GRASP/Ada

Graphical Representations of Algorithms, Structures, and Processes for Ada

The Development of a Program Analysis Environment for Ada

Reverse Engineering Tools For Ada

Task 2, Phase 2 Report

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1.0 INTRODUCTION

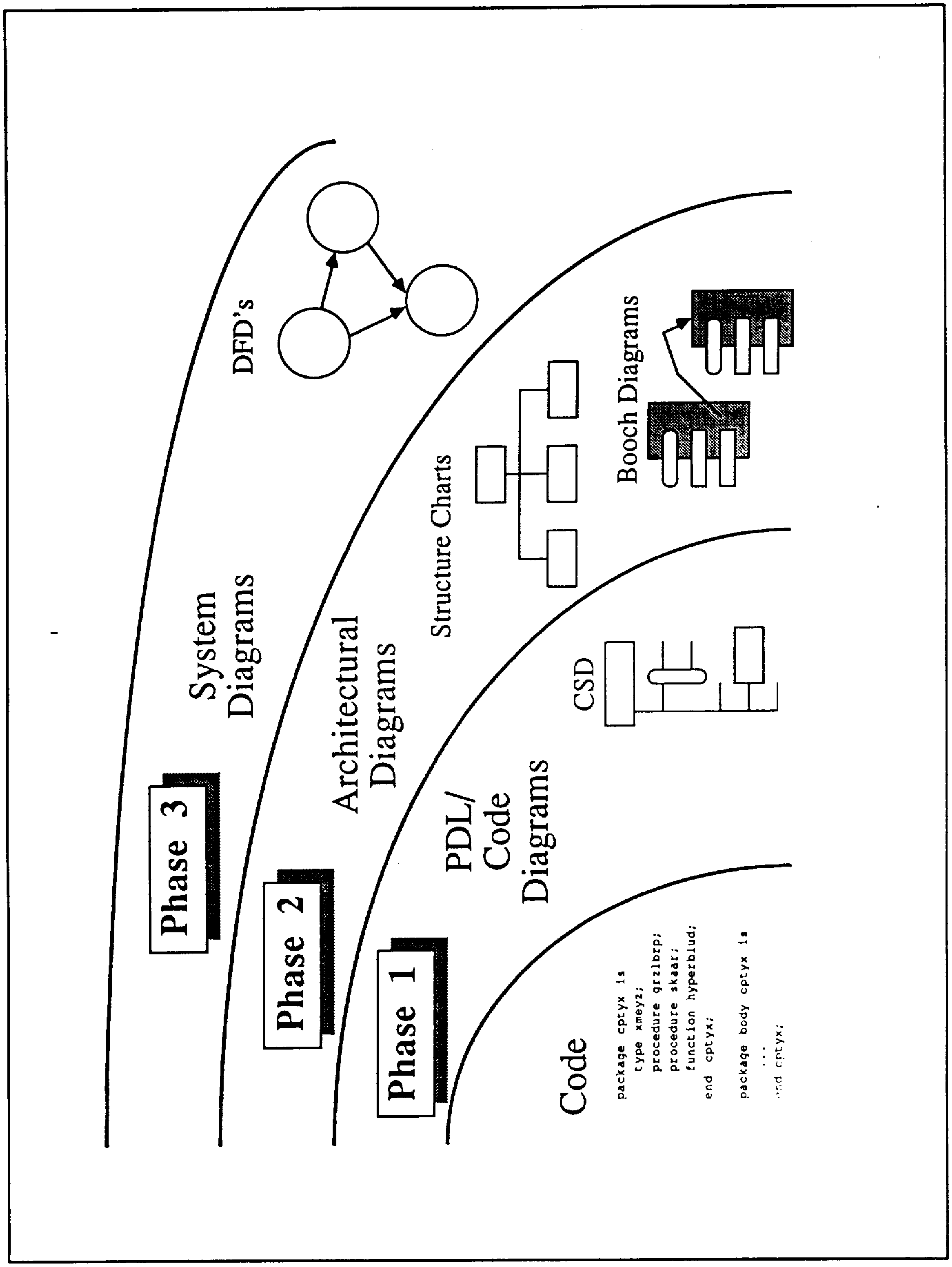
Computer professionals have long promoted the idea that graphical representations of software are extremely useful as comprehension aids when used to supplement textual descriptions and specifications of software, especially for large complex systems. The general goal of this research is the study and formulation and generation of *graphical representations of algorithms, structures, and processes for Ada* (GRASP/Ada). The present task, in which we describe and categorize various graphical representations that can be extracted or generated from source code, is focused on *reverse engineering*.

Reverse engineering normally includes the processing of source code to extract higher levels of abstraction for both data and processes. Our primary motivation for reverse engineering is increased support for software reusability and software maintenance, both of which should be greatly facilitated by automatically generating a set of "formalized diagrams" to supplement the source code and other forms of existing documentation. The overall goal of the GRASP/Ada project is to provide the foundation for a CASE (computer-aided software engineering) environment in which reverse engineering and forward engineering (development) are tightly coupled. In this environment, the user may specify the software in a graphically-oriented language and then automatically generate the corresponding Ada code [ADA83]. Alternatively, the user may specify the software in Ada or Ada/PDL and then automatically generate the graphical representations either dynamically as the code is entered or as a form of postprocessing. Appendix A contains a comprehensive taxonomy of reverse engineering, including definitions of terms.

Figure 1 shows the project divided into three phases, each of which corresponds to one of the following broad categories of graphical representations: (1) algorithmic (PDL/Code), (2) architectural, and (3) system level diagrams. Each of these categories may contain overlapping entries that depict, for example, data structure, data flow, or other useful relationships. Phase 1 of GRASP/Ada has been completed and a new graphical notation, the Control Structure Diagram (CSD) for Ada and supporting software tool is now being prepared for evaluation [CRO88, CRO89]. In Phase 2, the focus is on a subset of Architectural Diagrams that can be generated automatically from source code with the CSD included for completeness. These are described briefly in the order that they might be generated in a typical reverse engineering scenario. Phase 3 is described briefly in the final section of this report, entitled "Future Work."

1.1 Algorithmic Diagrams (PDL/Code)

As the complexity of software has increased, so has the utility of graphical representations for algorithms. The industry has progressed well beyond the simple constructs of sequence, selection and iteration promoted by the theory of structured programming in the 1970's. For example, Ada includes control constructs for concurrency (tasks and task rendezvous), exception handling, and loop exits, none of which fits well into the simple sequential control constructs of structured programming. Since the ANSI flowchart was introduced in the mid-50's, numerous notations have been proposed and utilized [MAR85, TRI89]. These notations typically include control



```
package cptyx is
   type xmeyz;
      procedure grzlbrp;
      procedure skaar;
      function hyperblud;
end cptyx;

package body cptyx is
   ...
end cptyx;
```

Figure 1. GRASP/Ada Overview

constructs for sequence, selection, and iteration, and several include constructs for concurrency and exits; however, none explicitly contains all of the control constructs found in Ada.

For the GRASP/Ada project, the Control Structure Diagram was selected as a basis for a graphical representation that maps directly to Ada control constructs. The CSD is a graphical notation intended to increase the comprehensibility of Ada PDL or source code by explicitly depicting control constructs and control flow. The traditional textual representation of PDL or source code has been extended with intuitive graphical constructs which are easily adaptable to editors and printers. The CSD has the attractive property that it has the appearance of being overlaid directly on prettyprinted Ada code. In fact, a CSD generator may be perceived as a "graphical prettyprinter." Appendix B contains a paper, entitled "Control Structure Diagrams For Ada," which describes and illustrates the CSD graphical constructs.

1.2 Architectural Charts and Diagrams

The next level of diagrams in the reverse engineering process is a group commonly known as architectural diagrams. Structure charts, data structure diagrams, and entity-relationship diagrams are traditional examples of these. The object/package diagram is a relatively recent addition at this level. Structure charts, object/package diagrams, and a collapsed version of the control structure diagram have been targeted for prototyping in Phase 2. Structure charts and object/package are each discussed briefly below in the context of automatically generating the diagram from source code or PDL. *Structure charts* are one of the oldest and potentially most useful diagramming notations available. We use the term here in the generic sense to refer to those charts and diagrams that depict the overall hierarchical organization of a software system without concern for the algorithmic details. In this sense, the structure chart is simply an invocation graph of functions and procedures in which redundant calls are omitted. IBM's HIPO, and Yourdon's structure chart are common examples in this category. Some versions indicate data items along the control lines between procedures to show data flow as well as limited detailed control flow information such as selection and iteration.

The structure chart offers the user a high-level solution-oriented view of the software. Although algorithmic details are suppressed, the user can still get a sense of what is going on from the perspective of solving the problem as well as a feel for the layers of procedures and functions involved. Unfortunately, structure charts generated during initial development of a system are rarely kept current without the aid of a CASE tool which links the diagram and corresponding code. A major role of reverse engineering in a CASE environment is to ensure the availability of an accurate set of structure charts as well as graphical representations for other software views such as algorithmic and data flow.

Automatic generation of structure charts from source code is relatively straightforward. In the case of Ada, the abstract syntax tree built during the parse must be traversed, capturing procedure and function calls (a task rendezvous has the appearance of a procedure call). A call to a procedure or function results in the traversal of its abstract syntax tree. Redundant calls from a single procedure are normally captured but not displayed. Data items and their direction of flow are identified syntactically by their IN, OUT, or INOUT designation in the parameter list. Additional program analysis is required to determine references to non-local variables that are not formal parameters.

The *Object/package diagram* made popular by Booch is a recent architectural level diagram that is useful for object-oriented software [BOO83, BOO86, BOO87a, BOO87b]. The object/package diagram shows all of the dependencies among packages and package components. This is an important view of the software with respect to its construction or composition from parts. For example, an Ada package may be used for encapsulation of types and operations to form abstract data types. These packages can then be considered objects from an object-oriented development perspective.

Object/package diagrams are generated from a syntactical analysis of the Ada source code. The basic dependencies are defined by the WITH clause. The actual package components that are utilized are determined by references to types, procedures and/or functions exported by the package. These objects or packages can be further graphically encoded by using icons, shading, and coloring.

Preliminary analysis has revealed that structure charts and object/package diagrams are complementary in nature and, furthermore, that in isolation each affords a somewhat incomplete view of the software. The hierarchical or layered structure chart is easily related to the software solution of the problem. That is, a reader can discern "what" is being done with respect to solving the problem or, from a reverse engineering perspective, which problem is being solved. The object/package diagram, on the other hand, offers a view of component packaging (e.g., how data and operations are packaged into objects). While Booch points out that the object/package diagram is much closer to the data flow diagram of the general specification of the problem (e.g., external entities and data stores become objects), it has been our experience that the dependencies shown in the object/package diagram provide little or no information regarding the interaction of the objects and operations. The structure chart and ultimately the control structure diagram do supply the additional information necessary for complete comprehension of the solution.

