be provided only when no boat is waiting to go that direction.

SOLUTION

General Strategy (text)

The simplest way to provide optimized requests is to maintain two counters of unsatisfied "up" and "down" requests. If no counter is 0, the request controller will alternate the request.
Note that it may happen that two "up" requests, for example, are to be served in a row if the "down" counter is zero. In that case, a "Down_Empty" mission must be sent to the Mission Controller.
If no mission is pending, Next_Mission returns "No_Mission".

PROVIDED_INTERFACE

TYPES

T_Mission

type description (text)

Describes the various possible missions, i.e. go up or down, with or without boat, or nothing at all.

type definition (ada)

```
type T_Mission is(No_Mission,Up_With_Boat,
                     Down_With_Boat, Up_Empty
                     Down_Empty);
```

OPERATIONS

Down_Request

operation spec. description (text)

interrupt routine called when the upper bell is rung, meaning a boat wants to go down

operation declaration (hood)

```
Down_Request;
```

Up_Request

operation spec. description (text)

interrupt routine called when the lower bell is rung, meaning a boat wants to go up

operation declaration (hood)

```
Up_Request;
```

Next_Mission

operation spec. description (text)

returns the next mission to be performed, considering outstanding requests

operation declaration (hood)

```
Next_Mission return T_Mission;
```

OBJECT_CONTROL_STRUCTURE

constrained operations

```
Down_Request CONSTRAINED_BY ASER --|by_IT|--;
Up_Request CONSTRAINED_BY ASER --|by_IT|--;
```

REQUIRED_INTERFACE

OBJECT Protected_Counter;

TYPES

```
Instance;
```

OPERATIONS

```
Increment; Decrement;
```

INTERNALS

TYPES

T_State

type description (text)

This type describes the state of the system when a "Next_Mission" is received, i.e. after sending an "up" mission, it is assumed that the system is up.
The "Unknown" state is the initial state. It forces a "Down-Empty" mission.

type definition (ada)

```
type T_State is (Up, Down, Unknown);
```

DATA

Up_Counter

data description (text)

Counter of requests to go up

data declaration (ada)

```
Up_Counter : Protected_Counter.Instance;
```

Down_Counter

data description (text)

Counter of requests to go down

data declaration (ada)

```
Down_Counter : Protected_Counter.Instance;
```

Current_State

data declaration (ada)

```
Current_State : T_State := Unknown;
```

OPERATION_CONTROL_STRUCTURES

OPERATION Down_Request IS

used operations

```
Protected_Counter.Increment
```

operation code (ada)

```
begin
  Increment(Down_Counter);
```

END Down_Request

OPERATION Up_Request IS

used operations

```
Protected_Counter.Increment
```

operation code (ada)

```
begin
  Increment(Up_Counter);
```

END Up_Request

OPERATION Next_Mission IS

used operations

```
Protected_Counter.Decrement
```

operation code (ada)

```
begin
  loop
  case Current_State is
    when Unknown =>
      return Down_Empty;
    when Up      =>
      if Is_Null(Down_Counter) then
        Decrement(Down_Counter);
        return Down_With_Boat;
      elsif Is_Null(Up_Counter) then
        return Down_Empty;
      end if;
    when Down      =>
      if Is_Null(Up_Counter) then
        Decrement(Up_Counter);
        return Up_With_Boat;
      elsif Is_Null(Down_Counter) then
        return Up_Empty;
      end if;
    end case;

    -- No request pending
    return No_Mission;
  end loop;
```

END Next_Mission

END Request_Controller

7. Protected_Counter

OBJECT Protected_Counter IS

PROVIDED_INTERFACE

OPERATIONS

Increment

operation declaration (hood)
```
Increment (Target : in out Instance);
```

Decrement

operation declaration (hood)
```
Decrement (Target : in out Instance);
```

Current_Value

operation declaration (hood)
```
Current_Value(Target : in Instance)
  return Natural;
```

OBJECT_CONTROL_STRUCTURE

constrained operations
```
Increment CONSTRAINED_BY RWER;
Decrement CONSTRAINED_BY RWER;
Current_Value CONSTRAINED_BY ROER;
```

END Protected_Counter

8. Generic_Gate

OBJECT Generic_Gate IS

FORMAL_PARAMETERS

CONSTANTS
```
Gate_Address;
```

DESCRIPTION

PROBLEM

Statement of the Problem (text)

The generic gate abstracts all services to operate the gates. The gate includes two main devices: the gates themselves, and the underwater door that controls the flows.

Analysis of Requirements

Behavioural Requirements (text)

Because of our constraint of not having any wait outside the mission manager, no operation should be blocking for a long time.

PROVIDED_INTERFACE

OPERATIONS

Start

operation spec. description (text)

operation to be called at initialization time to ensure a consistent state of the gate.

operation declaration (hood)

```
Start;
```

Open_Gate

operation spec. description (text)

opens the gate itself

operation declaration (hood)

```
Open_Gate;
```

Close_Gate

operation spec. description (text)

closes the gate itself

operation declaration (hood)

```
Close_Gate;
```

Stop_Gate

operation spec. description (text)

stops motion of the gate at its current position

operation declaration (hood)

```
Stop_Gate;
```

Open_Flow

operation spec. description (text)

opens the underwater door (lets water flow in or out).

operation declaration (hood)

```
Open_Flow;
```

Close_Flow

operation spec. description (text)

closes the underwater door (stops the flow).

operation declaration (hood)

```
Close_Flow;
```

Operation_Completed

operation spec. description (text)

returns true if the previous operation is completed, i.e. the associated motor is stopped.

