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AUTHOR'S PREFACE

'Lastly, I stand ready with a pencil in one hand, and a sponge in
the other, to add, alter, insert, expunge, enlarge and delete,
according to better information. And if these my pains shall be
found worthy to pass a second impression, my faults I will confess
with shame, and amend with thankfulness to such as will
contribute clearer intelligence unto me'.

Preface to 'The History of the Worthies of England'
Thomas Fuller (1662)

Such, as technical author of the Official Handbook of Mascot Version 3.1, has been my attitude over the
past two and a half years to the scientific worthies of the Mascot 3 Definition Team; albeit my pencil and
sponge are of an electronic variety. Some sections of the handbook, having stimulated particular
controversy among the Team or having been more than normally misunderstood by me or having been
especially savaged by the pre-publication reviewers, have been 'found worthy' of a whole long series of
impressions. But it has all been well worth the effort from my point of view. When, in 1984, I commenced
work as a freelance lecturer and writer, I could hardly have expected the good fortune of becoming
involved in such a stimulating and rewarding project. I am grateful to all concerned.

I would like to express my thanks, first of all, to the Royal Signals and Radar Establishment for financing
the task of writing the Handbook. My gratitude is specially due to Ken Hayter and Keith Oliver who shared
the job of Technical Authority for the project. I would also like to thank the Royal Military College of
Science, and particularly Tony Sammes as head of the Computing Science Group, for performing project
administration. To the members of JIMCOM I am greatly obliged for their faith in ratifying my original
appointment as author and for their forbearance in accepting a series of revised target completion dates
which seemed at times to be diverging to infinity. I would like to thank all those who, in the course of the
limited public review of the draft Handbook, provided helpful comments leading to clearer exposition and
pointed out many typographic, grammatical and orthographic errors.

Finally, to the members of the Definition Team itself and especially to Hugo Simpson, Ken Jackson, Tony
Riddiough and Bill Taylor, I owe an immense debt of gratitude. Throughout my period of involvement in
the work, they have striven to communicate their ideas to me and to correct my misconceptions with
 unfailing patience. While rightly insisting that the concepts of Mascot 3 be presented to the world with
technical accuracy and appropriate relative emphasis, they have allowed me to take full responsibility in
matters of presentation and have tolerated my occasional stylistic idiosyncrasy with commendable
resignation.

George Bate
Wantage, May 1987

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PREFACE

The development of complex, computer based systems poses major problems to the people involved. These problems encompass both managerial aspects, concerned with control of the overall development, and technical aspects concerned with the interaction of the individually designed components of the system. Mascot offers a wide-ranging and homogeneous approach to the development of such systems. It provides significant contributions to the solution of both managerial and technical problems.

Historical Background

Mascot was originated by Ken Jackson and Hugo Simpson over the period 1971 to 1975. After the initial implementation work was completed, the Royal Signals and Radar Establishment (RSRE) formed the Mascot Suppliers Association (MSA) in order to effect the transfer of Mascot technology into industry. The MSA, which consisted of individuals from several companies and MOD establishments, produced, in 1978, an 'Official Definition of Mascot'. This document described what came to be known, retrospectively, as Mascot 1 and provided a definitive reference for implementors and teachers of Mascot while ideas and methods continued to evolve.

In 1980 a sub-committee of the MSA, drawing its membership from the following:

Admiralty Surface Weapons Establishment
Royal Military College of Science
Royal Signals and Radar Establishment
Computer Analysts and Programmers (Reading) Ltd
Ferranti Computer Systems Ltd
GEC Computers Ltd
Software Sciences Ltd
Systems Designers Ltd

drafted a much more comprehensive presentation of the Mascot concepts as 'The Official Handbook of Mascot'. This handbook, which was reissued in 1983, constitutes the standard reference for Mascot 2 and has received an extensive distribution. A companion volume to the 1983 issue, 'Additional Features to Integrate Mascot with Coral 66', provides a formal syntactic description of a set of extensions to the MOD standard programming language which make it a 'suitable vehicle for Mascot applications. This language was named AF Coral 2.

The drafting of these documents was one of the last actions of the MSA before it was disbanded, having achieved its major objectives. Responsibility for maintaining the Mascot standard, in so far as it is intended...
for use in government projects, was taken over by the Inter Establishment Committee on Computer Applications (IECCA). A joint committee of the MOD and the DoI, IECCA is composed wholly of official representatives. In order that the liaison with industry and the computing community generally, so successfully initiated by the MSA, could be maintained and extended, another organisation, the Mascot Users' Forum (MUF), was set up in 1980. Informal symposia, open to all actual and potential Mascot users, suppliers and supporters, are arranged by the MUF and some 80 official, industrial and academic bodies have been represented.

To provide a convenient basis for the continued technical development of Mascot, IECCA and the MUF formed, in 1981, the Joint IECCA and MUF Committee on Mascot (JIMCOM). It is under the aegis of JIMCOM that the work on Mascot 3, the subject of this present version of the Official Handbook, has been carried out. This new Mascot definition has been developed by a team in which the following have been principal contributors:

Lawrence Ceillingbourne (Systems Designers plc)
Gerry Docherty (YARD Ltd)
Giles Forster (MOD -EQC)
Ken Jackson (Systems Designers plc)
Tony Riddlough (Software Sciences Ltd)
Hugo Simpson (British Aerospace plc)
Bill Taylor (Ferranti Computer Systems Ltd)

The enormous contribution of George Bate who was the technical author responsible for translating the ideas from the development team into a consistent, coherent text is gratefully acknowledged. Acknowledgement is also due for the support of RSRE. Finally the contribution of the people who commented on the draft versions of the Handbook is gratefully acknowledged.

**Handbook Organisation and Conventions**

This Handbook has been written principally for the benefit of users and potential users of Mascot. The presentation is therefore broadly tutorial. However, within this general approach an attempt has been made to be as helpful as possible both to the implementors of Mascot and to those concerned with assessing and evaluating the resulting implementations. There are three major sections. The first of these is introductory, providing the background to the present stage of Mascot development and presenting, in an informal manner, the main innovations of Mascot 3. Then follows the Official Definition which is the essential core of the book. It contains both descriptive passages suitable for those requiring an overall understanding of the ideas and rather more formal material intended to be used for reference purposes. Finally, there is a section devoted to guidance in the use of Mascot. It is of course only through practical experience that the optimum application of the Mascot 3 features will emerge but the advice given here reflects the rationale upon which they have been devised.
The new concepts which this handbook introduces into the Mascot philosophy demand an extended technical vocabulary for their description. Devising acceptable and consistent terminology has not proved easy. There are a limited number of possible words available (if we reject the idea of coining entirely new ones) and they are all inseparable from their existing associations in both technical and everyday usage. The importance of the glossary which appears at the end of the handbook can, therefore, hardly be emphasised too strongly. It contains definitions of all the Mascot technical terms. In order that the reader will be aware that a word is being employed in a precise sense, all such instances are signalled throughout the Definition by the use of bold type. This will help to make more comprehensible those passages in which technical terms have had to be used before being fully explained in the text. It will be advisable, even for those already familiar with earlier versions of Mascot, to consult the glossary regularly while reading through the handbook for the first time.

The only other typographical convention is the use of bold italic for text which would otherwise need to be in quotation marks. Examples include identifiers used in sample program fragments and names invented for the syntactic elements of the design representation language.

Mascot designs have two parallel forms of representation: graphical and textual. The former presents no problem here. Its conventions are well defined and are summarised in an appendix. There is no barrier to their standard use in all Mascot applications. The textual form, however, does raise difficulties. The Mascot tradition of programming language independence is retained in Mascot 3 even though, for many, the choice in the past has been 'any language provided it is Coral' and in the future will presumably be 'any language as long as it is Ada*'. Neither of these languages is ideal as a vehicle for expressing the textual form of the Mascot design representation though either will serve in practical use.

The solution adopted has been to invent a design representation language to fulfil a twofold purpose. First, it serves here to define and explain the design constructs in a rigorous and consistent manner and can be used for a similar purpose in future publications. Second, it is proposed as the notation in terms of which practical Mascot 3 designs will actually be devised and communicated. While it is very desirable that some automatic means of translation, such as a pre-processor, should be made available for mapping these designs into particular programming languages, there is no implication that this is an essential prerequisite to the use of Mascot. Experienced programmers have long recognised that the language 'in which they program' need not be the (more or less inadequate) implementation language which has to be used for other, often non-technical, reasons. The same considerations apply here and the sole criterion must be, as in the past, that the concepts described in the Mascot Definition are capable of being expressed in the chosen implementation language.

The design representation language is broadly Pascal-like in that, where a suitable Pascal convention exists, it has been adopted. This choice was made partly on the grounds that Pascal is widely familiar to the international computing community and partly because of its use as the base language in the
development of the NATO preferred programming language, Ada. The syntax of the language itself has been defined by means of the type of syntax diagrams first employed by Wirth to describe Pascal. The author’s experience of teaching programming languages at a variety of levels has produced a strong conviction that such diagrams provide the best available means of combining rigour with comprehensibility. A complete set is presented, for ease of reference, in appendix A which also presents the syntax in BNF together with an index to the Handbook itself. Where differences occur between the syntax diagrams used in the text and the corresponding diagrams in Appendix A, those in the appendix constitute the full definition.

* Ada is a registered trademark of the U.S. Government - Ada Joint Program Office
CHAPTER 1

INTRODUCTION
1. INTRODUCTION

Mascot is a Modular Approach to Software Construction Operation and Test which incorporates:

a) a means of design representation;
b) a method for deriving the design;
c) a way of constructing software so that it is consistent with the design;
d) a means of executing the constructed software so that the design structure remains visible at run time;
e) facilities for testing the software in terms of the design structure.

Of particular importance in the design representation is the ability to represent, directly, concurrent functions and the data flows between them. An equally important facet of the method is the fact that individual components in the design structure are decoupled from each other. This has a significant impact on both the design method and the testing strategy and leads directly to a form of 'component technology' familiar in all other branches of engineering. It causes a design to be expressed as a structure (or assembly) of interconnected components each of which is of a specific type. Thus each component type has its own characteristics and embodies constraints on where and how it may be connected to other component types. But, and this is a critical feature, no component refers directly to another component. Such interconnection information is specified in a separate form rather like an engineering drawing.

The software structure, by its insistence upon decoupling, also has a significant impact upon the components' potential for re-use and specifically makes the creation of test systems very much more straightforward.

Mascot can be and has been used in a wide range of application areas. It is however aimed primarily at real-time embedded application areas where the software is complex and highly interactive.

1.1 Structure, Modularity and Management

One important motivation for the provision of modularity stems from the need to employ a team of people on one single job. In such circumstances it is essential that each member of the team can be allocated a job to do which contributes to the overall success of the project. Many modularity schemes have been devised to address this problem. Most of them involve creating an overall design and then carving up the design into chunks which can be allocated to an individual team member. A key feature of Mascot is that, because the design is expressed as an interconnected network of otherwise independent components, each component can be developed in isolation from the others. Then the developed components can
be brought together into assemblies or sub-assemblies at a later stage in the secure knowledge that, because the interconnection constraints have been policed during development, the components will fit together and will have a high probability of working together correctly.

Thus, through a modularity scheme based on sound and secure component technology, Mascot provides not only the basic ingredients for sound team management, but also allows the use of traditional approaches to engineering management.

1.2 Derivation of Mascot

1.2.1 Historical (see also the Preface to this Handbook)

The antecedents of Mascot can be traced back to the period 1965 -1970. During this time the originators of Mascot were involved respectively with the development of control programs for an automatic computer controlled radar and a multi-access operating system for the control of on-line experiments in real time, and the in-service maintenance of various operational, embedded, real-time RAF systems. This early experience in tackling the problems of embedded real-time systems culminated in the successful development of a large air defence system. It was during this last project that the originators came together and began to investigate the possibility of creating an alternative and well defined method of software development. These investigations led to Mascot.

1.2.2 Technical

Much of the motivation behind Mascot lay in the apparent preoccupation with control-flow design which was prevalent in the late 60s. For complex real-time systems it was obvious that there could not be a unique control flow design which satisfied all the functional requirements because of the highly stochastic nature of the inputs. Therefore the originators looked to their training as electrical engineers for inspiration. Here they discovered that concurrency was a key feature together with the notion of data flow or information flow from one stage to another. For example, in a radio receiver RF signals are amplified by the RF stage and the output is detected by the demodulator stage. The demodulator output is fed to an audio amplifier and its output is fed to the loudspeaker. Thus there is the notion of information flowing from one (concurrent) stage to the next and the very important concept of well defined interfaces between stages to decouple the design of one stage from the next. There is no notion of control flow because each stage is performing its own special function all the time. Thus this model of analogue electrical circuits became the foundation for the Mascot design representation and method of software construction.

From the outset, the originators held the view that writing sequential programs (or modules) was not a problem - or rather it was not a problem which Mascot would address! Instead Mascot would concentrate on what was perceived to be a more difficult problem, namely that of representing concurrency and data flow in embedded real-time systems.
1.3 Software Structure in Mascot

1.3.1 General
One of the key problems with software is its intangibility and this is especially true of large systems. Hence, a way of describing the software is required which presents just sufficient detail for the purpose. This usually involves a top-down presentation so that an overall view can be given at first. Further, more detailed, views follow until the lowest level of detail, which is usually the source text in an appropriate programming language, is reached. The key requirement of a design representation medium is this ability to present a design at appropriate levels of detail.

In Mascot the starting point was to represent the design graphically with emphasis on the presentation of data flow and concurrency. From such a diagram one can gain an overall impression of what each component has to do and how the overall functionality of the software system is achieved. Also from the diagram it is possible to write down an equivalent textual representation of the whole system structure and of the individual components required to build that structure. Then the other details of the components can be added as the design effort proceeds. Once components have been built, test systems can be created in which the components can be tested. Finally the complete design structure can be built for system testing.

These characteristics are evident in both Mascot 2 and Mascot 3. In the following sections we describe first the Mascot 2 method and then indicate how and why Mascot 3 differs. A fuller introduction to Mascot 3 design representation can be found in section 2.1. Here we merely touch upon the salient features of both Mascot 2 and Mascot 3 in order to make the comparison and to identify the motivation for updating Mascot 2.

1.3.2 Mascot 2
The basic notion in Mascot is that the flow of data through a system, from input sensors to output actuators, is controlled solely by a set of concurrent software processes. These processes are known as 'activities' and are separately scheduled by a run-time system usually referred to as a Mascot 'kernel'. Data enter and leave the system through 'devices' which are software accessible registers in the hardware with which the software system communicates. The data are moved around the system and transformed by activities. Mascot activities thus need to co-operate with each other by passing data but they are not allowed to communicate directly; their immediate communication is with special modules, provided for this purpose, called 'Intercommunication Data Areas' and usually referred to as IDAs. IDAs are passive components which exist only to satisfy the intercommunication requirements of activities. They contain data areas which are completely private to the IDA and support the intercommunication requirements by providing a procedural interface which can be used by activities. Thus the designer can design in terms of concurrent processes which are purely sequential (ie activities) and IDAs which are passive but encapsulate the interactions between the activities.
This represents a significant separation of concerns:

- activities are sequential processes concerned primarily with performing a single function and communicating with a (usually small) set of IDAs.

- IDAs contain any data sharable by activities. Access to the data is provided by a procedural interface whose constituent procedures must ensure the integrity of the data in the IDA by using the synchronisation facilities of the Mascot kernel.

Two distinct classes of IDA have been identified in Mascot: the 'channel' and the 'pool'. The channel is used to pass data between activities on a 'producer/consumer' basis. Producer activities send messages via an input interface and consumer activities receive messages via an output interface. There can be a buffer of messages in a channel at any instant. These are messages which have been sent but not yet received (i.e., they are currently in transit). This property of a channel is useful in relieving the consumer activity of the necessity of running in synchronism with the producer activities.

The pool is used to hold data which may need to be referred to by activities and, in particular, in cases where the frequency or pattern of references to the data is completely independent of the frequency or pattern of operations which bring it up to date. Thus there could be many references without any change being made to the data or the data might be changed many times between successive references.

It is important to realise that Mascot does not provide a specific and fixed set of IDAs. Facilities are provided for a designer to define and build the specific types of IDAs required by his application.

The graphical representation used for Mascot 2 is known as the ACP (Activity, Channel, Pool) Diagram. An example is given below together with a key to the symbols used. Note that the producer/consumer characteristic of channels is indicated by connecting one side of the symbol to producer activities and connecting the other side to the consumer activity. The direction of data flow is indicated by the arrow heads.
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The ACP diagram depicts the instances of the activities, channels and pools required. The types of the components can also be depicted on the ACP diagram (usually by enclosing the type in parentheses).

As mentioned earlier activities do not reier directly to IDA instances. Instead they are defined and coded in terms of the set of IDA types with which they need to communicate. During the software construction process the activities are created (i.e. manufactured) and then 'connected' (i.e. assembled) to the set of IDA instances required by the design and expressed in the ACP diagram. The unit of construction in Mascot 2 is the 'subsystem'. This is merely a collection of activities which have been connected to their IDAs at the same time. The subsystem is also the unit which can be controlled at run time by being started, terminated, halted or resumed. This provides the facility for evolving a Mascot network. The operational network consists of the set of subsystems which have been 'formed' and 'started': By forming new subsystems, terminating old subsystems and starting the new subsystems it is possible to change an operational system as time passes.

1.3.3 Mascot 3
Motivation for the development of Mascot 3 has stemmed from two considerations. First, experience of Mascot 2 in practical use has inevitably revealed, within its proper province of application, some areas of weakness which it is desirable to remedy. Second, the emerging prospect of implementing systems for large, multiprocessor networks has brought with it a need for more powerful and flexible means of design expression than those available in Mascot 2. The aim has been, therefore, both to consolidate and to extend the Mascot method.

Perhaps the most significant refinement which Mascot 3 brings to existing Mascot concepts concerns the manner of expressing network connections. Mascot 2 networks are formed from system elements which have been created from templates held in a constructional database. Every activity template contains a fixed number of external connections each of which is expressed as a reference to an IDA template. An assembly of inert activities is converted into a network of communicating activities by supplying IDAs of the appropriate type, created that is from appropriate templates, to store information and control its transmission in each of the data flow paths. The choice of valid network configurations is thus constrained by a type checking mechanism based on the fact that activity templates contain direct references to IDA templates. Such an arrangement allows much greater flexibility than one in which the references are to specific IDA instances.

Although this Mascot 2 style of expressing design definition is very flexible it does contain one major restriction, namely that an activity template depends upon IDA templates. In Mascot 3 this dependency has been changed so that the inter-dependency between activities and IDAs is focussed on the interface which exists between them. This interface exists implicitly in Mascot 2 and consists of the set of access procedures implemented in the IDA. In Mascot 3 the procedural interface is specified explicitly and is
called an 'access interface'. Thus in Mascot 3 an activity template is specified in terms of its requirement to use one or more access interfaces. A component derived from that template may be connected to a set of IDA components (derived from their templates) subject to the condition that the access interfaces provided by the IDA are those required by the activity.

The terminology introduced into Mascot 3 to describe these ideas is that an IDA 'provides' an access interface at a 'window' and an activity 'requires' an access interface at a 'port'. Thus activities can have several ports, as indeed they could in Mascot 2. However, in Mascot 3, IDAs can provide several windows whereas in Mascot 2 an IDA could provide only a single window.

This greater degree of design decoupling provides several advantages in terms of design expression and eliminates some of the causes of inefficiency in Mascot 2 design. First, an activity may be connected to any IDA type provided that the port to window connectivity constraint is satisfied (ie that the access interface required at the port is that provided at the window). This means, for example, that for test purposes an activity can be connected to an IDA which is of a different type from the one to which it is connected in an operational network.

Second, the ability of an IDA to provide more than one window means that, in Mascot 3, a channel can provide two interfaces, one for the writers and one for the readers. The same idea can be extended to pools where a set of access interfaces can be provided each encompassing a limited capability corresponding to the particular requirements of the activities using it. The use of multiple windows by the designer is also valuable in identifying how the functions of a system are distributed in relation to the IDA's position in the network.

A third major advantage concerns the freedom, in Mascot 3, to design IDAs which provide several windows of the same type. Thus a special significance can be attached, within the IDA, to any of these windows. For example, one window might be given priority over the others or actions within the IDA can be made dependent on the location of the caller within the connected network. The ability of an IDA to provide several windows, combined with the decoupling arising from separate definition of the access interface, is considered to be one of the key contributions of Mascot 3.

Another major departure from previous Mascot philosophy is the adoption of hierarchical structure. A Mascot 2 design is conceived in terms of a flat, data flow network whose nodes consist of alternate data processing and data communication elements. While higher level descriptions may be used in the process of devising the network, they have no permanent standing and are not recognised as design entities by the supporting constructional database. The final, essentially two-dimensional structure may be partitioned into an arbitrary patchwork of subsidiary networks, the adjacent members of which share common communication elements. These are the Mascot 2 subsystems which subsequently constitute units of control at run time.

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In Mascot 3, the role of the subsystem has been greatly elevated. While it continues to represent a subsidiary network, it no longer possesses shared components but may be used as a network node in its own right. As such it is capable of being connected to either processing or communication elements and so may perform the function of either or behave as a mixture of the two. It may also possess lower level subsystems among its components so as to facilitate an hierarchical form of design expression. At the same time, with appropriate database support, it makes it possible to develop and capture a design progressively.

The modules of text which represent subsystems (and systems) in the Mascot 3 database contain, between them, all the information needed to establish the content and connectivity of the complete network. The processing of these modules, supported by all the remaining modules which define the system, leads to the construction of a template from which a complete collection of application software can be created and loaded into appropriate locations in the target hardware. They thus embody all the information which, in the Mascot 2 method of software construction, is provided at the stages of system element creation and subsystem formation.

Whereas in Mascot 2, therefore, the connectivity of the software network is not established until the last stage of construction, in Mascot 3 it is established as the first stage. The advantage of the Mascot 2 approach is that it readily supports evolutionary construction, the ability to make adjustments to the network without regenerating the system or even terminating its execution. This may be less easy to achieve in Mascot 3 but a compensatory gain, in addition to hierarchical design expression, is the facility of validating the overall design structure in terms of the inter-module dependencies before any detailed implementation coding has been submitted to the database.

It will be clear from the earlier discussion that a Mascot 3 subsystem is a composite entity. It defines a set of interconnected components. Most other design elements have composite as well as simple forms. For example, a composite IDA defines a network of internal, component IDAs. This is made possible by another extension of the Mascot philosophy which allows IDAs to communicate with each other directly without an intervening active element. Such relatively complex constructions are particularly useful where the IDA is required to control communication between activities located in different parts of distributed hardware.

The fundamental notion in Mascot 2 that activities must only communicate via IDAs is retained in Mascot 3. However, because Mascot 3 IDAs can have ports, it is possible that the interaction between any two activities may involve more than one IDA.

The concept of composite templates in Mascot 3 extends to sequential as well as network decomposition. An individual thread of execution, an activity, may be composed of a number of separately created components which communicate with each other through well defined procedural interfaces. These components share with the simple form of activity the ability to make external network
connections. Since the components may themselves be composite the facilities exist for hierarchical expression of this level of the design also.

The Mascot model for device handling is essentially unaltered in Mascot 3. It is, however, catered for in a more formal manner by the provision of a new class of design element, called a server, which is dedicated to communication with hardware devices. It is similar to the generalised, Mascot 3 form of IDA but is the only design element which communicates with devices and to facilitate this is allowed to contain an interrupt handler.

1.4 Method

In Mascot 2 the method could be divided into three phases:

a) Network Design - which created the ACP diagram and identified the purpose of each component
b) Component Design - in which each component was designed and coded
c) Integration and Test - in which each component was tested first individually and then in conjunction with other components

In Mascot 3 the same set of phases can be identified but there are some additional tasks within each:

a) Network Design in Mascot 3 is an iterative process involving (potentially) the creation of an hierarchy of subsystems, IDAs and servers.
b) Component Design in Mascot 3 can involve the decomposition of activities into lower level components
c) Integration and Test in Mascot 3 is similar to Mascot 2 except that it must take account of the additional levels of decomposition.

1.5 Development Environment

The Mascot 3 development environment is far less specific than that defined for Mascot 2. This is primarily because Mascot 3 is considered to be more capable of being used as a stand alone design method than Mascot 2. An important contributory factor here is the need to work with languages such as Ada which do not allow the intimate integration that has been possible with, say, Coral 66. Therefore, the Mascot 3 development environment has been defined in terms of a set of functions to control the progressive capture of a design. These functions are known as the 'status progression commands' and allow a template in Mascot 3 to be first 'registered', then 'introduced', and finally 'enrolled'. These operations work primarily on one specific template, but they also require a specific status to be achieved by other templates upon which that template depends.
1.6 Execution Environment

The execution environment of Mascot 3 is again very much less specific than for Mascot 2. None of the facilities specified have been significantly changed, but, in recognition of the existence of languages which directly support concurrency, the Mascot run-time facilities (ie those provided by the Mascot kernel) are no longer mandatory.
CHAPTER 2

DESIGN REPRESENTATION
2.1 AN INFORMAL INTRODUCTION

2.1.1 Introduction

This part of the Official Definition of Mascot, 'Design Representation', contains the quintessence of the Mascot approach. It is the portion of the Handbook to which those familiar with the earlier (1981) edition will wish to give closest attention in order to gain an understanding of the ideas which have been developed during the past five years. An attempt has been made to present these new concepts with the rigour and completeness befitting a formal definition while, at the same time, making it as easy to read as possible. Opinions will differ as to how successfully these objectives have been attained but it is a safe assumption that most readers will find some of the material relatively demanding. Hence the need for an informal introduction.

The exposition in this section is neither rigorous nor complete and should not be taken as definitive. While it is, of course, accurate as far as it goes, it is in no sense a substitute for the sections which follow but rather is intended to establish a framework within which the detail, presented later, may more readily be understood. It concentrates on the simpler aspects of each topic in order to introduce the principal concepts and terms. The Definition describes a set of facilities judged sufficiently powerful, in their entirety, for use in addressing the design of extremely complex computer systems. Here, however, the more complex constructions and most of the supplementary features are omitted in the interests of displaying the essential simplicity of the underlying ideas. In practice, the users of Mascot will adopt as many of its features as may be required for the application in hand.

2.1.2 Design Representation

The architecture of Mascot designs is expressible in two equivalent forms: graphical and textual. Each one may readily be derived from the other. For example, a design which is conceived and developed in the graphical form may be transformed, in a wholly mechanical manner, into the textual form and hence progressively captured in the Mascot database to establish the structure of the software. Implementation is then completed by specifying details of the interfaces through which the components of the system communicate, together with the data types with which they are concerned, and by supplying the executable code expressed in whatever implementation language has been adopted. Alternatively, a system might be designed directly in the textual notation and the graphical form subsequently derived from it to become the central feature of its design documentation and to provide a primary medium of discussion for everyone involved with the system throughout its lifecycle.

One of the prime features of the Mascot method is concurrency. A typical design defines, in an hierarchical manner, a set of parallel co-operating processes. At the higher levels of the hierarchy these parallel threads of execution are bunched together in constructional units called subsystems. Progressive expansion of the subsystems separates the larger bunches into smaller ones and eventually, at the lower levels, teases out the individual threads. These individual units of concurrency in
a Mascot design are known as activities. They are executed in a standard run-time environment provided by a collection of context software whose functions are implicitly available to the application software. The interface between the context and the application software is expressed in a form which is generally compatible with the style of the application software modules and is known as the context interface.

The hierarchical nature of this structure permits the design to be viewed at various levels of abstraction, examination of any one of which immediately highlights the second salient feature of the Mascot design representation. This is data flow. Each level of the design is conceived as a network through which data is transmitted from one active entity (subsystem or activity) to another. The ultimate sources and sinks of this information are provided by a set of hardware devices which are regarded as being outside the Mascot system but with which communication may take place through a class of software design elements called servers which are dedicated to this purpose.

2.1.3 A Sample Outline Design

In Section 5.1 of the Handbook the approach to the development of a Mascot design is described in detail. For our purposes here we will suppose that a design has already been completed to the point at which the overall software structure has been established. The diagram is drawn and there exists in the Mascot database a module, that is a named textual representation, for each of the design elements that has been used. Furthermore, all the inter module references have been checked and found valid.

We are not concerned with what our imaginary system is designed to do. Identifiers have deliberately been chosen for their inherent lack of meaning, or else to be so general as to achieve the same effect, in order that there shall be no temptation to be distracted by this question. This would, of course, be as reprehensible in a real design as failing to use meaningful identifiers in a sequential program. In practice it is recommended that template names reflect the function provided by the template; whereas component names should reflect the purpose of the component in the network which contains it.

The only purpose of the system we are about to examine, however, is to demonstrate aspects of Mascot design representation. It should not, in particular, be taken as exemplifying specially recommended practice.

The natural place to begin is with the diagram representing the top level of the design.
This diagram shows our example system. It corresponds to what, in the Mascot method, is called the 'initial design response'. It shows, on the outside of the system, the set of hardware devices the system is required to interact with. It shows, on the inside, a set of high level design components which represent the initial design of the system. The system itself is symbolised by the round cornered rectangle which identifies the boundary between hardware and software and indicates the flow of data into, out of and within the system in very broad brush terms. The name of this particular system is example_sys. It consists of five communicating components three of which, like the system itself, are symbolised by round cornered boundaries and represent subsystems. Throughout the Mascot graphical convention round corners generally indicate active entities and, although occasional exceptions can occur, it is normally safe to assume that a subsystem contains at least one of the concurrent threads of execution which constitute the active constituents of the system. The three components, s1, s2 and s3 may therefore be thought of as being executed in parallel.

The two remaining components of system example_sys illustrate the feature which, more than any other, distinguishes Mascot from other approaches to the problems of large scale concurrency. In order that asynchronously executed processes may exchange information in a secure manner, it is necessary to provide mechanisms to effect mutual exclusion and cross-stimulation for use at the points where data is transferred to or from common storage areas. As explained in Section 4.2 of the Handbook, failure to do this may lead to information becoming corrupt and failure to do it adequately may result in the processes becoming deadlocked. In many approaches to the organisation of parallel, co-operating processes, these
fundamental mechanisms are not made directly available by the run-time system. Instead, a set of higher level operations/facilities such as monitors, message passing or rendezvous are provided. In Mascot the view was taken that, in order to obtain the optimum performance which is always vital in in embedded systems, it was best for the run-time system to make the low level facilities directly available. This has the advantage of making the run-time system small and efficient. It also gives the designer freedom to design exactly the right set of higher level operations required for his application. The design entity in which all these requirements are satisfied is called an intercommunication data area or, more succinctly, an IDA. It is the responsibility of IDA designers to implement the required operations as access procedures (or functions) within an IDA. These operations use the low level synchronisation facilities to maintain both data flow and data integrity. A further contribution is made to system integrity by ensuring that only IDAs contain data which can be the subject of interaction from several activities and that only IDAs may use the low level synchronisation facilities. The most general form of IDA is represented graphically by a rectangle: \textit{s11} and \textit{s12} are examples.

The thin lines, bearing arrow-heads, which link the subsystem and IDA symbols into a network are lines of data flow known in Mascot as paths. Thus, data flows from subsystem \textit{s2} to subsystem \textit{s3} along the two paths, labelled \textit{ack} and \textit{rec} respectively, which enter and leave the IDA \textit{s12}. In IDA \textit{s11} a merging of information flow occurs with paths \textit{put} and \textit{trans}, from \textit{s1} and \textit{s3}, entering and path \textit{sig} to \textit{s2} leaving. It will be seen that in one instance a path, \textit{get}, links two subsystems directly. However, as we shall discover, this does not reflect any failure to carry out the necessary synchronisation. The concepts of both paths and IDAs will be discussed in greater detail later when our example system has been expanded to reveal the lower levels of its structure.

We shall eventually return to this system diagram and examine the module (textual unit) which is equivalent to it. For the moment, leaving some of its detail unexplained, we shall consider what further information is needed for software construction. Obviously it is necessary to know how to create the components. A pattern, or in Mascot terms a template, is required for each of the three subsystems and two IDAs. Consider, for example, the component labelled \textit{s3}. The identifier \textit{subsys_3} which appears inside the corresponding symbol is the name of the template from which this subsystem is created. Expansion to a further level of decomposition reveals the graphical representation of its internal composition.
It will be seen that the template's external connections match those of the component which it describes. Data flows into the subsystem along a path labelled rec and out along paths labelled get and trans, respectively. All three of these paths are connected, internally, to one of the template's two components, s4, which is immediately recognisable as another subsystem. The second component, called sv and represented by a D-shaped symbol, is an example of a server. This is the design element, referred to earlier, which is able to communicate with external, hardware devices. A device is represented here by a hatched rectangle joined to the server by a broken line. We shall return to this diagram later but, for the present, further discussion will once again be postponed in favour of performing one more level of decomposition. In order to show what is required for the creation of component s4, it is expanded to reveal its template, subsys_4.
No further network decomposition is possible in this branch of the hierarchy. The components of subsystem *subsys_4* include two individual activities, represented by the two large circular symbols labelled *a1* and *a2*. Activities, as already indicated, are fundamental processing elements. Each one is to be regarded as implementing a separate parallel thread. Any further analysis of them can only be in terms of sequential, rather than network, decomposition.

The template *subsys_4* also contains two IDAs. They are represented by slightly modified versions of the simple rectangular symbol seen earlier in the system diagram. This shows them to be special cases corresponding to the channels and pools of previous versions of Mascot. The channel is characterised by a destructive read operation: data flowing through it is temporarily accommodated in internal storage which may become full as a result of repeated write operations or empty as a result of repeated read operations. In a pool it is the write operation which is destructive. Its contents consist of a collection of variables which are given initial values when the system commences execution and which may subsequently be examined and updated.

### 2.1.4 The Communication Model

Having now looked briefly at the graphical representation of these three hierarchically related levels of the imaginary design, we shall now consider each in more detail. For this purpose it will be convenient to proceed from the lowest level upwards, examining the modules which represent the various templates as we go. But first it is necessary to deal with a topic which is so fundamental to Mascot as to
demand separate treatment. So far, data flow through a network has been taken for granted. It is now time to examine the Mascot communication model in more detail.

The fundamental concepts are illustrated in the diagram below which shows a simplified fragment of the subsystem *subsys_4*.

Here we have the simple case of a producer activity, *a2*, supplying data to a consumer activity, *a1*. The IDA (a channel), connected between the two activities and represented by a modified rectangular symbol labelled *ch*, acts as a temporary repository for items of data en route from *a2* to *a1*. An intermediate storage buffer, together with coding to operate on it, is encapsulated in the IDA. *ch* might, for example, contain a procedure which adds an item of data to the buffer and a procedure which removes items from the buffer. It is in the coding of such procedures, known as access procedures, that the mechanisms for effecting cross-stimulation and mutual exclusion are employed.

Procedures encapsulated by IDAs are made selectively available for use by activities through the concept of windows. These are represented graphically by the small, filled rectangles labelled *sw* and *fw* which appear, each at the end of a path, just inside the boundary of the IDA symbol. A window of an IDA makes externally available a sub-set of the interactions which the IDA is able to provide. The nature of the interactions provided at a particular window matches the type of the path connected to it. This is indicated on the diagram as an identifier labelling the path. Thus *sw* and *fw* are connected to paths of type *send* and *fetch*, respectively.

The type of a path is defined in a module called an access interface. This is classified as a specification as distinct from the templates which define the types of Mascot components such as activities, IDAs, servers, subsystems and systems. It contains sufficient information to allow the
corresponding set of interactions to be invoked. Typically this includes procedure headings and, indirectly, definitions of the data types which appear in their parameter lists. The types of the two labelled paths in our subsystem fragment, for example, might be defined as follows:

```
ACCESS INTERFACE send;
  WITH flow_data;
  PROCEDURE insert (item : flow_data);
END.

ACCESS INTERFACE fetch;
  WITH flow_data;
  PROCEDURE extract (VAR item : flow_data);
END.
```

The `WITH` clause which appears in each of these modules is a reference to the common source from which they obtain their definition of the data-type `flow_data` needed in both of the access procedures. This is provided by a specification known as a definition which might, in this instance, take the following form:

```
DEFINITION flow_data;
  TYPE
    flow_data = RECORD
      END;
END.
```

Definitions are the means by which other Mascot modules, whether representing specifications or templates, share data-type definitions. Depending on the particular programming language being employed, Mascot implementations may impose additional rules concerning the naming of definitions and the point in the progressive elaboration of a design at which they are required to be present in the database.