The remainder of this report is organized as follows. Section 2 discusses architectural diagrams that are currently in use, a brief review of efforts to extract architectural diagrams from source code and provides a summary of several general trends in visualizations in computing. Section 3 provides a discussion of the problem Phase 2 of the GRASP/Ada project is addressing. Section 4 provides a statement of requirements and a description of the prototype that is currently being developed to support the automatic generation graphical representations from Ada source code. These requirements include functional, interface, hardware, and system software. Section 5 provides an overview of Phase 3 of GRASP/Ada.

2.0 ARCHITECTURAL DIAGRAMS IN CURRENT USE

In this section, the term "architectural diagram" and other related terms are defined. This is followed by a brief survey of recent as well as traditional architectural diagrams which have been used for Ada. The specific needs for architectural diagrams for Ada software are examined. This section concludes with a brief discussion of trends in visualization for computing in general.

2.1 Definitions

An *architectural diagram* (AD) may be defined as follows: a graphical representation of the logical components of a software system, the interfaces between such components, and the hierarchical relationship among the components.

Logical components of a software system are those structures which group statements and components into cohesive units. In Ada, these structures include the package, procedure, function, and task. Most well-designed logical components are functionally cohesive, each providing a single and specific service.

The *interfaces* between the logical components of a software system show the invocation convention for communicating between components, including any parameters which are passed. Although in the simplest case there may be no parameters passed between a given set of components, usually parameters consist of items of complex types and, in the case of Ada, may even include tasks.

The *hierarchical relationship* among the logical components of a software system is shown as a utilization hierarchy. A connection between any two components represents a resource usage of one component by the other.

Two other terms that are of use when referring to hierarchical diagrams are *visibility* and *connectivity*. Each is a term referring to the scope of a given software component. Visibility refers to the set of components that may be invoked by a given component, regardless of whether the code actually specifies an invocation of such components. Connectivity refers to the set of components that are explicitly invoked by a given software component in the source program.

2.2 Graphical Representations for Architecture

In this section, several architectural diagrams currently in use are briefly discussed. This is followed by a brief review of representative efforts to extract architectural diagrams and related information from source code.

2.2.1 Common Architectural Diagrams

Perhaps the best-known architectural diagram is the traditional *structure chart* made popular by Yourdon and Constantine (see Figure 2). This diagram represents the architecture of a system using a set of boxes representing functions and procedures connected by lines indicating invocation. Small arrows are arranged along the lines of invocation to depict the flow of data between the modules. Typically, data flows are of two types: "pure" data items, which may be either simple or complex data types, and control data items, which are used to determine the execution of the invoked procedure.

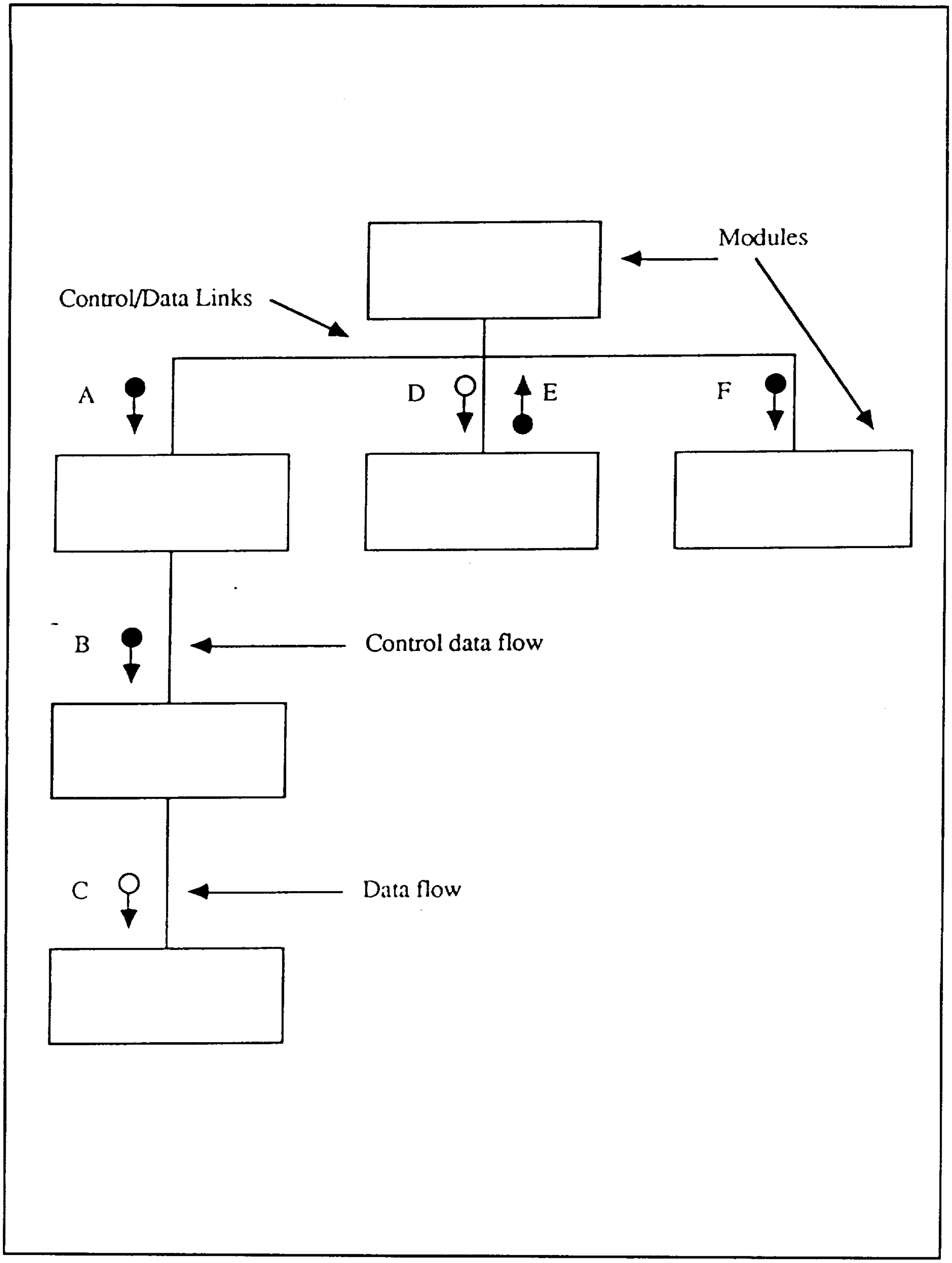


Figure 2. Structure Chart

Although the traditional structure chart is useful for depicting the architecture of systems written in simple languages such as Pascal, it lacks in the capability to represent advanced features found in Ada such as tasking and generic instantiation of procedures from templates.

CAEDE (Carleton Embedded System Design Environment) is a software CAD system developed at Carleton University by Buhr [BUH89] that uses modified *Buhr diagrams* to represent the architecture of an Ada program (see Figure 3). The structural CAEDE diagrams are block-oriented and include distinct symbols for tasks, packages, and procedures. Although the CAEDE system does include graphical representations for all of the Ada architectural components, it does not represent generics well. In addition, the nesting required to produce an accurate CAEDE diagram for a typical Ada program can become cumbersome. At this time, there is no existing tool for generating CAEDE diagrams from existing code.

OOSD (Object-Oriented Structured Design), developed by Wasserman [WAS89], is a method for designing the architecture of systems. The heart of OOSD is the *OOSD design chart*, a modified structure chart, that describes a set of architectural components, their invocation hierarchy, and the parameters passed among them (see Figure 4). At a lower level, information clusters provide an object-oriented description of the components depicted on the design chart. Because OOSD is designed to be language-independent, it does not correspond exactly to Ada, and therefore does not directly support all Ada features, especially the tasking constructs. On the other hand, OOSD does allow the designer to utilize some features that Ada does not provide. At this time, there is no existing tool for generating OOSD diagrams from existing code.