operation declaration (hood)

```
Operation_Completed return Boolean;
```

Equal_Pressures

operation spec. description (text)

returns true if the pressure is equal on both sides of the gate.

operation declaration (hood)

```
Equal_Pressures return boolean;
```

EXCEPTIONS

Illegal_Operation

exception description (text)

This exception is raised whenever the gate receives a command while not in an idle state (i.e. there should be no more than one command active at the same time).

exception definition (hood)

```
Illegal_Operation RAISED_BY Open_Gate,
Close_Gate, Open_Flow, Close_Flow;
```

REQUIRED_INTERFACE

OBJECT Motors_Library;

TYPES

```
Gate_Motor; Flow_Motor;
```

OPERATIONS

```
Set_Motion; Stop_Motion; Is_Stopped;
```

OBJECT Pressure_Sensors;

TYPES

```
Instance;
```

OPERATIONS

```
Pressures_Equal;
```

OBJECT STANDARD;

TYPES

```
BOOLEAN;
```

INTERNALS

DATA

Gate_Drive

data declaration (ada)

```
Gate_Drive : Gate_Motor (10*Gate_Address+1);
```

Flow_Drive

data declaration (ada)

```
Flow_Drive : Flow_Motor (10*Gate_Address+2);
```

Sensor

data declaration (ada)

```
Sensor:Pressure_Sensors.Instance
          (10*Gate_Address+3);
```

OPERATION_CONTROL_STRUCTURES

OPERATION Start IS

operation code (ada)

```
-- To be supplied later
```

END Start

OPERATION Open_Gate IS

used operations

```
Generic_Gate.Operation_Completed
Motors_Library.Set_Motion
```

propagated exceptions

```
Illegal_Operation;
```

operation code (ada)

```
begin
  if not Operation_Completed then
    raise Illegal_Operation;
  end if;
  Set_Motion (Gate_Drive, Opening);
```

END Open_Gate

OPERATION Close_Gate IS

used operations

```
Generic_Gate.Operation_Completed
Motors_Library.Set_Motion
```

propagated exceptions

```
Illegal_Operation;
```

operation code (ada)

```
begin
  if not Operation_Completed then
    raise Illegal_Operation;
  end if;
  Set_Motion (Gate_Drive, Closing);
```

END Close_Gate

OPERATION Stop_Gate IS

used operations

```
Motors_Library.Stop_Motion
```

operation code (ada)

```
begin
  Stop_Motion (Gate_Drive);
```

END Stop_Gate

OPERATION Open_Flow IS

used operations

```
Generic_Gate.Operation_Completed
Motors_Library.Set_Motion
```

propagated exceptions

```
Illegal_Operation;
```

operation code (ada)

```
begin
  if not Operation_Completed then
    raise Illegal_Operation;
  end if;
  Set_Motion (Flow_Drive, Opening);
```

END Open_Flow

OPERATION Close_Flow IS

used operations

```
Generic_Gate.Operation_Completed
Motors_Library.Set_Motion
```

propagated exceptions

```
Illegal_Operation;
```

operation code (ada)

```
begin
  if not Operation_Completed then
    raise Illegal_Operation;
  end if;
  Set_Motion (Flow_Drive, Closing);
```

END Close_Flow

OPERATION Operation_Completed IS

used operations

```
Motors_Library.Is_Stopped
```

operation code (ada)

```
begin
  return Is_Stopped (Gate_Drive) and
         Is_Stopped (Flow_Drive);
```

END Operation_Completed

OPERATION Equal_Pressures IS

used operations

```
Pressure_Sensors.Pressures_Equal
```

operation code (ada)

```
begin
  return Pressures_Equal (Sensor);
```

END Equal_Pressures

END Generic_Gate

9. Lower_Gate

OBJECT Lower_Gate IS

PARAMETERS

CONSTANTS

```
Gate_Address => LG_Address
```

PROVIDED_INTERFACE

OPERATIONS

Start

operation declaration (hood)

```
Start;
```

Open_Gate

operation declaration (hood)

```
Open_Gate;
```

Close_Gate

operation declaration (hood)

```
Close_Gate;
```

Open_Flow

operation declaration (hood)

```
Open_Flow;
```

Close_Flow

operation declaration (hood)

```
Close_Flow;
```

Equal_Pressures

operation declaration (hood)

```
Equal_Pressures return boolean;
```

Operation_Completed

operation declaration (hood)

```
Operation_Completed return Boolean;
```

Stop_Gate

operation declaration (hood)

```
Stop_Gate;
```

EXCEPTIONS

Illegal_Operation

exception definition (hood)

```
Illegal_Operation RAISED_BY Open_Gate, Close_Gate,
Open_Flow, Close_Flow;
```

REQUIRED_INTERFACE

OBJECT Hard_Configuration;

CONSTANTS

```
LG_Address;
```

OBJECT STANDARD;

TYPES

```
BOOLEAN;
```

END Lower_Gate

10. Hard_Configuration

OBJECT Hard_Configuration IS

PROVIDED_INTERFACE

TYPES

T_Device_Address

type description (text)

Physical address of a device

type definition (ada)

```
type Device_Address is range 0 .. +99;
```

CONSTANTS

UG_Address

constant description (text)

Base address of the upper gate.

constant definition (ada)

```
UG_Address : constant T_Device_Address := 0;
```

LG_Address

constant description (text)

Base address of the lower gate.

constant definition (ada)

```
LG_Address : constant T_Device_Address := 1;
```

END Hard_Configuration

F. Index