Coding capable of implementing procedures `insert` and `extract` is included in the template, `chan_1`, which defines the IDA `ch`. In outline, `chan_1` looks like this:

```
CHANNEL chan_1;
  PROVIDES sw: send;
    fw: fetch;

  ACCESS PROCEDURE insert (item : flow_data);
END;

  ACCESS PROCEDURE remove (VAR item : flow_data);
END;
  fw.extract = remove
END.
```

After the heading, which names the template, a `PROVIDES` section lists all the windows of the IDA, giving each a name and a type which relates it to an access interface. The procedures which implement the interactions specified in the interfaces are identified in the body of the IDA by the
language word **ACCESS**. Other procedures might be declared in the **template** together with data structures such as the storage buffer and its associated pointers. These program entities would all be local to IDAs (such as **ch**) created from the **template** and inaccessible to all other components.

This example demonstrates the two ways in which the correspondence between the **access procedures** and the **window** specifications may be established. In the case of procedure **insert** the correspondence is established implicitly by name. Procedure **remove**, on the other hand, is explicitly identified with the **access Interface** procedure specified as **extract**. This is achieved through an access equivalence list at the end of the **module**. Thus while simple cases can be dealt with simply, an unrestricted facility exists whereby internally defined procedures may be allocated between the **windows** of the **IDA**.

Returning to the fragmentary **subsystem** diagram, it will be seen that each of the two **paths** that we have been discussing connect, at the ends remote from the **IDA windows**, to small, filled circles labelled **sp** and **fp**, respectively. These are situated just inside the boundaries of the two **activity** symbols and are known as **ports**. They are the means of expressing the requirement of an **activity** for the interactions specified in an **access Interface**. For a valid network connection to be established between a **port** of one component and a **window** of another, they must refer to the same **access Interface**. Appropriate **ports** are specified in the **activity templates** **a_temp_2** and **a_temp_1** as follows.

```plaintext
ACTIVITY a_temp_2 :
  REQUIRES sp : send :
END.

ACTIVITY a_temp_1 :
  REQUIRES fp : fetch : 
END.
```

Thus **objects**, such as **a2**, created from **a_temp_2**, contain coding to invoke the interactions specified in **access Interface** **send**. The **port** name is used as a selector.

```plaintext
VAR
  val : flow_data :
BEGIN
  sp.insert( val ) :
```

With the interconnections as described, **activity component a2** would, by this means, invoke execution of procedure **insert** in the **IDA component ch**. Similarly, **activity a1** would invoke procedure **remove** (recall the access equivalence list) of **ch** by:

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Furthermore, the \textit{flow\_data} items can be transmitted, in this way, from one \textit{activity} to the other via a buffer in \textit{IDA ch} which is not directly accessible to either.

\subsection{A Subsystem Containing Activities and IDAs}

These, then, are the principal features of the Mascot communication model. All the internal features of template \textit{subsys\_4} should now be understandable from the diagram which, for convenience, is reproduced below.

In addition to the interactions just described in detail, \textit{a1} also transfers information into the \textit{pool p1} along a \textit{path} of type \textit{put}. Each of these internal \textit{paths} has a \textit{port} at its \textit{activity} end and a \textit{window} at its \textit{IDA} end. Notice that in this example data in some \textit{paths} flows from a \textit{port} to a \textit{window} and in others from a \textit{window} to a \textit{port}. Data flow in both directions along the same \textit{path} is also possible.

All the remaining connections on this diagram pass through the \textit{subsystem} boundary. They represent the external dependencies of \textit{subsystems} created from this template. As we have seen, the external dependencies of \textit{activities} and \textit{IDAs} are expressed as \textit{ports} and \textit{windows}. The same is true of...
subsystems which may possess both ports and windows. This one, for example, has three ports and one window as may be seen more clearly in the higher level diagram, representing the template subsys_3, of which it is a component.

All the coding of a subsystem template is encapsulated in its components and, consequently, each of the template's ports or window must be connected directly to a port or window of its components. Indeed, it is reasonable to regard the specification of a subsystem port or window as a method of making a port or window of one of its components available for connection outside the subsystem. This is illustrated on a diagram by 'port to port' and 'window to window' connections. Thus the window gw4 of type get on the boundary of subsystem subsys_4 is equated to the window gw of the same type belonging to the pool p1. The two names are, of course, local to their individual templates and arbitrarily chosen. Their types, however, must refer to the same access Interface if the equivalence is to be valid. Similarly each of the three ports of subsys_4 echoes a port of the same type belonging to one of its component activities.

Remembering that the program coding for our imaginary design has not yet been written, we will now examine some of the modules from the Mascot database which represent the templates and specifications we have been discussing in their graphical form. We will begin with a_temp_2, the template from which a2 is to be created:

```
ACTIVITY a_temp_2
    REQUIRES sp send
            op out
            rp rec
END
```

The local declarations and the program coding which implements this thread of execution will eventually be added after the three port specifications. The external interactions of objects created from the template are limited to those specified in the access Interfaces send, out and rec, to which it refers. The corresponding specifications take the form illustrated earlier (for send and fetch) and so need not be included here.

The channel template chan_1 which depends on another access Interface, fetch, is represented textually as follows:

```
CHANNEL chan_1
    PROVIDES sw send,
            fw fetch.
END
```

When the contents of the specifications send and fetch have been completed, access procedures and private data storage can be added to chan_1 and correspondence established between the procedures and the various interactions provided at the windows.
The existence in the database of access interfaces put, trans and get, together with any necessary supporting definitions, permits the external dependencies of the remaining template modules to be validated in the following form:

ACTIVITY a_temp_1 :
  REQUIRES tp : fetch ;
  tp : trans ;
  pp : put ;
END .

POOL pool_1 :
  PROVIDES pw : put ;
  gw : get ;
END .

We are now in a position to inspect the template text of subsys_4 itself. It is presented below in its entirety.

SUBSYSTEM subsys_4 :
  PROVIDES gw4 : get ;
  REQUIRES rp4 : rec ;
  otp4 : out ;
  tp4 : trans ;
USES pool_1. chan_1. a_temp_1. a_temp_2 ;
POOL p1 . pool_1 ;
CHANNEL ch.chan_1 ;
ACTIVITY a1 : a_temp_1 ( tp = ch.fw ,
  tp = tp4 ,
  pp = p1.pw ) ;
ACTIVITY a2 : a_temp_2 ( sp = ch.sw ,
  otp = otp4 ,
  rp = rp4 ) ;

gw4 = p1.gw
END .

After the module heading, which establishes the template's name, comes what is known as the specification part. This defines the dependency of this module on the existence of a number of access interfaces. In other words it specifies the subsystem's ports and window. The features of this part should, by now, be entirely familiar.

Then follows what is known as the implementation part. This is something new because none of the modules we have examined earlier contain any implementation. It starts with a USES section which is simply a list of all the templates needed to create the components of this subsystem. There is one for each activity and one for each of the IDAs and we have already examined all four of them. After the USES section the following four lines of the module specify what components are to be included and how they are to be connected together.
There are to be two IDAs called \textit{p1} and \textit{ch} created from templates \textit{pool_1} and \textit{chan_1}, respectively. Examination of these two templates shows that the resultant components each possess two windows which may be referred to as \textit{p1.gw, p1.pw, ch.sw} and \textit{ch.fw}. The connectivity of the network is established by using these window references in the specifications of the activity components which follow on the next two lines of the module. These indicate that there are to be two activities called \textit{a1} and \textit{a2} created from templates \textit{a_temp_1} and \textit{a_temp_2}, respectively.

The lists in parentheses define the network connections by means of the 'formal = actual' convention. The port names on the left of the equivalences (\textit{fp, tp} and \textit{pp} in the case of \textit{a_temp_1}) are analogous, in this context, to the formal parameters of a procedure. The corresponding 'actual parameters' specify the points in the network to which each port is to be connected. Where the connection is direct to an internal window, a reference to that window is given in the form indicated above. Where there is a port to port connection passing out of the template, the name of the appropriate port on the boundary of the subsystem is given. Thus, in the specification of activity \textit{a1}, the connections are:

\begin{verbatim}
port \textit{fp} <--------------- window \textit{ch.fw} 
port \textit{tp} of \textit{a1} <--------------- port \textit{tp4} of template 
port \textit{pp} <--------------- window \textit{p1.pw}
\end{verbatim}

and in the specification of activity \textit{a2}:

\begin{verbatim}
port \textit{sp} <--------------- window \textit{ch.sw} 
port \textit{otp} of \textit{a2} <--------------- port \textit{otp4} of template 
port \textit{rp} of \textit{a2} <--------------- port \textit{rp4} of template
\end{verbatim}

This caters for all the network connections apart from the single 'window to window' case. The last line of the module takes care of this by equating the subsystem window with that named \textit{gw} belonging to the IDA \textit{p1}. Thus 'port to port' and 'window to window' connections are dealt with differently in subsystem templates. The former are handled through the activity 'parameter list' and the latter through equivalence statements.

\textbf{2.1.6 A Subsystem Containing Another Subsystem and a Server}

We are now in a position to consider the template text of \textit{subsys_3} which utilises \textit{subsys_4} to create one of its components. Here, again, is the diagram:
The **template** for the second **component** of this **subsystem** in its partially completed state is:

```
SERVER serve_1 :
   PROVIDES otw : out ;
END .
```

**Servers** are closely related to **IDAs**. The main difference is that they provide means of interaction with peripherals. Consequently, as well as **access procedures**, which can be invoked by **activities** connected to an appropriate **window**, **servers** may also include **handlers**. These are sections of code which can be connected to hardware interrupts and which are entered for execution, on a pre-emptive basis, whenever the appropriate interrupt occurs. The function of the **handler** is typically to control data transfer and the operation of a hardware device. Transfer between the buffer and active Mascot **components** such as **activities** and **IDAs** is achieved in the normal way via a **path** connected to a **window** of the **server**. This particular **server template** specifies a single **window**, **otw**, which is of type **out**.

We have now looked at all the **templates** needed for the **components** of **subsys_3**. Here is the **template** of this **subsystem**:

```
SUBSYSTEM subsys_3 :

PROVIDES gw3 : get;
REQUIRES rp3 : rec;
     tp3 : trans;

USES subsys_4, serve_1 :
SERVER sv : serve_1 :
SUBSYSTEM s4 : subsys_4 ( rp4 = rp3,
      otp4 = sv.otw,
      tp4 = tp3 );

    gw3 = s4.gw4
END.

This should readily be understandable in the light of our earlier discussion of template subsys_4. The specification part specifies a window and two ports in terms of access interfaces get, rec and trans all of which we have already considered. The implementation part lists the required component templates before specifying the two components and their interconnections. There is to be a server called sv created from template serve_1 and a subsystem called s4 created from template subsys_4. The connections to the ports of s4 are:

port rp4 of s4 <--------> port rp3 of template
port otp4 <--------> window sv.otw
port tp4 of s4 <--------> port tp3 of template

The equivalence statement connects the window gw4 of the component subsystem s4 to the window gw3 of the template.
2.1.7 A System

Finally in our tour of this imaginary design, we return to our starting point: the system diagram.

A module to represent a system template is very similar to one for a subsystem. There are, however, no external network dependencies. In other words a system does not specify any ports or windows. On the basis of what we have already learned, and assuming the existence of the necessary additional supporting templates and specifications, it is easy to understand system example_sys:

```
SYSTEM example_sys:

USES subsys_1, subsys_2, subsys_3, sida_1, sida_2:
 IDA s1t : sida_1:
 IDA s1i2 : subsys_2:
 SUBSYSTEM s2 : subsys_2 ( sp2 = s1t.sw, 
ap2 = s1i2.aw):
 SUBSYSTEM s3 : subsys_3 ( tp3 = s1t.tw, 
 rp3 = s1i2.rw):
 SUBSYSTEM s1 : subsys_1 ( pp1 = s1i1.pw, 
 gp1 = s3.gw3):
END
```

2.1 Informal Introduction
In this informal survey of the features of the Mascot scheme of design representation we have discussed the function of ports, windows and paths and examined examples of two kinds of specification (access interfaces and definitions) and five kinds of template (activities, IDAs, servers, subsystems and systems). This selection corresponds roughly to the set of features in the mandatory subset of the definition. Study of the full definition will reveal many extensions to these basic concepts and, in particular, the optional availability of composite forms of most of the templates and specifications presented here in their simple form.

2.1.8 A Composite Activity

A composite module is one which is further decomposed in terms of lower level modules. Systems and subsystems clearly come into this category. They do not, in themselves, introduce coding but merely describe a set of related components. Composite forms of activities, IDAs and servers are described in the following sections. To complete this introduction we will look at just one of these forms: the composite activity. This is chosen because it exemplifies sequential decomposition rather than the network decomposition which we have already seen. An activity whose implementation is complex may be designed as a set of components which, in the executing system, communicate via procedural interfaces. The Mascot design representation provides both graphical and textual conventions to describe this form of construction.

We return now to a slightly modified form of the diagram representing subys_4.
This is the lowest level of the hierarchy that we have so far visited. The modification is that the component symbol $a1$ has been drawn with a thick boundary like that for the subsystem. The implication is that the corresponding module is a composite one. To investigate its structure we must expand the symbol to reveal a lower level template diagram.

![Diagram](image)

The coding of component $a1$ is to be divided into four separately developed modules. One of them, labelled $r$, is a design element known as a root. Every composite activity contains exactly one root as this is the component which contains the initial entry point of the coding. This particular root is created from a template called main which in turn possesses a port of type trans connected, via a port to port connection, out through the boundary of the activity template.

The other three components, $su1$, $su2$ and $su3$ are subroots created from templates sub1, sub2 and sub3, respectively. These are essentially collections of procedures and a composite activity may possess any number of them. Their relationships with the root and with each other are represented graphically by lines bearing hollow arrow heads and known as links. They indicate here that $r$ calls procedures, directly, in each of the subroots and that $su1$ and $su2$ both make calls on procedures in $su3$. Just as the types of paths in a network take the textual form of access interfaces, so link types are represented in the Mascot database by specifications called...
subroot Interfaces. Here is one of the three needed for the new version of template a_temp_1:

```
SUBROOT INTERFACE si1 :
...
END.
```

The contents of such modules, when complete, will be similar to those of access Interfaces. Principally, they are used to specify the headings of procedures which subroots make available to the root and to other subroots.

We can now examine the template, main, from which the component r is created.

```
ROOT main :
  REQUIRES t : trans :
  NEEDS s1 : si1 :
      s2 : si2 :
      s3 : si3 :
END.
```

The port is specified exactly as in a simple activity. The NEEDS section specifies the links which are connected to components of this type in terms of the subroot Interfaces. Coding will, of course, be added to this module before the final END.

We now turn to the template, sub1, for component s1. This is a subroot possessing a port together with links both entering and leaving.

```
SUBROOT sub1 :
  REQUIRES p : put :
  GIVES si1 :
  NEEDS s : si3 :
END.
```

The new feature here is the GIVES section. It specifies the subroot Interface which this subroot implements. Every subroot implements precisely one such Interface.

Template sub3 which, however, possesses no ports and no outward going links. It provides procedural interactions but does not make use of any.

We have now examined all the specifications and templates that are needed for the design of the composite activity a1. Here, in its complete form, is the template a_temp_1.
ACTIVITY a_temp_1 :
  REQUIRES fp : fetch :
    tp : trans :
    pp : put :

USES main, sub1, sub2, sub3 :
SUBROOT su3 : sub3 :
SUBROOT su1 : sub1 ( p = pp,
    s = su3 ) :
SUBROOT su2 : sub2 ( f = fp,
    s = su3 ) :
ROOT r : main ( t = tp,
    s1 = su1,
    s2 = su2,
    s3 = su3 ) :

END.

Following the **specification part**, identical with that of the earlier version, comes the **implementation part**. This begins with a **USES** section which lists the **root** and **subroot templates** needed to create the **components**. Then follows a specification of each **component** with its network and subroot connections. The former are all **port to port** connections and are dealt with in the same manner as in **subsystems**. The remaining parameters specify which **subroots** implement each of the the **subroot interfaces** specified in the corresponding **NEEDS** sections.

With this discussion of the Mascot facilities for the sequential decomposition of individual threads of execution we come to the end of this informal introduction to the Mascot scheme of design representation. All the principal concepts have been discussed and, if they have been understood, the formal definition which follows should present no insuperable difficulties.
In the remainder of this chapter all the design representation features of Mascot, mandatory and non-mandatory, are discussed. Together with the relevant parts of Appendices A, D and E, it constitutes a formal definition of this aspect of the method.
2.2 A NOTE ON PRESENTATION STRATEGY

In determining the order in which topics should be presented in this part of the Handbook it was considered important to focus particular attention on the subset of features mandatory in any Mascot 3 implementation. Not only are these features presented first but they are described without reference to the existence of the remaining features which make up the full definition. As a consequence of this strategy many of the diagrams defining the syntax of the Mascot design representation language appear, in the first few sections, in a simplified form. Where this is the case the simplified diagram has been identified as such by means of a rectangular frame. There are features of these framed diagrams whose significance may not be immediately clear. These include the apparently gratuitous use, for example, of the word *simple* in the name of a syntactic entity or the employment of an entity which expands directly into another. These matters can be clarified by reference to Appendix A. The mandatory subset is identified from the full set of Mascot features in Appendix E.
2.3 PATHS, PORTS AND WINDOWS

Description

The Mascot method addresses the problems of creating application software which consists of collections of communicating, parallel processes executed on processor configurations of arbitrary complexity. For any particular Mascot application, the software design is embodied in a set of hierarchically related templates. At the lowest level of each branch of the hierarchy, element templates provide patterns for fundamental software objects capable of performing either a data processing or a data communication function. A path between a pair of these entities denotes the existence of a set of operations (usually involving data transfer) provided by one of the participants for use by the other. All such transactions thus involve a passive component, concerned with information storage and transmission, and an active component, concerned with information processing. The nature of the interactions associated with any particular path is defined, in procedural terms, by a textual unit (module) called an access Interface. Thus an access Interface is a specification defining a set of operations, implemented by the passive component and which, when invoked by an active partner, transmit data in either or both directions.

Data-type definitions and constants relevant to these interactions may also be supplied to both participants from the access Interface. By associating definitions with a communication route in this way, conformity with the semantic rules of strongly typed implementation languages is made possible and consistency of usage between separately created communicating objects is ensured. This data-typing information is held separately in another kind of specification, known as a definition, from where it can be incorporated into those access Interfaces which require it.

Every path in a Mascot network is connected at one end to a port of a component. Ports are normally possessed by activities, which are the fundamental processing elements of a Mascot system, and by subsystems which may fulfill a similar role at a higher level of the design. They may, however, also occur in the fundamental communication element, the IDA. A port, as specified in a template, is a named reference to an access Interface. It expresses, in terms of the access Interface, a requirement to invoke data transfer (and other) operations which are implemented outside the component in which the port is specified. Establishing, in the specification, the type of the port to which a path is to be connected, thus determines the group of operations which are required.

At the other end of each path in a communications component (usually an IDA or a subsystem performing a data communications role) is a window. A window as specified in a template is, like a port, a named reference to an access Interface. It specifies, in terms of the access Interface, a set of operations to be provided. These operations may be invoked by other components connected to the...
window. Establishing, in the specification, the type of the window to which a path can be connected, thus determines the group of operations which are provided. Notice that whereas each port in a network is connected by a single path to the provider of the interactions which are required, any number of paths may be connected to a window. This is to say that any number of components, which possess matching ports, may invoke the interactions provided at a particular window.

Both activities and IDAs may be used at any depth within an hierarchy of subsystems. In the network diagram, a port may therefore be separated by the boundaries of a number of enclosing symbols, from the source of the operations for which it expresses a requirement. A window may similarly be separated from the nearest port along a given path. In these circumstances, the requirement expressed by the port and the provision expressed by the window are propagated along the communicating path through a series of identical ports and windows established in the higher level constructs.

Graphical Representation

The interactions between components readily lend themselves to diagrammatic representation in terms of static data flow networks in which the node symbols represent either individual elements or lower level networks. A path is the route along which information is transmitted from one particular element or network to another. Its diagrammatic representation is a thin line connecting the two symbols together. This is normally labelled with the name of the access interface which constitutes the type of the path and carries a solid arrow head to indicate the direction of data flow.

\[\text{put} \quad \leftrightarrow \quad \text{get}\]

\[\text{exchange}\]

The diagram below shows an active component, on the left, connected via a path to a passive component, on the right, with a port at the active end of the path and a window at the passive end.

Thus a port is represented in a Mascot network diagram by a small filled circle connected to a line representing a path. The port symbol may be labelled with an identifier, unique within the template.
which possesses it, which is used to distinguish between ports. The path itself, as we have seen, is labelled with the name of the access interface which defines its type so that, from an external point of view, a port represents a network connectivity constraint. As ports may function as either sources or sinks of data, the solid arrow head which indicates the direction of data flow may point either away from a port or towards it.

On a Mascot network diagram, a port symbol is placed just inside the boundary of the template or component to which it belongs.

![Diagram showing port symbols and data flow]

In cases where data are transmitted, along a path, across one or more boundaries, the port symbol is repeated at each boundary. This reflects the necessity of respecifying the port in the text of each template.

![Diagram showing repeated port symbols]

Different activities at the same or different levels of the hierarchy may share a set of operations provided by a common source. The diagram may be simplified in such cases by merging the paths. This is illustrated in the diagram below which shows two activities reading data from a common source and incorporated, at the same level, within a subsystem.
Performing the operations, defined by means of a port and its associated access Interface, demands the execution of code. This code is contained in the passive communication element of a Mascot system, the IDA, and is executed in response to direct invocation by one of the active processing elements. On occasions, especially where distributed processing hardware is involved, one passive component may need to use the operations implemented by another in order, for example, to propagate information from one hardware unit to another. It is thus necessary that communication components should be permitted to possess ports so that this type of requirement may be met. Despite the presence of a port on the boundary of the symbol shown below, it nevertheless represents a passive component and consequently is drawn with square corners.

A window is represented in a Mascot network diagram by a thin, filled rectangle connected to a line representing a path. The window symbol may be labelled with an identifier, unique within the template which possesses it, which is used to distinguish between windows. The path itself, as we have seen, is labelled with the name of the access Interface which defines its type so that, from an external point of view, a window, like a port, represents a network connectivity constraint. As windows may function as either sources or sinks of data, the solid arrow head which indicates the direction of data flow may point either away from a window or towards it.

On a Mascot network diagram, a window symbol is placed just inside the boundary of the template or component to which it belongs.
In cases where the operations provided transmit data along the path across one or more boundaries, the window symbol is repeated at each boundary. This reflects the necessity of respecifying the window in the text of each template.

An IDA inside a subsystem may provide operations to satisfy the common requirements of several port bearing activities or subsystems. The diagram may be simplified in such cases by merging the paths together. This is illustrated in the diagram below.
The module which defines the operations, required by a port, provided by a window, and hence defines the interactions along a path is the access Interface. This is a specification. In the mandatory subset of the Mascot definition, the contents of an access Interface are procedure headings. These provide sufficient information for interactions to be invoked by an active component. For each procedure heading in the Interface, a corresponding complete procedure, known as an access procedure, appears in the template for the passive component. The syntactic structure is shown in outline below:

![Diagram of access interface structure]

It consists of a name part, which establishes the class of the module and gives the specification a name:

```
acc_int_name_part
```

and a specification part which takes the following form:

```
simple_acc_int_spec_part
```

The specification part optionally begins with a 'WITH section' which expresses the dependency of this module on other modules. The simplest Interfaces (those which refer only to data-types which are basic to the implementation language) contain no dependencies, and the specification part then reduces to a set of procedure headings.
The following is an example of a simple access Interface with no external dependencies.

```plaintext
ACCESS INTERFACE send_1 ;
  PROCEDURE secure ;
  PROCEDURE release ;
  PROCEDURE transmit ( i : integer ) ;
END .
```

The 'WITH section' of an access Interface contains a list of references to definition specifications and so implements the mechanism, referred to above, by which definitions may be shared by several Interfaces.

```plaintext
with_section

WITH flow_data, table ;
```

The syntactic structure of a definition, which has no graphical representation, is as follows:

```plaintext
definition

<table>
<thead>
<tr>
<th>def_name_part</th>
<th>;</th>
</tr>
</thead>
<tbody>
<tr>
<td>def_spec_part</td>
<td>END</td>
</tr>
</tbody>
</table>
```

```plaintext
def_name_part

| DEFINITION  | identifier |
```

```plaintext
def_spec_part

<table>
<thead>
<tr>
<th>with_section</th>
</tr>
</thead>
<tbody>
<tr>
<td>def_detail_part</td>
</tr>
</tbody>
</table>
```
The content of a definition module is limited to the definitions of symbolic constants and data-types. It is beyond the scope of this Handbook to define precisely how types are defined in a definition module and how these types can be used by other modules, since this impinges on the syntax and semantics of the implementation language selected. However, a particular implementation may:

1. insist that any data-type used in the Interface will be defined in a definition module of the same name and named in the 'WITH section', or
2. allow any data-type used in the Interface to be undefined, on the assumption that it will be defined in one of the definition modules named in the 'WITH section', or
3. insist that any data-type used in the Interface is already defined in one of the definition modules named in the 'WITH section'.

The following examples illustrate the use of definitions.

```plaintext
DEFINITION colour :
    TYPE
      colour = (red, green, yellow, blue)
    END.

DEFINITION palette :
    WITH colour :
      CONST
        max = 10
      TYPE
        palette = ARRAY[1 .. max] OF colour
    END.

ACCESS INTERFACE spectrum :
    WITH palette :
      PROCEDURE paint( shade_card : palette )
    END.
```

**Ports**

The textual representation of a port is shown, in syntactic form, below:

```
port spec

REQUIRES acc_int_ref_list
```

2.3 Paths, Ports and Windows 2 - 30 Mascot Version 3.1
The following are examples of individual port specifications:

\[
\text{REQUIRES } g \text{ get,} \\
pa \text{ pb put.}
\]

where \textit{get} and \textit{put} are the names of access interfaces defining two sets of operations required in this template. The formal port names \( g, pa \) and \( pb \) are used for two main purposes. First they are used, in network modules, to express the connectivity of the components. Second, in a simple module, they must be used to identify a particular port procedure. The syntax of such a reference is as shown below:

\[
\begin{align*}
\text{port_identifier} & \rightarrow \cdots \\
& \rightarrow \text{procedure_identifier}
\end{align*}
\]

where the procedure identifier after the \( . \) is specified in the access interface which defines the type of the selected port.

**Windows**

The textual representation of a window is shown, in syntactic form, below:

\[
\text{window_spec} \\
\begin{align*}
\text{PROVIDES} & \rightarrow \text{acc_int_ref_list}
\end{align*}
\]

where the form of the list is the same as that shown above for port specifications.

The following are examples of window specifications:

\[
\text{PROVIDES } g \text{ get,} \\
pa \text{ pb put.}
\]
where get and put are the names of access Interfaces defining two sets of operations which this module makes available to the outside world. The implication of these specifications is that the module implements, directly or indirectly, the procedure headings in the bodies of the access Interfaces get and put.

The formal window names g, pa and pb are used for two main purposes. First, they are employed, in network modules, to express the connectivity of the components. Thus a construction such as:

\[
\text{ida_identifier} \rightarrow \text{.} \rightarrow \text{window_identifier}
\]

is used to refer to a specific window of a specific IDA component.

Second, the following construction:

\[
\text{window_identifier} \rightarrow \text{.} \rightarrow \text{procedure_identifier}
\]

(similar to that already discussed in connection with ports) may be used in establishing the correspondence between access procedures and the procedures made available at specific windows. References of this type are to be found in the access equivalence lists described in Section 2.6.
2.4 SYSTEMS AND SUBSYSTEMS

Description

Mascot supports progressive development of a design, from outline to completion, with checks performed for logical consistency at each stage. The detailed arrangements whereby this is achieved are described in Section 3.1. In this section we examine the design feature which makes hierarchical, top-down design expression possible in Mascot: the concept of systems and subsystems. These design elements perform a constructional role. Known formally as networks, they define, for part (subsystem) or all (system) of a Mascot application, the components which are to be created and how they are to be connected together.

In choosing the order of presentation of topics in this Definition, it has been judged desirable that the decompositional aspects of Mascot should be treated before embarking on detailed descriptions of the various forms of system component. Inevitably, then, this section is concerned with the construction of systems from building blocks whose nature remains to be fully revealed. This should present no insuperable difficulties provided that the general principles covered in Section 2.1 have been understood.

In its initial stages, a Mascot design may consist simply of a set of subsystems representing the principal functional or geographical units of the application. Since subsystems may possess ports and windows, they can be interconnected by paths which, through their associated access interfaces, define the nature of the interactions that are to take place. Subsequently, the details of the subsystems are added in the form of templates for networks of activities, IDAs and servers together with other, lower level, subsystems. It is this last feature, the ability to include subsystems within subsystems to any depth, which facilitates an hierarchical form of design expression. As a design entity a subsystem may play the role either of a processing or a communication element or of a mixture of the two.

As will be seen below, the graphical representation of a subsystem would lead one to suppose, on the basis of a familiarity with the rest of the Mascot graphical conventions, that it necessarily incorporated one or more independently scheduled threads of execution. However exceptions can arise. Since the existence of a subsystem is established before its internal design is carried out, there is always the logical possibility that subsequent decomposition will show that no component activities or subsystems are required. This is an allowable form and, where it arises, the subsystem is functionally identical to either a composite IDA or a composite server (both of which are the subject of later sections).
A system is a network which encompasses the whole of the application. Explicitly or implicitly, constitutes a complete description of the software. It is the highest or outermost level of the hierarchic design expression. Consequently it differs from a subsystem only in having, by definition, no external dependencies other than those which may be satisfied during system building (see later Section 2.8). A communication with hardware or software objects in its external environment is implicit. In the remainder of this section, attention will be directed largely to subsystems of which the system will be treated as a special case.

**Graphical Representation**

A subsystem is represented in a Mascot network diagram by a closed curve with rounded corners. A subsystem is by nature a composite entity, it is drawn as a thick or double line or in such other distinctive form as may have been adopted as a suitable convention. The shape is usually that of rounded rectangle. External dependencies are shown by lines which pass through the boundary of the symbol and where these represent paths they terminate in either a port or a window symbol.

The diagram below shows a subsystem as it might appear in the early stages of design. Its external dependencies are determined but not its internal structure.

This particular example possesses two ports and a window and its purpose is to process two input data streams to produce a single output stream. The next diagram displays the internal structure of the template `subsys_5`.
Two activities, \( a \) and \( a_1 \), created from templates \textit{act} and \textit{act_1} respectively, are connected to the two externally visible ports which evidently receive the two input streams. Each activity is connected via a separate path to a separate window of the \textit{IDA} \( m \). These two internal paths are represented by distinct access interfaces, \textit{trans} and \textit{trans_1}. Finally, it is \textit{IDA} \( m \), created from the template \textit{merge}, which provides the externally accessible window.

\textit{subsys_5} is a simple example but is relatively general in possessing both ports and windows. \textit{subsys_6}, below, on the other hand, has only ports and therefore externally resembles an activity.

Conversely, \textit{subsys_7} externally resembles a pure communication element.
As a final graphical example, *triplex*, to seasoned Mascot users an old friend in a new guise, illustrates a *subsystem* with embedded *subsystems* in its structure.

The thick lines of the symbols *dup_1* and *dup_2* reveal these *components* to be of a *composite* nature. They are *subsystems* and, furthermore, they are both instances of the same *template*, *duplicate*. Notice that the design would have to be expanded to at least another level down to reveal the *components* which actually provide the facilities, defined in *access interface get*, provided at the three *subsystem windows*. *triplex* itself possesses a *port*, *in*, and three *windows*, *out1*, *out2* and *out3* all of type *get*.

Mascot 2 users may be inclined to wonder at the complication of the well known elementary example of *triplicated expansion*. Under what circumstances would it be necessary to use a *subsystem* rather than an eminently simple *activity* to duplicate a data stream without transformation (for such is the traditional version of this example)? The explanation arises from the applicability, mentioned in the
Introduction, of Mascot 3 to very large distributed computing systems. If each of the three data streams associated with the two instances of subsystem template duplicate fall under the jurisdiction of different processors with private and shared memory units, something considerably more complicated than a two-statement activity may be needed.

**Textual Representation**

The syntactic structure of a Mascot subsystem template is shown, in outline, below.

```
subsystem
  → subsys_name_part → ;
  \                           \   
  ↓ subsys_spec_part         ↓
  \                         \
  ↓ network_imp_part        ↓
  \                      \    \ 
  END                     .
```

The `name part` establishes the `class` of the `module` and gives the `template` a name.

```
subsys_name_part
  → [SUBSYSTEM] identifier →
```

For example:

```
SUBSYSTEM subsys_5 :
```

The `specification part` specifies the network dependencies. Its syntax, in the mandatory subset, is defined in the diagram below.

```
subsys_spec_part
  → window_spec
  \                         \   \   
  ↓ port_spec
```

The form of `port` and `window` specifications is defined in the preceding section of the Handbook. For subsystem `subsys_5` the `specification part` is:

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An important point to understand is that the subsystem template contains no algorithmic coding. It merely defines the nodes and interconnections of a network. As explained above, the modules which represent its component parts, the nodes, are activities, IDAs and servers together with other subsystems. The interconnections are paths whose types are defined by access interfaces. All the information needed to create the components and connect them together is provided in the module's implementation part. Its syntactic structure is shown below.

It begins with a USES section which lists all the templates needed for the components of the subsystem. This list may not include a system template.

```
USES act, act_1, merge ; { subsys_5 }  
USES act_2, act_3, chan ; { subsys_6 }  
USES act_4, ch, ch_1 ; { subsys_7 }  
USES exp, copy, duplicate, dictionary ; { triplex }
```

Next comes the component part in which components derived from the templates mentioned in the USES section are specified.

```
component_part
```

---

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2 - 38  
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There are, including the two special varieties of IDA, six different classes of component which can be included in a subsystem.

Each component is individually introduced by the appropriate language word: ACTIVITY, IDA, CHANNEL, POOL, SERVER or SUBSYSTEM and given a name. These names are the component names that, in the graphical form, appear just outside the corresponding symbols. The template reference which follows is the name of the template from which the component is to be created. The component class must be the same as the class to which this template belongs. Where there are ports, their connections must be specified in the following manner:

This is equivalent to a set of actual parameters in the call of a procedure. To continue the analogy, the ports specified in the component templates correspond to the formal parameters. For every port a connection to a matching window must be established, either explicitly or by way of another matching
port on the boundary of the enclosing template.

Thus the interconnection information consists of a list of identities expressed in the 'formal = actual' convention. Where the connection is an internal one, the reference is to an explicit internal window. Window names must be qualified with the name of the component which provides them. Where the connection is an external one, the 'actual parameter' is the formal name of a port on the boundary of the subsystem.

Returning to the subsystem diagram for *triplex*, it is now possible to derive the equivalent textual representation. Its *specification part* is:

```plaintext
PROVIDES out1, out2, out3 : get;
REQUIRES in : get;
```

and its components are:

```plaintext
POOL look_up : dictionary;
SUBSYSTEM dup_1 : duplicate;
SUBSYSTEM dup_2 : duplicate;
ACTIVITY e : exp ( g = in,
               ep = dup_1.p,
               dp = look_up.dw);
ACTIVITY c : copy ( g = dup_1.g2,
               cp = dup_2.p);
```

The *port* specifications of the *exp* template are:

```plaintext
REQUIRES g : get; ep : put; dp : dict;
```
and that of the template *copy*:

\[ \text{REQUIRES } g : \text{get} ; \text{cp : put} ; \]

Notice that the **port** to **port** connection is represented by specifying \( in \) as the connection corresponding to the **port** \( g \) of activity \( e \). That is, instead of specifying an explicit **window** to satisfy this requirement, the **port** of the activity is identified with that of the enclosing **subsystem**. A corresponding **window** would have to be provided within any **system** or **subsystem** having a **triplex** component.

The next aspect of **subsystem templates** to be discussed is the representation of (boundary) **window** to (internal) **window** and (boundary) **window** to (boundary) **port** connections. These are dealt with by means of an **equivalence list** (not to be confused with the **access equivalence list** used in **IDA templates** to establish a correspondence between **windows** and **access procedures**).

\[
\text{equivalence_list} \\
\text{boundary_window_ref} \rightarrow \text{component_ident} \\
\text{boundary_port_ref} \rightarrow \text{window_ref} \\
\]

Using **subsys_7** as an example:

\[
p3 = c.pw ; \\
g3 = c1.gw1
\]

In the case of **triplex**, all the externally visible **windows** are provided by **subsystems**.

\[
\text{out1} = \text{dup_1.g1} ; \\
\text{out2} = \text{dup_2.g1} ; \\
\text{out3} = \text{dup_2.g2}
\]

To illustrate the boundary **window** to boundary **port** connection, a **path** straight through **subsys_8** (below) would be defined thus:

\[
g = p
\]
The following examples summarise the features of subsystem modules.

SUBSYSTEM subsys_5 : { name part }
{ specification dependencies }
PROVIDES g4 : get ;  { window specification }
REQUIRES p4 : get ;
c4 : com ;  { port specifications }
{ implementation dependencies }
USES act, act_1, merge ;  { component templates }
{ components and interconnections }
IDA m : merge ;
ACTIVITY a : act ( p = p4,
    tp = m.tw ) ;
ACTIVITY a1 : act_1 ( c = c4,
    tp1 = m.tw1 ) :
{ equivalence list }
g4 = m.g
END .

SUBSYSTEM subsys_6 : { name part }
{ specification dependencies }
{ PROVIDES .......... ;  no window specifications }
REQUIRES g2 : get ;
p2 : put ;  { port specifications }
{ implementation dependencies }
USES act_2, act_3, chan ;  { component templates }
{ components and interconnections }
CHANNEL c : chan ;
ACTIVITY a1 : act_2 ( gp = g2,
    pp = c.pw ) ;
ACTIVITY a2 : act_3 ( gp1 = c.gw,
    pp1 = p2 ) :
{ no equivalence list }
END .

2.4 Systems and Subsystems  2 - 42  Mascot Version 3.1
Finally in this section we turn to systems. As explained earlier, a system is simply a subsystem with no ports or windows. In the graphical form no paths cross the boundary of a system symbol which is otherwise identical to that representing a subsystem. The system diagram below uses three of the subsystems which have been discussed above.
The syntax which describes the textual form of a system is a modification of that for a subsystem to take account of the absence of ports and windows and the fact that no equivalence list is required.