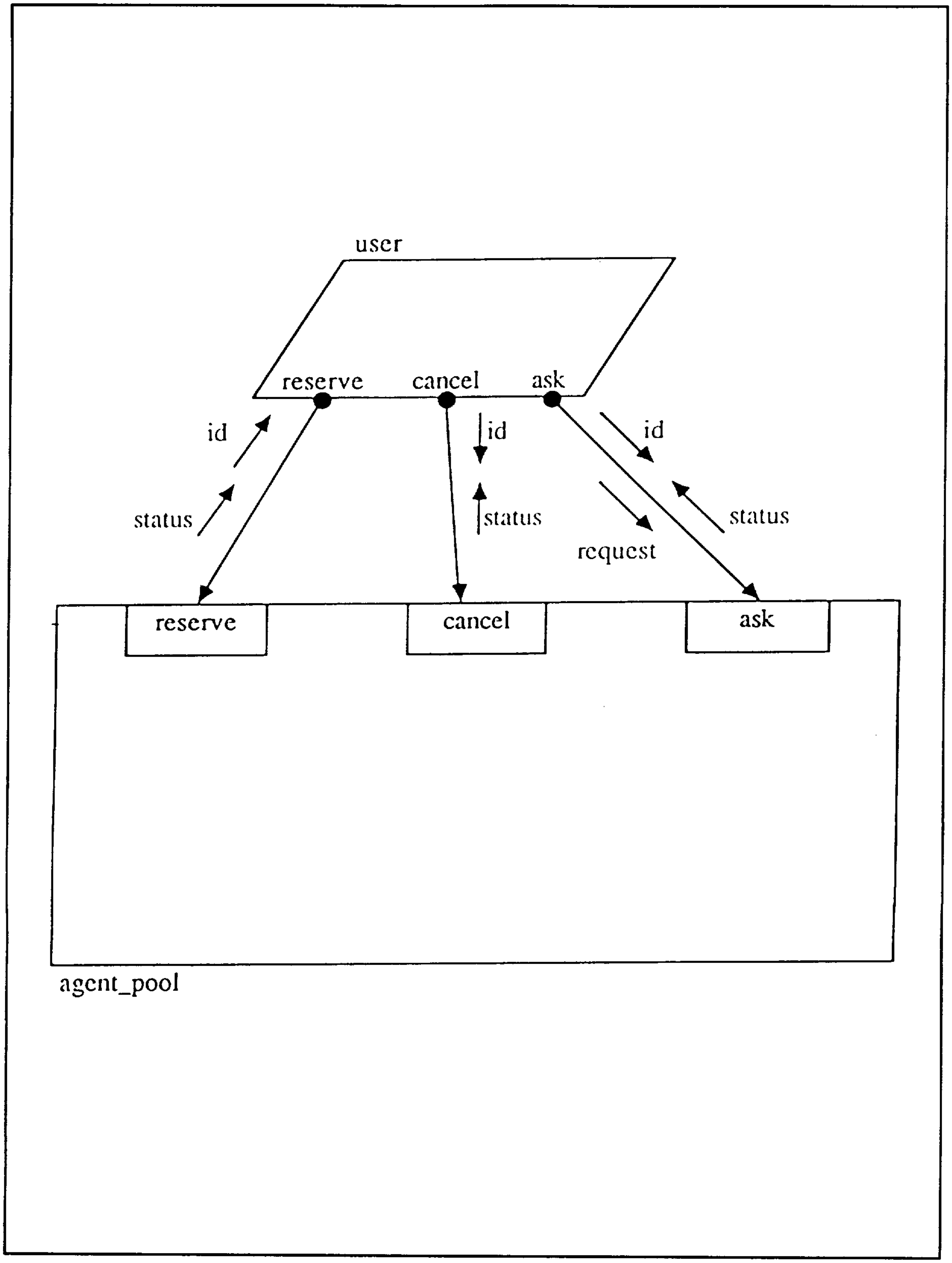


Figure 3. Buhr Chart

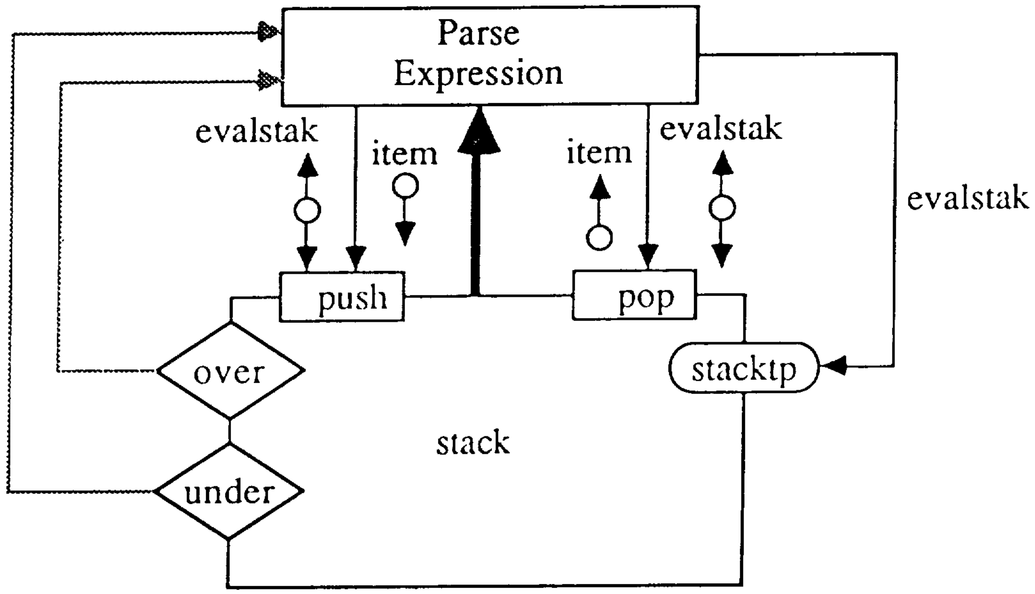


Figure 4. Example of an Information Cluster in OOSD

Hamilton Technologies, Inc., has developed an integrated hierarchical, functional and object-oriented modeling approach collectively called 001 technology. The 001 technology is based, in part, on USE.IT developed by Higher Order Software (HOS) [HAM79]. In 001, a system is defined in terms of a single control map which integrates both *function control maps (FMaps)* and *type control maps (TMaps)*, where an FMap defines a hierarchy of functions and a TMap defines a hierarchy of abstract types. The underlying specification language for these maps is 001 AXES, which is based on a set of control axioms derived from empirical data gathered during the development and operation of the existence of a universal set of objects. The leaves of the maps represent primitives implemented in a language for a particular native computer environment. When a system specified in 001 AXES is processed by the "Resource Allocation Tool," the result is a complete system in the source language of the primitives.

PAMELA (Process Abstraction Method for Embedded Large Applications) is a methodology developed by Cherry [CHE86] and supported by the *AdaGRAPH* environment on the IBM PC. A specification is written in PAMELA by first describing a system as a collection of flow diagrams. Next, the analyst is prompted to answer certain questions about each of the processes in the flow diagrams, resulting in corresponding annotations to the diagrams. Finally, the analyst completes the skeleton code generated from the flow diagrams by filling in the algorithmic details which can not be generated from the diagrams. It is interesting to note that the "automatic code generation" provided by PAMELA falls mainly into the area of providing correctly specified modules and communications between these modules. Generating procedural code is left to the analyst, although the AdaGRAPH environment does provide facilities for simplifying this.

IORL (Input/Output Requirements Language) is a high-level requirements language developed for the design of real-time embedded systems with the TAGS (Technology for the Automated Generation of Systems) methodology [SIE85]. TAGS embodies the hierarchical top-down development of a system, and relies upon graphical representations to present control flow within a process and data flow among different processes executing simultaneously (see Figure 5). A system may be viewed at any time from a number of levels: from a very high level showing an overview of the entire system, from a very low level showing the IORL primitives that make up a process, or from any level in between. The latest release of IORL utilizes an icon-oriented interface for the easy creation of IORL diagrams. Currently, Teledyne Brown Engineering is working on a "Simulation Compiler" which will significantly enhance the TAGS development environment by facilitating simulated execution of the IORL specification.

Booch diagrams [BOO83] provide a graphical representation of the architectural components of Ada along with some dependency information (see Figure 6). Experience indicates that the graphical representation of large systems using Booch diagrams often leads to a network decomposition rather than a strict hierarchical control organization. In addition, at the present time, only primitive tools exist for the extraction of Booch diagrams from Ada source code.

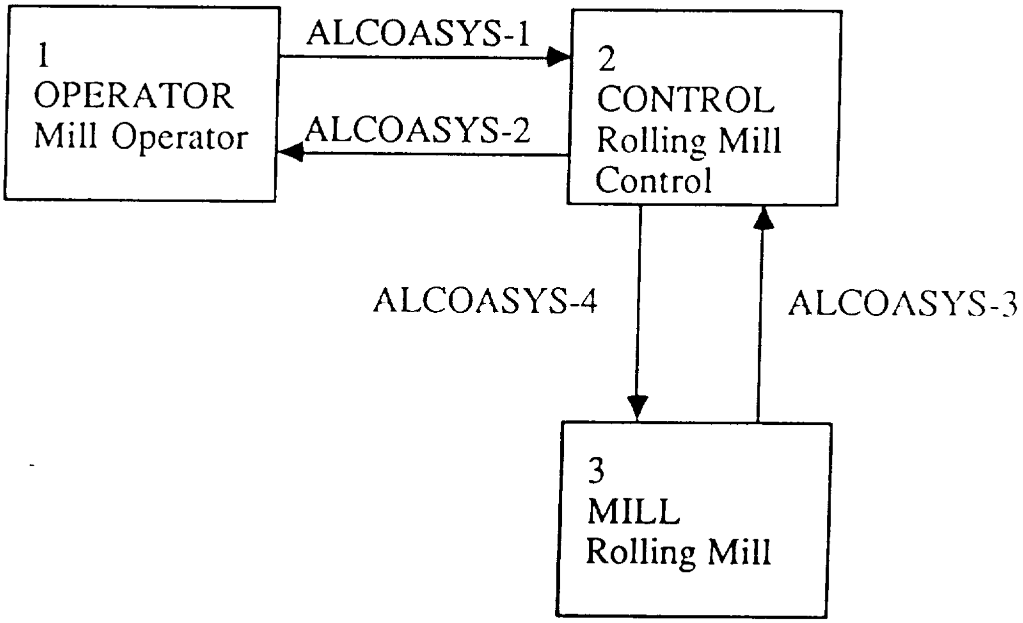


Figure 5. Example of a Schematic Block Diagram (SBD) in IORL

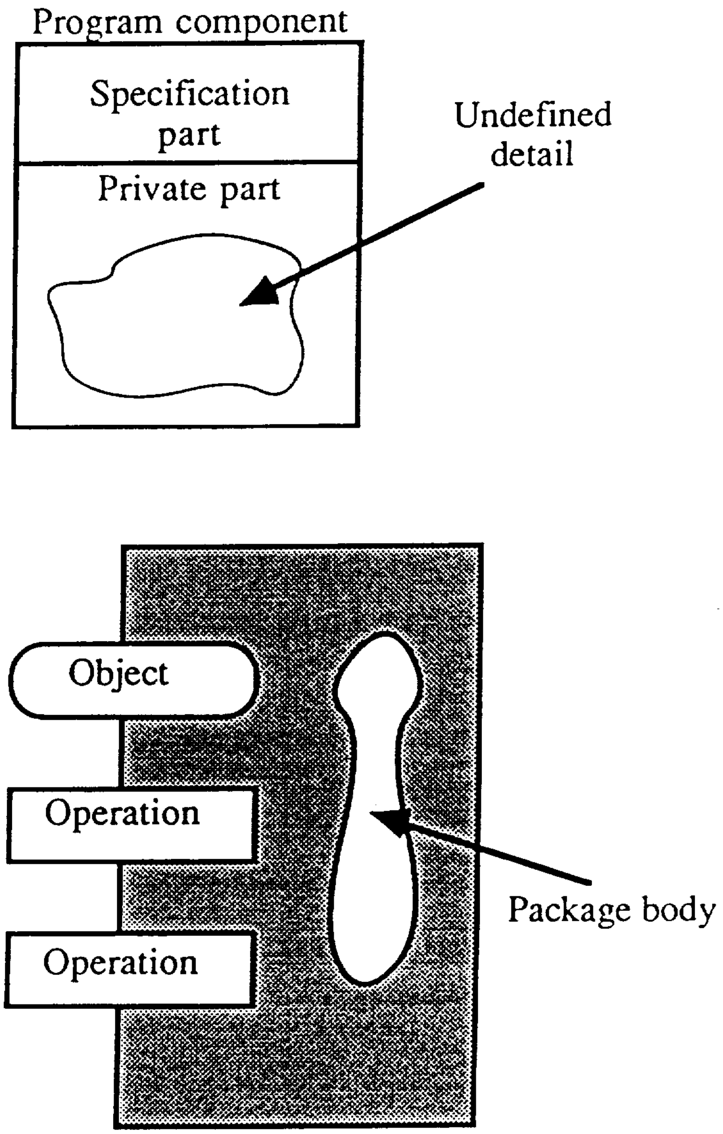


Figure 6. Examples of Booch Diagram Components

2.2.2 Extraction of Architectural Diagrams from Source Code

Numerous efforts to generate architectural diagrams and related information can be found in the literature. Most CASE tool vendors (e.g., those cited in the previous section) are attempting to develop reverse engineering capabilities which will enable the user to redocument existing software using their systems. Several other research efforts which are representative of those currently underway are briefly described below.

Choi and Scacchi at the University of South California have developed a module interconnection language called NuMIL from which hierarchical diagrams may be extracted [CHO90]. A NuMIL description of the source code is generated, and this description is analyzed in terms of resource flow among the various modules in the system, where resources include data types, procedures, and variables. Application of a restructuring algorithm then provides a hierarchical description of the system. It is interesting to note that the USC approach tends to focus on the extraction of the structural design and not its presentation. The graphical representation of the extracted information has not been addressed.

ARCH is a system developed by Schwanke et. al. of Siemens Corporate Research, Inc., to extract and display the structure of C programs [SCH89]. It uses a many-to-one mapping from the target program to a structure chart to abstract a large system into a form that may be easier to understand. The basis of the mapping is the data used by the various procedures in the target program: modules which operate on common data are assumed to be related and are grouped in subsystems. As with the NuMIL project at USC, the ARCH project has tended to focus more on the extraction and not the presentation of a system's structure.

DESIRE is a prototype of a design recovery tool developed by Biggerstaff of the Microelectronics and Computer Technology Corporation that analyzes a C program and produces a web that displays the relationships between the program's data and modules [BIG89]. The web is presented using a hypertext system, and the program structure is represented by links among the module names. The web is not hierarchical and does not make use of any graphical representations, nor does it depict the data flow passed between modules.

PathMap is an analysis tool developed by O'Brien of the Microcase Division of Cadre Technologies that works with Cadre's Teamwork/SD to produce annotated Constantine structure charts with information about the target program's runtime performance [OBR89]. The runtime data includes a count of the number of times the program was invoked and the percentage of CPU time it consumed. These items are represented in much the same way on the structure chart as parameters that are passed among modules. Other than this, PathMap provides no other graphical extensions or modifications to the Constantine structure chart.

2.3 Architectural Diagrams for Ada

Components of the Ada programming language that must be considered when developing architectural diagrams are examined below. This is followed by a discussion of special issues pertaining to the Ada programming language that must be considered during the development of any practical architectural diagram for Ada.

2.3.1 Architectural Components of Ada

Most high level programming languages have very few architectural components. For example, Pascal has only procedures, functions, and a single main program. However, Ada is much more complex, with constructs that are difficult to represent using traditional architectural diagrams. In this section, the architectural components of the Ada programming language are examined.

The architectural components of Ada may be subdivided into two categories: logical and physical. The logical components are those structures defined within the language that serve to group sets of logically related statements or components. The physical components are those components which serve more to assist the Ada compiler rather than the Ada programmer.

There are five logical components in the Ada programming language: packages, procedures, functions, tasks, and operators. Packages are structures which serve to group the other logical components into cohesive modules. Procedures, functions, and tasks are much alike in that they are small threads of executable code that generally provide a single specific service. Operators may be considered a special case of function that may take one or two arguments. Although operators are predefined in most programming languages, Ada allows them to be overloaded.

There are three physical components in the Ada programming language: library units, secondary units, and subunits. A library unit is a specification that defines a set of logical components and data declarations. A secondary unit is the body of code that implements each of the logical components defined in the corresponding library unit.

Finally, a subunit is a section of code that implements a logical component defined in a library unit but may be compiled separately.

In addition, the logical components may have properties associated with them. For example, a logical component may be a standard component, with all its data types explicitly defined. Or, it may be a generic component that may be instantiated for a given data type. Another property that logical components in Ada exhibit is that of visibility. A logical component may be visible, and accessible to any other component that refers to it, or it may be hidden, only accessible by other components in its package.

2.3.2 Special Issues

In this section, some of the special issues which must be addressed in the development of a set of architectural diagrams for Ada are discussed.

Representation of generics. The generic construct in the Ada language allows the definition of "templates" for software functions which describe a function's logic without making any commitments to data types. The generics may be easily instantiated to operate on any set of data types. In an architectural diagram, these functions would appear in many places as distinct functions, although they differ only in the data types on which they operate. Some method for capturing this similarity in the architectural diagram should be developed.

Representation of overloading. Ada allows a number of simple operators to be "overloaded." This is similar in respect to the notion of generic functions in that the only difference between functions is the set of data types on which they operate.

Representation of tasking. Architectural diagrams generally represent the invocation hierarchy among a set of procedures for a single thread of program execution. Ada introduces the concept of tasking, or simultaneous execution, whose graphical depiction has not been well investigated.

Representation of "static" vs. "dynamic" scope. In most high level languages, all of the components of a software system "exist" for the duration of the system's execution; this may be referred to as "static" scope. In Ada, however, components may exist only for portions of the system's lifetime, due to tasking and to the ability to embed components inside others; this may be referred to as "dynamic" scope. Some method for representing these on an architectural diagram must be developed.

Representation of scope of private functions and procedures. Ada allows packages to have private functions and procedures which are visible only to other functions and procedures in that package. There are no provisions for showing this in traditional architectural diagrams.

Representation of recursion. Ada, like most other high level procedural languages, supports both direct and indirect recursion. The simple methods for depicting this on a structure chart, which have been used in conjunction with other languages, may suffice until a representation more suitable for Ada is devised.

Representation of functions passed as parameters. Ada allows functions to be passed as parameters in the instantiation of generics. Traditional architectural diagrams have no means for showing components passed as parameters in an invocation.

Representation of embedded packages and tasks. Ada allows packages, procedures and tasks to be declared anywhere in a program that variables and data types may be declared. As a result, procedures with a dynamic lifetime may be declared that are callable by the component in which they are embedded but only for the scope of their declaration. There is no convention for showing this on an architectural diagram.

Representation of physical components of software. Traditionally, architectural diagrams show only the logical architecture of software and ignore the physical architecture. The "packaging" of most large systems is critical to the success of the system from both the developmental and maintenance perspectives.

Representation of architecture using layers. As the needs of software systems become more and more complex, the size of such systems has grown dramatically, often beyond the point where a single person could readily understand the inner workings of the systems. To render these systems more presentable to the software engineer, it is necessary to develop some method for layering the architecture of the system so that it may be presented in successive degrees of abstraction.

Representation of all Ada-specific components. For an architectural diagram for Ada to be practical, it must represent all of the architectural components of the Ada programming language.

Representation of visibility and connectivity. To assist the maintenance programmer, visibility and connectivity must be represented on the architectural diagram.

2.4 Visual Computing Trends

In this section, current trends in visualization in computing are presented. While much of the discussion focuses on visual programming, the ideas are relevant to all phases or levels of graphical representations. Although relatively new to the automation environment, visual programming techniques provide an effective as well as versatile means to perform a wide spectrum of analysis and design functions. It has been observed that the use of graphical representations to model, design, and evaluate complex programming processes greatly enhances the ability of the user to understand the process in question [SHU88, AMB89]. This concept of allowing a user to visualize information in a form other than textual is being utilized in numerous areas. The graphical representation of complex or enormous quantities of information is currently being employed in the fields of data design, program design, program execution analysis, software engineering, and visual programming languages.

The use of visual representations has evolved far beyond the simple mapping of textual data to that of a graphical representation. In fact, new developments in the field are leading to systems and environments that are graphically oriented by nature. Visual user interfaces modelled after a paradigm of overlapping windows, such as those found in Smalltalk, provide multiple views of a common internal database. Whenever any portion of the data is changed, all relevant views are updated to reflect that change. Graphically oriented language environments include Pecan, Cedar, and Software through Pictures [AMB89, FOR88].

Visual editing provides the user with the capability to modify existing programs or produce new ones through the use of templates that correctly reflect the language's syntax. Such current systems include the Cornell Program Synthesizer editor and the Aloe editor used in Gandalf. Several other graphical editors enforce logical consistency through the addition of rules regarding the structure of a program. Higher Order Software's Use.It and PegaSys are examples of systems that use this technique [AMB89].

The utilization of visual technology to edit programs written in traditional languages has been joined by a new philosophy of programming paradigms under a category referred to as "naturally visual languages" [AMB89]. Under these language environments the basic language constructs are visual rather than textual. A variety of approaches are used in such languages. The application of dataflow, constraints, form-based and program-by-demonstration paradigms serve as the bases for environment supported languages such as ThinkLab, ThinkPad, and Rehearsal World [AMB89].

Somewhere between the visual programming language and the textual languages one finds Conic. This programming environment uses a combination of text and graphics to define "configurations" that collectively make up a program [KRA89]. It focuses on the functionality of processes, their control characteristics, and communication interaction.

Although much emphasis has been placed on the role visual programming plays in user interfaces, editors, and programming languages, its potential far exceeds this scope. As stated above, the use of graphical representations has showed itself to be extremely useful in any area that inherently has large quantities of complex information. Two such applications utilizing visual techniques as a means to better understand actual events include performance debugging, specifically in regard to multiprocessor systems, and concurrent computations [LEH89, ROM89].

Carnegie Mellon University has demonstrated the usefulness of visualization through its special software development environment known as the Parallel

Programming and Instrumentation Environment or PIE. This system is designed to develop performance-efficient parallel and sequential computations by mapping parallel applications onto specific architectures, gathering data as the applications execute and producing graphical representations that reflect selected characteristics of the actual execution [LEH89].

The visualization of concurrent computations employs visual abstraction by "mapping from computational states to the states of graphical objects" [ROM89]. This approach has been used to insure the correctness of a process, consistency in execution and progress in the computation of a solution.

Visualization of programming has been demonstrated to be an effective means of representing complex processes, data structures, and computational events. The primary element that makes each of the systems examined above viable is its well defined utilization of graphical representations within the context of its application.

3.0 STATEMENT OF THE PROBLEM

In this section, the overall direction for the GRASP/Ada Phase 2 prototype is presented. First, the goals and objectives for the prototype are briefly discussed. Finally, the tentative architectural diagrams for Ada are introduced.

3.1 Overview

In Phase 1 of the GRASP/Ada project, the focus was on the algorithmic representation of Ada programs and the CSD (Control Structure Diagram) was developed to graphically depict Ada control constructs. In Phase 2, the focus was shifted to the structural (or architectural) view of Ada, and new diagrams must be developed to represent this view. Although one diagram (the CSD) was sufficient to represent the algorithmic view of Ada, multiple diagrams are needed to adequately represent the structural view of the software architecture.