```plaintext
system
  system_name_part ;
  system_imp_part END
```

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The list of templates in the USES section may not include a template for a system.

Using system total as a basis, the following example summarises the features of a system module.

```
SYSTEM total:
  { name part }
  { implementation dependencies }
  USES a, subsys_7, triplex, subsys_6, drive_1, drive_2, drive_3;
  { component templates }
  { components and interconnections }
  SERVER i1 : drive_1;
  SERVER i2 : drive_2;
  SERVER i3 : drive_3;
  SUBSYSTEM ss1 : subsys_7;
  SUBSYSTEM ss2 : triplex (in = ss1.g3);
  SUBSYSTEM ss3 : subsys_6 (g2 = ss2.out1, p2 = i1.p);
  SUBSYSTEM ss4 : subsys_6 (g2 = ss2.out2, p2 = i2.p);
  SUBSYSTEM ss5 : subsys_6 (g2 = ss2.out3, p2 = i3.p);
  ACTIVITY a1 : a (p = ss1.p3);
END.
```
2.5 ACTIVITIES

Description

Mascot application software is conceived in terms of a set of independent threads of execution which is mapped onto a hardware configuration containing an arbitrary number of processors. There are normally fewer processors than there are computational threads and it is the responsibility of the scheduling function of the Mascot Context software, acting either pre-emptively or in co-operation with the application software, to allocate the available processing power appropriately. The unit of scheduling for this purpose, an individual process, is known as an activity.

Thus activities are the fundamental processing elements in a Mascot application. Conceptually, all activities are executed in parallel. In practice, when any two communicating activities are considered, there may be literal parallelism resulting from their being mapped onto distinct processors or pseudo-parallelism if they share the same processor. In the latter case, depending on the mode of scheduling being employed, the synchronisation problems arising from their use of common data may be identical with those met with in true parallelism.

It is a principle of the Mascot philosophy that the mechanisms necessary to safeguard the integrity of data communicated between activities should be embodied not in the activities themselves but in a separate communication element. This is the intercommunication data area or IDA which is discussed in detail in a separate section. It encapsulates the shared data area and normally provides access to it through a procedural interface. Mascot activities therefore never communicate with each other directly but always through the intermediary of an IDA. In such transactions the activity is the active participant which invokes the operations specified in an access interface and provided by the passive IDA.

A consequence of this approach is that an activity's influence on the remainder of the application software is restricted to its interactions with the IDAs to which it is connected. In particular, it is uninfluenced by the existence of any other component. Its part in the overall application is limited to using, processing and transmitting the data which flows to it along the paths of the network.

A Mascot system consists of a network of activities and IDAs. Each of the activities present has been created from an activity template. In some cases several of the activities may have been created from the same template. Since each template is a distinct design entity, developed independently, it is important that there are means of exercising control over the formation of a network. The validity of the connections must be capable of being checked during the construction process. The formal arrangements whereby a Mascot database records the status or degree of validation of each module is described in Section 3.1.
The validation is carried out in terms of access Interfaces. An activity template establishes a network connection point by specifying a port. Each port implies a connection to a path of a particular type whose associated access interface specifies a set of data transfer or other operations. The coding necessary to implement these operations is provided by an IDA possessing a window of matching type. Valid activity to IDA connections are ones for which this type checking proves successful.

**Graphical Representation**

An activity is represented in a Mascot network diagram by a closed curve with rounded corners and drawn with a thin line. Normally, in accordance with historical convention, the curve is a circle. External network dependencies are shown by lines which pass through the boundary of the symbol and terminate, just inside the activity boundary, in the port symbol.

The diagram below shows an activity template. The name of the template, and of the module which represents it, is act_temp and this identifier is placed inside the activity symbol. As a general rule the name of an activity should clearly reflect its function. The activity possesses two ports, g and p, and, as the labels on the two connected paths indicate, the external requirements which they represent are specified by access interfaces get and put, respectively.

![Diagram of act_temp activity]

An activity component, as opposed to an activity template, would be represented as part of a network. In this case the symbol would represent a particular component created from a template and would be given a name distinct from that of the template itself. This name is placed outside the activity symbol. Examples are to be found in Section 2.4.

**Textual Representation**

In the mandatory subset of the Mascot definition, an activity module takes the syntactic form shown in outline, below.
The name part establishes the class of the module and gives the template a name.

For example:

```
ACTIVITY act temp;
```

The specification part specifies the network dependencies. Its syntax is defined in the diagram below.

```
port spec
```

The form of port specifications is defined in a preceding section of the Handbook.

```
REQUIRES p input g get;
```

Finally, the implementation part defines, explicitly or implicitly, the coding of this parallel thread of execution. Its syntax is shown in Pascal style below.

```
with section
```

```
program part
```

2.5 Activities
In its simplest form it consists solely of a block representing a set of private declarations and a sequence of program statements. The **program part** may define procedures, variables and constants etc which are local to the activity.

Definitions of globally used data-types and symbolic constants are normally specified in **definition modules** (described in Section 2.3). They are made available for use in an **activity module** through the WITH section of its **implementation part**. This simply lists the names of the relevant specifications.

```
WITH dataflow_types, real_constants;
```

The following outline example summarises the features of **activity templates** described above.

```
ACTIVITY act_temp; { name part }
    { specification dependencies }
REQUIRES p: put;
    g: get; { port specifications }
    { implementation dependencies }
WITH dataflow_types, real_constants; { global definitions }
    { local declarations }
    { activity coding with initial entry point }
END .
```
2.6 INTERCOMMUNICATION DATA AREAS (IDAs)

Description

Any scheme for the organisation of co-operating parallel processes must include mechanisms for the control of data intercommunication. Where these mechanisms are imposed, globally, by a run-time system they may often present themselves as a constraint on the software design process. The Mascot philosophy is to provide the designer with the means to create precisely the communication facilities that are required between any two activities in the system. Previous sections of this Definition have described how the external network dependencies of an activity are expressed in terms of the procedure specifications which constitute the body of an access interface. These procedures, which perform the necessary data transfers, are implemented in a Mascot design element called an intercommunication data area or, more shortly, an IDA. Wherever information is transmitted between activities it is communicated through an intervening IDA; wherever common information is shared by activities it is stored in an IDA. Thus, in general, IDAs encapsulate both the shared data and the custom-designed access mechanisms necessary to safeguard the integrity of information being held in or propagated through the IDA.

An IDA is a passive element. The code which it contains is never scheduled for execution in its own right. The independent threads of execution which form the run-time manifestation of activities simply pass through the IDA coding at points where intercommunication is taking place. Several such threads may simultaneously be active, or temporarily suspended, within an IDA which thus encapsulates the critical sections within activities where activities require concurrent access to the same data structure. When these critical sections arise they may involve more than one activity utilising the same access mechanism and there are actively using the same section of IDA code, or alternatively several different access mechanisms may be operating concurrently on the same items of data. The Mascot method, while leaving the software designer firmly in control of the means of solving the system's concurrency problems, restricts the location of the coded solutions to this one type of component.

An IDA, therefore, is an encapsulated data type whose detailed physical representation is hidden from its users and whose component values may be manipulated indirectly through a procedural interface. It fulfils two principal purposes in a Mascot network. By providing mutual exclusion wherever necessary between activities competing for the use of a common resource, it safeguards the integrity of data. By providing cross-stimulation between co-operating activities, it maintains the propagation of data in the network.

Through experience with earlier versions of Mascot, two simple classes of IDA have been found to be particularly useful. The first of these provides for unidirectional transmission of data from one or more producer activities to one or more consumers. It is known as a channel and is characterised by a destructive read operation and a non-destructive write. As a consequence it can become empty of data and, as its capacity is finite, it can also become full. The other specially useful type of IDA is known as a...
pool. In this case it is the write operation which is destructive and the read non destructive. A pool is therefore a suitable kind of IDA to represent a table or dictionary which activities periodically update. Many of the simpler Mascot networks can be built satisfactorily from activities, channels and pools. The graphical forms of such networks are normally referred to as ACP (Activity Channel Pool) diagrams.

In general, active and passive components, activities and IDAs, alternate along the paths of a Mascot network. Certainly adjacent activities never occur. However, it is sometimes necessary for data to be projected directly from one IDA to another. Typically this requirement might arise where the two IDAs are to be accommodated in separate storage units addressable by separate processors. Mascot caters for this contingency by allowing IDAs to possess ports as well as windows. Thus an IDA may use access mechanisms as well as providing them and so may be connected, by a path, to another IDA.

**Graphical Representation**

An IDA, in its most general form, is represented in a Mascot network diagram by a rectangle with square corners. The square corners of the symbol indicate the passive nature of the component it represents. Throughout the Mascot graphical notation, an exclusively square cornered symbolic outline, no matter how decomposed, to any depth, will not reveal an active element. A rounded corner, on the other hand, affirms the probability, but not the certainty, of one or more independently scheduled threads of execution being involved.

External network dependencies are denoted by lines which pass through the boundary of the symbol. These lines are terminated, within the boundary, by a window symbol. The diagram below shows an IDA template.

```
+-------------+         +-------------+         +-------------+
| ida_temp    |         |             |         |             |
|             |         |             |         |             |
| p            |         | g            |         | get          |
|             |         |             |         |             |
| transmit     |         |             |         |             |
```

The name of the template is `ida_temp` and this identifier is placed inside the rectangular box. As a general rule the name of the template should clearly reflect its function. The IDA possesses two windows, `p` and `g`, represented by the filled rectangular symbols with which two of the external connecting paths terminate. The labels on these paths show that the procedures provided by the IDA at the corresponding windows are specified in the access interfaces, `put` and `get`, respectively.
A third path, labelled *transmit*, is shown crossing the bottom boundary of the symbol and this terminates in the port, \( t \). The procedures specified in the corresponding access interface, *transmit* may be used by the IDA coding in order to project information directly to or from another IDA. This mode of data transfer takes place only when a thread of execution passes through the IDA.

An IDA component, as opposed to an IDA template, would be represented as part of a network. In this case the symbol would represent a particular component created from a template and would be given a name distinct from that of the template itself. This name is placed outside the IDA symbol. Examples are to be found in Section 2.4.

Two alternative graphical representations are available for channels and pools (described earlier) and these are shown below:

![Diagram](image)

The standard rectangular symbol is slightly modified in each case to make it more reminiscent of the original Mascot 2 channel and pool symbols.

**Textual Representation**

In the mandatory subset of the Mascot definition, an IDA module takes the syntactic form shown in outline below:

![Diagram](image)
The *name part* establishes the *class* of the *module* and gives the *template* a name. It also distinguishes between a generalised IDA and the two special cases: *channel* and *pool*.

```
IDA name part

CHANNEL

IDA

POOL

identifier
```

Examples are:

```
IDA ida temp :
CHANNEL chan temp,
POOL pool temp.
```

The *specification part* specifies the *network* dependencies. Its syntax is defined in the diagram below.

```
IDA spec part

window_spec

port_spec
```

The form of the *window* and *port* specifications is defined in a preceding section of this Handbook. Notice that at least one *window* must be specified.

```
PROVIDES p : put,
g : get ;
REQUIRES t : transmit ;
```

The *implementation part* defines, explicitly or implicitly, all the coding contained in the element. Its syntactic structure is defined below.
In its simplest form it consists solely of a declaration part. Program objects to which external access is provided, via a window of the IDA, are distinguished from purely local entities by the use of the word ACCESS in their declarations. Ignoring, for the moment, the WITH section an elementary example might begin:

```plaintext
CONST
    bufsize = 100;

VAR
    buffer  ARRAY[1 .. bufsize] OF data_flow_type;
    inq, outq, controlq:
    ACCESS PROCEDURE put_data (item : data_flow_type);
    ACCESS FUNCTION get_data : data_flow_type;
```

In this IDA, a data buffer is declared together with a pair of pointers and two control variables, inq and outq, whose significance in the Mascot method of process synchronisation is explained in the relevant section of this Handbook. In conformity with the principle of data hiding, all these variables are entirely private to the IDA. The procedure declaration section must include an implementation of every procedure made externally available in the IDA's PROVIDES list. Thus if this was

```plaintext
PROVIDES p : put, g : get;
```

then access interface put might contain the specification

```plaintext
PROCEDURE put_data (item : data_flow_type);
```

and access interface get, the specification

```plaintext
FUNCTION get_data : data_flow_type;
```

The purpose of the window identifiers, p and g, will be explained shortly.
Three other special procedures may be included in the declaration part and identified by the words INITIALISATION, RESET and TERMINATION respectively. Their execution is invoked by system control functions as described in Section 4.6 of the Handbook. Any other procedures declared here are local to the IDA. They can only be executed as a result of being called from either get_data or put_data. The procedures get_data and put_data themselves are of course invoked from activities connected by paths to the appropriate window. They constitute the mechanism whereby access is obtained to the hidden data buffer.

There is a need to establish the correspondence between the access mechanisms in an IDA and the procedures which the windows indicate are to be provided. This may be achieved by identity of names as in the above example, or alternatively by the optional access equivalence list shown in the implementation part of the syntax.

```plaintext
access equivalence list
```

Thus, there is provision for equating each identifier in each window with a corresponding identifier declared inside the IDA; this is known as window-to-local equivalence. In addition where, for example, data propagation takes place directly between two connected IDAs, an identifier in a window may be equated to an identifier in a port so that it is a second IDA which provides the functionality; this is known as window-to-remote equivalence. For the particular case where all the functionality of a window is to be provided externally there is a shorthand form which equates all the features of the window to those of a matching port in a single access equivalence statement; this is known as window-to-port equivalence.

Two examples of window-to-local equivalence are:

```plaintext
p put data = put data ;
g get data = get data
```

2.6 IDAs

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In general, using this notation, the corresponding procedure names need not be the same. Indeed, like the names of corresponding formal and actual procedure parameters, they may be expected to be different in other than simple instances of IDAs.

If our example IDA possesses a port:

```plaintext
REQUIRES t : put :
```

it could be equated with the matching window:

```plaintext
p \equiv t
```

implying that the the access interface procedure `put_data` is to be provided from elsewhere. Alternatively, an individual procedure in the window may be equated to a procedure in the port:

```plaintext
p.put_data = t.put_data
```

It will be observed that, in the above example, data-types are used which are not defined in the IDA. This will normally be the case with data-types and symbolic constants which are used in more than one module. In order to supply such global definitions, a specification module, known as a definition and described in Section 2.3 of the Handbook, is provided for them. It is the purpose of the WITH section in the implementation part of the simple IDA to import such additional global definitions that are needed but which are not inherited from an interface.

```plaintext
WITH data_type_defs, control_type_defs :
```

The following outline example summarises the features of simple IDAs described above:

```plaintext
IDA ida_temp : { name part }
   { specification dependencies }
   PROVIDES p : put :
   g : get : { window specifications }
REQUIRES t : transmit : { port specification }
   { implementation dependencies }
WITH .......... : { global definitions }
   { local declarations }

   ACCESS PROCEDURE ............... : { to match all procedures }
   { specified }
   ACCESS FUNCTION ................. : { in the windows provided }
   { access equivalence list }
END .
```
2.7 SERVERS

Description

A Mascot application interacts with its environment via a set of peripheral devices attached to the processor or processors on which it is running. These devices generally appear to the software as sources, sinks or temporary repositories of data. In some cases, however, they appear as initiators of signals, acquainting the software with information concerning external events. The range of processors for which Mascot systems are likely to be implemented possess a variety of different interrupt handling architectures. Absolute standardisation is therefore not possible and this section of the Definition is intended to establish guidelines as to what Mascot facilities are provided to allow devices to be handled in a manner appropriate to the application.

In order to enhance the portability and flexibility of a Mascot system, it is desirable that the application dependent details, relating to specific devices and to the architecture of particular computers, should be localised. This requirement is met by a Mascot design element called a server which encapsulates the mechanisms that control and transfer data to and from a particular device. Servers communicate with other Mascot components through access interfaces which enable them to be treated as far as possible, like IDAs. The aim is to hide the application dependent details in the same way as the physical representation of shared data structures is hidden.

The constituent parts of a server vary according to the characteristics of the device with which it is concerned and the uses to be made of this device by the application software. The interactions it provides will normally include 'driver' mechanisms to allow control signals and/or data to be sent to the device. When an interrupt occurs, the action of the Mascot scheduling function is overridden by hardware and control is transferred to a section of code encapsulated in the server and known as a handler. It is the handler which transfers information between the frequently volatile data registers of the device and the internal data structures of the server which are accessible to the Mascot network via windows.

Servers share many of the attributes of IDAs; they may possess both windows and ports. They differ from IDAs, however, in being the only Mascot design elements which may include handlers and other code which communicates directly with devices. Where the mechanisms used for device interaction are not available to the application software but are provided by low level procedures within the environment the use of these procedures is restricted to code encapsulated by a server.
Graphical Representation

A template for a server is represented in a Mascot network diagram by a D-shaped symbol as illustrated below.

This template is called `dev1_server` and possesses two windows, `g` of type `get` and `e` of type `enable`, and a single port, `i` of type `Init`. The various forms of connection are shown in their conventional positions. The rounded edge of the server symbol faces towards the device. Windows are placed on the opposite, square cornered edge and ports on one of the sides of the symbol (top or bottom of the D). The orientation of the complete symbol may be chosen to suit the layout of the diagram. The diagram also shows the device controlled by the server. This is represented here by a hatched rectangle but a schematic sketch of the hardware would be equally acceptable. The presence of the device symbol and its connection to the server are optional.

Textual Representation

In the mandatory subset of the Mascot definition, a server module takes the syntactic form shown, in outline, below.

```
server
  server_name_part
  ida_spec_part
  simple_server_imp_part
```

server name part

SERVER

identifier

The *name part* identifies the class of the module and gives the *template* a name. For example:

```
SERVER dev1 server
```

The *specification part* is identical with that of an IDA as described in the previous section of the Definition Reference. That section shows that *ports* may be included and that at least one *window* must be specified. Without the latter it could convey no information to the network and, therefore, perform no useful role.

The syntactic structure for the *implementation part* of a *server* is shown below:

```
simple_server imp_part

with section

serverDecl part

access_equivalence_list
```

First an optional *WITH* section allows globally accessible data type definitions to be imported from *definition specifications*. The explicit contents of the *server template* are contained in the succeeding *declaration part*. This is similar to that of an IDA. It shares with the IDA the requirement that its procedure declarations include implementations (distinguished by the word *ACCESS*) of the procedure headings offered by its one or more *windows*. Correspondence between the *access interface* headings and the internally declared procedures is established, as for IDAs, either by name identity or by means of an *access equivalence list*, the form of which is described in the previous section of the Definition. *INITIALISATION*, *RESET* and *TERMINATION* procedures may also be included (see Section 4 6 of the Handbook).

Unique to this type of *template* is the ability to declare *handlers*. These routines are distinguished from other procedures by use of the design language word *HANDLER* in place of *PROCEDURE*. Now follows an outline example, based on the earlier graphical example, of a complete *module* representing a *server*.
SERVER dev1_server : { name part }
   { specification dependencies }
   PROVIDES g : get ;
       e : enable ; { window specifications }
REQUIRES i : init ; { port specifications }
   { implementation dependencies }
WITH ............ ; { global definitions }
   { local declarations }
ACCESS PROCEDURE ............ ; { including all procedures }
   { specified }
ACCESS FUNCTION ............ ; { specified }
HANDLER ............ ; { handler declaration }  
   { access equivalence list }
END .
2.8 TEMPLATE CONSTANTS

Description

This feature is not part of the mandatory subset of the Mascot definition.

Collections of objects, of any kind, although all created from the same template, may nevertheless be required to behave differently from each other in minor ways. These individual secondary characteristics may be bestowed by specifying, in the template, constants whose values are to be supplied to individual components of this type. Such constants constitute another form of external dependency and are known in Mascot as template constants.

The range of template constant types is dependent on the implementation language, but could be expected to include any of the implicit data types of the language. The use made of these values is again dependent on the implementation language but they could typically be used for:

- device addresses (in a server)
- interrupt levels (in a server)
- buffer sizes (any simple template)
- iteration control (any simple template)

This latter use might for instance govern the number of terms in a series to be evaluated and hence the accuracy and computation time of a result.

Just as network paths may be carried via 'port to port' or 'window to window' connections across the boundaries of composite design elements, so template constants may be transmitted in a similar way to individual components. Indeed powerful use of the facility may be made by bringing template constant dependencies out to the enclosing system to be supplied dynamically during system building (see Section 3.2 of the Handbook).

Template constants may be specified either individually or in the form of arrays in any template.

Graphical Representation

A template constant is distinguished from a communication path, in a Mascot network diagram, by the absence of any terminating symbol (such as those representing ports and windows) inside the boundary of the template or component to which it belongs. Taking an activity template as an example:
The template `act_temp_a` possesses a template constant, of type integer, known internally as \( m \). Assigning `act_temp_a` to be used to generate a component of a surrounding subsystem whose instantiation is to supply the value of \( m \), this would be indicated graphically as shown below:

![Diagram showing template constant and subsystem](image)

This diagram shows that the template constant, which is to be known as \( k \) in the subsystem, is to be given the value 10 when the subsystem is itself created. Similar diagrammatic conventions apply to all other types of template.

**Textual Representation**

Reference to the complete syntactic descriptions (to be found in Appendix A) of any of the Mascot templates shows that template constants may be specified at the beginning of their specification parts. In the case of a subsystem, for example, the complete syntactic structure of its specification part (as opposed to that previously presented for the mandatory subset) is:

```
...`
The additional syntactic structure is shown below:

```
subsys_spec_part
  → temp_const_spec
  → window_spec
  → port_spec

const_spec_list
  → identifier, : implicit_type ;
  → ARRAY [ integer_type ] OF
```

Using the graphical example above to illustrate the textual form, the activity template would include:

```
ACTIVITY act_temp_a :
  CONSTANT in : integer ;
END
```

The enclosing subsystem transmits the constant through the connection specification of the component derived from template `act_temp_a`. This is the same notation as that used to provide port to window and port to port connections. The complete syntax for a `connection_spec` is:
The additional structure required to identify template constants is:

```
connection_spec

temp_const_ident

port_window_connect

port_port_connect

The additional structure required to identify template constants is:

temp_const_ident

constant

constant

const_identifier

This identifies a template constant with either its ultimate value or with another constant identifier at a higher level. Thus, the subsystem in our example would contain:

```
SUBSYSTEM subsys_9 :
  CONSTANT k : integer .

ACTIVITY act : act temp( m = k ;
  p = .... ;
  g = .... ) :

END:
```

and the system:

```
SYSTEM sys :

SUBSYSTEM s : subsys 9 ( k = 10 ; ......... ) :

END
```

2.8 Template Constants
Finally, an array of template constants might be specified as:

```
CONSTANT c : ARRAY[1..10] OF char ;
```

and its values provided by a construction similar to an Ada positional aggregate:

```
c = ( 'a', 'b', 'c', 'd', 'e', 'f', 'g', 'h', 'i', 'j' )
```

Alternatively, the array name `c` may be equated with that of an assignment compatible array at a higher level of the design hierarchy.
2.9 LIBRARIES

Description

This feature is not part of the mandatory subset of the Mascot definition.

In Section 2.12 of the Handbook it will be seen that facilities exist in Mascot for the sequential decomposition of activities. The products of decomposition are roots and subroots whose relationships to each other, and to the adjacent parts of the data flow network, are formally shown on the diagram. This feature is limited to activities but all simple templates are open to procedural decomposition in terms of libraries which may be shared by any number of templates. A library, which may be instantiated in any composite module, consists of a set of externally accessible procedures encapsulated with other purely private declarations. It does not contain static data and cannot be used as an IDA.

A Mascot library implements one or more library Interfaces specifying which of the program objects declared in a given library may be used by templates possessing a LIBRARY statement which refers to that interface. Candidates for including such a specification are simple IDAs, libraries, simple activities and the simple components of composite activities. It is clear, therefore, that libraries like IDAs must be capable of supporting multi-threaded operation. However they must not allow interaction between the threads and so are not involved in problems of process synchronisation.

Graphical Representation

Neither libraries nor library Interfaces are represented on Mascot network diagrams.

Textual Representation

Library Interface

A library Interface specification has the following outline syntax:

```
library interface

lib_int_name_part

;

lib_int_spec_part

END
```

2.9 Libraries 2 - 66

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The optional `WITH` section allows global type and symbolic constant definitions to be imported to the library interface.

Notice that variables are not allowed in a library interface. Some examples follow:

```
LIBRARY INTERFACE trig functions :
    FUNCTION sin ( x : real ) : real ;
    FUNCTION cos ( x : real ) : real ;
    FUNCTION tan ( x : real ) : real ;
END .

DEFINITION complex :
    TYPE
        complex = RECORD
            real_part : real ;
            imaginary_part : real
        END ;
END .

LIBRARY INTERFACE complex 1 :
    WITH complex ,
        FUNCTION add ( x , y : complex ) : complex ;
        FUNCTION sub ( x , y : complex ) : complex ;
    END .

LIBRARY INTERFACE complex_2 :
    WITH complex ,
        FUNCTION div ( x , y : complex ) : complex ,
        FUNCTION mult ( x , y : complex ) : complex ;
    END .
```
Libraries

The outline syntactic structure of a library module is shown below

The specification part permits the specification of template constants and requires that the library interface for which this template describes an implementation, should be identified in a GIVES section.

Where a library is to give more than one interface, the interactions provided in the specifications must be distinguishable from each other.

It can be seen from the syntax of the implementation part, given below, that definition and library dependencies may be included.
A library specification may appear in any activity, IDA, server or library template. Thus in the complete Mascot definition, an activity implementation part takes the form in Pascal style:

```
library_spec
```

The additional structure is a list of library interfaces:

```
library_spec
```

The remainder of the library implementation part takes the form of a set of declarations which must, however, include variables. This reflects the fact that static variables are not allowed in a library. In some implementation languages this prohibition might be expressed in a different manner. The procedure declarations must include all the procedures specified in the given interfaces correspondence is by procedure name.
The following is an example of a library template.

```
LIBRARY trig_lib;
  { specification dependencies }
  { CONSTANT ............ : no template constants }
GIVES trig_functions ;
  { implementation dependencies }
  { WITH ............ : no definition dependencies }
  { LIBRARY ............ : no library dependencies }
  { local declarations }
PROCEDURE .... ; { including all procedures specified }
FUNCTION ........ ; { in library interface trig_functions }
END .
```

Finally, a library module may be instantiated within any composite module and then becomes implicitly available throughout all the other components. Thus the full syntax for the the component_class in the implementation part of a network module (given in part in Section 2.4) is:

```
component_class

ACTIVITY

SUBSYSTEM

SERVER

IDA

CHANNEL

POOL

LIBRARY
```

Taking subsystem subsys_6 (Section 2.4) as an example, library trig_lib could be made available to the two activities, a1 and a2, and the IDA c by extending the subsystem module as shown below:
SUBSYSTEM subsys_6 : { name part }
    { specification dependencies }
    { PROVIDES ........ ; no window specifications }
REQUIRES g2 : get ;
    p2 : put ;
    { port specifications }
    { implementation dependencies }
USES act_2, act_3, chan, trig_lib ; { component templates }
    { components and Interconnections }
LIBRARY t : trig_lib ;
CHANNEL c : chan ;
ACTIVITY a1 : act_2 ( gp = g2 ,
    pp = c.pw ) ;
ACTIVITY a2 : act_3 ( gp1 = c.gw ,
    pp1 = p2 ) :
    { no equivalence list }
END .

The library template name has been added to the USES statement and a library component, derived from this template, defined in the module. An instance name for the new component is included for the sake of consistency but is not used for any practical purpose.

Use of the library interface, trig_functions, implemented by trig_lib, would be indicated in the template act_2 as follows:

ACTIVITY act_2 : { name part }
    { specification dependencies }
REQUIRES gp : get ;
    pp : to ;
    { port specifications }
    { implementation dependencies }
WITH ........ ;
    { global definitions }
LIBRARY trig functions ;
    { library interfaces used }
    { local declarations }
END
END .

The coding of the activity could then call the functions \textit{sin}, \textit{cos} and \textit{tan}.

Libraries may also be instantiated in modules which represent sequentially \textit{composite} design entities rather than \textit{networks} (see Section 2.12).
2.10 COMPOSITE IDAs

Description

This feature is not part of the mandatory subset of the Mascot definition.

Often, where a network of interconnected IDAs occurs in a Mascot design, it takes the form of a composite component. Such composite IDAs furnish another means of performing network decomposition in Mascot, supplementing that described in Section 2.4. A composite IDA consists of a network of internal IDAs connected by paths and thus utilises the facility described in Section 2.6, whereby IDAs may possess ports.

Graphical Representation

Composite IDAs are represented in higher level network diagrams by symbols of the same shape as those used for simple IDAs. Their possible external dependencies, paths terminating in either windows or ports, are also represented in an identical manner. The following diagram illustrates a template for a composite IDA. Its composite nature is indicated by the use of a thick line for its boundary. Alternatively a double line would have the same significance and other conventions, defined for some specific set of documents, would be acceptable.

![Composite IDA Diagram]

The squared corners proclaim that this symbol represents a wholly passive entity. The template is called cida and its external dependencies are embodied in windows p and g, expressing the fact that it provides procedures specified in access interfaces put and get.
The internal structure of IDAs created from template *cida* involves three components called *ip*, *op*, and *ex*. Each of these is a simple IDA and each is derived from its own template. The three templates are called *ip_ida*, *op_ida*, and *ex_ida*, respectively. In the more detailed diagram it can be seen from the window to window connection at the left of the diagram that the interactions associated with the externally visible window, *p*, are provided by a corresponding window, named *pp*, of the internal IDA, *ip*. In a similar way window, *gg*, of the internal IDA, *op*, is echoed to the outside world at the right of the diagram.

The IDA, *ex*, is a purely private component of this template. Its single window, *ev*, provides facilities, defined by access interface, *vis*, which are required by both of the other components. Here, then, is a more complete example of direct IDA to IDA communication.

Further levels of network decomposition are possible. A thick line boundary to any of the component IDAs of a composite IDA would indicate this. Such an hierarchical network structure is illustrated in the diagram below in which it is the component previously called *ex* which has become composite. It would be necessary to expand the new template, *cex_ida*, to at least one level down in order to determine the component which actually provides the interactions defined in access interface *vis* in this case.
Where the module scheme provides for both simple and composite forms of IDA, the syntax is as follows:

```
ida
    └── ida_name_part → ;
    └── ida_spec_part
    └── ida_imp_part → END → .
```

The specification part is as for the simple IDA.

It is in the implementation part that the distinction between simple and composite forms occurs:

```
ida_imp_part
    └── simple_ida_imp_part
    └── network_imp_part
```

Like all other composite Mascot entities, the composite form of an IDA contains no explicit coding. It merely defines the nodes and interconnections of a network. The modules which represent its component parts, the nodes, are simple IDA templates or other composite IDA templates or a mixture of both. The interconnections are paths represented by access interfaces.

The name and specification parts are identical to those of the corresponding simple form. Windows and ports are specified in the normal way. The implementation part takes a similar form to that of a subsystem.

Thus the implementation part begins with a USES section which lists the simple and composite IDA templates from which this composite IDA is to be constructed. Referring back to the graphical representation of the composite IDA cida.
USES ip_ida, op_ida, ex_ida:

Notice that references to definitions are not allowed at this level; there is no code to make use of their contents.

Next comes a list of components. Their syntactic form is as described for subsystems earlier in the Handbook except that the allowed component classes are IDA, CHANNEL, POOL and LIBRARY. Finally, an equivalence list establishes which of the windows provided by the internal components satisfies each window of the enclosing template.

To complete this section, the template diagram, cida, is used as the basis of a summary of the features of the textual representation of a composite IDA.

```
IDA cida : { name part }
    { specification dependencies }
    { CONSTANT ............ : no template constants }
    PROVIDES p : put ;
        g : get ; { windows }
    { REQUIRES ............ : no ports }
    { implementation dependencies }
    USES ip_ida, op_ida, ex_ida ; { component templates }
    { components and interconnections }
    IDA ex : ex_ida ;
    IDA ip : ip_ida (ei = ex.ev) ;
    IDA op : op_ida (eo = ex.ev) ;
    { equivalence list }
    p = ip.pp :
    g = op.gg
END .
```
## 2.11 COMPOSITE SERVERS

### Description

This feature is not part of the mandatory subset of the Mascot definition.

A composite form of server is provided in Mascot which consists of a network containing at least one simple or composite server and any number of IDAs. These components communicate with each other by means of paths.

### Graphical Representation

When drawn with a thick line the D symbol is to be interpreted as representing a composite server. Its constituent network of servers and IDAs, drawn inside the symbol, completes the representation of the composite template.

![Diagram of composite server](image)

The template shown here, c_serve_temp, represents a composite server with components consisting of one simple server and one simple IDA. The former, s, is of type ser. Its two windows, via window to window connections, are accessible from outside the template. Its single port is connected to a window of the IDA component, d, of type detail, whose other window is carried to the outside world.

### Textual Representation

Where the module scheme provides for both simple and composite forms of server the syntax is as follows:
The *name* and *specification parts* of a *composite server* are entirely similar to those of the corresponding *simple form*. *Windows* and *ports* may be specified in the normal way. It is in the *implementation part* that the two forms are distinguished:

```
SERVER ser :
  PROVIDES sg : get :
    se : enable :
  REQUIRES si : init :

END.