3.2 Introduction of Taxonomy

To assist in the development of a layered approach to the graphical depiction of Ada, a tentative taxonomy of graphical representations has been developed. This taxonomy defines five distinct views of Ada software: the *code view*, the *algorithmic view*, the *connectivity view*, the *visibility view*, and the *logically related view* (see Figure 7).

The *code view* is the base view of Ada software, consisting of the source code itself. This code may be optionally augmented with some additional information such

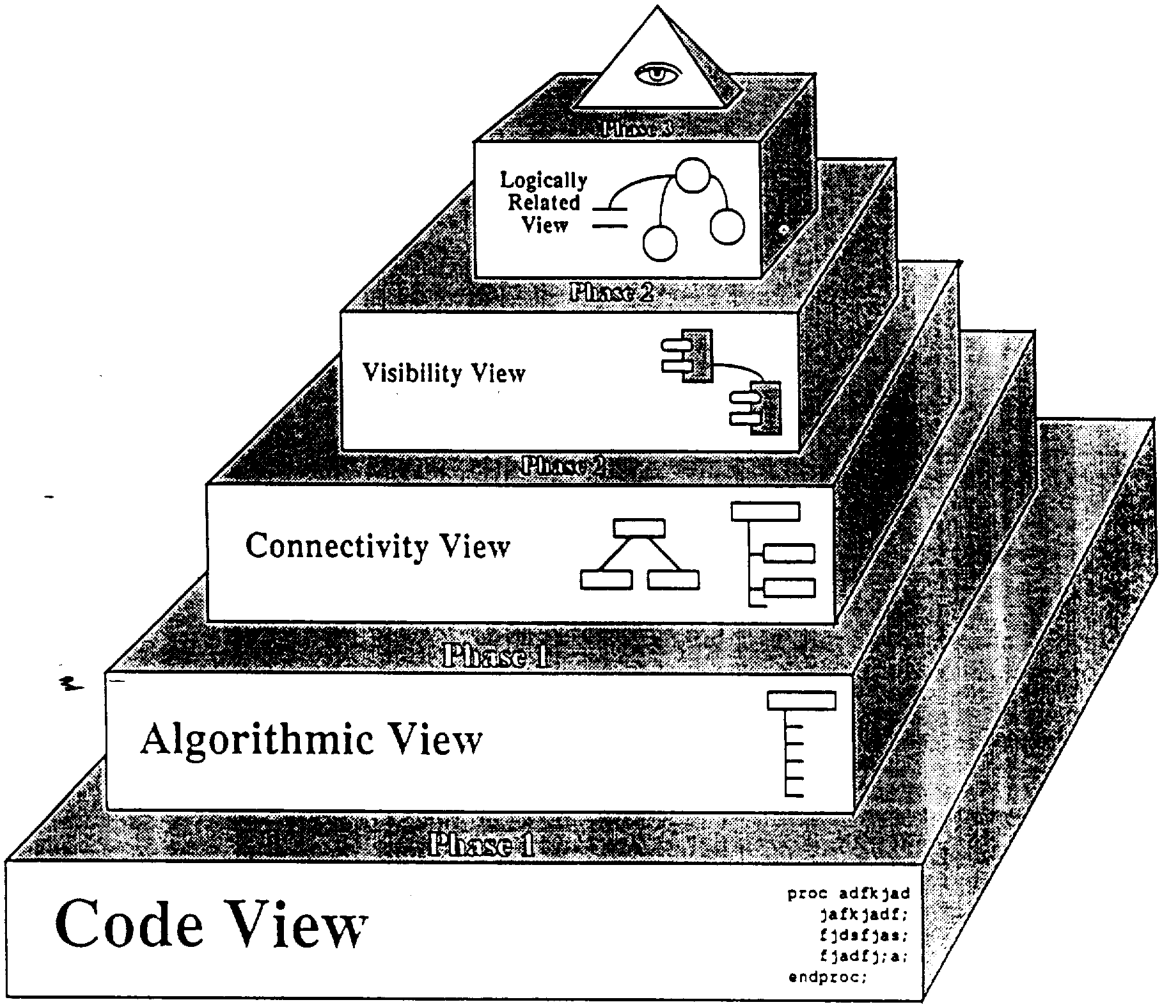


Figure 7. Taxonomy of Architectural Graphical Represention

as line numbers, nesting data, and a cross-reference, but its low-level nature renders it difficult for the software engineer to quickly comprehend the code.

The *algorithmic view* of Ada is intended to enhance the code view by graphically representing control structures. The CSD developed in Phase 1 of the GRASP/Ada project serves this purpose by augmenting Ada code with small iconic representations of the various control structures. These graphics are embedded in the code in the area normally used for "white space," and thus coexist with the code without requiring significant spatial reorganization.

Phase 2 of the GRASP/Ada project is focused on the *connectivity view* and the *visibility view* of Ada. The connectivity view shows the architectural components of an Ada system with their invocation hierarchy and associated parameters. This view is most like the traditional structure chart, yet has been enhanced and represented by two distinct graphical representations in the GRASP/Ada system. The first is the Level 1 architectural diagram which consists of a "collapsed" CSD that shows the architectural components and the control logic that leads to the statements that show each of the components being invoked. The second graphical representation is the Level 2 architectural diagram that utilizes a traditional structure chart with appropriate modifications and extensions for Ada.

The visibility view of Ada represents a set of architectural components and their associated scopes, both static and dynamic. Whereas the connectivity view shows which component are explicitly called (or invoked) by other components, the visibility view shows which components may be invoked by other components. This view also denotes the dependency relations among Ada software components, and will be graphically represented using modified Booch diagrams.

The *logically related view* of Ada will be the focus of the proposed Phase 3 of the GRASP/Ada project. This view shows the data flow among logically related groups of software architectural components, and may be considered an abstraction of the visibility view. Although the proposed GRASP/Ada graphical representations for this view have not yet been fully developed, they will include a set of modified data flow diagrams and tasking diagrams.

3.3 Derivation of Base Set of Architectural Diagrams

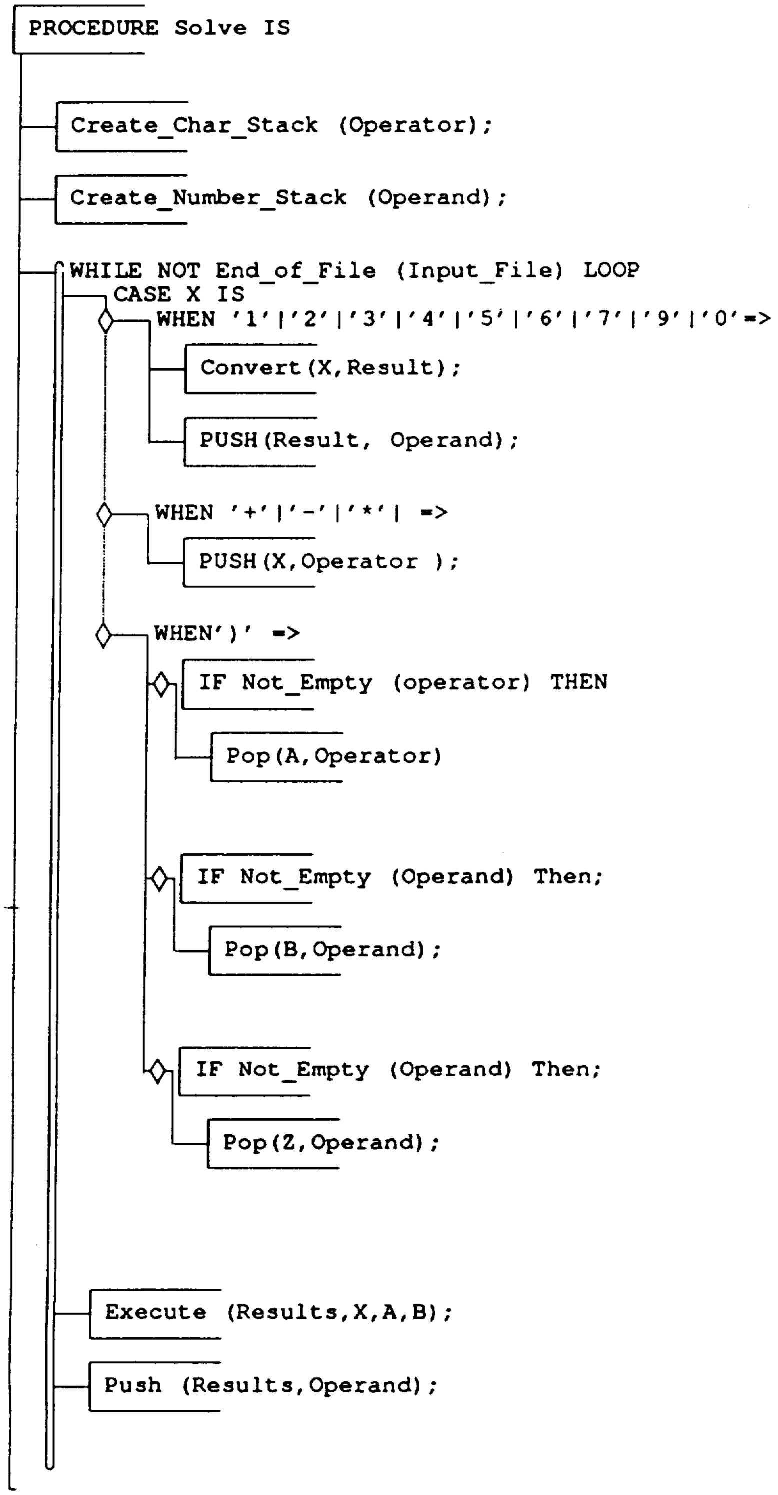
In this section, the tentative base set of architectural diagrams for Phase 2 of the GRASP/Ada project are described. There are three proposed graphical representations for this phase: the Level 1 architectural diagram, the Level 2 architectural diagram, and the Level 3 architectural diagram.

3.3.1 Level 1 Architectural Diagram

The Level 1 architectural diagram bears a close resemblance to the CSD used for representing algorithmic details. Figure 8 contains source code for procedure Solve which uses package Stack_Package to calculate the result of an expression read in as a character line. Figures 9 and 10 show two of several alternatives under consideration for the Level 1 architectural diagram. This graphical representation is designed to incorporate the features of the detailed level CSD as depicted in GRASP/Ada, and those of the traditional structure chart to derive a diagram called the architectural CSD

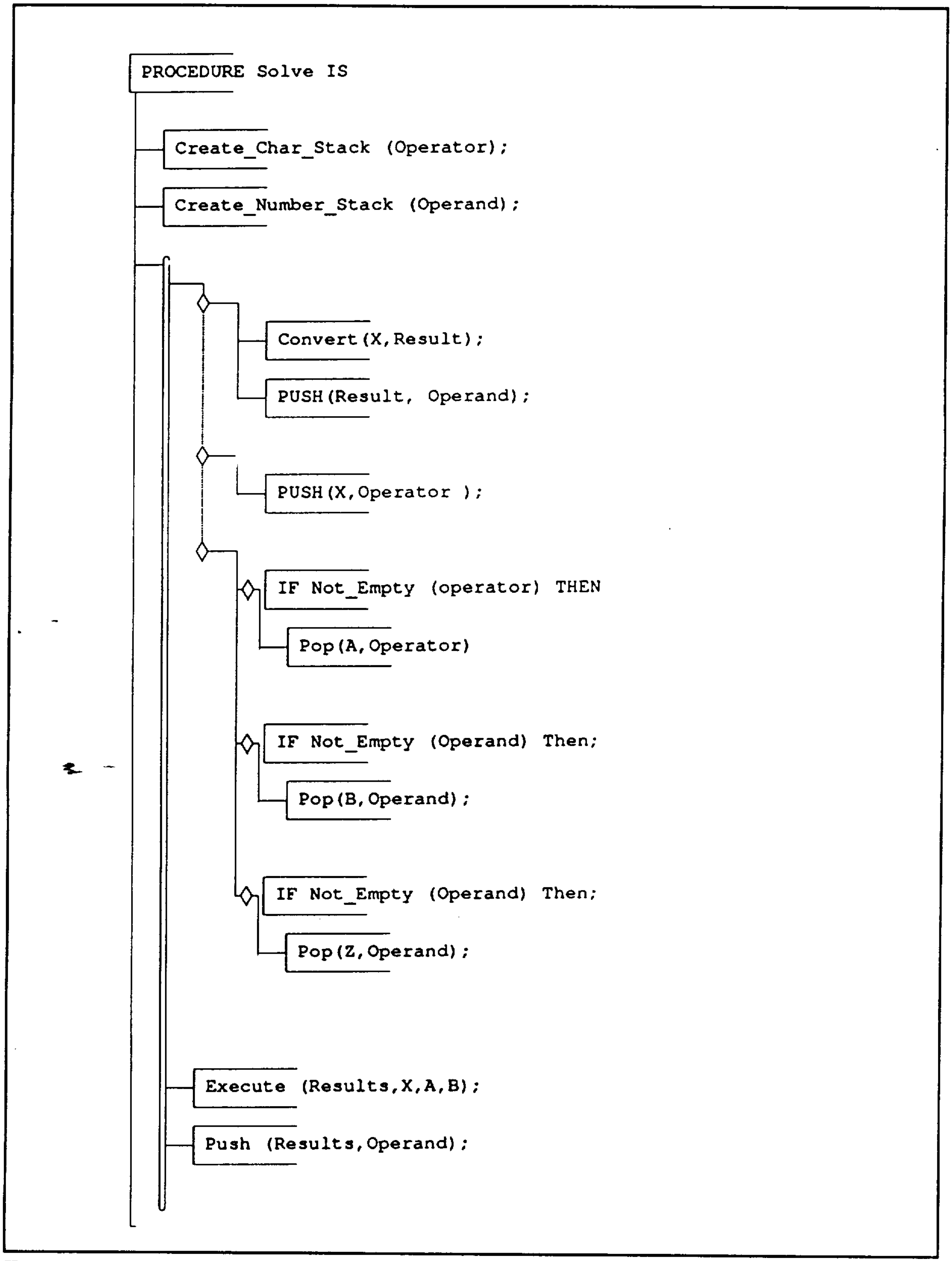
```
  -------------------------------------------------------------
  -- This program is designed to read a single line
  -- of character input and evaluate its value as a simple
  -- equation.
  -- An example input would be: ((1 + 7)*((4 - 1)*(3 * 8)))
  -- With a result of 432
  -------------------------------------------------------------

  WITH Text_IO, Stack_Package;

  PROCEDURE Solve IS

     PACKAGE Type_Integer_IO IS NEW Integer_IO (Integer);

     PACKAGE Character_Literal_IO IS
        NEW Enumeration_IO (Character);

     X,Y,Z : CHARACTER;
     Result,A,B : REAL;
     Operand : Number_Stack_Type;
     Operator : Char_Stack_Type;
     Input_File, Output_File : File_Type;

 BEGIN
     Open (Input_File, In_file, "Input_Expression.In");
     Create (Output_File, Out_File, "Results.Out");
     Create_Character_Stack ( Operator );
     Create_Number_Stack ( Operand );
     Get (Input_File, X);
     WHILE NOT End_of_line (Input_File) LOOP
         CASE X IS
             WHEN '1'¦'2'¦'3'¦'4'¦'6'¦'7'¦'8'¦'9'¦'0' =>
                 Convert(X, Result);
                 Push (Result, Operand);
             WHEN '+'¦'-'¦'*' =>
                 Push (X, Operator);
             WHEN ')' =>
                 IF Not_Empty (Operator) THEN
                     Pop (X, Operator);
                 END IF;
                 IF Not_Empty (Operand) Then
                     Pop (A, Operand);
                 END IF;
                IF Not_Empty (Operand) Then
                     Pop (B, Operand);
                 END IF;
            WHEN OTHERS =>  NULL;
        END CASE;
        Execute (Result, X, A, B);
        Push (Result, Operand);
        Get (Input_File, X);
    END LOOP;
    Put (Output_File, Results, 0, 10);
END Solve;
```

Figure 8. Ada Source Code For Procedure Solve



```
PROCEDURE Solve IS
    Create_Char_Stack (Operator);
    Create_Number_Stack (Operand);
    WHILE NOT End_of_File (Input_File) LOOP
      CASE X IS
        WHEN '1'|'2'|'3'|'4'|'5'|'6'|'7'|'9'|'0'=>
            Convert(X,Result);
            PUSH(Result, Operand);
        WHEN '+'|'-'|'*'| =>
            PUSH(X,Operator );
        WHEN')' =>
            IF Not_Empty (operator) THEN
                Pop(A,Operator)
            IF Not_Empty (Operand) Then;
                Pop(B,Operand);
            IF Not_Empty (Operand) Then;
                Pop(Z,Operand);
      Execute (Results,X,A,B);
      Push (Results,Operand);
```

Figure 9. Architectural CSD With Conditions



```
PROCEDURE Solve IS
    Create_Char_Stack (Operator);
    Create_Number_Stack (Operand);
            Convert(X,Result);
            PUSH(Result, Operand);
            PUSH(X,Operator );
            IF Not_Empty (operator) THEN
                Pop(A,Operator)
            IF Not_Empty (Operand) Then;
                Pop(B,Operand);
            IF Not_Empty (Operand) Then;
                Pop(Z,Operand);
        Execute (Results,X,A,B);
        Push (Results,Operand);
```

Figure 10. Architectural CSD Without Conditions

or ArchCSD, which represents an intermediate level of abstraction. This collapsed version of the CSD is expected to provide a compact visualization of the architectural aspects of the software while preserving the essential control characteristics. Not only will it show the architectural components which it includes, but it will also display the invocations of these components, and the control logic leading to those invocations.

As stated earlier, the two graphical representations of particular interest to this research are the traditional structure chart and the control structure diagram. The structure chart was first made popular by Yourdon and Constantine. They represented a system's basic architecture through the linking of boxes. Each box represents a module such as a function or procedure. These diagrams were able to show data flow to a limited extent. The structure chart does have limitations in that, in practice, it generally does not attempt to address the details of control flow leading to invocation of a module. Specific details regarding the sequence of processes, their conditional selection, or the number of times they are called are not explicitly included [PRE87,MAR85]. Although efforts have been made to represent this information through structure charts augmented with additional symbology, such representations have difficulty representing complex programs with procedural invocations that are nested in sophisticated conditional constructs. In certain cases, the conditions leading to a procedural invocation may itself involve multiple function calls.

More recent CASE tools have found that this type of representation is critical in the forward design process. The developers of HIPO II (Hierarchy plus Input-Process-Output), for example, realized the need for such information and incorporated control flow directly into their hierarchy chart [ROE90]. Previous experiences with the original HIPO indicated that control information was critical to the user's ability to communicate an overview of the programs function. One of the observed disadvantages to the HIPO II implementation is its non-distinct symbology. Its main graphical constructs are limited to single and double lines and two text symbols to represent control flow. Although this may be adequate in forward design, more information is needed in reverse engineering. This is particularly true with complex languages such as Ada.

The CSD, in contrast, uses a distinct graphical symbol for each major control flow construct, and had ease of automation as a central design objective. The successful implementation of the CSD tool for a large high-level language such as Ada tends to support this claim regarding ease of automation.

Although the CSD was designed to depict control flow at all levels of program abstraction, it is also suitable for use during detailed design as an extension to pseudocode or PDL. Designed with the primary purpose of reducing the time required for program comprehension, it is a natural tool for reverse engineering [CRO88]. In addition, it provides a sound basis for developing an architectural diagram which elides much of the detail found in the CSD.

The Level 1 architectural diagram may be obtained using the same technique utilized in the CSD generator developed in Phase 1 of the GRASP/Ada project. Although the implementation of such a diagram presents some new problems with respect to the traditional scan and parse approach to CSD prettyprinting, initial research shows that the generation of such a graphical representation from source code is possible. In fact analysis indicates that the generation can occur with the time complexity of O(N), where N is the number of statements in the source code.

It is important to note that this proposed tool is not designed to replace any of the architectural representations currently in use. The ArchCSD is a supplemental view of a program that depicts information that previously was omitted from traditional architectural diagrams, implicitly included, or only obtainable at the source code level. The availability of this diagram should aid implementation and maintenance programmers to better understand the role of different modules within the a system. With the ever increasing size and complexity of programs, the ArchCSD should provide valuable insight.

3.3.2 Level 2 Architectural Diagram

The Level 2 architectural diagram may be thought of as an extensively modified structure chart that has been customized for Ada. The diagram consists of two parts: a set of modules, which define Ada architectural components such as procedures and functions, and a set of control/data links, which define the invocation hierarchy among the components and the data passed among them (see Figure 11).