IDA detail :
  PROVIDES di : init :
    dp : put :

END.
```

This section ends with an outline example, based on `c_serve_temp`, of a complete *composite server template*.
SERVER c_serve_temp : { name part }
  { specification dependencies }
  { CONSTANT .......... ; no template constants }
PROVIDES g : get ;
  e : enable ;
  p : put ;  { window specifications }
REQUIRES .......... ;  { no port specifications }
  { implementation specifications }
USES ser, detail ;  { component templates }
  { components and interconnections }
  IDA d : detail ;
SERVER s : ser (si = d.di) ;
  { equivalence list }
g = s.sg ;
e = s.se ;
p = d.dp
END .
2.12 Composite Activities

Description

This feature is not part of the mandatory subset of the Mascot definition.

Activity templates have both the simple and composite forms. The latter type is not, of course, concerned with network decomposition but represents the sequential decomposition of the detailed coding of an activity. The principal product of this sequential decomposition is a design element called a root which contains the initial entry point of the composite activity. The remaining products of decomposition consist of one or more subroots.

Communication between the components of a composite activity is expressed and controlled in a manner analogous to that employed for network interactions. Corresponding to the path between the elements of a network there is the link between the sub-elements of a composite activity. A subelement link like a path, possesses a type in the form of a specification: in this case a subroot Interface which defines a set of interactions that a root or subroot is said to need and which is correspondingly given by another subroot. The validity of root and subroot connections is checked in terms of the type of the link, the subroot Interface, exactly as network connections are checked in terms of access interfaces.

Further levels of sequential decomposition are available through templates for composite subroots. By this means a subroot may by decomposed into a set of internal subroots which together perform the same function as a simple subroot. That is to say, the ensemble is able to give the interactions specified in exactly one subroot Interface.

External network connections may be made from any component of a composite activity. Thus ports may be specified in a root or in any subroot to correspond with those specified in the template which describes the composite activity at its outermost level. The nature of this correspondence is discussed in more detail in connection with the graphical and textual forms of representation.

Graphical Representation

The graphical conventions for roots and subroots, in composite activities, are similar to those for simple activities. They are normally represented by circular symbols to which port connections may be made but they also possess sub-element links to illustrate sequential decomposition. The latter connections are shown as thin lines broken by hollow arrow heads which indicate the direction of procedure invocation. The following diagram illustrates a template for a composite activity. Its
The composite nature is indicated by the use of a thick line for its boundary.

The rounded corners proclaim that it defines an active design element. The template is called `compact` and its dependencies are embodied in ports `g` and `p` expressing requirements specified by access interfaces `get` and `put`.

The internal structure of activities created from this template involves four components, a root called `r` and three subroots called `su1`, `su2` and `su3`. The templates which define these four components are called `maina`, `sub1a`, `sub2a` and `sub3`, respectively. Three subroot interfaces, `si1`, `si2` and `si3` specify the interactions which the three subroots make available via sub-element links. `r` makes use of all three sets of interactions while `su1` and `su2` utilise only the set `su3`.
defined in s13.

The manner in which these internal components relate to the template's external dependencies is shown by the port to port connections which continue through the outer boundary. From these it can be seen that both rand sul utilise the operations defined in access interface get and that r and su2 use those in access interface put.

Since roots and subroots contain sections of coding which are all conceptually part of the same activity, ports may be established anywhere in the internal structure. This is illustrated in the template compact_1, below.

Further levels of the sequential decomposition of activities, in the form of composite subroots, possess a similar graphical representation. However, a composite subroot will show a link which penetrates its boundary and terminates on a simple internal root component derived from an appropriate subroot template.

Further levels of the sequential decomposition of activities, in the form of composite subroots, possess a similar graphical representation. However, a composite subroot will show a link which penetrates its boundary and terminates on a simple internal root component derived from an appropriate subroot template.
Subroots established at these deeper levels of nesting retain all the usual properties inherited from activities. Thus, on the diagram below, two components of the composite subroot possess ports.

**Textual Representation**

Before describing the textual form of a template for a composite activity it is necessary first to discuss the templates for its component parts and their interconnections, namely roots, subroots and subroot interfaces. The latter has a structure similar to that for an access interface.
The *name part* employs the appropriate alternative language word to establish the *class* of the module.

**sub_int_name_part**

```
SUBROOT INTERFACE identifier
```

while the remainder of the *module* is exactly as defined for the *access interface* since the *specification part* is common to these two types of Mascot *interface*.

The following examples illustrate some of the possible forms:

{ *subroot interface* with procedure specifications }

```
SUBROOT INTERFACE locprocs:
  FUNCTION factorial(i : integer) : integer;
  FUNCTION modulo(i, j : integer) : integer;
END.
```

{ *subroot interface* with definition dependency }

```
DEFINITION conventions:
  TYPE
    vector = RECORD
      x_coord : real;
      y_coord : real;
      z_coord : real
    END;
    direction_cosines = RECORD
      cos_alpha : real;
      cos_beta : real;
      cos_gamma : real
    END;
END.

DEFINITION diagram:
  TYPE
    diagram = RECORD
      END
    END.
```
SUBROOT INTERFACE geometry :
WITH conventions, diagram ;
PROCEDURE translate( d : diagram; v : vector ) ;
PROCEDURE rotate( d : diagram; dc : direction_cosines ) ;
END .

A template for a root naturally bears a close resemblance to a template for a simple activity. Ports and template constants may appear in the specification part ; definition and library dependencies may be expressed in the implementation part whose block section also contains the initial entry point of the composite activity of which it is a component.

root

root_name_part

root_spec_part

simple_act_imp_part

END

The specification part of a root module differs from that representing a simple activity only in its ability to express dependencies which are satisfied through subelement links. The following diagram shows how this feature is incorporated.

root_spec_part

act_spec_part

NEEDS

identifier

subroot_int_ref
There follows a possible outline for the root module in the composite activity template compact shown in graphical form earlier.

```
ROOT maina : { name part }
   { specification dependencies }
   { CONSTANT ........ ; no template constants }
REQUIRES rg : get;
   rp : put ; { ports }
NEEDS s1 : si1 ;
   s2 : si2 ;
   s3 : si3 ; { outward subroot links }
   { implementation dependencies }
WITH ........ ; { global definitions }
   { LIBRARY ........ ; no library dependencies }
   { local declarations }
BEGIN
   { statement sequence }
END
END .
```

The syntax of a subroot module differs from that of a root in ways which reflect the following different properties:

(a) A subroot may appear at either end of a subelement link. That is, it may implement facilities for use by a root or by other subroots as well as using such facilities.

(b) A subroot may be composite.

(c) Unlike a root, a subroot cannot be entered for execution directly. The executable code that it contains is all encapsulated in procedures which are called through a subroot interface. It therefore has no outer block statement sequence.

Difference (a) implies an addition to the specification part, compared with a root module, and (b) and (c) involve variations in the implementation part. As elsewhere, the outline syntax is presented first with an expansion of the name and specification parts.

```
subroot

   subroot_name_part

   subroot_spec_part

   subroot_imp_part

   END
```

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The diagram describing the *specification part* shows that, after optionally specifying ports and template constants, a GIVES section identifies the subroot interface which is implemented by this template. It should be noted that there is precisely one such interface. On the other hand, like a root, a subroot may utilise (keyword NEEDS) the services of any number of other subroots through subelement links.

Turning now to the *implementation part*, a distinction has to be made between the simple and composite forms.

For a simple subroot the *implementation part* is similar to that for a simple activity except for the omission of the statement sequence.
Thus, global definitions and library sub-threads may be used exactly as in simple activities and in roots. In the declaration part, constants, types and variables, private to the subroot, may be defined. These are followed by definitions of the procedures which are specified in the subroot Interface mentioned in the GIVES section, together with any purely private procedures which the Interface procedures use.

It is now possible to provide, in outline, the text needed to represent templates for each of the components of the composite activity illustrated earlier as compact. But first the interfaces must be specified. Two access interfaces are required for external network communication and three subroot interfaces for internal communication between the root and subroot components.

```plaintext
DEFINITION network_data_def ;
  TYPE
    network_data = .......... ;
END .

ACCESS INTERFACE put ;
  WITH network_data_def ;
  PROCEDURE write( item : network_data ) ;
END .

ACCESS INTERFACE get ;
  WITH network_data_def ;
  FUNCTION read : network_data ;
END .

DEFINITION subroot_data_def ;
  TYPE
    subroot_data = .......... ;
END .

SUBROOT INTERFACE sil ;
  WITH network_data_def, subroot_data_def ;
  FUNCTION process_1( item : network_data ) : subroot_data ;
END .
```

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SUBROOT INTERFACE si2:
  WITH network_data_def, subroot_data_def;
  FUNCTION process_2( item : subroot_data ) : network_data;
END.

SUBROOT INTERFACE si3:
  PROCEDURE calculate( in : integer; VAR out : integer );
END.

Templates for the root and the three subroots can now be outlined:

ROOT maina :
  { specification dependencies }
  { CONSTANT ........... ; no template constants }
  REQUIRES rg, rp : get;
    { ports }
  NEEDS s1 : s1;
    s2 : s2;
    s3 : s3 ; { outward subroot links }
  { implementation dependencies }
  WITH ........;
    { global definitions }
  { LIBRARY ........ ; no library dependencies }
    { local declarations }
      { root coding with initial entry point }
END.

SUBROOT sub1a :
  { specification dependencies }
  { CONSTANT ........... ; no template constants }
  REQUIRES gg : get;
    { ports }
  GIVES s1 ;
    { inward subroot link }
  NEEDS s : s3 ;
    { outward subroot link }
  { implementation dependencies }
  WITH ........;
    { global definitions }
  { LIBRARY ........ ; no library dependencies }
    { interface procedures }
  FUNCTION process_1( i : network_data ) : subroot_data ;
END.

SUBROOT sub2a :
  { specification dependencies }
  { CONSTANT ........... ; no template constants }
  REQUIRES pp : put;
    { ports }
  GIVES s2 ;
    { inward subroot link }
  NEEDS s : s3 ;
    { outward subroot link }
  { implementation dependencies }
  WITH ........;
    { global definitions }
  { LIBRARY ........ ; no library dependencies }
    { interface procedures }
  FUNCTION process_2( i : subroot_data ) : network_data ;
END.
SUBROOT sub3:
    { specification dependencies }
    { CONSTANT ................ no template constants }
    { REQUIRES ........... no ports used }
    GIVES si3; { inward subroot link }
    { NEEDS ........... no outward subroot links }
    { implementation dependencies }
    WITH........; { global definitions }
    { LIBRARY ........... no library dependencies }
    { Interface procedures }
    PROCEDURE calculate( in : integer ; VAR out : integer );

END.

To see how to express the template for compact itself, it is necessary to return to the discussion of activities and, in particular, to the composite form which has yet to be described. The name and specification parts are entirely similar to those of the corresponding simple template. Thus, ports may be specified in the normal way. The implementation part, however, as in the case of a root, takes alternative forms for simple and composite activities.

It begins with a USES section which lists the root template and the highest level subroot templates from which the activity is to be constructed. Referring back to the graphical representation of the composite activity compact

USES maina, sub1a, sub2a, sub3.

2.12 Composite Activities
This indicates which templates are needed to create the component parts of the activity. Notice that references to definitions are not allowed at this level. The implementation part contains no local declarations or program statements. This is a composite module and its purpose is to specify the internal structure of the activity in terms of root and subroot components, created from the templates mentioned in the USES section, and the subroot interfaces through which they communicate.

Every composite activity specifies a single root component together with any number of subroots and any libraries which are to be made available to the components. The specification of each component defines any connections it possesses to ports of the activity and any links to subroots.
The general form of the connection specification is very similar to that already encountered for a subsystem. The syntax of port to port connections and template constant identities have already been described in earlier sections of the definition. The subelement link syntax is given below.

sub_element_link

Each outward link of the component being defined is equated with the subroot component which is to give the required interconnections.

The template for the composite activity compact may now be written

\[
\text{ACTIVITY compact}
\begin{align*}
&\text{specification dependencies \\
&\{ CONSTANT \} \text{ no template constants } \&
\text{REQUIRES } \{ \text{ ports } \} \\
&\text{implementation dependencies } \\
&\text{USES } \{ \text{ component templates } \} \\
&\text{components and interconnections } \\
&\text{SUBROOT } \text{sub1 : } \text{sub1a} ( g g = g, \\
&s = su3 ) , \\
&\text{SUBROOT } \text{sub2 : } \text{sub2a} ( p p = p, \\
&s = su3 ) , \\
&\text{SUBROOT } \text{sub3 : } \text{sub3a} , \\
&\text{ROOT } \text{main : } \text{maina} ( g g = g, \\
&ip = p, \\
&s1 = su1 , \\
&s2 = su2, \\
&s3 = su3 ) . \\
\end{align*}
\]

2.12 Composite Activities

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One topic remains to be covered to complete the syntactic description of activities. This is the composite form of the subroot. Like the composite activity, it differs from its simple form only in the implementation part. Furthermore, this differs from the corresponding part of a composite activity only in that it cannot contain a component derived from a root template. Instead, the root component is derived from a subroot template which gives the appropriate interface.

The template diagram, compsub, at the end of the description of graphical representation will now be used to illustrate the application of these syntax rules.

```plaintext
SUBROOT compsub :
    { specification dependencies }
    { CONSTANT .......... ; no template constants }
    { REQUIRES ...... ; no ports }
    GIVES si ; { inward subroot link }
    { NEEDS ...... ; no outward subroot links }
    { implementation dependencies }
    USES sub, sub1c, sub2c ; { component templates }
    { components and interconnections }
    SUBROOT su1 : sub1c ;
    SUBROOT su2 : sub2c ;
    ROOT su : sub ( s1 = su1, s2 = su2 ) ;
END .
```


2.13 ARRAYS OF PORTS AND WINDOWS

Description

This feature is not part of the mandatory subset of the Mascot definition.

Templates for both the simple and composite forms of IDAs, activities and servers together with subsystems, roots and both simple and composite subroots may specify ports by means of a REQUIRES section in their specification parts. The identifiers so introduced represent ports which may be referred to in the code sections of the simple templates. In some cases it may be required to transmit data via each member in turn of a group of ports from a program loop. It is therefore valuable to be able to specify such a group as an array. Since all or some of the paths associated with an array of ports may pass through the boundary of an enclosing composite design element it is also useful to be able to use arrays at that level.

Of the above list of template types, simple and composite IDAs and servers together with subsystems may also specify windows by means of a PROVIDES section. These identifiers are used in the connection specifications of simple templates and the equivalence lists of both forms. Here again it is useful to have arrays in order to express logical groupings of windows.

The complete definition of Mascot caters for both these requirements.

Graphical Representation

An array of ports or windows may be represented by a single symbol or, alternatively, each element may be shown individually. Where the elements are shown individually the array index should also appear.

Textual Representation

The extension of the design language syntax to accommodate arrays of ports and windows in REQUIRES and PROVIDES lists (see Section 2.3) is shown below:
Thus the REQUIRES list of an activity, say, might be:

```
REQUIRES p_set : ARRAY[1 .. 5] OF put;
```

where put is an access Interface. This would facilitate coding such as:

```
FOR line := 1 TO 5 DO
BEGIN
  p_set[line].send(item[line]);
END
```

where send is a procedure specified in the access Interface.

An array of windows in an IDA, say, might be specified as:

```
PROVIDES w_set : ARRAY[1 .. 3] OF get;
```

and utilised in an equivalence list as:

```
w_set[1].fetch = fetch1;
w_set[2].fetch = fetch2;
w_set[3].fetch = fetch3
```

to designate three separate ACCESS procedures for use in connection with three logically related paths.

2.13 Arrays of Ports and Windows
2.14 COMPOSITE PATHS, PORTS AND WINDOWS

Description

This feature is not part of the mandatory subset of the Mascot definition.

Mascot allows a system design to be expressed in an hierarchical form such that components at the top level are decomposed into the more detailed components at lower levels of the hierarchy. It follows that the granularity of the interactions on a path in network diagrams, at different levels in the hierarchy, may vary. The definition presented so far has only provided for one level of granularity to be used for paths; that is the access interface's procedures. The composite path is provided, in the full Mascot definition, to allow different levels of granularity to be represented.

The basic concept is that a composite path represents a 'trunk' route between two subsystems of a network. The module which defines the type of a composite path is an access interface which itself comprises a set of lower level access interfaces. A composite path is treated exactly like a simple path until it needs to be split into its component parts, at which points, a special form of 'adaptor' is used: the composite port or the composite window.

Graphical Representation

A composite path is represented on a Mascot network diagram by a thick line connecting a port of one component with a window of another.

This is illustrated in the diagram above in which the two components are a subsystem s and a subsystem d. The name of the composite path which connects them is cp1. The template for the subsystem dsdmpx, where the decomposition takes place, shows how the composite window dswn is represented.

2.14 Composite Paths/Ports/Windows 2 - 95  Mascot Version 3.1
Like a simple window, the composite window is drawn as a rectangular shape. However it is hollow and, like all composite entities, it has a thick outline. It can only occur on the boundary of a subsystem template. On the outside of the template to which it belongs there is an external connection labelled with the name cp1 of the composite access interface which describes, indirectly, the interactions it provides. Inside the composite window symbol the individual component windows are shown and labelled in the normal way. In this case, two of them, a and b, are simple and are connected via simple paths, both of type ai1, to simple IDA components q1 and q2. The third is itself composite and is connected via the composite path cp2 to a subsystem component p1. It can be seen from this diagram how a composite window acts as an adaptor to 'demultiplex' a composite path.

The template for subsystem ss shows how the composite port sspn is drawn.
The composite port *sspn* is shown as a hollow semi-circle, with a thick boundary, inside which are the 'demultiplexed' ports *a*, *b*, and *c* which it makes visible. Two of these are simple and are connected via paths of type *all* to corresponding ports of the subsystem's components. *c* is itself composite and is connected via the composite path *cp2* to a port of the component *three*. The external connection is labelled to show that the interactions which it requires are defined, indirectly, by the composite access interface *cp1*. Since a composite port connected to a composite window must be defined by the same access interface, not only the types but also the names of the constituent ports and windows must match in order that constituent ports and windows of the same type may be distinguished from each other.

The symbols used to represent composite ports and windows may be drawn larger than the normal size so as to be more in proportion to the thickness of the path. This is illustrated by the window *c* and the ports *p1* and *c* in the above diagrams.

**Textual Representation**

The module which defines the operations, required by a port, provided by a window, and hence defines the interactions along a path is the access interface. This is a specification which if composite defines, indirectly, the possible interactions by specifying the set of access interfaces, simple or composite, of which it is comprised. The complete syntactic structure for an access interface shows how the composite form is catered for:

The **specification part** of the composite form has the following structure.
Taking the interface \textit{cp1} from the above graphical examples:

\begin{verbatim}
ACCESS INTERFACE cp1;
  COMPRISES a, b : ai1;
  c : cp2;
END.
\end{verbatim}

\textit{ai1} it will be recalled is a simple interface while \textit{cp2} is composite.

A port or window to handle a composite path arises in the normal way as a reference in a list following the keywords \texttt{REQUIRES} or \texttt{PROVIDES}. However in order to indicate that a composite path is to be decomposed within a composite template, the composite access interface must be referred to in the \texttt{USES} list of the template. The syntax is:

\begin{verbatim}
network_imp_part
  USES comp_acc_int_ref
    comp_acc_int_ref
    template_ref
  component_part
    equivalence_list
\end{verbatim}

The manner of expressing the connections which fan out from composite ports is revealed by the complete syntax diagram for a \texttt{port} to \texttt{port} connection as it appears in a connection specification:
Returning to the earlier graphical examples, the following is the textual form of the subsystem \texttt{ssdmpx}.

\begin{verbatim}
SUBSYSTEM ssdmpx;
  REQUIRES sspn : cp1;
  USES cp1, ss2, ss3, act;
  SUBSYSTEM two : ss2 (p1 = sspn.a);
  SUBSYSTEM three : ss3 (p1 = sspn.c);
  ACTIVITY a1 : act_5 (p1 = sspn.a, p2 = sspn.b);
END.
\end{verbatim}

At the other end of a composite path, connections fan out from a composite window. These, being window to window connections, are defined in an equivalence list for which the complete syntax diagram is:

\begin{verbatim}
equivalence_list
  boundary_window_ref = component_ident
  comp_window_ref
  window_ref
  boundary_port_ref
  comp_port_ref
  port_ref
\end{verbatim}

Thus the \texttt{template} for the subsystem \texttt{ssdmpx} in the graphical examples is expressed as:
SUBSYSTEM dsdmpx:
  PROVIDES dswn : cp1:

USES cp1, idap, idaq:
IDA q1 : idaq;
IDA q2 : idaq;
SUBSYSTEM p1 : ssp:

dswn.a = q1.qa;
dswn.b = q2.qb;
dswn.c = p1.pc.
END.

and for completion here is the template for the system which connects the subsystem and the composite IDA together:

SYSTEM example:
  USES dsdmpx, ssdmpx;

  SUBSYSTEM d : dsdmpx;
  SUBSYSTEM s : ssdmpx (sspn = d.dswn);
END.
2.15 DIRECT DATA VISIBILITY

Description

This feature is not part of the mandatory subset of the Mascot definition.

One of the essential objectives of Mascot is to control access to shared data from concurrently executing activities. The responsibility for this control, and hence for the integrity of the shared data, is normally exercised solely by the IDA. In special circumstances, however, it may be necessary to bypass the protection normally afforded by the access procedure mechanism and to allow activities to manipulate IDA data directly. There are two classes of problem which may be solved by this means:

1. The first problem concerns the location of code and data on multi-processor configurations. It may be necessary to locate shared data, that is IDA data areas, and the code which operates on them in separate areas of memory. This problem may also arise in single processor configurations which possess non-homogeneous memory. A possible solution is to use a composite IDA and to provide direct data visibility in the interfaces between its components. Instances of the component IDAs can be placed in the appropriate memory locations during the building of the application software.

2. The second problem is concerned with efficiency of access to data. There are some occasions when the overhead associated with the call of an access procedure far outweighs the processing time and memory space required by the access mechanism code itself. If this applies in a path along which data transfers occur at a high frequency, the overall efficiency may become unacceptably low. In such cases direct data visibility could be used to eliminate the access procedure calls.

The advantage of solving problems like these by means of direct data visibility is that it is easy to implement and does not imply great complexity in the Mascot building process. Furthermore, where activities are scheduled for execution in a co-operative manner (see Section 4.4), direct manipulation of IDA data need present no threat to their integrity. Under a regime of pre-emptive scheduling safe access may be achievable by very careful programming.

The use of direct data visibility should only be considered, however, where the conventional Mascot methods are incapable of achieving the required results. Where it is adopted it should only be used in a disciplined manner. Direct visibility involves extending the traditional sole responsibility of the IDA, in respect of data integrity and propagation, to a group of several components. The scope of this collective responsibility needs to be well defined and should be limited as far as possible by the use of...
The programming system in use for a particular application may provide an alternative approach to the problems of efficiency and code and data location. One of the following techniques, where available, is generally to be considered preferable.

1. An option provided by a number of modern compilers allows a procedure body to be included, inline, in the object code at the point of call and, subsequently, optimised. Where such a facility is available it might be applied to calls of an access procedure, hence achieving an improvement in performance similar to that obtainable through direct visibility. The feature may also provide a means of appropriately locating the code.

2. The problem of explicitly locating code and data may sometimes be solved by means of compiler segmentation options. Many existing compilers provide facilities for splitting compilation units into segments which may be independently located in memory. In simple cases this may involve division into code and data segments but, if steering directives are embedded in the source text, more complex separation is possible. Mascot building software could be developed to exploit such compilation facilities. For example, IDA code could be placed in shared memory, it could be duplicated in its entirety in the private memory of each processor which uses it, it could be segmented manually and segments duplicated in private memory as necessary or the segmentation could be performed automatically so as to minimise the duplicated code. These examples would achieve progressively greater efficiency of memory usage in return for progressively greater complexity of the building software.

**Graphical Representation**

There are no special diagrammatic conventions associated with direct data visibility. The diagram below shows a composite IDA in which data in component ex is made directly visible to the other two components through the access interface data_vis. In this example, for which modules are outlined below, ip and op are required to be located in the private memory areas of two separate processors while ex is to be located in a shared memory area. This arrangement is reflected by the broken lines on the diagram.
IDA data may be made directly visible by specifying them in an access interface that appears in the PROVIDES list of the module. Reference to Appendix A shows that the specification part of a simple access interface, in its complete form, is:

```
simple_acc_int_spec_part

<table>
<thead>
<tr>
<th>with_section</th>
</tr>
</thead>
<tbody>
<tr>
<td>acc_int_detail_part</td>
</tr>
</tbody>
</table>
```


dp_in dp_ex dp_out

de

data_vis
data_vis

2.15 Direct Data Visibility
Thus variables and read-only constants may appear in an **access interface** together with the procedure headings already discussed. It should be emphasised that **interfaces** contain specifications and not declarations. Storage space for **interface** variables and read-only constants, like the coding for **interface** procedures, must be supplied by any **component** which provides a **window** of that type.

Referring to the graphical example given earlier, here is the **module** for the composite **IDA** **dp-chan**:

```plaintext
IDA dp_chan;
  PROVIDES in : in_ch;
    out : out_ch;
  USES dp in, dp out, dp ex;
  IDA ex : dp ex,
  IDA ip : dp in (e=ex e),
  IDA op : dp out (e=ex e);
  in = ip in
  out = op out
END
```

There are three **access interfaces**, one of which is used internally and involves direct data visibility. It could, for example, be of the form:

```plaintext
ACCESS INTERFACE data vis;
  VAR
    max CONSTANT integer:  { reading and writing operations }
    data integer:          { are assumed to be indivisible }
  END
```

The two **interfaces** provided by **dp-chan** are conventional in containing only procedure specifications. They are outlined in sufficient detail for present purposes below:

```plaintext
ACCESS INTERFACE in_ch;
  PROCEDURE write( item : integer );

END

ACCESS INTERFACE out_ch;
  FUNCTION read : integer;

END
```

For the purposes of explanation, the following examples are expressed in a Pascal like notation. **Template dp_ex** is given in full. Notice the use, in the design representation language, of **ACCESS VAR** by analogy with **ACCESS PROCEDURE**. **max** has been rendered as a read-only constant whose value is set in the **IDA template** in order to demonstrate the facility. In practice it would probably
be a template constant. The equivalence statements are not strictly required as name identity gives unambiguous correspondence.

```
IDA dp_ex;
  PROVIDES e : data_vis;

  ACCESS VAR
    max : CONSTANT integer := 50;
    data : integer;

    e.data = data;
    e.max = max
END.
```

Only those parts of template `dp_in` which are relevant to the present discussion are included in the module below. Access procedure `write` places input values directly into the internal store `data` of IDA `ex` which is located in the shared memory region.

```
IDA dp_in;
  PROVIDES in : in_ch;
  REQUIRES e : data_vis;

  ACCESS PROCEDURE write (item : integer);
  BEGIN
    e.data := item;
  END.

  in.write = write
END.
```

The template `dp_out` provides access function `read` at its window `out`. This removes values directly from the store in `ex`.

```
IDA dp_out:
  PROVIDES out : out_ch;
  REQUIRES e : data_vis;

  ACCESS FUNCTION read : integer;
  BEGIN
    read := e.data;
  END.

  out.read = read
END.
```

Finally, to assist in maintaining integrity when using direct data visibility, consideration should be given to the use of the qualifiers SINGLE, READ_ONLY and IDA_ONLY (see later section on this topic).
The qualifier SINGLE, associated with an IDA window specification, indicates that only a single thread of execution may pass through this window. This effectively limits the scope of any variables directly visible at the window. The READ_ONLY qualifier can be used to ensure that externally visible variables are not altered by direct access via that Interface. The effect of the IDA_ONLY qualifier associated with an access Interface is to restrict its use to the ports and windows of IDAs. As a result, responsibility for the integrity of visible data is limited to the components of a composite IDA or equivalent network.
2.16 QUALIFIERS

Description

This feature is not part of the mandatory subset of the Mascot definition.

Mascot provides a rich set of facilities for representing the structure of concurrent software. The use of these facilities is constrained in various ways in the interest of maintaining the consistency of the design and the integrity of the resultant software. Such constraints, built into the definition, apply generally to all Mascot systems. However, it will sometimes be found desirable to introduce additional, more severe constraints which apply locally to particular aspects of a design. The concept of a qualifier has been devised to meet this requirement.

Examples of Mascot entities to which qualifiers may be applied are ports, windows, Interfaces and their components. The effect produced by adding a qualifier might be to impose or relax some form of constraint on network connectivity, to limit the operations which may be applied to shared data, to indicate (in the textual form of representation) the direction of data flow, to limit the use of selected context facilities to certain classes of template or to influence the action of the compilation system.

It is open to the implementors of a Mascot development environment to provide support for any qualifiers that are considered useful for the expected applications. For each qualifier that is supported it is required that the following be defined:

- the name of the qualifier
- the purpose of the qualifier
- where the qualifier may be placed and how it is represented
- the effect of the qualifier
- whether placing one qualifier requires the placement of other similar or complementary qualifiers and, if so, what the rules are
- any other information thought to be relevant such as whether violation of the rules constitutes an error or merely results in a warning

Some examples showing how this information might be presented are given later in this section.

Graphical Representation

Qualifiers do not normally appear on Mascot diagrams.
**Textual Representation**

As indicated above, the representation of **qualifiers** in **modules** is implementation dependent. It is, however, suggested that qualified **windows** and **ports** might take the following form:

```plaintext
REQUIRES a, b/READ_ONLY, c : get;
PROVIDES d/SINGLE : put;
```

where the proposed significance of these **qualifiers** is described below.

**Examples**

The sample **qualifiers** given below are those which were suggested during the discussion of this concept in the course of development of the Mascot 3 definition. They are divided into categories each of which is now briefly introduced.

**Connectivity Constraints**

The default connectivity requirement for a **window** is that at least one **port** must be connected, and possibly several. Use of the **qualifiers** in this category has the effect of adjusting these requirements.

**Data Access Constraints**

The **qualifiers** in this category place limits on access to variables made directly visible via an **access interface**.

**Data Flow Indicators**

These **qualifiers** are used to indicate the direction of data flow with respect to **ports** and **windows**.

This is information which, in the mandatory subset of Mascot, is expressible only in the graphical form of a design.

**Context Qualifiers**

In this category, the **qualifiers** enable the designer of a context interface (see Section 4.1) to determine which facilities are available to which **classes of templates**. In some cases the limitation is to particular features of a **template class**.

**Code Generation Constraints**

The **qualifier** in this category can be used as a possible alternative to making variables visible and directly accessible via **windows**. For a more detailed discussion of this point see Section 2.15 of the Handbook.
### CONNECTIVITY CONSTRAINTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Place</th>
<th>Description</th>
</tr>
</thead>
</table>
| SINGLE| window of IDA or server | **Purpose**: to indicate that the designer of the IDA or server has optimised the implementation in such a way that only a single activity may use that window.  
**Effect**: Only one activity port may be connected to this window.  
**Additional Information**: Care is needed in applying this constraint where composite design entities are involved. In particular the 'singleness' of a window must be passed out to the windows of the enclosing composite structure and the number of internal port to port connections within enclosing subsystems must be determinable. |
| OPEN  | window                 | **Purpose**: to indicate that a window need not necessarily be used in an operational network. It may, for example, have been included purely for testing purposes.  
**Effect**: The ENROL operation will not issue a warning if a window qualified as OPEN has no port connected to it.  
**Additional Information**: OPEN windows may have zero or more connections. Windows marked as both OPEN and SINGLE may have zero or one port connected |
### DATA ACCESS CONSTRAINTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Place</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>READ ONLY port</td>
<td>window</td>
<td><strong>Purpose</strong>: to prevent the values of variables, visible through the window, being altered via port(s) connected to the window.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Effect</strong>: Any attempt to write data through a READ ONLY port/window connection is identified as an error when the ENROL operation is applied.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Additional Information</strong>: Where a window is qualified as READ ONLY, it should only be connected to a similarly qualified port. However, a READ ONLY port may be connected to any window. In order to limit the scope of cross-checking, it may be desirable to insist that the READ ONLY qualifier must appear on all of the ports and windows associated with the path.</td>
</tr>
<tr>
<td>IDA ONLY window</td>
<td></td>
<td><strong>Purpose</strong>: to ensure that only ports of IDAs are connected to the qualified window.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Effect</strong>: Any attempt to connect the port of an activity (directly or indirectly via intervening subsystem boundaries) to an IDA ONLY window will result in an error being identified when the ENROL operation is applied to the network which contains such a connection.</td>
</tr>
</tbody>
</table>
### DATA FLOW INDICATORS

<table>
<thead>
<tr>
<th>Name</th>
<th>Place</th>
<th>Description</th>
</tr>
</thead>
</table>
| IN     | window or port | **Purpose:** to indicate the direction of data flow.  

**Effect:** The direction of data flow may be expressed in the textual form of a template. |
| OUT    | window or port | **Purpose:** to indicate the direction of data flow  

**Effect:** The direction of data flow may be expressed in the textual form of a template. |
| IN_OUT | window or port | **Purpose:** to indicate the direction of data flow  

**Effect:** The direction of data flow may be expressed in the textual form of a template. |
### CONTEXT QUALIFIERS

<table>
<thead>
<tr>
<th>Name</th>
<th>Place</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SERVER_ONLY</td>
<td>context Interface</td>
<td><strong>Purpose:</strong> to make qualified facilities available only to servers. <strong>Effect:</strong> The use, in a template which is not a server, of facilities qualified in this way will result in an error being identified when the ENROL operation is applied to the template.</td>
</tr>
<tr>
<td>HANDLER_ONLY</td>
<td>context Interface</td>
<td><strong>Purpose:</strong> to make qualified facilities available only to handlers. <strong>Effect:</strong> The use, in a template which is not a server, of facilities qualified in this way will result in an error being identified when the ENROL operation is applied to the template. Further, when a server template is enrolled, only the code of any handlers inside it will be allowed to use the qualified facilities. Any other uses will result in an error being identified and cause the ENROL operation to fail.</td>
</tr>
<tr>
<td>NOT_HANDLER</td>
<td>context Interface</td>
<td><strong>Purpose:</strong> to prohibit the use of qualified facilities by handlers. <strong>Effect:</strong> The use, by a handler, of facilities qualified in this way will result in an error being identified when the ENROL operation is applied to the server template which contains it.</td>
</tr>
</tbody>
</table>
IDA_ONLY context Interface or component of context Interface

**Purpose:** to make qualified facilities available only to IDAs.

**Effect:** The use, by any template which is not an IDA, of facilities qualified in this way will result in an error being identified when the ENROL operation is applied to the template.

ACTIVITY_ONLY context Interface or component of context Interface

**Purpose:** to make qualified facilities available only to activities.

**Effect:** The use, by any template which is not an activity, root or subroot will result in an error being identified when the ENROL operation is applied to the template.
## CODE GENERATION CONSTRAINTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Place</th>
<th>Description</th>
</tr>
</thead>
</table>
| INLINE | port or window | **Purpose**: to avoid the overhead involved in calling access procedures.  
**Effect**: The compilation system is forced to copy the code of the access procedures, available at a qualified window, into the code of a calling template at the point of call.  
**Additional Information**: It would be reasonable to provide a facility whereby the INLINE qualifier may be suppressed by means of an IGNORE_INLINE option of the BUILD operation. |
3.1 STATUS PROGRESSION

Introduction

An essential feature of a Mascot development environment is a database capable of containing a collection of modules from which, together with their derived products, application software may be created. As will be demonstrated later, Mascot modules are so defined as to facilitate the progressive, incremental elaboration of a design. In support of this, the database accords formal recognition to the attainment of certain important progress milestones in the development of a module. A status value associated with each module, provides a measure of the level of recognition attained and consequently of the module’s fitness for use. This value reflects not only the progress made in defining the module itself but also the state of other modules to which direct or indirect reference is made. It is assumed throughout this section that status values are maintained automatically in the database by the Mascot development environment but a manual recording procedure would also be possible. A development environment may provide facilities to display the module status and possibly the inter-module dependencies.

As status progression is closely associated with module structure this is reviewed first.

Module Structure

Reference to the syntax diagrams in Appendix A shows that every Mascot module begins with a name part which defines its class and gives the template or specification it represents a unique name. This is followed by a specification part whose purpose is to define that part of the module which needs to be known when it is used by other modules. It establishes the external view of the module.

For specifications, the specification part consists of the detail of the module together with a statement of its dependency on other modules. Such external dependencies occur only in simple specifications and are limited to the importation of data-type definitions from other specifications. They are expressed in the form:

WITH definition module list

For templates, the specification part consists of the information required for components of that type to be included in a composite template. This information includes several varieties of external dependency. Connections between objects are expressed in their templates by means of references to specifications. There are two different kinds of connection which are expressed in this manner and in each case the active partner in the transaction is distinguished from the passive partner. First there are those which convey network interactions and are concerned with communication between
ports and windows. These dependencies take the form:

\begin{verbatim}
REQUIRES port list  \{ network interactions \}
PROVIDES window list
\end{verbatim}

Second there are those which convey sequential program interactions between the individual, separately developed components of a single thread of execution:

\begin{verbatim}
NEEDS subroot interface list  \{ sequential program interactions \}
GIVES subroot interface list
\end{verbatim}

A third form of external dependency, closely related to the second category above, occurs in the case of a template which describes a collection of shared library facilities. The set of interactions which this passive entity makes available are expressed as:

\begin{verbatim}
GIVES library interface list  \{ provision of library services \}
\end{verbatim}

The final possible element of a specification part is the template constant expressed as:

\begin{verbatim}
CONSTANT template constant list  \{ template constant \}
\end{verbatim}

Templates (but not specifications) possess a further section known as the Implementation part which defines the internal details of the template. For simple templates this defines the program. For composite templates it defines the components together with their connections and template constant values. Simple templates may import data-type definitions directly from specifications and may make use of facilities provided by library modules. These dependencies are expressed in the form:

\begin{verbatim}
WITH definition module list  \{ Importation of data-types \}
LIBRARY library interface list  \{ use of library services \}
\end{verbatim}

A composite template depends on those templates from which its components are derived. These are listed:

\begin{verbatim}
USES template list  \{ templates for components \}
\end{verbatim}

Appendix C (Summary of Keyword Usage) lists all the inter-module dependencies in terms of the representation language keywords used to express them and distinguishes between those associated with the specification and implementation parts of a module.

**Status Values**

The status value of a module directly reflects the state of completion and validation of the three sections of its structure. There are thus three primary status values, registered, introduced and

3.1 Status Progression
enrolled, the attainment of which record the progressive successful validation of the name, specification and implementation parts of the module, respectively. The operations, computer-assisted or manual, which establish these status values are REGISTER, INTRODUCE and ENROL.

A module's primary status value may be qualified to reflect the status of the other modules which belong to the specification and implementation dependency trees of which it is the root. Thus, a module whose specification part is present and correct, but which has specification dependencies still at registered status, may be raised to the status of partially introduced. It qualifies to become fully introduced when all its specification dependencies have achieved this status.

For a composite template there is a status value of partially enrolled. This status can be achieved when all three sections of the module are present and correct and all its specification and implementation dependencies are at least partially introduced. As will be demonstrated in the example below, the partially enrolled status conditions enable the system designer to complete a network design before considering the interface and algorithmic details of the design.

The formal rules governing the achievement of these status values are summarized in a table at the end of this section. Their application is illustrated below. In the example, status progression is shown as an orderly increase in status from registered to enrolled. In practice, facilities must be provided to support iteration and the consequent backtracking.

Example of Status Progression

The following example illustrates how a subsystem might be developed progressively. The detailed features of the Mascot development environment employed in this example are not mandatory to the Mascot definition. The subsystem chosen for illustration is the one called subsys_4 in Section 21 of the Handbook.

The status progression commands may be used to control the development of a system by a team of people. We shall assume, as the starting point for our example, that subsystem subsys_4 has been introduced and has achieved partially introduced status. This implies that the access interfaces required and provided by subsys_4 have been registered and that the only information known to the Mascot database about subsys_4 is the following:

```
SUBSYSTEM subsys_4.
    PROVIDES gw4 get.
    REQUIRES rp4, rec, otp4, out, tp4, trans.
```

3.1 Status Progression Mascot Version 3.1
Our task in the example is to develop **subsys_4** and we shall define a series of states through which the **subsystem** and its constituents must pass. These states will be visible in the **Mascot database** as a result of applying the **status progression commands** and can thus be used to control, record and monitor progress.

There are three significant states which arise during the development of **subsys_4**:

1. Design structure recorded for **subsys_4**.
2. Ready to start implementation of **templates** from which the **components** of **subsys_4** are derived.
3. Completion of implementation of all **templates** used by **subsys_4**. This implies that **subsys_4** may be built.

State 1 is reached when **subsys_4** is **partially enrolled**. This implies that the **templates** for all of its **components** have been **Introduced** and have achieved **partially Introduced status**. State 2 is reached when all the **simple templates** for the **components** of **subsys_4** have achieved **fully introduced status** and state 3 is reached when **subsys_4** is **fully enrolled**.

**Reaching State 1**

To move from our starting point to state 1, it is necessary to design the internal structure of **subsys_4**. This will most probably be represented graphically first and, if a graphics tool is available, could be recorded directly in this form. In such a circumstance the graphics tool can, via interactions with the user, determine which additional **modules** need to be **registered** and **Introduced** in order to render **subsys_4** capable of achieving **partially enrolled status**. However if a text based design checking tool is used, then the next step would be to transcribe the graphical representation of **subsys_4** into its textual equivalent, thus:

```
SUBSYSTEM subsys_4;
  PROVIDES gw4 : get;
  REQUIRES rp4 : rec; otp4 : out, tp4 : trans;
  USES pool_1, chan_1, a temp_1, a temp_2,
  POOL p1 : pool_1,
  CHANNEL ch : chan_1,
  ACTIVITY a1 : a temp_1 (fp = chfw, tp = tp4, pp = p1 pw),
  ACTIVITY a2 : a temp_2 (sp = ch sw, olp = otp4, rp = rp4);
  gw4 = p1 gw
END.
```

From this (or directly from the graphical representation) it can be seen that in order to **enrol** this design, it is necessary to have the four **templates** pool_1, chan_1, a_temp_1 and a_temp_2 at **Introduced status**. Further, before these templates can be **Introduced**, it is necessary to

3.1 Status Progression 3 - 4 Mascot Version 3.1
register them and the access interfaces upon which they depend

The specifications for the four component templates of `subsys_4` are

```
ACTIVITY a temp 1,
REQUIRES tp fetch, tp trans, pp put;

ACTIVITY a temp 2,
REQUIRES cp send, otp out, rp rec;

CHANNEL chan 1
PROVIDES sw send, tw fetch;

POOL pool 1
PROVIDES gw put, gw get;
```

It can be seen that the four component templates between them make use of seven access interfaces of which four are visible at the subsystem template. These four will already have been registered to allow `subsys_4` to achieve partially introduced status. Therefore we need to register the three additional interfaces fetch, send and put. Having registered the four templates and the three access interfaces we can introduce the templates and thereby submit them for formal checking of their specification parts.

The INTRODUCE operation first checks that the name parts of the modules have not been changed since they were registered and then checks the specification part. The specification part must itself be syntactically correct and all other modules to which the modules being introduced refer must be at least at registered status. These are the minimum requirements for the INTRODUCE command to succeed. If our example design, these minimum requirements are met. Therefore the four templates can then be partially introduced status.

The INTRODUCE operation will also check whether the preconditions for fully introduced status are satisfied. At this stage none of the content of our example these conditions are not met because the Interfaces are not yet introduced. Therefore the status achieved is partially Introduced.

It is now possible to enrol the design structure for `subsys_4`. This operation checks that the specification part has not been changed since the module was introduced and that the design details represent a consistent use of the templates and interfaces involved. As a result, `subsys_4` will achieve partially enrolled status. State 1 has now been reached.

**Reaching State 2**

In order to reach state 2, it is necessary to have all seven of the access interfaces specified in detail and for them to be raised to introduced status. For the three internal access interfaces we, as the nominated design authority (see section 5.1), can proceed immediately. For the four external access
Interfaces we must liaise with other groups, who are developing modules which also use these access interfaces, and with the nominated design authority for them.

When the internal details have been agreed, they are recorded as the texts for the access interface modules and any definition modules found to be necessary. These details are then submitted for checking and entry into the Mascot database via the INTRODUCE command. The sequence of commands is as follows: REGISTER all new definition modules; INTRODUCE definition modules; INTRODUCE access interface modules.

Assuming that these operations are successful we now have all the access interfaces for subsys_4 at fully introduced status. In order to reach state 2 though, we have to bring the Mascot database up to date by re-introducing the four simple templates a_temp_1, a_temp_2, pool_1 and chan_1 and finally re-enrolling subsys_4.

Reaching State 3

The action necessary to reach state 3 is to provide the implementation details for each of the simple templates used for the components of subsys_4. This is a programming task and each module can be assigned to a different individual within the team who will then add the details and submit the assigned module for enrolment. When all the implementation details have been provided and checked to be consistent with the fully introduced interfaces by the ENROL command, we have almost reached state 3. It only remains to re-enrol subsys_4 so that it can be related, in the Mascot database, to the fully enrolled simple templates. Then subsys_4 can achieve fully enrolled status and our task is completed.

This state formally constitutes the end of the implementation phase for subsys_4 and signals the start of the testing phase for that module. Depending upon the testing strategy adopted, there might well be other subsystems developed specifically to provide test harnesses for subsys_4. The development of these subsystems and indeed the test system required to execute them, will follow similar lines to that described and use the same commands.

More Sophisticated Status Progression Commands

The status progression commands as described here are very simple and operate purely on one module at a time, although they do require checks on the status of other modules. It is envisaged that more sophisticated versions of the INTRODUCE and ENROL commands could be provided. These would be especially useful for large systems particularly during the later stages of integration and during maintenance.
In the above example, the requirement to re-apply the INTRODUCE and ENROL commands, as the details of the design are added, has been identified. Doing this manually is possible but tedious and error prone. If one of the commands was omitted in error, this could result in a system being built which failed to incorporate some recent module amendments. The possibility of this happening increases as the size of the system being developed increases. Therefore, more sophisticated forms of the ENROL and INTRODUCE commands are defined which automatically seek out any later versions of modules and re-apply the appropriate command. Hence the extended form of the ENROL command, possibly invoked as: ENROL subsys_4 FULLY, would be interpreted to mean re-enrol subsys_4 and any modules which it directly or indirectly depends upon. Thus this leads to a recursive application of the ENROL command.

Similarly the extended form of the INTRODUCE command, possibly invoked as INTRODUCE FULLY, would result in recursive application of the INTRODUCE command.

A more far-reaching extension of the ENROL operation would allow re-introductions as well as re-enrolment. This interpretation may be of value when an interface change is made either late in the development of a system or during the maintenance stage. It provides a simple way of bringing all the components of a system to consistency with the latest issue of the design.
<table>
<thead>
<tr>
<th>Operation</th>
<th>Status to be achieved</th>
<th>Module Class</th>
<th>Preconditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Register</td>
<td>Registered</td>
<td>All</td>
<td>Name part defined and legal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No other module with same name</td>
</tr>
<tr>
<td>Introduce</td>
<td>Partially Introduced</td>
<td>All</td>
<td>Registered preconditions satisfied</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Specification dependencies Registered</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Specification part defined and legal</td>
</tr>
<tr>
<td>Full</td>
<td>Full</td>
<td>All</td>
<td>Partially Introduced preconditions satisfied</td>
</tr>
<tr>
<td>Enrol</td>
<td>Partially Enrolled</td>
<td>Composite Templates</td>
<td>Implementation dependencies introduced</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implementation part defined and legal</td>
</tr>
<tr>
<td>Fully</td>
<td>Fully Enrolled</td>
<td>Simple Template</td>
<td>Fully Introduced preconditions satisfied</td>
</tr>
<tr>
<td>Enrolled</td>
<td></td>
<td></td>
<td>Implementation dependencies Fully Introduced</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implementation part defined and legal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Composite Templates</td>
<td>Partially Enrolled preconditions satisfied</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implementation dependencies Fully Enrolled</td>
</tr>
</tbody>
</table>
3.2 SYSTEM BUILDING

Introduction

Building is the term used in the Mascot definition to describe the stage of development which, starting from a fully enrolled system template, produces a representation of the network in an executable form. The process which achieves this must take into consideration the target configuration for which the application is to be built: the number and type of processors to be employed, the accessibility of memory from each processor and any special requirements for interfacing with devices. In view of this strong target dependence and the wide variation in the range of building facilities required for different kinds of application, the Mascot definition does not legislate on the precise form which the facilities should take or on the linguistic support which a Mascot development environment should provide in this area. Rather, in this section, an attempt is made to discuss all the factors which need to be considered and to recommend and justify some preferred modes of working practice.

Building Strategies

The ultimate objective of building is the construction of a complete operational system. However to facilitate development, particularly during the phase when individual modules are being tested, it is desirable to be able to build test systems which incorporate only part of the final system. This can be achieved by means of a system template, specially created for the purpose, which encapsulates the components to be tested. By associating such test systems with the test procedures and results, the development process can be documented reliably and specific test exercises can be repeated should the need arise.

In general, the object of a test will be a subsidiary network extracted from the complete system design and possessing, in consequence, components with unconnected ports and windows. A test system must therefore contain additional components to supply these missing connections. Thus, the test network may be completed by means of a dedicated test harness capable of supplying any required input and of recording and possibly checking any generated output. Alternatively, input and output could be achieved by direct connection to external devices such as a set of files on a host computer. In this latter case the additional components would consist of servers.

While it may be acceptable for a small test system to be re-built from scratch each time amendments are made to the modules from which it is derived, this is likely to be a rather laborious and time consuming procedure for the large systems typical of Mascot applications and even for the bigger test systems employed during the integration phase of development. The time taken to build a system image may be reduced if a number of the component subsystems have previously been separately built. The context software for a particular computer is an obvious candidate for being made available as a partially...
built image. However, this approach is more suited to some target architectures than others. It is, for example, particularly useful when building for a multi-processor target where the constraints are uniform. But where a memory mapping scheme is employed in the target, the builder requires an overall view of the system in order to achieve optimal results and so building speed, in this case, might have to be paid for in reduced efficiency.

During module and integration testing, the same system may be built and re-built many times. A sophisticated builder might detect that, between one build operation and the next, only a few components had changed and so could save time by re-building as little of the system as possible. A more limited builder might achieve the same result with a little assistance from the user.

Linguistic Support for Building

A simple constructional task would be that of building a system for a target consisting of a single processor of a predetermined type, which has access to sufficient memory, all of a uniform type, and making use of a predefined context. This could be performed by a dedicated builder supplied with no more data than the identity of the system template and the values of any template constants. This information could readily be accommodated as a set of parameters to a BUILD operation:

```
BUILD total sys. 100, 50
```

It would be preferable however, even in so simple a case, for the data to be presented in a BUILD module to which reference could be made in initiating a BUILD operation:

```
BUILD build mod
```

This approach allows the image to be brought under configuration control so that its regeneration can be guaranteed. The range of information held in the BUILD module can be extended for use by more powerful builders. Where a choice of contexts and processor types exist, for example, the selections could be specified in the module.

To cater for more complex targets, more build-time information must be supplied and a decision must be made on whether to hold it all in the one data module or to introduce others. Suppose, for example, that the builder supports target configurations with disjoint memory blocks or non-homogeneous memory with differing speeds or modes of access. The size of each memory block, its address range and its properties must be made available to the builder together with instructions as to where the system components are to be located among the various memory blocks. Placing all this information in a single BUILD module would necessitate its replication for each system built for the same target configuration and so it might be preferable to use a separate TARGET module to hold details of the target.
Separation of the build-time data in this particular way would still prove inflexible where there was a requirement to build images of the same system for several target configurations. A possible solution would be to define the target in software terms, such as computers and memory regions, and to define the location constraints in terms of these regions. The target could then be defined in hardware terms, such as processors and memory blocks, and a correspondence given between the two views. For maximum flexibility, this information could be divided between four separate modules each belonging to a distinct class:

BUILD
TARGET
HARDWARE
SOFTWARE

The location constraints could then be spread among any number of LOCATOR modules.

It may be that devices in the target configuration are memory mapped. In such a situation, communication with the devices may be through pre-determined normal or special memory locations. If the necessary device access information is not embedded in the applications software then it must be supplied via the builder, perhaps by the use of template constants.

Further build-time data is required to support target configurations consisting of multiple processors with shared memory. The builder needs to know which memory blocks are private to a processor and which can be or which are to be shared by more than one processor. It may also need an indication of which components are to be allocated to each processor. Where the target processors are memory mapped, the builder may require guidance as to how each logical memory region is mapped into a physical memory block.

In its full generality then, the BUILD module might supply information to the builder as indicated in the diagram below.
System Building

**BUILD module**
- Software to be built
- System templates
  - Constant values
- System location constraints
- Context for each target computer
- Context location constraints
- Target configuration

**LOCATOR module**
- System templates
- Constant values

**CONTEXT module**
- System location constraints
- Target configuration

**TARGET module**

**LOCATOR module**

**HARDWARE module**

**SOFTWARE module**
3.3 DEVELOPMENT CONFIGURATIONS

Introduction

In discussing, in this section, a range of hardware configurations appropriate to the development of Mascot software, a distinction is made between a host system, on which the software development takes place, and the target system, on which the operational software is to be executed. The different host-target combinations which are encountered in practice vary in the degree of similarity which exists between the two systems.

At one extreme, the host and target may be the same system or the host may combine a processor which is identical to that of the target with a subset of the target's peripherals. Alternatively, because development involves requirements not relevant to operation and because the target peripherals are frequently of an exotic nature, the host peripherals may be different to those of the target while the processors are the same.

In other arrangements, the processor in the host system may possess a similar instruction set and number representation to those of the target but may differ in other respects such as the manner in which input output is performed. Sometimes the host and target have a common number representation while their instruction sets differ. Finally, development may take place on a host system whose processor has nothing in common with that of the target at all.

Commissioning Configurations

The hardware configurations mentioned above may be employed to support formal or informal execution of the software for the purpose of quality assurance and for the diagnosis and correction of errors. Where the host and target processors are identical, the validity of testing depends only on considerations, including those discussed below, which relate to the run-time environment. The four most commonly encountered configurations in which host and target systems differ are examined here in order to highlight their relative advantages and disadvantages.

Native Code Execution on the Host

In the first configuration, tests may be executed on the host in its own native code. Results may be obtained rapidly in advance of the target system becoming available for use. Since, in general, the host can handle much larger programs than the target, it is possible to test the complete system in the presence of dedicated test software such as simulators and scenario generators. Good diagnostic facilities can be provided and all the host peripherals can be made accessible to the tests. In many host systems the passage of system time can be controlled though usually in a relatively crude manner.
Where the host processor differs from that of the target, especially in respect of word-length, but also and accuracy of the arithmetic results obtained in tests, may not represent a true indication of the performance to be expected on the target. Other aspects of the system may not be sufficiently exercised. For example, as is common, only co-operative scheduling is available on the host, the testing of mutual exclusion and other stimulus within IDAs is not wholly adequate. Some parts of the code such as that involved in handling interrupts, usually have to be omitted from testing altogether.

It is important that host and target should be compatible in respect of high level program statements which must, of course, be compiled for execution on the target when testing on the host has been completed.

**Emulation on the Host.**

In this second approach, source code compiled for the target is interpretively executed on the host. Since there is one processor that for the target, there is no question of incompatibility between host and target, the results will be accurate and reliable provided the emulation is accurate. This means no processor required, the host's capabilities and performance to include peripherals than that displayed above. In particular, it affords an opportunity to incorporate run-time checking of selected function blocks can be performed, for example, for arithmetic accuracy, for the use of predefined macro instructions, for the execution of code,

The principal advantage is that execution time from input data to result may longer than on the host. Results can be obtained in this way and the code excludes all real-time aspects that the

**Emulation on the Target.**

A third configuration involves execution of tests on the target for the efficient execution of the host via a direct link. The results may however, still be limited because of the need to handle communication with the host. A number of features can be used to simulate which contain facilities, such as interrupt, which are not to be a direct in the final operational system. Provided that the target is machine equipped with a full set of controlling peripherals, they can be tested. Only a small number of the required and these are certain source code, which is with the host. Potentially, the host's capabilities are as much as the previously discussed arrangements.

The disadvantage is that while access to all the host's resources can be provided for host, the limited bandwidth. It is not normally possible to control the passage of system time so as to compensate for the additional overheads attributable to the absence of host components and to the link to the host.
Stand-alone Execution on the Target

In the fourth, and final, configuration discussed here tests are carried out on a free standing target utilising only the peripherals connected to that system. Such an approach has none of the advantages of the host-linked arrangement described above but interference from the link is eliminated. It is unlikely that the target system provides a suitable environment for testing purposes and so tests will be laborious and time consuming to set up and carry out. The diagnostic capabilities are likely to be very limited and the available peripherals may consist of no more than a control panel or a keyboard terminal.

Both methods in which testing is performed on the target encounter further complications when the target consists of multi-processors which have some shared memory. In this case, the target system may not, during some phases of testing, be fully equipped with processors.

The Software Environment for Test Execution on the Host

It is normally desirable, in most development environments, to perform at least some of the testing on a host system. Among the many reasons for this is lack of availability of the target system during the testing phase of a project. This may simply arise from the problem of inaccessibility which is due to the target's location at a remote site and is likely to be exacerbated during the maintenance phase after the system has been installed. Frequently however, the software development team obtains access to the target system only at a very late stage of production and the system may even then not include all the specialised peripherals. Thus testing on a host permits hardware and software development to proceed in parallel.

As was made clear above, in the discussion of test configurations, the target system is likely to contain few of the diagnostic tools which are commonly available on a host. Furthermore, the target may not have the peripherals necessary to support diagnostic output. Shortage of memory may also be a problem. It will rarely be possible to find storage space for test software since all the memory which can physically be accommodated will in practice be needed for the application. If it were not, the space would be used for other equipment.

A further disadvantage of testing on the target arises from the length of time taken to transfer code from the host. Transfer may be via a relatively slow link or indeed, may be performed through the use of a magnetic medium such as a cassette. A PROM-based target represents an extreme manifestation of this problem involving as it does the transfer of executable code into PROMs. Difficulty may also be encountered in transferring test data and results to and from the target. Even a direct link may be inconveniently slow for this purpose and may result in excessive distortion of the real-time aspects of system performance.

The degree of compatibility between host and target machines is the most significant factor affecting the usefulness of testing on the host. Unless the two processors are identical, the degree of compatibility is
determined principally by the choice of language and compilers and by the level of support for compatibility provided by the development environment. Where the code of at least the majority of the application templates can be executed on either the host or the target, with similar results, then host testing is likely to be useful. It is quite feasible in this case to test almost all the software, up to and including the full system, on the host. Those small sections of program which cannot be dealt with in this way can be tested after transfer to the target and before proceeding to the integration tests. Some iteration involving a return to unit testing on the host may be implied by the detection of errors during integration.

Where host and target are incompatible for all, or the majority, of the application templates the advantages of host testing are lost since the source code must be edited before being transferred to the target. This presents a serious maintenance problem and, in addition, necessitates the tests being repeated on the target system.
In any software system it is normally possible to distinguish between functions which are part of a particular application and those which are more properly to be regarded as part of the environment in which the software operates. In Mascot, this division is reflected by the distinction between application and context software. A Mascot development environment may be expected to offer a collection of supporting services from which software designers can select the set of services needed for a particular application. These may include, for example, the conventional Mascot primitive operations described in Section 4.2. The context may also include application specific items such as procedures for controlling peripheral devices. The general principle is that a set of procedures, constants and data-types provided in the context for a particular application is implicitly available. The set may be subdivided so as to restrict the use of defined subsets of the context facilities to specific classes of design entity such as servers, IDAs or activities.

The interfaces which the context offers to the application are described in a form which is consistent with the Mascot modularity scheme. The term context interface is used to embrace all those interfaces which are implicitly available to the application software. The precise form in which it is expressed is implementation dependent but should be generally compatible with the style of the application software modules. Its components, however expressed, are a mixture of those associated with the library interfaces, access interfaces and definitions described elsewhere.

In a simple case, the context interface might be expressed as a combination of a library interface and a definition which together specify procedures to be called and define data-types for use as parameters. The procedure specifications might include control queue primitives together with a peripheral library:

```
DEFINITION TYPE
  CONTEXT INTERFACE con proc

WITH cq def
  
  } Control queue primitives
  PROCEDURE join VAR q controlq;
  PROCEDURE leave VAR q controlq;

  } Peripheral library
  PROCEDURE switch on device;
  PROCEDURE switch off device.

END
```

Alternatively, the context interface can be expressed in a composite form, comprising a number of interfaces. The above example could thus be expressed:

```
4.1 Context Software
```
LIBRARY INTERFACE cq_prims;
WITH cq_def;
PROCEDURE join( VAR q : controlq );
PROCEDURE leave( VAR q : controlq );
END.

The peripheral library specification could then be placed in a conventional form of library interface:

LIBRARY INTERFACE periph_lib;
PROCEDURE switch_on_device;
PROCEDURE switch_off_device;
END.

and the context Interface itself expressed in the composite form:

CONTEXT INTERFACE context;
COMPRISES cq_prims, periph_lib;
END.

An access Interface might feature as a component of a context Interface in order to give access to an IDA or server in the support software. Special, implementation dependent calling mechanisms may also be provided by the context through additional Interface types and qualifiers.

The Mascot definition lays down no firm rules for the expression of context Interfaces. The above are merely examples of some acceptable forms within the general spirit of the definition. However, procedure names in the context must be unique and any implementation must define the context facilities provided and the means for context extension.
4.2 Synchronisation of Activities

The Use of Implementation Language Concurrency Facilities

Implementations of Mascot development environments prior to the advent of Mascot 3 have invariably supported programming languages such as Coral 66, which make no provision for concurrency. With the planned extensive use of languages such as Ada, which include concurrency as a feature, this situation may be expected to change. Consequently the Mascot facilities described in this section, which cater for the necessary synchronisation of separate parallel threads of execution, are to be regarded as constituting a model. This model may be implemented directly in a conventional programming language, as in the past, or mapped onto equivalent features in a concurrent language.

In any implementation of a Mascot development environment for which the application language provides direct support for concurrency, the implementor should consider mapping activities onto the appropriate languages’ features. Since the Mascot definition demands that the total network of activities, IDAs and servers should be invariant at run-time and, in particular, forbids the dynamic creation of activities, then facilities which allow the creation of additional threads of execution should be made unavailable to the application programmer. The implementor must document how the language facilities have been used to create the Mascot model of concurrency and which facilities have been suppressed.

Any language which supports concurrency will probably also provide suitable mechanisms to allow inter-activity communication between the separate threads of execution. The implementor should consider these facilities in this area, in the light of the Mascot model, to determine whether or not they can adequately support inter-activity communication through an IDA or server as prescribed by the Mascot model.

If the implementor’s development environment elects to utilise the language features for concurrency and inter-activity communication, the mapping of the Mascot activities, IDAs and servers onto these language features should be described. The mechanisms whereby the IDA or server designer may ensure the necessary mutual exclusion and cross-stimulation between separate processing threads must also be documented. Furthermore the use of these mechanisms should be restricted to the access procedures of IDA and servers;

The Mascot Synchronisation Model

Synchronisation in Mascot covers the mutual exclusion of competing processes and the cross-stimulation of co-operating processes. Explicit synchronisation is achieved by four primitives which operate on special objects called control queues. Since synchronisation takes place only in respect of access to IDAs and servers, each control queue is conceptually part of the structure of an IDA or a...
server. Synchronisation primitive operations are only available within an access procedure. The control queue is defined as an object on which the primitives have the effects defined below, and which may be given a priority specification to influence the scheduling algorithms.

**Mutual Exclusion - JOIN and LEAVE**

Mutual exclusion of competing activities is effected by the calls of the paired primitives JOIN and LEAVE, each of which takes a control queue as its single parameter. Between the times when it performs a JOIN operation and the subsequent LEAVE operation, an activity is said to be in the queue. A control queue is said to be empty if there is no activity in that queue.

JOIN and LEAVE form brackets around critical sections of code in which only one of the competing activities in the queue is allowed to proceed. This activity is said to be at the head of the queue, and is therefore its owner. The use of the primitive operation LEAVE by an activity which is not the owner of the specified queue constitutes a run-time error as does the performance of a JOIN operation by an activity which is already the owner of the nominated queue. An implementation of a Mascot development environment defines the action that results. It is recommended that the occurrence of an error be recorded and that the activity be prevented from further execution.

The algorithm that determines how an activity reaches the head of the queue is not defined by the Definition but first-in first-out is normal practice. The algorithm must be documented.

**Cross-stimulation - STIM, WAIT and WAITFOR**

A stimulus response mechanism between activities is provided by the primitives STIM and WAIT, each of which takes a control queue as its single parameter. An alternative form of WAIT providing a time out facility is WAITFOR which takes two parameters, a control queue and a time delay. The STIM operation may be performed at any time by an activity, but the WAIT and WAITFOR operations may only be performed by the activity which is the owner of the named queue.

An activity which performs a WAIT operation on a control queue is prevented from continuing its processing unless or until a corresponding STIM has been applied to the same control queue.

A WAIT operation has one of two possible effects:

(a) If a STIM is being held (see below), that STIM is consumed and the activity is allowed to continue.

(b) If no STIM is being held, the activity is prevented from continuing until the next STIM is applied.

4.2 Synchronisation of Activities 4 - 4 Mascot Version 3.1
A STIM operation has one of three effects:

(a) If there is an activity WAITing, the STIM is used immediately to make the WAITing activity eligible for scheduling.

(b) If there is no activity WAITing, and no unused STIM for the queue is being held, then the STIM is held for use by the next WAIT operation on the queue.

(c) If there is no activity WAITing and an unused STIM for the queue is being held, then the further STIM has no effect.

The use of the WAIT primitive by an activity which is not the owner of the specified queue constitutes a run-time error. An implementation of a Mascot development environment defines the action that results. It is recommended that the occurrence of the error be recorded and that the activity be prevented from further execution.

The WAITFOR operation is similar to WAIT except that the activity which performs it becomes eligible for scheduling on expiry of the time delay, given as a parameter, if no STIM has been applied to the queue in the meantime. The reason for the activity being released from WAITing may be indicated through a function value return mechanism or output parameter.

Control Queue Ownership - CHECK

An access procedure normally contains paired JOIN and LEAVE instructions. This is known as a closed access protocol and it forces correct usage. Alternatively an open protocol may be used in which the JOIN and LEAVE instructions are contained in different access procedures. Such an approach allows more discretion to the application program. This can lead to greater simplicity and an improvement in efficiency.

The purpose of the CHECK primitive is to allow an access procedure which does not contain a JOIN-LEAVE pair to check that the calling activity is the owner of the nominated queue. The primitive takes a control queue as its single parameter. If the activity which issues the CHECK instruction is the owner of the specified control queue, the CHECK primitive returns control to the activity with no further action. The use of the CHECK primitive by an activity which is not the owner of the specified queue constitutes a run-time error. An implementation of a Mascot development environment defines the action that results. It is recommended that the occurrence of the error be recorded and that the activity be prevented from further execution.
4.3 DEVICE HANDLING

Introduction

The mechanisms by which peripheral devices are controlled vary significantly from computer to computer. On some machines the contents of device registers are manipulated through normal operations on specific memory locations. Other machines provide special instructions for device control. These instructions may be part of the normal set available to all programs or may be privileged instructions requiring a special mode of compilation for their generation from a high level language. Thus, modules which interact with peripherals may require special privileges or facilities not appropriate to other modules.

In Mascot, as we have seen in an earlier section, the handling of peripherals is the domain of the server. This is made easy by a class of template allowing code to directly manipulate peripheral control registers or which utilises special facilities provided by the context for that purpose. All the necessary facilities may therefore be made available automatically to the modules which require them, during the construction of a network.

One of the most important considerations in connection with the interaction of a real-time systems with a device is whether the device must be polled in order to detect the completion of an operation, or whether completion is signalled by an interrupt. It is the latter of these two options which is the more common and which requires the specialised facilities described in this section.

Interrupts

An interrupt is a signal generated by a device to inform the processor to which the device is attached that a peripheral operation has been completed. Its effect, subject to consideration of relative priorities, is to cause the processor, on completing the execution of its current instruction, to abandon temporarily the current process and to commence execution of instructions stored at a predefined address. This new set of instructions is called an interrupt handler. Depending on the computer architecture, a handler may be unique to a particular interrupt, unique to the priority level of the interrupt, common to all interrupts or common to a defined sub-set of interrupts.

When control is transferred to a handler, the contents of at least some of the registers being used by the interrupted process are saved. This is known as context switching and the amount of information automatically saved, for subsequent restoration when the process is resumed, also varies considerably with the architecture of the machine. It may be as little as the value of the program counter or the context switch may be so complete as to provide the handler with its own register set and, where appropriate, virtual memory map.
The precise nature of an interrupt handler is thus determined by the number of devices with which it is concerned and the degree of automatic context switching which takes place when one of these interrupts occurs. In order to minimise the impact of interrupt handling on the normal operation of the system, it is customary to confine the operations performed in the handler to a minimum. Thus for a simple device the next operation might be initiated from within the handler, while a device which requires a large amount of data to be transferred to or from it, between operations, might be restarted from elsewhere.

**Interrupt Handling in Mascot**

Given the range of computer architectures to be catered for and the need for efficiency in real-time systems, it is not possible to define a single mechanism for interrupt handling which is completely transportable. Mascot therefore provides a set of facilities which allow suitable solutions to be developed to meet a range of circumstances. These facilities are:

(a) **(HANDLER)** the ability to declare handlers in server templates.

(b) **(CONNECT)** the ability to associate a handler with a particular interrupt.

(c) **(DISCONNECT)** the ability to disassociate a handler from an interrupt.

(d) **(ENDHANDLER)** the ability to signal completion of processing of the current interrupt and

(e) **(STIMINT)** the ability to STIM a control queue from a handler.

Here (a) is a keyword in the design representation language, used in place of PROCEDURE, and the other four facilities are kernel primitives. CONNECT takes two parameters:

\[
\text{CONNECT(handler interrupt no)}
\]

to identify the interrupt handler and the interrupt with which it is to be associated, respectively. DISCONNECT is applied to the interrupt identification:

\[
\text{DISCONNECT(interrupt no)}
\]

STIMINT, which is applied to a control queue, differs from STIM (see Section 4.2) only in guaranteeing that it will not result in an immediate reschedule. The documentation of the run-time system in a Mascot

4.3 Device Handling
development environment must describe the means by which the above facilities are made available.

Ideally it should be possible to design an interrupt handler for minimum execution time and store usage without needing to take any account of the activity which has been interrupted. However, this can only be achieved where the hardware provides automatic vectoring to a handler, uniquely associated with the interrupt being serviced, and full automatic context switching. Most hardware used for real-time systems is not as sophisticated as this.

In practice, it may be necessary to provide some support in the Mascot context even for interrupts which are connected to handlers located in the servers of the application software. The following table, which differentiates between different degrees of hardware vectoring to a particular handler and different degrees of completeness in automatic register saving and restoring, indicates the range of options.

<table>
<thead>
<tr>
<th>Vectoring</th>
<th>Register Save</th>
<th>Data Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>Hardware</td>
<td>Handler in Server</td>
</tr>
<tr>
<td>Hardware</td>
<td>Hardware</td>
<td>Access Mechanism in Server</td>
</tr>
<tr>
<td>Hardware</td>
<td>Server</td>
<td>Handler in Server</td>
</tr>
<tr>
<td>Hardware</td>
<td>Server</td>
<td>Access Mechanism in Server</td>
</tr>
<tr>
<td>Hardware</td>
<td>Context</td>
<td>Handler in Context</td>
</tr>
<tr>
<td>Hardware</td>
<td>Context</td>
<td>Access Mechanism in Server</td>
</tr>
<tr>
<td>Hardware</td>
<td>Context</td>
<td>Handler in Server</td>
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<tr>
<td>Hardware</td>
<td>Context</td>
<td>Access Mechanism in Server</td>
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<td>Context</td>
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<td>Handler in Server</td>
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<td>Context</td>
<td>Context</td>
<td>Access Mechanism in Server</td>
</tr>
<tr>
<td>Context</td>
<td>Server</td>
<td>Handler in Server</td>
</tr>
<tr>
<td>Context</td>
<td>Server</td>
<td>Access Mechanism in Server</td>
</tr>
<tr>
<td>Context</td>
<td>Context</td>
<td>Handler in Context</td>
</tr>
</tbody>
</table>

In the above table, 'Server' is used to denote a server in the application software. The term 'Context' should be taken to include the possibility of a server in the context.

**Design Considerations**

There are a number of considerations, some of them imposed by the computer architecture, which influence the design of interrupt handlers and their execution. Three of the most significant issues are discussed below.

**Nesting of Interrupts**

Devices may be classified on a scale of priorities such that a handler, in course of execution, may itself be interrupted by a device possessing a higher priority. When the higher priority interrupt has been
handled, control returns to the handler of the lower priority interrupt before eventually being returned to the originally interrupted activity. Several levels of priority may be catered for in this way. In such circumstances it is acceptable for the individual handlers to be somewhat more complex since their execution does not lock out higher priority interrupts. Control is still taken away from the software scheduler, however, and more stack space is required to provide local storage for the handlers than in the non-nested case.

Stack Management

Local working space for a handler may be provided from the stack of the interrupted activity. This avoids the necessity of switching stacks when control passes to or from a handler. However, it also means that every activity stack must be large enough to accommodate the maximum possible depth of interrupt nesting if this is employed. Alternatively, a separate stack may be allocated either to each handler or to each level of interrupt, again allowing for interrupts to be nested, or a single stack can be shared by all handlers if there is no nesting.

Pre-emption

After an interrupt has been handled (ENDHANDLER), control may be returned to the interrupted activity or, alternatively, the interrupted activity may be transferred to the current lists and control passed to the Mascot scheduler (see Section 4.4). The latter strategy results in the better system response at the possible cost of a slight reduction in throughput. If it is adopted, a further question arises as to whether the interrupted activity should be added to the head or the tail of the current list. If it is placed at the tail, this results in a 'round-robin' scheduling operation within a priority level (there will normally be a current list for each level). Placing it at the head of the list may be regarded as more 'fair' since then each activity is allowed to complete its slice of execution before any other activity of the same priority is scheduled. Notice that this is not the same as the co-operative mode of scheduling as higher priority activities are allowed to run at any point.
4.4 SCHEDULING AND PRIORITIES

Introduction

In any concurrent system where the number of parallel processes exceeds the number of processors, a scheduling function is required to allocate processing time amongst the competing processes. Each processor, periodically, must cease the execution of one process and commence execution of another. Associated with these re-schedule points there are two decisions which have to be made. The first is to determine when the current slice of execution on a given processor is to end and the second is to select which process is to be allocated the next slice. It is normal practice to assign a priority level to each process to assist in determining, for the purposes of the second of these decisions, which of a number of waiting processes is the most urgent. The choice of scheduling strategy is usually governed by the desire to optimise the response to external events for a given amount of processing power.

In these respects Mascot systems are the same as any other concurrent system. The Mascot definition does not prescribe the use of any particular scheduling strategy though it does require that the selected strategy be documented for the information of users of the development environment. The choice of scheduling algorithm is deliberately left to the implementor in order to allow the optimum algorithm for the application to be adopted. The more important of the possible scheduling and priority schemes are discussed below in Mascot terms.

Co-Operative and Pre-Emptive Scheduling

One of the major factors affecting the responsiveness of a concurrent system is the basic mode of scheduling adopted co-operative or pre-emptive. Under a co-operative regime responsibility for the first of the two scheduling decisions, slice termination, is vested in the application rather than in the Mascot kernel. An activity continues its slice of execution until it volunteers to give up the processor by invoking one of the kernel primitives. This may be one of the scheduling primitives such as JOIN (on a JOINed control queue) or WAIT-WAITFOR (on an unSTIMmed control queue) or a re-schedule may be invited more directly by means of the SUSPEND primitive.

Provision of SUSPEND is mandatory in a development environment which supports co-operative scheduling. Its use guarantees re-scheduling provided that there is at least one activity, of at least equal priority, waiting to run. If there are no such schedulable activities, the activity issuing the SUSPEND is re-ordered for another slice of execution.

Development environments which support the timing group (see Appendix E) of primitives provide another means of directly surrendering the use of a processor. This is the DELAY primitive which takes a time period, in implementation defined units, as its argument. An activity invoking DELAY is not
considered for re-scheduling until the nominated period has elapsed irrespective of whether there are other schedulable activities or not. The other primitive in the timing group is TIMENOW which is a function returning current system time. The units and range of system time are implementation defined.

There are two other synchronising primitives whose use may, even under co-operative scheduling, result in a re-schedule. These are LEAVE and STIM when they have the effect of releasing an activity which has previously been held up. The decision on whether to re-schedule in these circumstances is implementation defined.

Under a co-operative regime it is guaranteed that, immediately after an interrupt has been handled, a reschedule will not take place. Control is always returned to the interrupted activity. This mode of working tends to minimise the time spent in performing context switches; an important consideration on hardware in which the context switch is inefficient. It also leads to simplification of the kernel code and, in the application, exclusive use of a resource can be guaranteed without recourse to special synchronising primitives such as JOIN and LEAVE. There are, however, complicating effects. Contrary to the normal Mascot philosophy, the activity programmer must take account of the execution time of any long sequences of code and add calls on SUSPEND at strategic points in order to avoid taking excessively long slices. This is generally unsatisfactory and, indeed, the overheads imposed by frequent calls on SUSPEND may cancel the original gains. In the limit, a faulty activity containing a closed loop would bring the remainder of the system to a halt unless the kernel clock handler checks for processor hogging and takes action to TERMINATE the offending activity.

Co-operative working effectively limits the ability of the scheduler to optimise the system's response. The alternative is pre-emptive scheduling under which the kernel is free to re-schedule following an interrupt. The arrival of an interrupt is an event which is likely to alter the state of the system. An activity which has been awaiting this interrupt may well have become the most urgent. Under pre-emptive scheduling, it can be entered for execution without delay. An activity which is hogging a processor is less damaging than under a co-operative regime though it may still be detected and TERMINATED. The opportunity of re-scheduling after a clock interrupt makes time slicing possible by setting a maximum slice time.

**Priority Schemes**

The simplest priority scheme, if it can properly be so called, is one in which all activities are given the same priority. A single current list, containing all the currently schedulable activities, is maintained on a first-in first-out basis. The scheduler always selects the activity which has been waiting longest, that is, the activity at the head of the list. This scheme is the fastest possible in execution but provides little scope for improving the response of the system to external events. Indeed this can only be achieved by the crude mechanism of adding calls on SUSPEND in order to increase the number of re-schedule points. As the length of the current list cannot be determined by an activity, such a strategy is not very effective and may, in addition, prove wasteful of processor resources if carried to excess.
in the next priority scheme to be considered, several priority levels are employed to which all activities are allocated, once for all, on first being executed. A first-in-first-out list is maintained for each priority level and these are scanned by the scheduler in priority order to select the activity at the head of the first occupied list. The choice thus falls on the most urgent task which has been waiting the longest. Compared with the single priority approach, this strategy results in greater flexibility at the expense of greater complexity and, in general, a heavier drain on processor time. It possesses the advantage that the response to external events can be tailored by changing the relative priority levels of activities without altering the coding of any templates. The response problem is not, however, totally solved since no matter how high its priority level an activity may be held up in the pending list of a control queue behind one of lower priority.

Finally, in an attempt to overcome this problem of the collision of two activities, of different priorities, competing for ownership of a control queue, multi-level priority schemes may be extended to encompass dynamically varying priorities. Cross-stimulation between co-operating activities is not affected. Although, at first sight, variable priorities may seem to present an added complexity, they can be easier to use in practice than fixed priorities. This is because a priority level can be associated with a resource in such a way as to reflect its scarcity and this is often easier to assess than the average urgency of executing a particular activity. Two of the many possible algorithms which may be used to determine priorities in this type of scheme are discussed below.

A single priority may be associated with a control queue. Any activity which JOINs such a queue assumes this priority if it is higher than its own current priority. The activity's priority reverts to its previous state when the control queue is released. This scheme is relatively easy to implement although the retention of priority on LEAVE can present some difficulties if multiple JOINs and LEAVEs are not allowed. It does, however, complicate the coding of the primitives and extend the execution time required for JOIN and LEAVE. Also the lower priority activities execute at higher priority than is desirable when there is no collision.

As a further refinement, control queue priority may itself be made variable. Initially minimum priority is allocated and the priority of an activity JOINing the queue is not affected. However when an activity is placed on the pending list, the priority of the control queue is set to the higher of its own and that of the activity. Thus the priority of the queue owner is maintained as that of the highest priority activity in the queue. The queue reverts to minimum priority when the pending list becomes empty. The result is that activities are executed at their assigned priorities except when in collision with a higher priority activity. This improvement is achieved at the cost of further complication of the code and increased execution time for JOIN and LEAVE.

4.4 Scheduling and Priorities
4.5 MULTI-PROCESSOR CONFIGURATIONS

Introduction

Multi-processor target configurations for Mascot applications can be classified in a variety of ways on the basis of their distinguishing characteristics. They may differ, for example, in respect of any of the following:

(1) **Inter-Processor Relationships.** There are three principal types of configuration. One processor may be designated as master with all others acting as slaves. A symmetrical arrangement of identical processing elements is possible in which the storage and input/output resources of the system are all shared. Finally the processors may operate autonomously each with its own private set of resources.

(2) **Memory Visibility.** The possibilities here are that the system's memory resources may all be accessible to all processors, may be divided into units each of which is available for use by one processor only or a combination of these arrangements may be employed with a mixture of common and private storage.

(3) **Number of Mascot Kernels.** Multi-processor configurations may contain a single copy of the Mascot kernel or many copies, for example one per processor.

(4) **Allocation of Activities.** The selection of a processor for the task of executing a Mascot activity may be performed on either a static or a dynamic basis.

It is also possible to envisage complex configurations employing, within the same system, more than one of the possibilities listed under (1) and (4) above. Two classes of configuration using at least some shared memory are discussed below, those configurations employing a single Mascot kernel being considered first and then those with multiple kernels. Finally configurations with no shared memory are discussed very briefly.

The following discussion is in terms of a control queue based implementation. Similar considerations apply to any alternative run-time implementation strategy and, when considering such alternatives, the arguments should be interpreted accordingly.

**Single Kernel Configurations**

In a master/slave arrangement, the single kernel has one processor, the master, dedicated to its execution and so need not be re-entrant. The diagram below, which illustrates this configuration, shows...
two slave processors although there might be any number. The simplest example of this arrangement, where there is just one slave processor, comes nearest to the familiar single processor case and, in general, the software configuration is simple.

As the kernel data are accessible to only one processor no protection is required. Equally, an activity being executed on a slave processor has no direct access to kernel facilities and some software mechanism must be provided to permit such activities to invoke primitive operations. Some common memory is therefore essential.

In a symmetrical arrangement, the processing elements are identical and almost all memory and input/output facilities must be common. A three processor, symmetrical configuration is illustrated in the diagram below. The common store contains the system's single, multi-thread kernel. Separate copies of read-only components may be held in local memory for efficient access while there is potential lockout on shared kernel data and the application's control queues must be protected for concurrent access. Control of the kernel passes from one processor to another but only one can be 'master' at any one time. An activity could be executed on different processors for different slices.

A major advantage of this type of configuration is that the workload of the processors is balanced. If one processor fails, the system is able to continue with reduced performance or with support for some of its functions withdrawn. Extra processors can be added with minimal rebuilding. This is an attractive arrangement provided sufficient common memory can be made available without significant access time penalty.
Multiple Kernel Configurations

Providing each processor with its own copy of the Mascot kernel, in private memory, leads to the autonomous arrangement (illustrated below) in which the processors act independently and the kernels perform almost as in a single processor configuration. Each processor has private input/output devices but some shared memory is desirable. Activities are assigned, permanently, to a particular processor at build-time. Kernel data, such as for example pending lists, may need to be shared between kernels.

The key consideration which further distinguishes configurations of this type is the means by which application or context software running on one processor can communicate with software running on another processor. At the most fundamental level, communication between processors can be by polling or can be interrupt driven. At a level more relevant to the present discussion the choice is between communication effected directly by the application software or by the kernel acting on its behalf. The extent of the common memory available is one important factor in determining the method.
Communication between Mascot activities involves access procedures, control queues and IDA data. With total support from the kernel, and given an adequate amount of shared memory, communication among activities assigned to different processors may take place in a wholly transparent way. The sharing of IDA data presents no problem. The sharing of access procedures avoids duplication of code at the cost of the additional access time associated with common memory. It is the sharing of control queues which requires special support from the kernel.

When all primitives are available for application to shared control queues, the pending list of such a queue may contain activities whose execution is administered by different kernels. Ownership of the queue passes from one kernel to another. A kernel needs to be aware, therefore, when one of the activities under its control has been STIMmed remotely (that is, by an activity running on another processor). This information can be supplied by polling or by interrupt.

The main advantage of such an arrangement is that a component of the application software can be relocated for execution by a different processor without any changes being necessary to its source template. On the other hand, the need to hold pending lists in shared memory and the continual change of processor owning a shared control queue is not very desirable for efficient and fault-tolerant operation.

An alternative approach is one in which inter-processor communication is restricted to the ability of an access procedure, running on one processor, to apply a STIM to a control queue controlled by the
kernel of another processor. The pending list for such a queue only contains activities which belong to the local kernel so that ownership of the queue remains with a single kernel. Thus while IDA data are shared, pending lists can be held in local memory. The operation of a remote STIM involves drawing the attention of the local kernel to the fact that a waiting activity, under its control, is now available for scheduling or, if there is no activity waiting on the queue and no previous STIM being held on that queue, that there is now a STIM to be held for future use. All that need be communicated, in order to convey this information, is the identity of the control queue involved. This can be done through shared memory, allowing all the control queues to be held in local memory.

This method reduces the overheads of a multi-processor target to a minimum. However, communications restrictions between processors prevent the 'processor boundaries' from being transparent to the design and/or implementation of the application. Thus, changes in the distribution of components may require changes to the network.

**Communication Linked Configurations**

Finally it should be mentioned that multi-processor working may take a form in which there is no common memory. Communication, in this case, is affected by a 'communications bearer', such as a local area network (LAN), independently of the kernel. Some support may, however, be offered by the context.
4.6 EXECUTION CONTROL

Introduction

In this section the execution control facilities which are mandatory in a Mascot development environment are presented first. There follows a discussion of the additional facilities which it is desirable should be provided to support software commissioning. A set of commands is then described for the application of control functions to individual activities, IDAs and servers. Finally further additional facilities are described which support the hierarchic control of networks.

Mandatory Facilities

When a Mascot system has been built, each of its components is said to be in an unestablished state. Before any constituent activity can be executed it is necessary that it, and the IDAs and servers to which it is connected, be initialised. Part of the process of establishing an IDA or server is the execution of any initialisation procedure contained. When a component has been successfully initialised, it achieves the state value of established. An established activity may be started once all the IDAs and servers to which it is connected have been established. Thus, the minimum necessary set of execution control facilities consists of INITIALISE which establishes a component and START which sets an established activity running. All Mascot development environments must, therefore, support these two functions. The corresponding state change diagram is given below.

An activity enters the crashed state after a fatal run-time error has been detected.
The two mandatory functions may be provided either as part of the build-time facilities or as on-line, run-time commands. The mechanism of the former approach is implementation defined. In the latter case, unless the mechanism is automatic, the functions should be made available through an appropriately named interface which may be defined either as part of the context or as an application module. Any parameters will be expressed in a form which is consistent with the other language facilities. A development environment may also provide a command interpreter which uses the interface.

**Additional Non-Mandatory Facilities**

While the mandatory facilities described above fulfil the minimum requirements for an operational Mascot system, additional facilities are desirable during the software commissioning phase of a project. A Mascot development environment may therefore provide four further functions, HALT, RESUME, RESET and TERMINATE which should be made available as on-line, run-time facilities. Associated with these functions is a further state **halted**. The full state change diagram is shown below.

The **halted** state is entered as a consequence of the application of the HALT function. While in the **halted** state, an activity is not eligible for scheduling although a timeout may expire or the activity may become the owner of a control queue.
The full Mascot definition allows activities, as well as IDAs and servers, to contain initialisation procedures (see Appendix E). Termination procedures may also be included in all three of these module classes and reset procedures may be included in IDAs and servers. Where such procedures are catered for in a Mascot development system, their execution is initiated as part of the INITIALISE, RESET and TERMINATE functions. Note that once INITIALISE has been applied it cannot be re-applied without first returning to the unestablished state by means of TERMINATE. The reset procedures of IDAs and servers may, however, be executed in the established state by means of the.RESET function.

The functions HALT, RESUME and TERMINATE are not normally considered to be suitable for use in an operational system because of their drastic side effects. In the case of HALT, an activity is prevented from further execution until RESUMED. If the activity is executing an access mechanism of an IDA or server, this may prevent other activities completing execution of access mechanisms in the same IDA or server, and hence will potentially stop the remainder of the system. The operation of TERMINATE also has drastic side effects in that an activity may be aborted while executing an access mechanism. This, in general, can result in the contents of IDAs or servers becoming inconsistent. While these side effects are tolerable during software commissioning, they are not normally tolerable during system operation. If there is no alternative to the use of HALT TERMINATE, it may be necessary to introduce special facilities to prevent the side effects.

**Command Description**

The INITIALISE Function

If we assume all its components to be in the unestablished state, a complete system may be initialised in the following manner. First the INITIALISE function is applied to each IDA and server. If the operations are successful all these components will become established. It is then possible to establish the activities by applying the INITIALISE function to each of them in turn. This ordering may be relaxed where it is guaranteed that the initialisation code within an activity does not interact with any of the IDAs or servers to which it is connected.

The effect of applying the INITIALISATION function is to cause the initialisation procedure to be executed. After successful application of the INITIALISATION function an activity, IDA or server is in the established state.

A run time system may place restrictions on the facilities available to an initialisation procedure provided that these restrictions are documented. In particular, since the initialisation procedure may be invoked by the run time system, rather than by an activity, it may be inappropriate to use the control queue primitives other than STIM or STIMINT.
In a development environment which supports the INITIALISE function on line there must be at least one parameter, namely the activity, IDA or server identity whose preferred form is defined by the syntax diagram below.

The system name may be omitted or any values where only one system is allowed so that there is no possible ambiguity.

If the passing of a parameter to IDA or server is a routine procedure is supported then means of specifying the value to be passed will be different. Where a command interpreter is provided the command will take the form shown below.

The \textbf{START Function}

The \textbf{START} function can only be applied to an activity which is the \textbf{established} state and for which all the connected IDAs and servers are also \textbf{established}. The effect of its successful application is to put the \textbf{activity} into the \textbf{running} state and to inform the scheduler that the \textbf{activity} is eligible for.
scheduling from its initial entry point

In a development environment which supports the START function on-line, the function accepts either one or two parameters. These are the element identity and, if the development environment supports priority change at start, a priority value. Where a command interpreter is provided, the command will take the form shown below.

![START Diagram](image)

Where a priority value is accepted it overrides the the priority specified during building. If dynamic priority adjustment is supported, this value may itself subsequently be overridden. If the START function cannot be applied to the activity then an error or warning message will be generated to specify the identity of the activity and the reason for the failure. For example:

```
START Error Activity STABILISE FILTER is crashed.
START Warning Activity MMI COMMAND INT already running
```

The criterion which determines the nature of the message is whether the desired effect has been achieved or not. Thus attempting to START a running activity should generate a warning while attempting to START a crashed activity should result in an error message.

**The HALT Function**

The HALT function may only be applied to an activity which is in the running state. Its effect is to put the activity into the halted state and to inform the scheduler, or that the activity is not eligible for executing. When a command interpreter is provided the command takes the form:

```
HALT Warning Activity STABILISE FILTER is activity halted
```

**The RESUME Function**

The RESUME function may only be applied to an activity which is in the halted state. Its effect is to put the activity into the running state and to inform the scheduler that the activity is now eligible for
scheduling. Where a command interpreter is provided the command takes the form

\[ \text{RESUME} \rightarrow \text{activity\_identity} \]

The function accepts a single parameter which is the identity of the activity to be resumed. If the RESUME function cannot be applied to the activity then an error or warning message will be generated to specify the activity identity and the reason for the failure. For example:

```
RESUME Error Activity STABILISEFILTER is crashed
RESUME Warning Activity MMI COMMANDINT already running
```

The TERMINATE Function

The TERMINATE function can be applied to an activity which is in any state but unestablished. If IDA or server termination procedures are supported then TERMINATE may be applied to an established IDA or server provided that all connected activities are either unestablished or established.

The effect of the TERMINATE function applied to an activity is to put it into the unestablished state and inform the scheduler that the activity is not eligible for scheduling. The activity is removed from all internal queues and lists within the runtime executive and is removed from all control queues it has joined.

Where a command interpreter is provided the command takes the form

\[ \text{TERMINATE} \rightarrow \text{element\_identity} \]

The function accepts a single parameter which is the identity of the activity IDA or server to be terminated.

The effect of the TERMINATE function applied to an IDA or server is to execute the termination procedure if such is supported by the development environment.

If the TERMINATE function cannot be applied to an activity IDA or server then an error or warning message will be generated to specify the identity and the reason for the failure. For example:

```
TERMINATE Error Channel STABILISE MESSION is connected to running activities
TERMINATE Warning Activity STABILISE SHIP is unestablished
```
The RESET Function

The RESET function may only be applied to IDAs and servers which are in the established state. Its effect is to cause the execution of the reset procedure and it leaves the element established. Where a command interpreter is provided the command takes the form

```
RESET element_identity
```

The second parameter if provided is passed to the reset procedure. If the RESET function cannot be applied to an IDA or server then an error message will be generated to specify the identity and the reason for the failure. For example,

```
RESET Error IDA STABLE, MESSCHAN is unestablished
```

The RESET function provides a means of re-initialising an IDA or server without needing to TERMINATE the associated activities.

Hierarchic Control Facilities

The control facilities described above operate on individual elements. Mascot development environments may be extended to support hierarchic control of systems, subsystems and composite IDAs and servers. These facilities operate by applying the functions already described recursively to the elements and lower level networks within a specified network unit. Prior to the use of these facilities, the operator may wish to consult the function descriptions and these are described below.

A development environment is required to define the effect of an hierarchic control command. The control operates by a much wider range of exceptional situations can occur such as, for example, the application of the RESET function to a network which contains a crashed activity. It is worth noting that individual components of a network can be in different states making the concept of an overall network state meaningless.

Hierarchic Identity

The preferred form of identity described above for activities, IDAs and servers, must be utilised to allow the omission of trailing fields. The function is then applied to the named structure in order to list the possibilities for error actions applying to the system as a whole should require the system name to be specified. It could however still be omitted for subsystems and composite IDAs and servers.
INITIALISE Applied Hierarchically

The hierarchic form of the INITIALISE function should first initialise all the IDAs and servers and then the activities of the network being initialised. If the development environment is not capable of determining the necessary order of initialisation according to the dependencies then it must provide a mechanism for specifying this.

The development environment must define the method of handling parameters of initialisation procedures.

START Applied Hierarchically

The development environment must define how the start priority value is to be interpreted in connection with a system or subsystem.

HALT, RESUME and TERMINATE Applied Hierarchically

The order of application must be defined for the development environment. If these functions are provided by means of an interface which is accessible to the application then the development environment must ensure correct operation when a command is issued by an activity which is itself within the scope of that command.

RESET Applied Hierarchically

The hierarchic form of RESET is similar to the hierarchic form of INITIALISE except that it only affects IDAs and servers. Again the development environment must define the method of handling parameters.
4.7 ERROR HANDLING

Introduction

As stated in the introduction to this Handbook, Mascot is aimed primarily at the development of real-time, embedded software. Such applications usually demand a high degree of fault tolerance. In the face of a wide range of run-time errors, systems are expected to continue operation, albeit in a degraded mode in which some functions are no longer available or are available at reduced efficiency. Error detection and handling are therefore of considerable importance in the operational software. During the development stage, it is essential to have good facilities for error reporting and for some applications this facility must be retained, possibly in a modified form, when the system becomes operational.

Mascot Error Handling Requirements

Errors may be detected at all three levels and handled by either of the software levels. At the hardware level, such events as arithmetic overflow or underflow and memory protection violation are detected and normally signalled by means of an interrupt mechanism. Response to these signals may be provided by either the executive or the application software. In the case of the application level, the coding which checks the hardware status for errors may be programmed explicitly or may be included implicitly by the compilation system.

Other errors are detected directly by the software. The executive detects such faults as the illegal use of primitives and, under a co-operative scheduling regime, an excessive time slice. In the application software, checks may be made explicitly for errors related to the logical significance of the program; example might be a mutually inconsistent set of data values. For a wide range of errors, the division between those which must be catered for explicitly and those which are automatically trapped by code embedded by the compiler, depends heavily on which implementation language is being used and its provisions for data typing. Languages such as Pascal and Ada provide the programmer with a great deal more assistance in these matters than, for example, Coral 66. Range checks on individual values fall into this category.

The question of handling the error once it has been detected, this in fault tolerant mode, is the responsibility of the application software. Consequently, error handling in the form of error signals originating from the hardware or of directly detected errors, normally passes information on to the application. In a few instances, however, the executive may handle itself in a manner which is transparent to the application. In a paging
implementation, a page fault could be dealt with in this way. In other cases, where the error is too serious for recovery, the execution thread containing the error may be aborted and a message transmitted to the error reporting system. Where an error has been detected by or communicated to the application software, the mechanism whereby control is passed to the appropriate handling code is again very language dependent with Ada, PL/1 and RTL/2 providing built-in facilities of varying degrees of sophistication.

The Mascot definition calls, under various circumstances (see for example Section 4.2), for the generation of error or warning messages. Concern with the foregoing is otherwise limited to the possibility that analysis of the message may be used to trigger recovery action. A Mascot development environment is required to provide error reporting facilities which may be used by both the executive and application parts of the software in a uniform manner. These facilities are defined in terms of three elements: an error notification interface, an error channel and a standard error reporting network. Support for these elements is mandatory only during development and not in an operational Mascot system.

**Example Error Handling Facility**

In this section error reporting facilities are described, for convenience, in the form of a particular implementation. This implementation is not part of the standard. The documentation of a Mascot development environment must specify the precise mechanisms which are supported and suitable means of amending these facilities should be provided.

The diagram below illustrates how the standard facilities could be provided.
The purpose of the network is to take messages, convert them to a suitable textual form and transmit them to an appropriate device. Messages passed to the network are stored initially in a channel of type mascot_error_chan. Input is via a window which provides the standard error notification interface which, in our example, has been named report_error.

```
ACCESS INTERFACE report_error;
  PROCEDURE error(message : text_string; ..);
  PROCEDURE fatal_error(message : text_string; ..);
END.
```

Thus there are to be two access procedures error and fatal_error each of which place in the channel a message which contains, in addition to the text itself (possibly represented by an error number), an indication of the severity of the fault and the identity of the activity which originated the message (or on whose behalf it was originated by the executive). Other, user generated, components may also be included in the message. The procedures may take other parameters as defined in the documentation of the development environment.

Procedure fatal_error has the additional effect of setting the state of the activity, in which the fault has occurred, to crashed and informing the scheduler that the activity is no longer eligible for scheduling. In the above example network these actions are represented by a port which propagates information out of the error channel. If the activity is selected for monitoring, calling either access procedure will result in the generation of an appropriate monitor record (see Section 4.8).

The error channel provides an output window of type mascot_error to give access to the messages which have been generated by the system. The access interface takes the form:

```
ACCESS INTERFACE mascot_error;
  WITH error_message:
  PROCEDURE get_error(VAR message : error_message; ..);
END.
```

where

```
DEFINITION error_message;
  TYPE
    severity = (error, fatal);
  error_message = RECORD
      text : text_string;
      fault_type : severity;
      act : act_id;
    END
END.
```

Any additional parameters of access procedure get_error are defined for the Mascot implementation.
The development environment documentation will also define other characteristics of the error channel including its behaviour when full, the queuing algorithms (eg priority levels of messages) and the behaviour where no consumer activity is connected to the channel.

The standard error reporting network is required to contain facilities for taking messages from the error channel, via the mascot_error window, converting them to textual form and transmitting them to the output device via a window of type mascot_text_out. In our sample system these facilities are illustrated as an activity text_formatter with access to a message pool and connected to a server window of the appropriate type. Access interface mascot_text_out is of the form:

```
ACCESS INTERFACE mascot_text_out;
   PROCEDURE text_put(mess : text_string);
END;
```

The format of the message displayed by the device is as follows:

```
activity identity : error type  error message  parameter(s)
```

where the preferred form of an activity identity is

```
subsystem name  activity name
```

The 'error type' takes its value from the severity component of the message (error:fatal) and any additional parameters must be defined for the implementation.

It should be possible for the user to adapt the standard error reporting facilities by replacing the server and/or replacing the processing element. In the latter case the application error handling might analyse the error message and determine some network level recovery action. For example, receipt of a warning message that a channel has reached 95% of capacity might trigger an action to filter incoming data more heavily in the hardware and so reduce the number of events being processed.
4.8 MONITORING

Introduction

The problems of testing and diagnosis in a real-time, multi-threaded system differ considerably from those encountered during the corresponding phase in the development of a sequential program. In particular, the standard interactive tools will usually be inappropriate in that it is neither possible nor desirable to suspend execution of the system or to execute it in single step mode. The Mascot approach encourages the planning of testing and diagnosis during the design phase of a project and a Mascot run-time system should provide a range of facilities to assist in this aspect of the design.

The use of the set of facilities provided for this purpose is known as monitoring and the primary purpose is to collect and display an ordered list of significant interactions within a system being commissioned. These interactions may be between the elements of the system or between these elements and the context. It is obviously desirable that the collection of this data should, as far as possible, be a function of the run-time system rather than of the application software. The monitoring facility should provide, therefore, a means of recording the interactions without the need to incorporate special code in the application templates.

The basic concept employed in Mascot is that the collection of monitoring information should be decoupled from the processing and display of that information. The recommended collection system maintains the time ordering of the information gathered and is designed to have a minimal impact on the normal execution of the components under investigation. The remaining facilities include provision for selecting subsets of the possible information and the means of processing the gathered data and displaying it in a readable form.

Monitoring is presented, in this section, in the form recommended for a run-time system which supports the Mascot primitives (see Section 4.2). For a run-time system which does not support these primitives, some form of monitoring facility should still be provided. In this latter case, the range of events to be monitored is more difficult to define but is likely to be broadly similar.

Events to be Monitored

In a run-time system which supports the Mascot primitives, the events which would be candidates for monitoring include the following:
Control Queue Primitives:
JOIN
WAIT
WAITFOR
LEAVE
STIM
STIMINT
CHECK

Timing Primitives:
DELAY
TIMENOW

Interrupt Related Primitives:
CONNECT
DISCONNECT
ENDHANDLER

Occurrence of Errors:
ERROR
FATAL_ERROR

Scheduling Operations:
Selection of an activity for scheduling (START_SLICE)
Ending of period of activity execution (END_SLICE)

Tracing of Control Flow:
Automatic recording (where provided for by the compiler) of such events as procedure entry and return (TRACE)

Miscellaneous Primitives:
SUSPEND
ENDROOT

The monitoring facility also provides a mechanism for recording, in addition to the events listed above, application specific events (record points). This mechanism is known as the RECORD facility and is normally provided in the form of one or more primitives which have implementation defined parameters.

**Selection**

In even the smallest application, the volume of data gathered and displayed by the monitoring facility is potentially overwhelming. It is therefore necessary to be able to select sub-sets from the totality of monitorable events. The control mechanisms, recommended for this purpose, provide a set of filters which select the desired sub-set dynamically. Experience has shown that the most useful criteria are:

- Which **activities** are to be monitored?
- Which primitives are to be monitored?
- Which **control queues** (where relevant) are to be monitored?
- Which record points are to be active?
- Is the automatic trace data (if any) to be recorded?
For an event to be recorded, all of the relevant selections must be in force. Thus, for a control queue primitive, the control queue, the primitive and the activity must all be selected.

The recommended control facilities are provided by the operations SELECT and EXCLUDE which respectively extend and reduce the set of events to be recorded. These operations require two parameters. The first of these is the identity of the group to which it applies:

```
ACTIVITY
PRIMITIVE
CONTROL Q
RECORD
TRACE
```

and the second is the identity of the member of that group. The recommended form of reference to activities, control queues and record points is by the element identity as defined in Section 4.6 of the Handbook extended by the addition of the structure:

```
corlq_name
```

to the identity of the IDA or server containing the control queue, and by the addition of the structure:

```
.record point_name
```

to the identity of the element containing the record point.

The hierarchic form of element identity, described in the Section 4.6, may be used as a shorthand means of SELECTing or EXCLUDing a collection of activities, control queues or record points in a single operation. Thus, by the omission of trailing fields, reference can be made, for example, to all the activities in a subsystem, all the control queues in an IDA or all the record points in an activity.

Identification of the TRACE records to be monitored is entirely dependent on the identification information which the development system associates with each trace point.

Primitives should be selected by the names used under the heading of 'Events to be Monitored'. The term SLICES should be used to represent the START_SLICE, END_SLICE pair, and ERRORS to represent ERROR and FATAL_ERROR.
Group references may be supported in a Mascot monitoring facility through the keywords:

- **ALLPRIM** - All primitives
- **ALLACT** - All activities
- **ALLCQ** - All control queues
- **ALL RECORD** - All record points

All selections remain in force until explicitly excluded by means of the EXCLUDE function.

It will be appreciated that there are some elements of any system which must not be selected for monitoring. The operations of the monitoring facility itself are an example. The system builder should therefore provide facilities to inhibit monitoring of nominated activities and control queues. These inhibitions should be transmitted to the run-time monitoring system and should be used to override the effects of individual selection of the specified items or the effects of ALLCQ and ALLACT.

In summary, the parameters of the SELECT and EXCLUDE functions are:

- **PRIMITIVE** primitive name
- **ACTIVITY** activity name
- **RECORD** record point name
- **TRACE** (additional parameters implementation dependent)
- **ALLACT**
- **ALLCQ**
- **ALLPRIM**
- **ALLRECORD**
- **SLICES**
- **ERRORS**

**Recording**

It is recommended that the events selected for recording by a Mascot monitoring system are written into the monitor buffer, in strict order of occurrence, in one of the following modes:

- **REAL_TIME**
- **IN_LINE**

In the default mode of IN_LINE, all the selected events are captured. If necessary execution of the activities being monitored is held up in order to ensure that no monitoring information is lost. In this mode of operation it is permissible to disallow selection of interrupt and scheduling events.
In REAL TIME mode snapshots of the monitored events are taken while the system is allowed to run with the minimum of interference. Data are written to the monitor buffer until it becomes full. When this has happened, all further monitor data are discarded until the contents of the buffer have been processed for display. The number of monitored events lost in this way should be reported to the processing function.

Three further options are recommended for the control of recording:

- HOLD
- EMPTY
- OFF

HOLD prevents further entries being written to the monitor buffer while preserving the current contents. Further data are discarded until REAL TIME or IN LINE mode is selected.

EMPTY clears the buffer and causes further data to be discarded until REAL TIME or IN LINE mode is selected.

OFF disables all monitoring (both recording and processing) until REAL TIME or IN LINE mode is selected.

These five options may be selected using the SELECT operation with the appropriate parameter.

**Processing**

The function of processing is to convert the coded information in the monitor buffer into a readable form and display it by means of a suitable peripheral. Facilities must be provided to perform this either on-line or off-line.

The on-line facility allows processing to be turned either on or off. It is controlled by the SELECT and EXCLUDE operations, in the normal way, using the keyword PROCESS. While processing is disabled, it is recommended that the contents of the monitor buffer be circularly overwritten in either REAL TIME or IN LINE mode of operation. This ensures that the buffer always contains a record of the most recent events ready for processing and display as an aid to problem diagnosis.

The off-line facility should permit the contents of the monitor buffer to be examined following a system crash.
5.1 METHOD AND USE

Introduction

This section describes the method whereby a design may be derived through the use of the Mascot design representation language and graphical notation set out in earlier sections of the Handbook. The domain of applicability of Mascot includes the development and subsequent maintenance of software for large, distributed, embedded, real-time data processing systems. Without excluding the possibility of applying sub-sets of the notation and the method to smaller systems, Mascot places particular emphasis on the word 'large'. Large, that is, in the sense of large numbers of people involved in the development, a large amount of program text to be written, a large number of requirements to be serviced simultaneously, a great variety and quantity of hardware resources, and a project whose development extends over a long time scale. The adoption of this emphasis on large systems has resulted in the evolution, in Mascot, of the techniques necessary for handling the scale and complexity which seem to be inescapable features of modern software developments.

The Mascot design method provides a basis for managing both the concurrency in development which arises when many people are deployed simultaneously on a task, and the iteration which arises when lower level design causes previously taken higher level design decisions to be changed. The method can be viewed as a process where there are multiple sites of execution and where earlier stages may need to be revisited.

Development Management

The Mascot method is based on the progressive and repeated application of a simple but powerful technique, that of alternating the requirement and design viewpoints in the course of establishing an hierarchic structure. At each level of decomposition, a design is postulated to meet a set of requirements. Implementability is thus kept firmly in mind when elaborating the design structure. This encourages a closed loop approach to the development process whereby the functions provided and the performance achieved by a design at any level can be related, directly and easily, to a corresponding set of requirements.

Great emphasis is placed on design visibility throughout software development. This is achieved by using the various composite structures to give an hierarchic form of design definition. In this way large problems can be partitioned to contain the complexity at any point in the design, and to allow work to be shared amongst members of a team. Skill, experience and good management are required during this process which is essentially creative, but is highly visible and amenable to control.
Mascot is not prescriptive, thus it does not provide any recipes for establishing or filling out the framework for a given design problem. However, it does permit integration with a wide range of complementary software system analysis and design methods. In this way the benefits of Mascot structural description and development control can be combined with the advantages provided by other well proven or emerging software engineering techniques.

**Design Decomposition**

Each software component of a Mascot system is derived from a **template** and for every template there is a uniquely defined design task. The Mascot method, therefore, includes stages which relate to specific classes of templates: the operational system, networks, elements or subelements, simple templates and test systems. Each of these stages is further elaborated in terms of substages. The diagram below, in which each box represents a substage, summarises the common approach used in all stages.

---

**General Decomposition Diagram**

At any point in the decomposition process a design is postulated which will satisfy the external interactions and functional requirements derived from earlier stages. Each external interaction is an identifiable set of operations and/or data flow constraints and each functional requirement specifies a transformation which relates to operational and/or data flow effects on one or more interactions. Design
decomposition at any stage identifies a set of components each with its own functional requirements and interactions. For each software component, the requirements for the corresponding template are then derived (substage 3) together with its interactions (substage 4). These, in turn, lead to the functional requirements and external interactions for further decomposition. Note that the Mascot graphical conventions give explicit identification of interactions. a dashed line indicates interaction between a component and a device, a path indicates an interaction within a network and a link indicates an interaction within an element.

A template has to be designed to meet functional requirements and to service or generate external interactions which are determined by previous stages of the design. Thus, for example, the design of the operational system may place requirements and interaction constraints on a component subsystem whose template in turn places requirements and interaction constraints on a component element. The element template may be further decomposed and, in the process, places requirements and interaction constraints on component subelements.

In the decomposition of a template (substage 1) the following are identified: any hardware elements to be employed, the software components and the internal interactions. The characteristics of the hardware elements are described in substage 2. The template specification and functional requirements for each component are defined in substage 3. The semantic and dynamic properties of the internal interactions are defined in substage 4 while the syntax of the interfaces is defined in substage 7. Finally, the functional requirements and interactions associated with testing the template are defined in substages 5 and 6.

The results, with the exception of those produced by substage 2, flow forward as data for lower levels of decomposition. The complete design process is bounded, at the beginning, by the given framework in which development is to take place and, at the end, by programming the indivisible elements and subelements which form the atoms of the design, and by designing test systems for each of the templates.

**Technical Authority**

From a development management point of view, the responsibilities relating to each design task (each template) may be expressed in the roles played by a designer and a technical authority. The designer of a template is responsible for carrying out all the substages relevant to the template design task. These include the integration of the components identified in the template in order to be satisfied that the template requirements and interaction constraints have been met. The technical authority for a template is responsible for design task definition and for the verification and acceptance of the work carried out by the designer of that template.

5.1 Method and Use
Normally the technical authority for a template will be the designer of the enclosing template (in which it is identified). This ensures that the technical authority is responsible for all the requirements and interaction constraints relevant to the design task to be undertaken by the designer, these include:

(a) Interaction Descriptions. These are the definitions of the data flows and operations on the paths, links and device interactions which components, to be created from the template must generate or respond to (that is the output from substage 4 of a previous design task).

(b) Interface Specifications. These are the formal specifications of the procedures in the Mascot Interface modules (that is the output of a previous substage 7).

(c) Template Functional Requirements. These define the transformations, expressed in terms of the interactions described above, to be carried out by any component created from the template.

Some formality must be attached to the transfer of work between a technical authority and a designer. Before a design task is placed by a technical authority on a designer, a Requirements Review must be carried out. The formality of this review will be dependent on the extent of the definition detail at the time the design task is initiated. Mascot allows work to proceed against incomplete design definitions (for example, with specification modules at registered status only) and this partial statement of requirements must be subject to some sort of review. Later, when full specifications are available, a more thorough review can be undertaken.

When the design task has been completed a Verification and Acceptance Review must be undertaken. This will involve at the least a review of all the substages of the design task. Additionally, Verification Analyses and Acceptance tests may be undertaken at this point.

**Design Definition**

The principal structural features of Mascot are the decomposition from systems through networks to paths and links being identified on the wire.

At the top of the structure are the primary systems. These meet primary operational requirements, are components for some internal task.

Between templates and components, interaction specifications evolve in terms of:

Each component:

- Interface specifications.
multiple components derived from the same template, or the creation of the same type of component in different execution environments for prototyping, testing or re-use.

The principle of 'containment of complexity' should ruthlessly be applied during design structure elaboration. At each stage of decomposition a significant measure of partitioning should be achieved but without generating overly complex internal component structures. The final hierarchical design structure should contain the minimum number of levels consistent with the ability to see easily how each component, at any level, plays its part in satisfying the requirements generated by the next level up.

Application of the Mascot method is likely to result in a large number of names. These names must be chosen with care and, in the case of very large systems, it may be necessary to introduce special naming conventions and/or measures to limit the potentially global scope of template names. The value of
clear, meaningful names cannot be over emphasised. **Template** names should reflect the general functional capability of a **module**, whereas **component** names should be chosen to indicate the particular role of the **component** in the **composite module**.

Not shown in the diagram are various additional **modules** which are not involved in the primary decomposition in terms of **networks**, **elements** and **subelements**. The set of additional **modules** and the purpose for which they are required is as follows:

(a) **Context Interface**. This defines the operating environment of the Mascot software.
(b) **Library Interface**. This defines a set of facilities to be provided by a **library component** within the application software. It may, on occasions, represent the existence of a piece of (possibly custom designed) hardware.
(c) **Library Template**. This defines a set of **library algorithms**.
(d) **Definition**. This defines one or more data types and associated constants.
(e) **Build Modules**. These define the mapping of software design components onto target hardware.

During development, the definition of the design structure will evolve in parallel and be subject to iterative change. This process will be recorded in the **Mascot database** using the **status progression** facilities. The **Mascot database** is similar to a Data Dictionary but has far more emphasis placed on the relationship between entries. The structure at any time captures the current state of the design and allows assessment of the degree of completion.

The quality of the documentation at the end of development will significantly affect the maintainability of the system and the potential of any of its **templates** for re-use. When the development task is 'finished', the documentation set must include the rationale for the 'final' structure. Those parts of the design which have been discarded during the iterative development process need not be retained in full, although the history of the development and any major lessons learnt should be summarised in a design record.

**Potential for Re-use.**

Mascot is essentially a form of software **template** technology. The output from the decomposition process (substage 1) expresses the design in terms of the functionality of, and interactions between, the **components**. When the interactions are defined (substage 4) their descriptions are generalised so as to maximise the potential for re-use. In the same way, in the definition of the **template** (substage 3), the transformations to be performed by any **component** derived from the **template** are expressed in terms of the generalised interactions derived above. It is possible to identify a number of circumstances frequently encountered when designing a **template** for a particular **component**.

5.1 Method and Use

Mascot Version 3.1
(a) Unique Template. This is where a template must be designed from scratch. Nothing exists (or there is no knowledge of it) which can be used as a starting point for the template design.

(b) Adapted Template. This is where a template can be designed using an existing template as the base line for the development.

(c) Common Template. This is where a common requirement exists at several different places in the overall design structure and where it is possible to satisfy this requirement with a common design. Control of the common design should be exercised from at least the lowest common point above the places where it is used in the design hierarchy. A common template may be parameterised in various ways, or may be produced in variant forms using automatic program generation techniques, to give some flexibility in use.

(d) Standard Template. This is similar to a common template, but with applicability across a range of projects.

(e) Existing Template. A existing unique or adapted template may be adopted for use elsewhere. In being so used it is made into a common or standard template and control of its design should be exercised accordingly. Whenever it is decided to make use of an already existing template it is likely that this will to some extent affect the interactions and component requirements in the enclosing design structure; these must now be tailored to accommodate the existing item.

**Design Stages**

As already indicated, the design process can be broken down into a number of stages and substages. This must not be construed as a linearisation of the essentially iterative and concurrent design actions which take place in a large software development. However some means of identifying different aspects of the design process is needed and it is for this reason that the stages and substages are defined, each being given a number for ease of reference. Thus, although the work of a development will not proceed strictly in accordance with the stage numbering, the sequence indicates the order in which the design of individual items is elaborated.

The rationale for the 'final' design, or any design which is thought to be good at any particular point of development, may well give the impression that it has been arrived at by orderly sequential application of the design stages. Indeed it is important that it is possible to describe the design in this way. The Mascot method is specifically geared to the problems of controlling the evolution of a design, during which mistakes may be made and requirements changed. The method maximises the formality with which an evolving design structure can be expressed, whilst maintaining flexibility by allowing changes to be made in well defined localised regions.

5.1 Method and Use
Before embarking on the first stage of the design it is necessary to begin by establishing the framework in which the development will take place. Although work on this is started right at the beginning of the project it is likely that the bulk of the detail will need to be deferred until the first stage of decomposition has been completed. Subsequent stages may well result in addition, deletion or amendment to the results of this preliminary work. The following aspects need to be considered:

(a) **Hardware Environment.** This includes establishing the number and type of processors to be used, the size and type of each main storage unit, the means by which hardware modules are to communicate and the number and nature of the peripheral devices which are to be handled by the system. It is necessary to complete this to a degree which is adequate to support any hardware interactions in subsequent stages of the design, and to identify any processing or communication constraints which may affect the design structure.

(b) **Development System.** This includes the facilities provided by the programming and project support environments together with such items as the means of prototyping and the provision of test harnesses. All these facilities are central to the software development and must be well defined early on.

(c) **Context(s).** This involves establishing the primitives and standard support facilities which are to be made available through one or more Mascot **context interfaces.**

(d) **Libraries.** These are standard support facilities which are to be created outside the context and made available through **library interfaces.** Both libraries and contexts are directly supported by the Mascot design representation facilities; their definition must be completed in time to support the programming stage of the work.

The method includes six main stages as follows:

Stage 1: External Requirements and Constraints
Stage 2: Design Proposal
Stage 3: Network Decomposition
Stage 4: Element Decomposition
Stage 5: Program Definition
Stage 6: Test System Definition

Each of these will be illustrated by means of an individual diagram derived from the general one already presented. The seven substages, introduced earlier in connection with the general decomposition model, represent specific design actions related to the decomposition process in each of the six main stages. Work on the various substages of any particular stage will proceed in parallel and need not be complete before work is started on further stages of decomposition. Some substages are not present in all the six stages, as will be illustrated by means of the individual diagrams, and some may optionally be
omitted if they are not required in the elaboration of a particular design item. An arrow leaving a box in any of the diagrams represents a flow of information to a further stage of decomposition (in some cases within the same stage of the method such as where a network is decomposed into lower level networks).

**Stage 1 External Requirements and Constraints**

This stage establishes the general requirements and external constraints. The substages of which it is comprised are illustrated on the diagram below and are now described individually.

![Diagram](image)

**Stage 1**

**Stage 1.1 (Requirements Analysis)** involves analysis of the complete system (hardware and software) with particular emphasis on identification of the software system requirements and interactions. Analysis techniques compatible with the data flow and network principles of Mascot (such as CORE, SSADM, JSD etc.) are particularly relevant during this stage.

**Stage 1.2 (Hardware System Requirements)** describes those parts of the system whose functions are to be performed by hardware units. They are not, in the Mascot method, to be subjected to further decomposition (box 1.2 possesses no output arrow) but such hardware units are not of course precluded from containing independent items of software.

**Stage 1.3 (Software System Requirements)** describes what the software has to do in terms of transformations of data and responses to events originating outside the software system.
Stage 1.4 (Software System Interactions) describes the nature and purpose of each implicit interaction between the software system and the external hardware or software (including communication with an operator).

Stage 1.5 (Overall System Test Requirements) describes the way in which the complete system (hardware and software) is to be tested.

Stage 1.6 (Overall System Test Interactions) identifies particular test data, expected results and the operator control sequences required to carry out the tests on the complete system. No data is carried forward to later stages as such tests are applied to the total system operating in its natural environment.

Stage 1 must be well advanced before any further stages of the development work are started. Although this stage does not produce any formal Mascot design definitions (apart from the name of the system template) it is likely to involve the application of formal techniques for requirements analysis. Notice that this stage produces the requirements and device interactions for a Mascot software system which may itself contain embedded hardware components (where these are deemed to be supportive of the software design rather than placing constraints upon it as does the 'non negotiable hardware' discussed before embarking on this stage). There could also be several software systems, rather than just one, interacting through intermediate hardware. The overall system test requirements (stage 1.5) and interactions (stage 1.6) are not, in principle, needed until the end of the development when hardware and software have to be integrated; however stages 1.5 and 1.6 should be carried out as early as possible since they provide a useful measure of requirements analysis verification. Indeed in all stages which generate test definitions, the fact that the corresponding tests are not to be performed until later should not be allowed to delay work on their definitions.

Stage 2 Design Proposal

This stage results in a top level design proposal based on the software system requirements and interactions identified in the stage 1 Requirements Analysis. It is the first point at which a Mascot design structure emerges. The corresponding diagram is shown below.

Stage 2.1 (Software System Decomposition) describes the top level application software design in terms of a Mascot system.

Stage 2.2 (Hardware Element Requirements) describes what each of the items of supportive hardware appearing as top level components of the Mascot system has to do.

Stage 2.3 (Software Template Requirements) describes the template requirements for each software component in the top level software system design.
Stage 2.4 (Interactions) describes the nature and purpose of the internal interactions (paths) between system components.

Stage 2.5 (Mascot System Test Requirements) describes the way in which the Mascot system is to be tested. No data is carried forward to later stages as such tests are applied to the total software system.

Stage 2.6 (Mascot System Test Interactions) describes the particular test data, expected results and the operator control sequences required to carry out the Mascot system test.

Stage 2.7 (Internal Interaction Elaboration) identifies the definitions (2.7.1), access interfaces (2.7.2) and composite access interfaces (2.7.3) required to describe the paths between system components and the types of the data which flow along them.
No further stages of decomposition can be started until at least the system template has achieved enrolled status, the components have achieved introduced status, and the access Interfaces have achieved registered status. In addition, the internal paths must be described in terms of semantic and dynamic properties and any serial ordering constraints which apply to data flow along the paths. When the template requirements have also been defined then this is sufficient to allow further stage 3 or stage 4 decomposition. The stage 5 program design of an element or subelement connected by an interface identified in stage 2 cannot be started until the definitions (2.7.1) and access Interfaces (2.7.2) have been established. Likewise the detail of the composite access Interfaces (2.7.3) must be complete before a composite path can be expanded in a subsequent stage 3 subsystem decomposition.

The result of the initial attempt, at this stage, to identify a component as a subsystem (to 3.1), or an element (to 5.1) is necessarily provisional. The ultimate decision as to whether a template should be further decomposed can only be made in the light of its designer's more detailed examination. In the case of an element this examination may indicate that further decomposition is desirable. In these circumstances stage 5 is abandoned and stage 3 or stage 4 invoked, as appropriate. It is also possible that subsequent decomposition fails because design constraints cannot be met. In this case stage 2 must be repeated.

Stage 2 is the point at which the Mascot method starts to exert its influence in relating software design structure to external requirements and constraints identified during stage 1. Ideally, the top level of software design expression would be expected to contain the following components:

(a) A subsystem (or activity) for each major system function.
(b) A subsystem (or IDA) for every major system data requirement.
(c) A subsystem (or server) for every major interaction with external devices or software outside the system.
(d) A subsystem for every system-wide internal communication requirement.

For a large application such an ideal would be impractical, resulting in an unmanageable number of top level components. However, these components would be expected to appear during the first few applications of Stage 3 (Network Decomposition), being grouped into convenient and meaningful subsystems at higher levels. As a rule of thumb, the number of components at any one level of decomposition should be not more than twelve.

Stage 3 Network Decomposition

This stage is concerned with the progressive decomposition of a network in terms of lower level networks and elements and is illustrated diagrammatically below. It is applied initially to each network template which has resulted from the application of stage 2 (inputs from 2.3, 2.4 and 2.7) and to any network templates identified as necessary for testing purposes (input from 6.3 in stage...
described later). Subsequently, it is re-applied to every lower level network which results from the decomposition of a higher level one (inputs from 3.3, 3.4 and 3.7). This process is continued until the design is expressed purely in terms of elements. The whole stage may be omitted if stage 2 has not produced any components which are networks.

Stage 3.1 (Network Decomposition) describes a network in terms of its components.

Stage 3.2 (Hardware Element Requirements) describes the characteristics of each hardware element identified at this stage of the design. Hardware components at this and lower levels can be regarded as embedded in the software design.

Stage 3.3 (Software Template Requirements) describes the template requirements for each component of the network design which is to be implemented by a Mascot component.
Stage 3.4 (Interactions) describes the nature and purpose of the internal interactions (paths) between network components.

Stage 3.5 (Network Test Requirements) describes the way in which the network is to be tested and identifies a test system.

Stage 3.6 (Network Test Interactions) describes the particular test data, expected results and the operator control sequences required to test the network.

Stage 3.7 (Internal Interaction Elaboration) identifies the definitions (3.7.1), access interfaces (3.7.2) and composite access interfaces (3.7.3) required to describe the internal paths and the types of the data which flow along them.

Stage 3 carries on the network decomposition process started in stage 2. It differs from stage 2 only in that it is totally concerned with internal design decomposition and does not address the problem of matching the software design to the external environment. This results in two significant differences. First, the driving input for stage 3 emerges from previous Mascot design work (stage 2, stage 3 and stage 6 (where the decomposition process is being used for test network design)). Second, a formally defined test system is required to test a stage 3 network; hence the output to stage 6 (note that stage 3.5 will identify the name of the test system for subsequent elaboration in stage 6).

As for stage 2, the result of the initial attempt, at this stage, to identify a component as a subsystem (to 3.1), or an element (to 5.1) is necessarily provisional. It is also possible that subsequent decomposition fails because design constraints cannot be met, and in that case the current stage must be repeated.

Stage 4 Element Decomposition

Stage 4 is concerned with the decomposition of an activity in terms of subelements and, if necessary, of subelements in terms of lower level subelements. IDAs and servers are precluded from single thread decomposition in terms of subelements. This form of activity decomposition is an alternative to conventional program structuring techniques (for example, local procedures, blocks etc.). It has the advantage of producing a software structure visible in terms of Mascot diagrams and of increasing the potential for re-usable modules by the linking of separately compiled units. It allows selective servicing of the paths which are connected to the enclosing element or subelement and generally improves testability.

Stage 4 is illustrated diagramatically below. Stage 4 is applied initially to each element, chosen for decomposition, which has resulted from the application of stage 2 or stage 3 (inputs from 2.3, 2.4, 2.7, 3.3, 3.4 and 3.7) and to any similar element identified as necessary for testing purposes (input from 6.3.
in stage 6 described later). Subsequently, it may be re-applied to lower level subelements which result from the decomposition of a higher level element or subelement (inputs from 4.3, 4.4 and 4.7). This process is continued until the design is expressed purely in terms of simple subelements. The whole stage may be omitted if stages 2, 3 and 6 do not produce any activities which need to be decomposed.

**Stage 4.1 (Element/Subelement Decomposition)** describes an element or subelement in terms of subelements.

**Stage 4.3 (Template Requirements)** describes the template requirements for each component.

**Stage 4.4 (Interactions)** describes the nature and purpose of the internal interactions, (that is links) between components.

---

**Stage 4**

5.1 Method and Use

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Stage 4.5 (Element/Subelement Test Requirements) describes the way in which the element or subelement is to be tested.

Stage 4.6 (Element/Subelement Test Interactions) describes the particular test data, expected results and the operator control sequences required to test the element or subelement.

Stage 4.7 (Interaction Elaboration) identifies the definitions (4.7.1) and subroot interfaces (4.7.2) required to describe the internal links and the types of the data which flow along them.

Stage 5 Program Definition
Stage 5 is the programming stage during which the source text for each simple module is produced. Its diagrammatic representation is:

Simple templates, produced in any of the previous 3 stages, form the input to stage 5 (from 2.3, 2.4, 2.7, 3.3, 3.4, 3.7, 4.3, 4.4 and 4.7). Further simple templates, needed for testing purposes, may be derived from stage 6 (6.3) which is described later.

Stage 5.1 (Program Decomposition) describes the design of simple templates in terms of algorithms and data structures.

Stage 5.5 (Simple Template Test Requirements) describes the way in which the simple template is to be tested.

Stage 5.6 (Simple Template Test Interactions) describes the particular test data, expected results and the operator control sequences required to test the simple template.
If during the program decomposition it is found that further structural decomposition would be desirable then stage 5 may be abandoned and stage 3 or stage 4 invoked, as appropriate. Thus stage 5 terminates the primary design process as far as Mascot is concerned, although it may result in a requirement for supporting work on test system design. Any conventional technique for program design may be used within this stage provided it is used consistently. However, its use should be confined to the expression of algorithms and data structures within a single module; decomposition in terms of separately compiled modules is regarded as a stage 4 design action and should use the appropriate Mascot design feature. If the functional requirements cannot be met within the constraints then the previous stage must be re-invoked.

Stage 6 Test System Definition
Stage 6 is concerned with the integration and testing of application software. Its diagrammatic representation is:

Input to stage 6 consists of the test requirements and interactions for networks, elements:subelements and simple templates, respectively, identified in stage 3, stage 4 and stage 5 (from 3 5, 3 6, 4 5, 4 6, 5 5, and 5 6).

Stage 6.1 (Test System Decomposition) describes the structure of the test system.

Stage 6.3 (Test Template Requirement) describes what each test template required to create a component specifically identified for test purposes, has to do.
Stage 6 is concerned with the first level of test system decomposition. The requirements for networks, element/subelements and simple templates identified in stage 6.3 are fed back to stages 3, 4 and 5, respectively for further decomposition as necessary. Notice that if a standard harness can be used for testing, and if no special test components are required, then stage 6.3 may be omitted. Stage 6 designs will work entirely in terms of the substage 6 test interactions and substage 4/substage 7 operational interactions derived from the previous stages.

**Status Progression**

Throughout all six stages of the development the Mascot design notation is used to record the product of the design process, and the status progression facilities are used to record progress and to control the use to which the various parts of the design definition may be put. Mascot formality is limited to these aspects but any other formal techniques for function or data flow definition may be used in conjunction with Mascot with direct reference to templates, components, Interfaces, paths or links in the design structure.
5.2 DOCUMENTATION

Introduction

The use of the Mascot method should be supported by a suitably structured approach to the documentation requirement at each stage in development. Well-structured documentation will support the system throughout its life-cycle by relating system design to requirements and external constraints, allowing descriptions to be created and maintained in a recognisable framework and facilitating access to this information by the wide variety of personnel who need it.

It is not intended in this Handbook to provide prescriptive techniques or standards for documentation, because there is a wide range of diverse documentation standards to which Mascot systems will be required to conform. However, it should be recognised that software documentation does not exist in a vacuum and must be part of the overall documentation strategy. The documentation structure for a medium-to-large project is inevitably large and complex and involves many inter-dependencies. It is essential that this structure is planned at the outset of a project and used by the development team as the project progresses. Used correctly, a recognised structure will reduce duplication/overlap in documentation, facilitate access to information, allow consistency checking and localise the effects of software amendments on documentation.

The following points should be taken into account when planning the documentation structure:

- The Mascot method assists in re-usability of software, and the re-usability of associated documentation is an important consideration. As far as possible, information which is project-specific should be isolated, in documentation terms, from re-usable information.

- A single template can be used to create several components in a typical Mascot application, and so information concerning the creation of components should be separated from the formal software descriptions and documentation of the template.

- The development and target environments for embedded software, for example tools and hardware configurations, are liable to change in the potentially long life (say, 20 years) of a typical Mascot application. The documentation should lend itself to such amendment by separating information describing the environment from formal software description.

The primary aim of documentation is to aid comprehension. Without compromising this aim, it is possible
to use the Mascot module classes as a framework for re-usable documentation. Wherever feasible, description should be restricted to the scope of the object being documented. For example, the documentation of a template module should avoid reference to the functionality of elements beyond the interfaces which it provides and requires.

The result of this approach is documentation which is both abstract and localised in nature. Although this achieves the goal of re-usability, there is a danger that over-zealous abstraction may lead to documentation which is disjoint, making it difficult to comprehend overall functionality without reference to numerous items of documentation. It can be seen that the goals of comprehensibility and re-usability are not always compatible.

As a general rule, the characteristics of a description should be similar to those of the object being described. If a module is created for widespread general use then re-usability of documentation is of paramount importance. If a module has many dependencies on the characteristics of external objects (say, for efficiency reasons), then the requirements of comprehensibility must take precedence. Most software is a compromise between the desire for re-usability and the needs of a specific application, and so engineering judgement is required when determining what form of documentation should be used for individual modules and module classes.

Template Documentation

By way of illustration of the above, consider the requirements for the documentation of an individual template. The documentation must describe the functionality of the template and the interfaces which it provides and requires (the specification documentation). If the template is composite, the documentation must identify the internal structure of the template in terms of components and their inter-connectivity (the implementation documentation).

In all cases, the descriptive content of the specification documentation must be detailed, complete and unambiguous. This is the lowest level in the hierarchy at which this documentation will be presented.

The more difficult aspect of template documentation concerns the level of detail of the implementation documentation. Clearly, the rationale behind the decomposition within the template must be presented in full. The level of description given for the components and their inter-connectivity must be carefully considered.

It would be possible to identify the components and internal interfaces by name only, and refer the reader to lower level modules whose specification documentation will provide the information on the functionality of individual items. Whilst this would meet the goal of re-usability, such an approach would tend to be abstract to the point of obscurity. Alternatively, if detailed descriptions of the means by which internal components achieve their functions are provided, then this leads to undesirable duplication.
within the documentation hierarchy.

Experience indicates that the preferred approach in most circumstances is to describe in full how the template achieves its required function, and to provide brief descriptions of the components and their inter-connectivity, referring the reader to lower levels of the documentation hierarchy if more detail on a particular component is required. This approach allows a reader to assimilate sufficient concise information to understand how the internal elements of a template achieve the necessary functionality of that template, without unnecessarily duplicating the specification documentation of the lower level modules.

The Mascot method encourages isolation of information by recognising the independent nature of active and passive elements, interfaces, definitions, libraries, etc. As far as possible, without losing sight of the need for comprehensibility, the documentation strategy should follow the same approach.

Control of Documentation

In a project of any reasonable size, a large quantity of documentation must be administered and controlled. The documentation is the primary method of communicating information about the structure and status of the system under development to all interested parties in the project. As the system is developed and amended, so, too, is its associated documentation. It is clearly necessary for the documentation to be in step with the system it describes at all stages. Generally, this can be achieved for documentation in the form of in-line comment, because this is retained within the module it describes and is subject to the configuration management and quality control procedures applied to individual modules.

Some project documentation is not directly related to a specific class of Mascot module (for example, requirements, quality reports, design rationale documents). Nonetheless, it is strongly recommended that all project documentation is held in a machine-readable form under the same configuration management database as that used to administer software development. Wherever possible, documentation relating to a specific module should be held as part of that module. Although this does not guarantee that documentation will be updated in line with the software, its proximity will encourage good practice and ease consistency checking.

The configuration management database can be used to create and maintain a knowledge of the dependencies between documents and modules. When a module or document is updated, the dependency relationships can be used to identify other modules or documents which may be affected by the change. Status progression is the minimum facility provided by the Mascot database, and will generally deal with identifiable Mascot module classes. In some cases, it may be possible to provide similar mechanisms for documents.
If, for some reason, documentation is not held in a machine-readable form and related in a controlled fashion to the system being described, procedures must be adapted to provide confidence that documentation and software will proceed through development in a consistent manner. Configuration management and quality assurance procedures must be applied to the documentation, even if only by manual means.

**Access to Documentation**

The existence of documentation does not in itself guarantee its accessibility. The sheer extent of documentation can make it difficult to identify and retrieve precisely that part of the documentation which is necessary to understand a particular facet of the system and carry out an item of work. The problem of collating and constraining relevant information is not new, however, and it is important to provide such a facility if work is to be carried out efficiently.

The publication of, and adherence to, the overall project documentation structure will assist in the identification of relevant information. However, in many cases the information needed to build a clear picture of the context in which a piece of work is to be carried out will be distributed through many modules. These modules will also contain material which is extraneous to the individual's requirement. There is a strong case, when employing Mascot, to consider the use of a documentation tool which will assimilate the specification documentation and implementation documentation of a number of modules into a single document. This will allow a reader more easily to comprehend the role of a template in the overall system. The existence of such a tool may reduce the temptation to duplicate documentation at different levels of the document hierarchy.

The tool would be achievable by identifying (say, by a keyword mechanism) the specification documentation and the implementation documentation within each module. In order to see more clearly the role of, say, a subsystem, a user potentially could gather together into a single document:

(a) the implementation documentation of the enclosing subsystem,

(b) the specification and implementation documentation of the subsystem under scrutiny and

(c) the specification documentation of the components and interfaces which comprise the subsystem

using the relationships between the modules and the documents established by means of the configuration management database.

5.2 Documentation 5 - 22 Mascot Version 3.1
Purpose of Documentation

There are two major categories of documentation according to its prime purpose: documentation of the project and documentation of the resultant system. These are now discussed in turn.

Documentation of the Project

Documentation is created and amended throughout the system life-cycle in order to capture and express the current status as development proceeds. However, it is not sufficient merely to maintain current status information. The development of documentation through the system life-cycle reflects the design decisions and rationale which invariably affect and shape the path to the final system. It is important, therefore, to capture and maintain the documentation as it existed at various major points in the system's evolution. If an 'audit trail' of this form can be created, it will allow analysis of the design process which led to the complete system. Further, if this information can be allied to quality records, modification records, etc., then analysis can prove extremely valuable to future projects and can be exceptionally useful during maintenance and support of the system.

In many cases, collation of the information required for this analysis is difficult as it exists in different forms (some as part of modules in the host system, paper records held by the quality assurance department, etc.), and results in an incomplete and disjoint record. The use of a suitable configuration management tool (possibly allied to the Mascot database) incorporating design change control and quality assurance recording mechanisms will assist in collating information in a manner which is coherent and provides a convenient form of reference.

Documentation of the System

The descriptive information required to support the resultant system incorporates not only the documentation of the templates and associated modules used to create the network components, but also the documentation of the testing mechanisms used to verify functionality. The relationship between documentation of these areas requires careful organisation. There is not necessarily a one-to-one correspondence between test systems and templates. However, there must be a mechanism for relating the template documents to the test system documentation, preferably one which does not adversely affect the re-useability of the documents.

The documentation of a template may refer to a test system created to test that template. It should not refer to test systems which test sub-networks in which the template is used. Test system documentation should refer to all components/templates in the sub-network under test. The result is that the test documentation structure reflects the network structure and the documentation of the sub-networks should refer to the test systems used to verify functionality.
**General Documentation Requirements for Module Classes**

There are generalised requirements for the documentation of all modules in a Mascot system, as outlined below.

The following categories should be considered in the documentation of all modules, although some categories may not be applicable directly to a particular module class:

- Language dependencies
- Environment dependencies
- Machine dependencies
- Code characteristics (e.g., conditional compilation, assembler inserts)
- Test status
- Quality assurance status
- Test mechanism

For each module under development, the following must be available, either embedded in documentation or controlled by tools:

- Version number
- Modification audit trail
- Mascot database status

All modules must refer to, or include in-line, the requirement which they are designed to meet.
5.3 SYSTEM TESTING

Introduction

During the design and development stages of a project there are several techniques which have traditionally been used to establish confidence in the software being created and to demonstrate that it meets its requirements. These include formal techniques for proving correctness, design reviews, in which, among other activities (see Section 5.1), program source text is subjected to the collective scrutiny of the project team, and testing, in which the behaviour of the corresponding executable code is systematically exercised through the use of test data. Testing is, and is likely to remain, the most widely used of these techniques. This is partly because of its wider scope including, as it does, the effects of production tools, operating system, hardware and external environment, and partly on account of the greater psychological assurance which it engenders ('seeing is believing'). It is also, at the present time, the only practical method.

Mascot, in common with other software development methods, contains a graphical form of design representation which can be exploited to advantage in carrying out a design review. It is in the sphere of testing, however, that Mascot provides significantly greater assistance than most other methods. In particular the modularity scheme of Mascot, together with the unique template-component model, constitutes a powerful support mechanism for testing. In addition, the ability to supply a separate system template for each test network provides a sound basis for the configuration management of testing. The template/component model makes it possible to create test systems which can co-exist with the application systems. This greatly simplifies the handling of regression testing during maintenance.

Provided that suitable run-time environments are available, and that the application templates contain no hardware specific features, the test networks may be executed on either host or target systems (see Section 3.3).

In this section the general considerations for the testing of Mascot systems are discussed and a specific testing strategy is proposed.

General Considerations

The testing of any substantial piece of software, from a large sequential program to a full blown system involving concurrency on a large scale, needs to be carried out in a modular fashion. There are two widely recognised approaches to this known respectively as top-down and bottom-up.

In the top-down approach the highest level unit is produced first and 'stubs' are created to replace the units at the next lower level. These stubs are sections of program which normally perform some simple
actions such as signalling the fact that they have been evoked and reporting the values of any input data with which they have been supplied. In some cases, however, a stub may partially emulate the actions of the unit in whose place it stands. Testing involves examining the pattern of invocation of the lower level entities. Stubs are then progressively replaced by the corresponding application units accompanied, where necessary, by a further level of stubs. The great merit of this approach is that testing and integration proceeds in a series of roughly equal steps. The last step is no more significant in itself than any of the others and no more likely to reveal any fundamental defect. Also application units can be constructed using their stubs as a starting point.

In the bottom-up approach it is the lowest level units which are produced first. Specially written drivers are then used to test them, first individually, and then in larger and larger groups until the entire application has been built. New drivers are needed at each stage and discarded after use. The final step in this process is highly significant as it may show that the overall structure is incorrect. Despite these disadvantages the bottom-up approach is widely used in practice and is considered by many programmers to be the natural way to test software.

While a strong case can be made out, at least in theory, for application of the top-down approach to testing sequential programs, it is more difficult to see how to apply it to the networks of concurrent processes required to solve real-time problems. In Mascot, therefore, its application is likely to be limited to the testing of the implementation details of simple activities, roots, subroots and libraries. The testing of Mascot networks is likely to be carried out bottom-up.

In devising a general strategy for testing Mascot modules it is necessary to cater for three groups: specifications, simple templates and composite templates. Since specifications have no direct realisation in the executable software there is no direct testing associated with them.

Simple templates constitute the algorithmic building blocks of the system, and the testing of these templates is primarily aimed at detecting algorithmic and programming errors. For this purpose a mixture of 'black box' test data, based on the design specification, and 'white box' test data based on the actual design is appropriate. At the very least these latter data should exercise every sub-condition of each conditional expression so as to ensure that every statement in the program is executed at least once.

Composite templates are groupings of components derived from simple and composite templates. The primary aim in testing them is to detect errors of communication between the components and to verify the real-time behaviour.

An Example Testing Strategy

This section describes a specific testing strategy developed from one that has been used successfully in several projects which employed an earlier version of Mascot. It supports testing of both simple and
composite templates and serves here as an example of recommended practice. It was designed to meet the following major requirements:

1. The test strategy and supporting tools should support both formal (that is Quality Assurance) and informal (that is development) testing in a consistent and reproducible manner.

2. The production and maintenance of the test data should require a minimum of special tools.

3. The tools should support interactive diagnosis with data entered from the terminal and results displayed at the terminal.

4. To facilitate regression testing, the performance of tests and the interpretation of results should require a minimum of manual intervention.

5. Since in many cases the target hardware does not become available until late in the software production cycle, it should be possible to perform the majority of the testing on the host computer.

The strategy is based on the concept of a test script containing, in a machine-readable form, the directives necessary to initialise a test system, data which are to be presented to the unit under test and results which are to be expected if the unit is correct. A test script is prepared in a textual form which may be manipulated by means of standard text editors. If used directly in this form, execution time is taken up, during the test, in performing the necessary type conversions. An alternative is to employ special tools to convert the script, separately, to a binary form but this was not adopted in view of general requirement 3 above.

A test script may be interpreted by a standard network of test-administering components, supported by application specific type conversion components. These two sets of components, together with the unit under test, form a test system.

The precise nature of the conversion components is dictated by the communication requirements of the unit under test. For testing IDAs, servers and libraries an activity is the natural choice since such components need to be driven. A root can most readily be used to convert data for a subroot which is under test, while for testing roots and activities an IDA may be chosen as the conversion component.

The role of the standard test components is to provide textual information, from a test script, to the conversion components. The latter convert this information to a suitable form and transmit it to the unit under test. This process is reversed in handling the responses. These are taken from the unit under test by the conversion components, transformed into text and passed to the standard test components which generate the results.

5.3 System Testing
Thus, each conversion **component** refers, in general, to three **interfaces** describing, respectively, text input, text output and communication with the unit under test. The textual **interfaces** are usually **ports** which may be connected to **windows** of the standard test **components**. One or other of the text **interfaces** may be omitted in some cases. The **interface** to the unit under test may be an **access interface**, a **subroot interface** or a **library interface**. The Mascot monitoring facilities may be used, during testing, to provide evidence of completeness.

An example of a test **network**, in which the conversion **components** are **activities**, is shown on the following page. **Subsystems** have been shaded in this diagram in order to improve readability.

**Operation of the Example Test Network**

Existing operating facilities are used to assign the input and output (files) to the **servers** input_server and **output_server**. When the system is STARTed, each of the conversion **activities** declares its identity to the **IDA text** and receives in return a unique key. The relevant arrowheads on the **network** connections through which this initialising transaction takes place are omitted from the diagram so as to avoid unnecessary complication. Subsequently, messages directed to a particular conversion **activity** can be obtained by the **activity** from the **IDA**, by quoting the appropriate identifying key.

The command interpreter **activity**, cl, reads a command line from **input_server** and copies it directly to **output_server**. The purpose of logging the input text together with the results of the test in this way is to allow the sequence of events during the test to be deduced from inspection of the output file. This has been found to work well in practice even when quite large portions of the final **network** are being tested.

The input line is then examined by the command interpreter to see if it contains a command which can immediately be executed and, if so, the required action is performed. Commands whose execution may be initiated by the command interpreter include Execution Control commands, Monitoring Control commands and special commands to, for example, control the timing of events in the **network**. If the command line cannot be dealt with in this way, it is passed to **IDA text** where it becomes available to the conversion **activity** whose identity it contains. An error message is generated if the line contains no recognisable identity.

The unit under test in this example may be any passive network fragment, that is one possessing only **windows** on its boundary. Messages received by conversion **activities** from **text** are converted to a suitable form and passed to the appropriate access mechanism of the unit under test. Any response is made available at another **window** for use by a converter which processes it for output.

Thus, to handle output, the converters call the appropriate access mechanism, translate the response into textual form and pass the result to **output_server**. Under some circumstances it is necessary for output conversion to be controlled from the test script. Hence the connection of all converters in the
diagram to the IDA text. The need for this most commonly occurs when testing a pool where the input line may contain a command to read the pool contents. However, another possibility is that the input line contains a copy of the expected results which the converter handling output can compare with the actual results and so signal whether the test has been passed or failed.
The syntax of the Mascot design representation language is included here for reference purposes. It is presented in two equivalent forms. A set of syntax diagrams, as used for description throughout the body of the Handbook, appears first together with an index. These diagrams follow the conventions established by Wirth in connection with the Pascal programming language. All valid constructs may be generated by tracing all possible paths through each diagram, as indicated by the arrow heads, from the top left until the path terminates on the right. Loops may be repeated as often as required. At each box a basic symbol of the language is generated. Where the box has rounded corners or is circular, the symbol is literally that contained in the box. This has been further emphasized in the former case by the addition of background shading. A rectangular box is a reference to another syntax diagram.

The diagrams are complete, in Mascot terms, in that they include all the non-mandatory features. They are incomplete in the sense that they contain a number of undefined symbols whose definition is dependent on the choice of implementation language. Such undefined symbols are indicated by means of a '*' near the top right-hand corner of the syntax box. A second group of symbols for which no defining diagram is included, are marked with a '$'. These are all identifiers, they appear under a variety of names so as to incorporate some semantic information. Where a syntax box is missing, on any and the corresponding definition diagram appears on page 'n' of the appendix. Where a syntax box contains a '*' a symbol which is defined on the same page on which it is used.

The design language syntax is then presented in a meta-language based on LISP and 'N'. In this form it is made specific to the use of Pascal as the implementation language. Many construct names are explicitly connected to the Pascal syntax definition. The form and organization of presentation is such as to facilitate reference to the subsection, in the body of the Handbook, where each construct is discussed. It is followed by an alphabetically ordered list of terms. Where each contains appropriate subsection references. It should be noted that for B N notation, the case of all the equivalent syntax diagrams, it has been necessary to introduce additional syntactic categories. A few category names which in the diagrams have been shortened so as to save space are given in the B N form, for example 'acc_int_spec_part' becomes 'access interface specification part'.

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PROVIDES

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identifier

acc_int_ref

, acc_int_array_descip

;

acc_int_array_descip

ARRAY

simple_type

OF

, acc_int_ref

$
Neither a composite IDA nor a composite server may refer to a composite access interface in its USES list.
component_part

component_class

connection_spec

Appendix A Syntax
simple_act_imp_part

with_section

library_spec

program_part
act_connection_spec

\[
\begin{align*}
&\text{sub_element_link} \\
\end{align*}
\]

\[
\begin{align*}
&\text{out_link_identifier} = \text{subroot_ref} \\
\end{align*}
\]
A composite subroot may not contain a component derived from a root template but must contain a root component derived from a subroot template. This latter component gives the interface to the composite template.
simple_subroot_imp_part

with_section

library_spec

declaration_part

A8

A27
A composite IDA may contain only IDA, channel, pool and library components.
A composite server must contain at least one server component and may also contain IDA, channel, pool and library components.
temp_const_spec