Modules are depicted using a compartmented box, with each Ada procedure, function, task and overloaded operator mapping into distinct boxes. The upper compartment is used to indicate the overall flow of items in and out of the module. An IN indicator shows that all of the parameters passed to the module are of type IN. An OUT indicator shows that all of the parameters passed to the module are of type OUT. An IN/OUT indicator shows that the parameters passed to the module may be of type

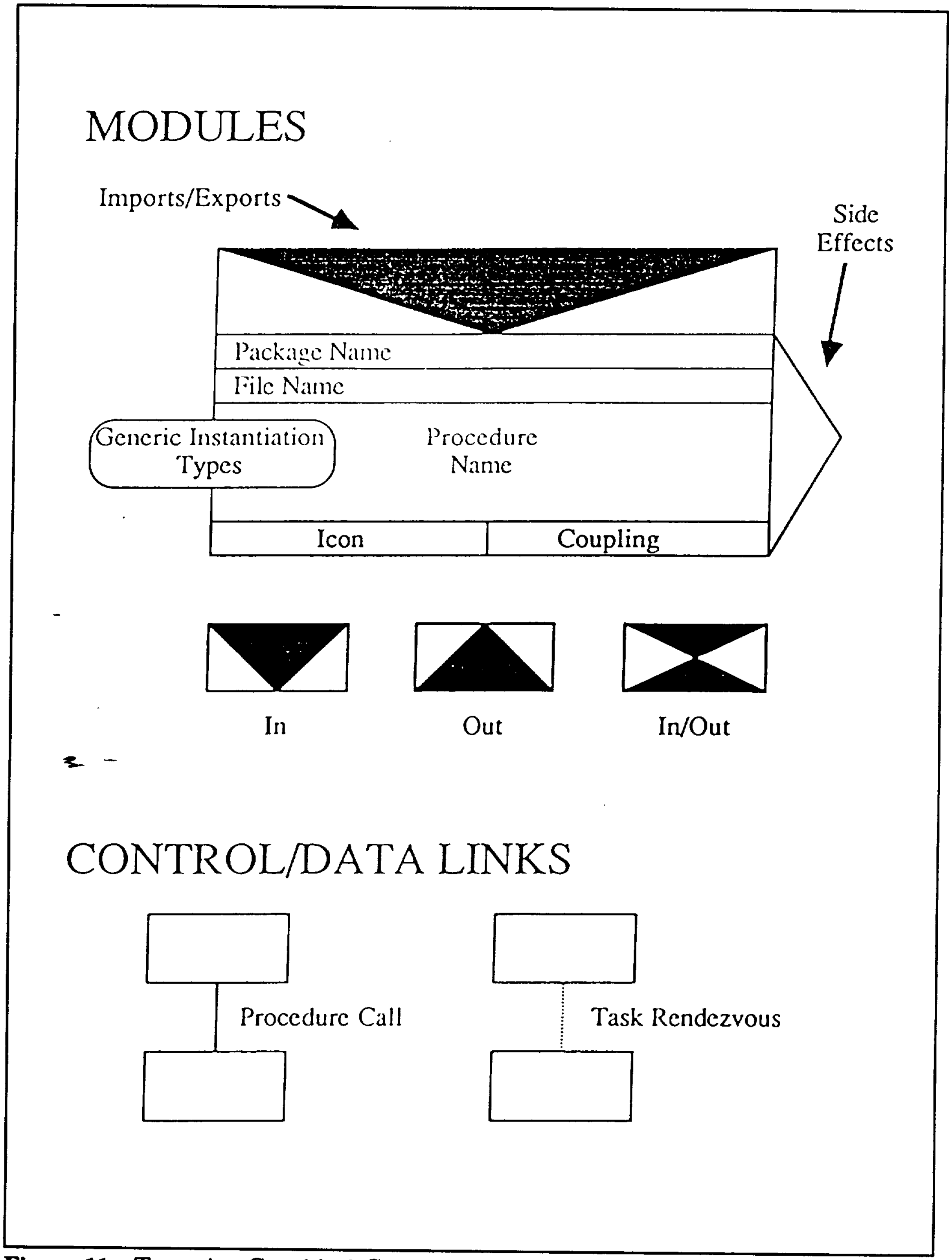


Figure 11. Tentative Graphical Constructs for Level 2

IN, OUT, or IN/OUT. Finally, a null indicator shows that the module has no parameters. Note that the graphical nature of the indicator allows the software engineer to quickly determine the overall flow of data within a program's architecture.

The second and third compartments in the modules indicate the logical and physical names associated with the module. The logical name shows the name of the logical structure (usually a package) in which the module is directly embedded, if such a structure exists. The physical name shows the name of the file containing the specification for the module. With these two pieces of information, the software engineer can easily determine where a particular module fits into the logical architecture of a system as well as find the code associated with the module.

The fourth compartment in the modules indicates the name of the software architectural component. This name may correspond to either a procedure, a function, a task, or an overloaded operator.

The data in the fifth compartment in the module will not be automatically generated, but will allow the software engineer to customize a reverse engineered system for ready visual reference. The engineer may define an icon for each package in a system that can be included in the architectural diagrams. For example, a stack icon might be created to visually set apart those modules which are part of a stack package.

The sixth compartment in the modules indicates the type of coupling that the module shares with the component that invoked it. Although determining formal coupling as defined by Myers is a difficult problem, there have been attempts at determining coupling using program metrics. It is this approach that the GRASP/Ada project will take in determining the degree of coupling among software architectural components.

The inclusion of an arrowhead on the right side of a module indicates that the module exhibits side effects. Typically, this pinpoints the use of a data item or data structure that was not declared within the module or passed to it. Although well-designed systems refrain from using this approach whenever possible, it does frequently occur in practice and can lead to frustration when trying to understand a complex system.

The last compartment in the modules is used to indicate a generic instantiation. If the module was instantiated from a generic template, the data types used to instantiate the module are listed along the left edge. In this way, identical modules that operate on distinct data types may be easily distinguished in the architectural diagram.

Control/data links are shown using a solid line in most cases. However, when one of the two components in an invocation is a task, a dashed line is used to indicate a rendezvous is in progress. This suggests that a task rendezvous is similar to a procedure call, which is a reasonable analogy. A procedure call might be thought of as a task rendezvous where the task that initiated the rendezvous suspends execution until the task with which it rendezvoused completes the associated *accept*. An example of a Level 2 architectural diagram for a stack package is shown in Figure 12.

3.3.3 Level 3 Architectural Diagram

The Level 3 architectural diagrams will show the visibility view of Ada rather than the connectivity view exhibited by the Level 1 and 2 diagrams. Although the

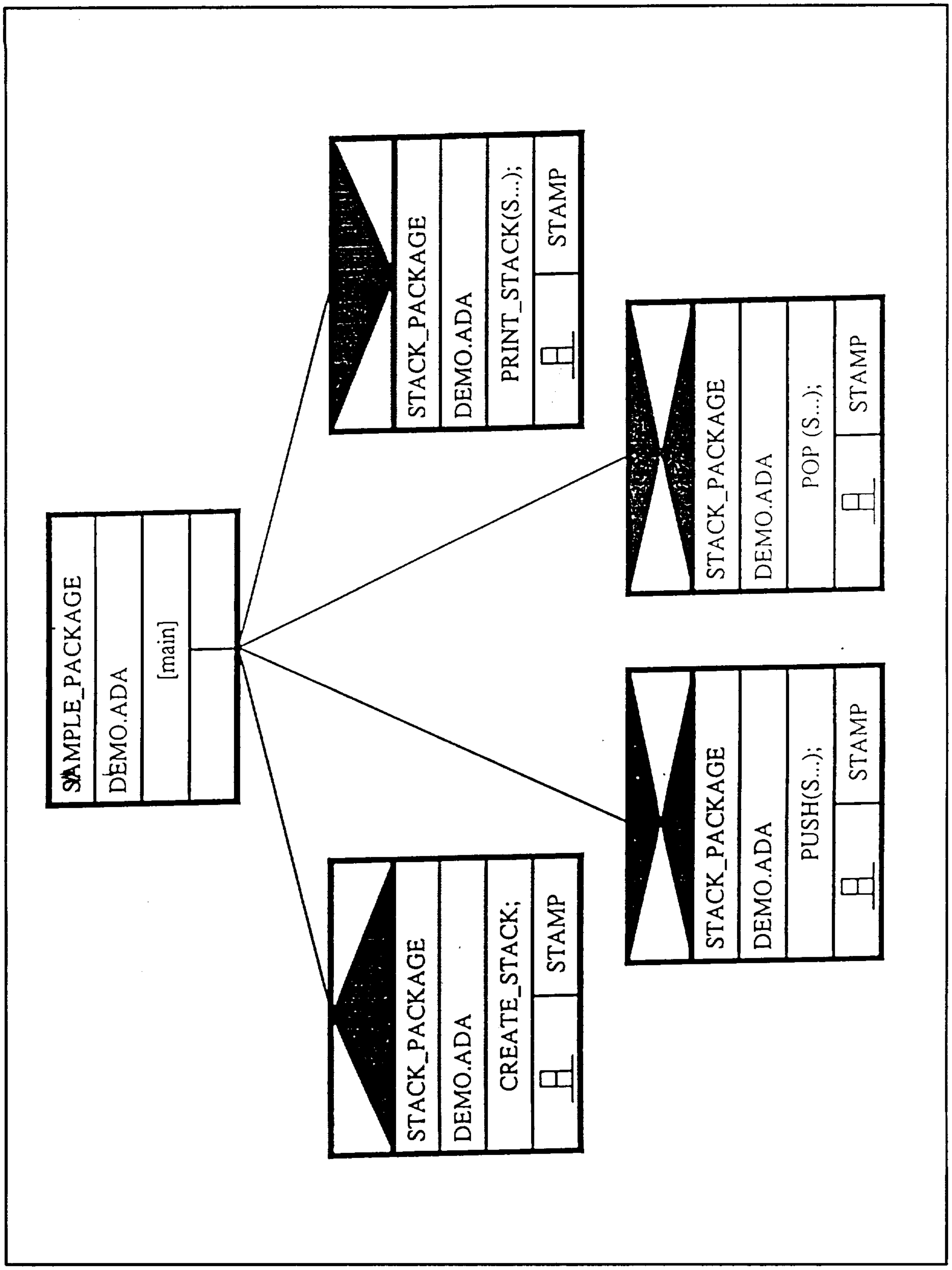


Figure 12. Example Using Level 2 Constructs

diagrams are still under development at this time, they will be based upon the Booch diagram and will convey the dependency information that the Booch diagrams exhibit, while extending the diagrams to more fully suit Ada and customizing them for inclusion in the GRASP/Ada system. Currently, the Object-Oriented Structured Design (OOSD) notation, briefly described in Section 2, is a serious contender for the GRASP/Ada Level 3 diagram component. Since it has been widely distributed and is non-proprietary, it has the potential to become the defacto standard.