```
CONSTANT -> const_spec_list
```

const_spec_list

```
identifier $ -> : -> implicit_type -> ;
ARRAY [ integer_type ] OF ,
```

temp_const_ident

```
const_identifier $ -> = -> constant
constant
constant )
.
const_identifier $,
```
Variables may not be declared in a library implementation part.
library_spec

comp_acc_int_spec_part
The form of Bachus Naur syntax used is as follows:

a) Normal font lower case words, some containing embedded underlines, are used to denote syntactic categories.

b) Bold font words and symbols are used to denote Mascot reserved words and symbols.

c) Underlined words are used to reference Pascal constructs. For further expansion of these constructs refer to a Pascal syntax definition.

d) Italicised prefix words are used to convey semantic qualification of the following non-italic root. For example, if an identifier is required which must be the name of a template, the following compound name is used:

```
template identifier
```

e) Square brackets enclose optional items (NB Bold square brackets occur in the syntax definition. These refer to symbols in the Mascot design language.)

f) Braces enclose a repeated item. The item may appear zero or more times.

g) A vertical bar separates alternatives. They are always used to separate alternatives for the construct being defined, never as alternatives for part of a construct.

Section 2.3

```
access interface = access interface name part ;

access interface specification part end ;

access interface name part = access interface identifier

simple access interface specification part =

[with section] access interface detail part
```
with_section ::= 
   with definition_identifier {, definition_identifier} ;

procedure_or_function_heading ::= procedure_heading | function_heading

definition_unit ::= 
   definition_name_part ; definition_specification_part end .

definition_name_part ::= definition_identifier

definition_specification_part ::= 
   [with_section] definition_detail_part

definition_detail_part ::= 
   constant_definition_part
   | [constant_definition_part] type_definition_part

port_specification ::= requires access_interface_declaration 
   {access_interface_declaration}

access_interface_declaration ::= 
   identifier_list : access_interface_definition ;

window_specification ::= provides access_interface_declaration 
   {access_interface_declaration}

**Partially in Section 2.3, fully in Section 2.13**

access_interface_definition ::= access_interface_identifier
   | access_interface_array_description

**Partially in Section 2.3, fully in Section 2.14**

access_interface_specification_part ::= 
   simple_access_interface_specification_part
   | composite_access_interface_specification_part
Partially in Section 2.3, fully in Section 2.15

access_interface_detail_part ::= 
  [read_only_constant_specifications] 
  | [read_only_constant_specifications] variable_specifications 
  | [read_only_constant_specifications] [variable_specifications] 
  procedure_or_function_heading [procedure_or_function_heading]

Section 2.4

subsystem ::= subsystem_name_part ; subsystem_specification_part 
  network_implementation_part end . 

subsystem_name_part ::= subsystem identifier 

network_implementation_part ::= 
  uses template_definition { , template_definition} ; 
  component {component} [equivalence { , equivalence}]

component ::= component_class identifier : template_identifier 
  [connection_specification] ;

component_class ::= activity | subsystem | server | 
  | ida | channel | pool | library 

connection_specification ::= ( connection { , connection} ) 

port_window_connect ::= port_identifier = component_identifier 
  . window_identifier 

system ::= system_name_part ; system_specification_part 
  system_implementation_part end . 

system_name_part ::= system identifier 

system_implementation_part ::= uses template_identifier 
  { , template_identifier} ; component {component}
Partially in Section 2.4, fully in Section 2.8

subsystem_specification_part ::= [template_constant_definition]
  [window_specification] [port_specification]

connection ::= template_constant_identity
  | port_window_connect | port_port_connect

Partially in Section 2.4, fully in Section 2.14

template_definition ::= composite_access_interface_identifier
  | template_identifier

port_port_connect ::= port_identifier = port_definition

port_definition ::= boundary_port_identifier
  | composite_port_identifier . comprises_identifier

equivalence ::= window_window_equivalence | window_port_equivalence

window_window_equivalence ::= window_declaration = component_identifier.
  window_identifier

window_port_equivalence ::= window_declaration = port_definition

window_declaration ::= boundary_window_identifier
  | composite_window_identifier . comprises_identifier

Section 2.5

activity ::= activity_name_part ; activity_specification_part
  activity_implementation_part end .

activity_name_part ::= activity_identifier

Partially in Section 2.5, fully in Section 2.8

activity_specification_part ::= [template_constant_specification]
  [port_specification]
Partially in Section 2.5, fully in Section 2.9

\[
\text{simple\_activity\_implementation\_part ::= [with\_section] [library\_specification] [declaration\_part] compound\_statement}
\]

Partially in Section 2.5, fully in Section 2.12

\[
\text{activity\_implementation\_part ::= simple\_activity\_implementation\_part}
\]
\[
| \text{composite\_activity\_implementation\_part}
\]

Section 2.6

\[
\text{ida\_name\_part = ida\_class identifier}
\]

\[
\text{ida\_class ::= channel | ida \_ pool}
\]

\[
\text{access\_equivalence ::= renaming\_equivalence | simple\_equivalence}
\]

\[
\text{renaming\_equivalence ::= window identifier . access\_interface\_declaration identifier = renamed\_declaration}
\]

\[
\text{renamed\_declaration = internal\_declaration identifier}
\]
\[
| port identifier port\_declaration identifier
\]

\[
\text{simple\_equivalence ::= window identifier = port identifier}
\]

Partially in Section 2.6, fully in Section 2.8

\[
\text{ida\_specification\_part ::= [template\_constant\_specification] window\_specification [port\_specification]}
\]

Partially in Section 2.6, fully in Section 2.9

\[
\text{ida ::= ida\_name\_part ; ida\_specification\_part ida\_implementation\_part end .}
\]
simple_ida_implementation_part ::= [with_section]
    [library_specification] declaration_part
    [access_equivalence ; ; access_equivalence]]

Partially in Section 2.6, fully in Section 2.10

ida_implementation_part ::= simple_ida_implementation_part
    | network_implementation_part

Section 2.7

server_name_part ::= server_identifier

Partially in Section 2.7, fully in Section 2.9

server ::= server_name_part ; ida_specification_part
        server_implementation_part end.

simple_server_implementation_part ::= [with_section]
    [library_specification] declaration_part
    [access_equivalence ; ; access_equivalence]]

server_implementation_part ::= simple_server_implementation_part
    | network_implementation_part

Section 2.8

system_specification_part = [template_constant_specification]

template_constant_specification =
    constant template_constant_group {template_constant_group}

template_constant_group ::= identifier_list :
    [ array [ integer {, integer } of ] standard_scalar_type

template_constant_identity ::= 
    template_constant_identifier = template_constant_definition
template_constant_definition ::= 
( constant {, constant} ) 
| constant 
| constant_identifier

Section 2.9

library_interface ::= library_interface_name_part ; 
library_interface_specification_part end .

library_interface_name_part ::= library Interface identifier

library_interface_specification_part ::= [with_section] 
   procedure_or_function_heading {procedure_or_function_heading}

library ::= library_name_part ; library_specification_part 
   library_implementation_part end .

library_name_part ::= library identifier

library_specification_part ::= [template_constant_specification] 
gives library_interface_identifier 
{, library_interface_identifier} ; 

library_implementation_part ::= [with_section] [library_specification] 
   library_declarative_part

library_declarative_part ::= [constant_definition_part] 
   [type_definition_part] procedure_and_function_declaration_part

library_specification ::= library library_interface_identifier 
   {, library_interface_identifier} ;

Section 2.12

composite_activity_implementation_part ::= 
uses template_definition {, template_identifier} ; 
activity_component_part {activity_component_part}

Appendix A Syntax A - 34 Mascot Version 3.1
activity_component_part ::= activity_component_class identifier
               | template identifier [activity_connection_specification] ;

activity_component_class ::= root | subroot | library

activity_connection_specification ::= ( activity_connection
               {, activity_connection} )

activity_connection ::= template_constant identifier
               | sub_element_link | port_port_connect

sub_element_link ::= out_link_identifier = subroot_identifier

root ::= root_name_part ; root_specification_part
               simple_activity_implementation_part end .

root_name_part ::= root identifier

root_specification_part ::= [activity_specification_part]
               [needs_list]

needs_list ::= needs needed_interface (needed_interface)

needed_interface ::= identifier_list : subroot_interface_identifier ;

subroot_interface ::= subroot_interface_name_part ;
               simple_access_interface_specification_part end .

subroot_interface_name_part ::= subroot_interface_identifier

subroot ::= subroot_name_part ; subroot_specification_part
               subroot_implementation_part end .

subroot_name_part ::= subroot identifier

subroot_specification_part ::= activity_specification_part
               gives subroot_interface_identifier ; [needs_list]

subroot_implementation_part ::= simple_subroot_implementation_part
               | composite_activity_implementation_part

Appendix A Syntax

Mascot Version 3.1
simple subroot implementation_part ::= [with_section]
   [library specification] declaration_part

Section 2.13

access_interface_array_description ::= 
   array [ simple_type | simple_type ] of 
   access_interface_identifier

Section 2.14

composite access_interface_specification_part ::= 
   comprises comprise declaration [comprise_declaration]

comprise_declaration ::= 
   identifier_list : access_interface_identifier :

Section 2.15

read only constant specifications ::= 
   parameter_group {parameter_group}

variable specifications ::= 
   var parameter_group {parameter_group}

Appendix B

mascot 3 unit = definition unit | interface_unit | template_unit

interface_unit ::= access interface | subroot_interface
   | library interface

template_unit ::= system | subsystem | activity | server | ida | root
   | subroot | library
SYNTAX INDEX

In the list given below, each syntactic category is followed by the section where it is defined. In addition, each syntactic category is followed by the names of other categories in whose definition it appears. An ellipsis (...) is used when the syntactic category is or can be a reserved word or symbol. All uses of parentheses are combined in the form "()". The italicised prefixes used with some terms are deleted here.

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- = Prohibited

1+ = One or More

0+ = Zero or more

* Channel, Pool and Server have identical characteristics

Appendix C Keyword Usage C - 1 Mascot Version 3.1
APPENDIX D

DEFINITION OF SUMMIT CONVENTION
DEFINITION OF GRAPHICAL CONVENTIONS

The purpose of documentation is to convey information to the reader. One technique for achieving this is the use of diagrams. The Mascot definition contains equivalent graphical and textual design representations. Conventions are defined for annotating the diagrams in the graphical representation so that they reflect all but the program code of the corresponding modules. However, a diagram containing too much detail can actually convey less information than a less detailed diagram. The optimum level of detail could well depend on the purpose for which the diagram is intended. Design and implementation documents, for example, form two relatively independent sets. Documents may be explanatory or definitive in purpose. In the course of design, omission of detail may reflect the postponement of decisions.

The definition recognises sufficient variability in the use of the standard graphic conventions to allow for local variance and for the desirability of employing different levels of detail for different purposes provided that consistency is maintained within sets of related documents.

Symbology

Symbols are introduced, in the appropriate sections of the Handbook, for the various entities employed in Mascot designs. This appendix presents the complete set of symbols and is to be regarded as the definitive document for this purpose.

Simple Forms

The simple forms of activities, channels, pools, generalised IDAs, servers and subroots, together with roots, constitute the elements and subelements of a Mascot design (see Appendix B). They are symbolised as follows:

Simple Activity
Root
Simple Subroot

In accordance with long established Mascot practice, the circular form should normally be used. The rounded rectangular form is appropriate where it is desirable to provide additional space for the presentation of information within the boundary of the symbol. This might be the case, for example, with an activity, root or subroot which possesses an unusually large number of network and/or subelement connections.
The channel and pool symbols are based on those used in earlier versions of Mascot. These have been modified so that, like the activity symbols, they allow information to be presented within the boundary of the symbol. They may be used where an IDA conforms to the accepted definition (see Section 2.6) of one of these special forms. The rectangular symbol is a generalised form of IDA. It may be used to represent any IDA but must be employed where the IDA in question is not strictly a channel or a pool.

The symbol which represents a server is a combination of those representing activities and IDAs. It thus emphasises the hybrid nature of the server which behaves in the passive manner of an IDA as far as network interactions are concerned but, by virtue of being permitted to contain interrupt handlers, also possesses an active aspect. If the device to which the server is connected is also to be depicted on the diagram, it should be in the form shown below:

The hatched rectangle may, however, may be replaced by a schematic drawing of the device.

Composite Forms
The same symbol is used to represent a template and a component. By definition, a component must be part of a composite template. This may be a system or a subsystem:
which is symbolised by any smooth closed curve, drawn with a thicker line than that used for the \text{simple} entities, but should normally take the form of a rounded rectangle.

For the \text{composite} forms of activity, \text{IDA}, \text{server} or \text{subroot}, the symbols used are the same as for the \text{simple} forms but normally drawn with thicker lines as they are throughout the Handbook.

Alternatively, for all the \text{composite} forms, double lines, or some other convenient locally defined means of making the distinction, may be used. The same convention should be employed to denote \text{composite components} where the information is known and is considered relevant.

\textbf{Paths, Ports and Windows}

Symbols, illustrated below, are defined for \text{simple ports and windows} and the \text{path} which joins them. The lines which denote data \text{paths} may, if desired, be drawn as curves. Arrowheads are used to denote the direction of data flow and should normally be shown.
There are special rules governing the placement of **ports** and **windows** in servers:

The **windows** should appear on the straight edge opposite to the semi-circular end of the symbol and the **ports** on either of the two adjacent sides.

Where **paths** pass through the boundaries of enclosing **composite** design entities, **port** or **window** symbols and data flow arrowheads are repeated at each boundary:

Since any number of **ports**, of the appropriate type, may be connected to a single **window**, diagrams frequently depict **paths** which merge. Normally, these lines are joined at a **window**. However, where it is more convenient, they may be merged at an intermediate point provided that merging is in the direction from **port** to **window**. This is illustrated in the diagram below in which the direction of data flow has deliberately been omitted as irrelevant to the point at issue.

**Subelements and Subelement Links**

The **subelement links**, between the **components** of a **composite activity**, are represented graphically as follows:

Appendix D Graphical Conventions D - 4 Mascot Version 3.1
where the hollow arrowheads indicate the direction of procedure invocation and may be repeated where the link crosses enclosing boundaries:

Links may be merged, in a manner similar to that employed for paths, in the direction of procedure application:

Composit Paths, Ports and Windows

For the template in which a composite access Interface is decomposed into its constituent Interfaces, special symbols are defined to denote the composite ports and windows. At this level of decomposition, the composite path should be denoted by a thick (or double) line, where this is considered relevant:
The port and window at each end of a composite path may be represented by a proportionately larger than normal port or window symbol if so desired.

The internal structure of a composite port is represented by a semi-circle, drawn with a thick line, and with its component ports illustrated inside the boundary.

The internal structure of a composite window is represented by a rectangle, drawn with a thick line, and with its component windows illustrated inside the boundary.
**Annotation**

A template is annotated inside the symbol by the template name. A component of a network is annotated inside the symbol by the corresponding template name and on the outside by the component name. The example given below shows a subsystem template called *merge*. Its components are called *a1*, *a2* and *ch* and are derived from the templates *act_1*, *act_2* and *chan*, respectively.

![Diagram of merge template]

A path is annotated by the name of the corresponding access Interface and windows and ports by their local names:

![Diagram of access interface and path]

A subelement link is annotated with the name of the corresponding subroot Interface and the active end of the link by its local name:

![Diagram of subelement link]

Where a component or template possesses a template constant, the name, type and value of the constant may be shown on the diagram:
and the value may be depicted as being supplied across one or more enclosing boundaries:

```
'value'  data type  constant
        identifier
```

Annotation Options

In the sense of their inclusion in a Mascot diagram, template names and path names are essential but component names and window/port names are less important. This is especially so where no ambiguity arises as, for example, where the components are all derived from different templates or the windows or ports of a template or component are of different (access interface) types.

Extensions

In addition to the name associated with an access interface, it may be considered desirable to annotate a path by the name of the data objects and/or the type of the data objects that flow along the path. This could be indicated by the name of the definition module which defines the type of the object.

Port, window and Interface qualifiers can also be used to annotate the appropriate features of a diagram.

Although intended to denote only one level of decomposition at a time, it is sometimes useful to show multiple levels of decomposition in one diagram. The consequent increase in the amount of information to be conveyed would probably necessitate showing only a subset of that available.

The Mascot diagram can give a one-to-one representation of the information contained in the specification part of a simple module. It is therefore biased towards design expression. However, during design derivation, it may be highly desirable to use 'Mascot-like' diagrams which use a subset of the standard conventions. For example, a path may be identified between two components before the decision is made as to which component possesses the port and which the window (which possesses the 'motive power'). This is acceptable.
For information purposes only, it may be desirable to generate Mascot diagrams showing only a subset of the components (for example omitting pools or channels or servers). Again this is acceptable provided the diagrams are described as such.
APPENDIX E

CLASSIFIED SUMMARY

MAS 704 FRACTURES
CLASSIFIED SUMMARY OF MASCOT FEATURES

Introduction

The purpose of this appendix is to provide a summary of all the Mascot features defined elsewhere in the Handbook and to identify those parts of the definition which are mandatory in any Mascot 3 development environment. These mandatory features have been selected on the basis of a standardisation philosophy whose objectives are to enable products to be assessed for conformance with the definition and to enable designs to be portable between Mascot development environments. This philosophy is presented below.

Philosophy of Standardisation

As the first element in the philosophy of standardisation, every effort has been made to define all the Mascot features in an unambiguous manner. Secondly, a mandatory subset of the definition has been identified. This is reflected in the order of presentation of material in the Handbook sections on the design representation facilities and is summarized for reference at the end of this appendix. All mandatory features must be provided by any Mascot 3 development environment. Where features not included in this subset are implemented, they are required to conform to the definition given in the Handbook.

The third element of the philosophy is the requirement that a development environment include adequate linguistic support for the features which are mandatory. The design representation language used in the Handbook provides definitive guidance as to what cannot need to be expressed but need not necessarily be literally implemented. The linguistic support may take the form of an Additional Features design language (e.g., Coral 2 for Mascot 2) for the programming language or languages supported by the development environment. This should be considered the preferred option as it will reduce the resources required to verify design compliance of Mascot software and will enhance software portability.

Alternatively, the Mascot 3 module classes could be implemented in a native programming language, without additional features, by a code of practice. In this case the mapping of each characteristic of each module class onto the programming language must be defined as part of the code of practice. This should be done in a form which provides a suitable basis for tool development for transporting a design and for design conformance checking or other verification of application software designs.

The fourth element of the philosophy is that module classes do not need to be supported in full. A mandatory subset of characteristics has been defined for each class. Thus the definition contains characteristics which not all development environments will implement even within the mandatory classes. This element of the philosophy guarantees a minimum level of portability as it defines the
minimum characteristics of all Mascot 3 development environments. It also defines the minimum set of characteristics which must be provided for each non mandatory module class implemented. Where a non mandatory characteristic is supported it must be supported in all appropriate module classes. It is recognised that design authorities may wish to control or restrict the use of certain facilities, such as direct data visibility, and therefore warning reports of their use may be generated by a development environment.

The fifth and final element of the philosophy concerns extensions to Mascot 3. It is recognised that the definition cannot be maintained, either in scope or in functionality, in advance of users' requirements and that therefore certain applications will need facilities added to their development environments that are not covered in the Mascot 3 definition. Implementing a superset of the facilities, whilst not encouraged, is therefore permitted. Implementors must define fully any extensions provided and must declare them to any testing authority so that they may be documented in a test report. Such additional features must not, of course, interfere with or partially overlap any of the defined facilities.

The Mandatory Subset

The mandatory facilities have been divided into three categories: module classes, commands and primitives. The mandatory facilities specified below must be provided by all Mascot 3 development environments. However, users are not obliged to use all the mandatory features. Thus, for example, all development environments must support the use of the WITH keyword within access interfaces. However, it is possible to have a syntactically correct access interface which does not use the feature. It is not required that support for unused features be present in target systems.

(a) Module Classes
The diagram of Appendix B shows the complete set of Mascot module classes, the mandatory subset being highlighted by means of a shadowed font. All Mascot 3 development environments must provide these classes. The first of the tables below specifies all the defined characteristics of the subset and identifies, with an M for mandatory, those features which it is obligatory to provide.

The second table specifies all the features of the non-mandatory module classes. Mascot 3 development environments which support any of these classes must provide support for use of the characteristics identified with an M.

The third table specifies the features of particular module classes which become mandatory when specific non mandatory features are supported.

(b) Commands
It is mandatory to provide facilities for registration, introduction, enrolment, building, initialisation and starting which accord with the Mascot definition. They may be provided in one of two ways: either
explicitly through a command interpreter in the form shown in the fourth table below, or by use of other user facilities such as those provided by most computer operating systems. When a command interpreter is not being used the documentation of the Mascot development environment must define explicitly how the functions are provided.

(c) Primitives

There are no mandatory primitives in Mascot 3. However, there are inter-dependencies between the primitives described in the Handbook. The fifth of the tables below divides these primitives into sets which are required to be implemented together as a group. It also indicates which of the other primitive groups are also mandatory for each group supported.
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## 2. CHARACTERISTICS OF NON-MANDATORY MODULE CLASSES

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<td>M Procedure specifications</td>
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<td>M Variable specifications</td>
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<td>M Read-only data constants</td>
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<td>LIBRARY INTERFACE</td>
<td>M WITH</td>
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<td>M Procedure specifications</td>
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<td>M Read-only data constants</td>
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<td>Window-to-port equivalence</td>
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Appendix E Summary of Features  E - 7  Mascot Version 3.1
## 3. MANDATORY GROUPS OF MASCOT 3 MODULE CLASSES

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Group</th>
<th>Requirements</th>
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<tr>
<td>COMPOSITE ACTIVITY</td>
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<td>ROOT SUBROOT</td>
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<td>COMPOSITE SUBROOT</td>
<td>Implement COMPOSITE ACTIVITY group</td>
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<td>LIBRARY</td>
<td>LIBRARY INTERFACE</td>
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<td>LIBRARY template</td>
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<td></td>
<td></td>
<td>Support library</td>
</tr>
<tr>
<td></td>
<td></td>
<td>instantiation at least in SYSTEM</td>
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Appendix E Summary of Features  
Mascot Version 3.1
4. MANDATORY GROUPS OF MASCOT 3 OPERATIONS

<table>
<thead>
<tr>
<th>Group Name</th>
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<tr>
<td>Status progression</td>
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<td>Building</td>
<td>BUILD</td>
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<tr>
<td>Execution Control</td>
<td>INITIALISE START</td>
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### 5. GROUPS OF MASCOT 3 PRIMITIVES

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<tr>
<th>Group Name</th>
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<tr>
<td>Control Queue</td>
<td>JOIN</td>
<td>Control Queue</td>
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<td>WAIT</td>
<td>Control Queue</td>
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<td></td>
<td>STIM</td>
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<td>Basic Interrupt</td>
<td>STIMINT</td>
<td>Control Queue</td>
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<td>ENDHANDLER</td>
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<tr>
<td>Interrupt Connection</td>
<td>CONNECT</td>
<td>Basic Interrupt</td>
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<td>DISCONNECT</td>
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<td>RESET</td>
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If any primitive in a group is implemented then all primitives in that group and in any 'groups required' must be implemented.
MASCOT GLOSSARY

Access Interface
A specification defining the possible interactions (eg procedure specifications) between the components connected by a path. In its composite form it comprises a set of other access Interfaces.

Access Procedure
A procedure, implemented in an IDA or server, and corresponding to a procedure heading specified in an access Interface to which a window specification of the IDA or server refers. It provides a network interaction along a connected path of the appropriate type.

Activity
The Mascot design entity representing a single independent information processing element. An activity module is a template which may be used to create activity components each of which is an independently scheduled single sequential program thread, conceptually executing in parallel with other activities. An activity usually specifies one or more ports each of which defines a connection to be established from the activity to a window on a neighbouring component in the execution environment. A composite form of activity is provided for sequential program decomposition in terms of subelements known as roots and subroots.

Building
The process by which executable software is created from its defining templates, which must have achieved fully enrolled status.

Channel
A special case of an IDA having destructive read properties. The channel provides facilities for transmission of information.

Class
The category of a Mascot design entity. Design entities are grouped into specifications and templates. Specifications comprise the classes: access Interface, subroot Interface, library Interface and definition. Templates comprise the classes: system, subsystem, activity, channel, pool, IDA, server, root, subroot and library.

Component
A constituent of a composite template. The type of a component is identified by the name of the template which is used in the definition of the component.
Composite

A composite module is one which is further decomposed in terms of lower level modules. For specifications the decomposition is in terms of the same class of specification. For templates the decomposition depends on the class of the template. The only specification with a composite form is the access interface. The following templates have composite forms: system, subsystem, IDA, server, activity, subroot.

Context

That part of the executable software which supports (but is not part of) the application software defined by the system template. It implements the facilities specified in the context interface.

Context Interface

A special form of specification which defines the facilities offered (implicitly) by the context to all applications modules. It is usually a collection of other specifications.

Control Queue

An object, declared in an IDA, which may be operated upon by a set of primitives to ensure mutual exclusion and cross-stimulation between activities. The relevant primitives are CHECK, JOIN, LEAVE, STIM, STIMINT, WAIT, WAITFOR.

Definition

A specification defining a set of data types and named constants for use by simple interfaces and simple templates. It may refer to other definition modules.

Element

A fundamental Mascot design entity: simple activity, simple IDA, simple server, composite activity.

Enrol

The enrol operation checks that the name part, specification part and implementation part of a template module have been defined and are legal. It may involve using information in the specification parts of the modules to which it refers. If the checking is successful, then the module will be accorded partially or fully enrolled status, depending upon the type of the module itself and on the status of the modules to which it refers.

Fully Enrolled

A status value achieved by a template module as a result of a successful enrol operation. For a composite template, the status indicates that all the templates which define the module's components have also achieved fully enrolled status.
Fully Introduced A status value achieved by a module as the result of a successful Introduce operation. The status indicates that all specification modules referred to in the module's specification part have also achieved fully Introduced status.

Handler A routine invoked as a direct consequence of a hardware interrupt. All handlers are located within servers.

IDA The Mascot design entity representing a passive independent information storage or information transmission element. In the simple form it contains both shareable data and the access mechanisms which can operate on this data; these access mechanisms safeguard the integrity of information within or passing through an IDA and sustain information propagation for intercommunication between activities. An IDA module is a template which may be used to create IDA components each of which allows several independently scheduled single sequential program threads to be simultaneously active or suspended within the IDA. An IDA specifies one or more windows defining the connections which can be established from ports on neighbouring components in the execution environment. An IDA may also specify ports each of which defines a connection to be established from the IDA to a window on a neighbouring component; such ports allow data to be projected from one IDA to another with no intervening activity. A composite form of IDA is provided for network decomposition in terms of internal IDAs.

Implementation part The part of a template module which defines the internal details of the template. For simple templates it defines the data and algorithms together with references to the required definitions and library interfaces. For composite templates it defines the components and their interconnections. For simple templates this corresponds to the information necessary to achieve fully enrolled status. For composite templates it corresponds to the information required to achieve at least partially enrolled status.

Interface A specification for a connection between two components. There are three types of interface: access interface, library interface, subroot interface. An interface may refer to one or more definitions to import supplementary specifications.

Introduce The introduce operation checks that the name part and specification part of a module have been defined and are legal. If the checking is successful, then the module will be accorded partially or fully Introduced status, depending upon the status of the modules to which it refers in its specification part.
Library

The Mascot design entity implementing the set of procedures specified in one or more library interfaces. This module supports procedural decomposition of simple templates and must be capable of multi-threaded operation. It differs from an IDA which is also multi-threaded in that there is no interaction between the threads.

Library Interface

A simple specification defining the operations which a library makes available to any simple template.

Link

A control flow connection from one subelement to another. Its diagrammatic representation is a line which carries a hollow arrowhead to indicate the direction of invocation. The type of a link is a subroot interface which defines the nature of the interactions between these subelements.

Mascot Database

The collection of all Mascot modules, their status and their derived products known to a particular support environment.

Module

A textual unit (or possibly a set of such units) representing a specification or a template. It possesses an explicit class which reflects its contents. In their completed form, all classes of module have a name part and a specification part, and in addition the template modules have an implementation part.

Name part

The section of a module which defines the class and name of the template or specification which the module represents.

Network

A set of interconnected Mascot components (elements and other networks) which constitutes the whole (system) or part (subsystem, composite IDA, composite server) of a Mascot application.

Partially Enrolled

A status value given to a composite template module for which the enrol operation was successful, but which failed to achieve fully enrolled status. It indicates that at least one of the templates which define the module's components has not yet achieved fully enrolled status.

Partially Introduced

A status value given to a module for which the introduce operation was successful, but which failed to achieve fully introduced status. It indicates that at least one of the specification modules referred to in its specification part has
not yet achieved fully introduced status.

Path

A data flow connection between a port of one component and a window of another. Its diagrammatic representation is a line which normally carries a solid arrowhead to indicate the direction of data flow. The type of a path is an access interface which defines the nature of the interactions between these components. A composite form of path is available, where the type of the path is a composite access interface.

Pool

A special case of an IDA having destructive write properties. Data in a pool is overwritten on a write operation but may be read repeatedly.

Port

A named reference to an access interface by means of which a template expresses its requirement for interactions with other templates. Externally it expresses a connectivity constraint of the template. Internally, the port name is used as a means of selecting between ports. A port is the active end of a path. Its diagrammatic representation is a small filled circle on the boundary of a component. A composite form of port is available.

Registered

A status value indicating that the name part of a module has been defined and is legal.

Root

The Mascot design entity representing the subelement which contains the initial entry point of a composite activity. A root usually specifies one or more subroot interfaces which define connections to be established to subelement components in the same activity. A root may also specify one or more ports each of which defines a connection to be established from the root component to a port of the enclosing activity. A root module is a template which may be used to create root components.

Server

The Mascot design entity representing a single independent device handling element; it is the only form of design entity which can be used for this purpose. It has all the features of an IDA and in addition may contain one or more handler routines to be invoked as a direct consequence of hardware interrupts. A server module is a template which may be used to create server components each of which allows several independently scheduled single sequential program threads to be simultaneously active or suspended within the server. A composite form of server is provided for network decomposition in terms of internal servers and IDAs.
Simple  A simple module is one which is not further decomposed in terms of lower level modules. Some templates and all specifications have a simple form which is described in detail under the appropriate heading. The following templates have simple forms: activity, IDA, server, root, subroot, library.

Specification  A module defining an interface or definition. All have a simple form but only an access interface may be composite.

Specification part  The part of a module which specifies the external view of the template or specification which it represents. In the case of a specification, it completes the module. In the case of a template, it contains sufficient information for components of that type to be included in a composite template. It also constrains the implementation part. It corresponds to the information required to achieve at least partially introduced status.

Status  An attribute associated with a module indicating the degree of progress made in the definition and checking of the module and of any other modules to which it refers, and hence indicating its fitness for use by other modules. Five status values are defined: registered, partially introduced, fully introduced, partially enrolled and fully enrolled.

Subelement  A Mascot entity supporting sequential decomposition of an element or subelement (ie a root or subroot).

Subroot  The Mascot design entity representing a subelement. A subroot specifies a single subroot interface defining the connections which may be established from other subelement components in the same activity. A subroot may specify one or more subroot interfaces which define connections to be established to other subelement components in the same activity. A subroot may also specify one or more ports each of which defines a connection to be established from the subroot component to a port of the enclosing activity. A subroot module is a template which may be used to create subelement components. A composite form of subroot is provided for decomposition in terms of internal subroots.

Subroot Interface  A simple specification defining the possible interactions (eg procedure specifications) between the components connected by a link.
Subsystem
A network representing part of a Mascot application. Subsystems may possess both ports and windows and may therefore communicate directly with each other. Where a subsystem contains no activity, either directly or indirectly, it is functionally identical to a composite IDA or a composite server.

System
A network representing the outermost level of software description. When supported by all the modules referred to explicitly or implicitly, it constitutes a complete Mascot application software description.

Template
A pattern from which components may be created during building. The creation of these components is controlled by definitions within composite templates.

Template Constant
A constant, named in the specification part of a template, for use within the implementation part. Its value is usually supplied when components to be created from the template are named in a (higher level) composite template. In the case of a system template, the value is supplied as part of the building process.

Window
A named reference to an access interface by means of which a template expresses the interactions it provides for use by other templates. Externally, it expresses a connectivity constraint of the template. Internally, the window name is used as a means of allocating internal features between windows. A window is the passive end of a path. Its diagrammatic representation is a small filled rectangle on the boundary of a component. A composite form of window is available.