4.0 REQUIREMENTS AND PROTOTYPE IMPLEMENTATION

The prototype tool in Phase 2 of GRASP/Ada is a reverse engineering tool for automatically deriving graphical representations of Ada source code. Graphical representations include the Control Structure Diagram for depicting control flow and various hierarchical diagrams. The following hierarchical diagrams are currently being addressed:

- Subprogram invocation graphs
- Package/compilation unit dependency diagrams

The current focus has been on the subprogram invocation graph, commonly known as the structure chart.

During Phase 2, several Ada development tools were considered and evaluated as foundations on which to base the GRASP/Ada tool. Among those examined were two compiler-based Ada development systems, namely the VERDIX Ada Development System (VADS) and Telesoft Ada development system. Of special interest were the library management and product consistency facilities and the availability of the intermediate representations. The VADS system was selected primarily due to the availability of its interface to the DIANA intermediate representation, a representation whose study had already consumed much time and effort.

The *Software through Pictures* CASE tool from Interactive Development Environments is currently being evaluated with respect to its object-oriented structured design (OOSD) notation. Early impressions suggest that the OOSD symbology is a comprehensive synthesis of all the design representations available. However, further evaluation is required regarding the symbology's suitability to real-world examples, amenability to reverse engineering, availability of graphical formats, and implications of integration with the Software through Pictures tool.

Many of the requirements described herein have been and will continue to be adjusted to take advantage of interfaces provided by the VADS tool and others. The requirements will be discussed along with the state of progress toward their fulfillment. Many of these requirements are also applicable in Phase 3 of this research project and should be met during that phase.

4.1 Functional Requirements

The following sections describe the requirements for the functionality of the tool. Discussed are the requirements for the input of source code to the tool, the processing of the code by the tool, and the display and printing of results by the tool.

4.1.1 Input Requirements

The user will have several modes of inputting Ada code to the tool. These alternatives are described below. For instance, it should be quite feasible to call a text editor (e.g. **vi** and Xedit) from the tool. For the Phase 2 tool, editing capabilities will be text editing only, rather than syntax-directed editing or graphical editing. In addition, no incremental recompilation or reconstruction of diagrams will occur during the editing process.

A second input alternative involves the querying of an existing Ada library (for instance, a VADS library). Such a scheme seems feasible because an Ada library should contain all dependency information among units within a system. This option has been discarded, however, due to schedule constraints and because such an input scheme could become too dependent upon the format chosen by a compiler vendor for its library files.

A third alternative for input involves the direct entry of or selection of file names. The file names need not reflect the true compilation order, since one of the purposes of the tool is to determine that order.

Two important considerations which have not been satisfactorily resolved are assumptions concerning code completeness and user knowledge of the code. These considerations affect the input mechanism of the tool. It is not uncommon to compile source code which represents an incomplete solution and to generate at least partial graphical representations for the disparate components.

The fact that the tool is building on VADS constrains options somewhat. Random file selection can lead to gaps in the compilation list which prevents full compilation of units dependent on absent units. It is important, therefore, that the compilation lists resulting from file selection be complete.

4.1.2 Processing Requirements

This section will describe the general scenario of tool operation. Once the user has selected the Ada files to submit to the tool, he will invoke compilation of the selected files, in turn producing the DIANA form of the Ada code for each unit compiled, deriving dependency information among the units compiled (including noting deficiencies in the supplied compilation list).

The user will select the diagrams that he wishes to generate. The tool will then generate the necessary graphical descriptions. Among the options open to the user are:

- CSD
- Architectural CSD
- Subprogram invocation graph (e.g., hierarchical diagram)
- Object/Package diagram (e.g., Booch Diagram)

A direct association can be made between the components of the architectural diagrams and the Ada components that they represent, whether or not the Ada components are compilation units. This direct association should enable the GRASP/Ada system to localize and isolate needed changes in the diagrams corresponding to changes in the code. In particular, regeneration of all diagram components associated with units involved in the subsequent recompilations resulting from alterations in the code will be unnecessary.

4.1.3 Display Requirements

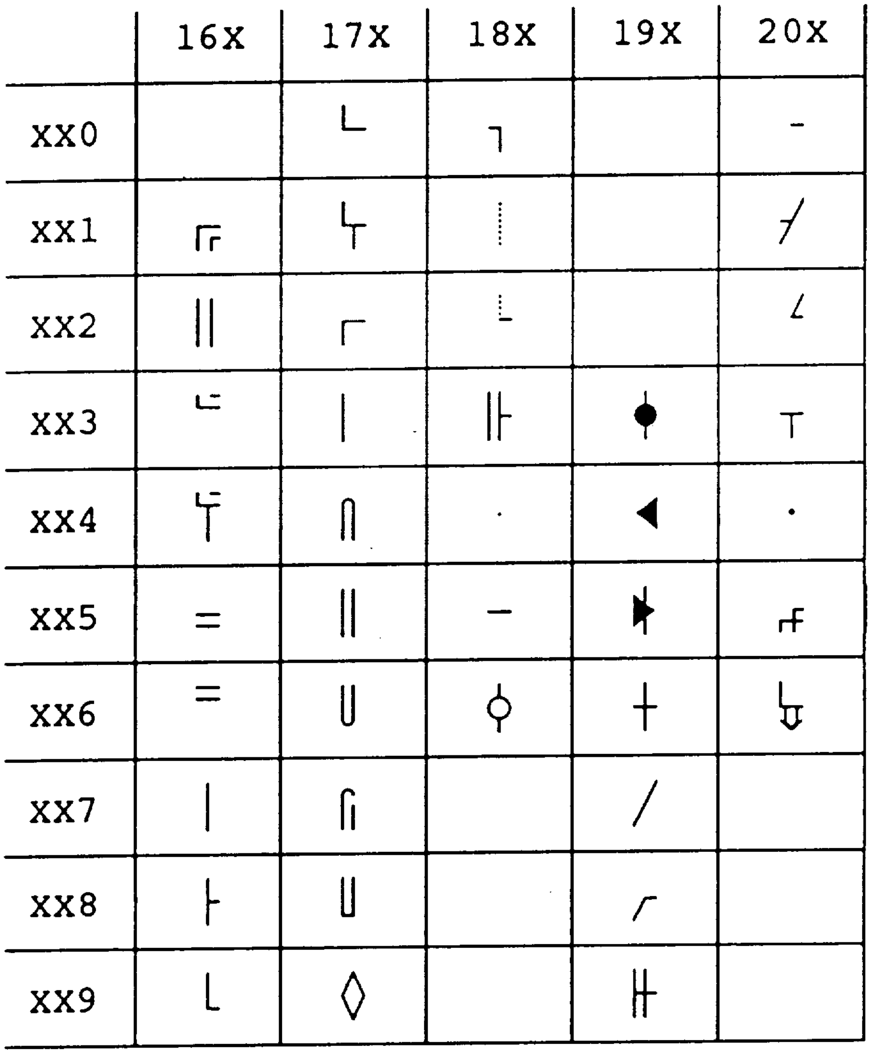
Once the tool has generated diagrams, the user may select specific diagrams to be displayed from among the four views available (i.e. CSD, Architectural CSD, subprogram invocation graph, object/package diagram). Each view selected will have its own display window which can be moved around the screen, resized, and scrolled both horizontally and vertically in the X Windows user interface. Display layout should be improved by a rule base which specifies heuristics for icon placement and connection.

4.1.4 Output Requirements

All hardcopy output will be provided using either of two supported printers: a Hewlett-Packard LaserJet Series II (HPII) compatible printer, or a PostScript compliant printer. The fonts used for both devices are based on a 10 point monospaced courier font. The font used on the HPII is a permanent downloadable font which must be transferred to the printer's memory, and remains available until the printer is either turned off or the font is specifically deleted. Using the Hewlett-Packard Printer Command Language (PCL) raster graphics commands, individual bit-mapped images of each standard ASCII character and additional CSD graphical character are defined [BEN88, HPC87]. Figure 13 contains the CSD specific characters.

Problems have been encountered when downloading the HPII soft font to a network printer, but does not effect the use of any fonts once they are resident in the printer. The printer daemon interprets some of the bit-mapped data, as apposed to passing it on to the printer, thus resulting in a corrupted font definition. This problem does not occur when the font is downloaded to non-network printers. As a consequence of this behavior, we have used a stand-alone (MS-DOS) computer connected to the printer's parallel port to download the font. After the font has been downloaded, the printer can be used as a network resource without further problems.

The font used on PostScript printers is a dictionary which must be downloaded to the printer. The dictionary is used by the PostScript interpreter to obtain definitions that generate character shapes, and consists primarily of Postscript procedures to produce the individual character shapes. The procedures for each standard ASCII character and additional CSD graphical characters have been successfully implemented



	16X	17X	18X	19X	20X
XX0		└	┐		-
XX1	Γr	└┬	┆		⟋
XX2	‖	┌	┆_		∠
XX3	L=	|	‖├	●	⊤
XX4	Ŧ	∩	·	◀	•
XX5	=	‖	–	▶	┌F
XX6	=	∪	φ	+	└⊽
XX7	|	⋒		/	
XX8	├	∪		⌐	
XX9	L	◊		╫	

Figure 13. GRASP/Ada Extended Character Set

and no problems have been encountered using PostScript printers [ADO85, ADO88, HOL88, HOL89].

4.2 User Interface Requirements

This section describes the general requirements for the user interface and the basic approach used for the prototype. The discussion includes X Windows, the user, the design method, goals, decisions and implementation. A great deal of effort was expended on the user interface during Phase 2 which included porting the key Phase 1 components from the VAX VMS environment to Sun UNIX and X Windows.

4.2.1 Development Tool/Environment

The X Window System is the window-based environment selected to develop the GRASP/Ada user interface. It meets the GRASP/Ada user interface requirements of an industry-standard window based environment which supports portable graphical user interfaces for application software. Some of the key features which make X attractive for this application are its availability on a wide variety of platforms, unique device independent architecture, adaptability to various user interface styles, support from a consortium of major hardware and software vendors, and low acquisition cost. The X Window System is available on most UNIX systems, Digital's VAX/VMS operating system, and on many personal computers. With its unique device independent architecture, X allows programs to display windows on any hardware that supports X protocol. X does not define any particular user interface style or policy, but provides mechanisms to support many various interface styles from command-line to pop-up menu. A consortium of major hardware and software vendors has made a commitment to X as a standard base for user interfaces across each of their product lines; Apple Computer Incorporated, Digital Equipment Corporation, Hewlett Packard, IBM and Sun Microsystems are just a few of the consortium members. X can be acquired on a 9 track, 1600 bpi tape directly from MIT for $200 (US dollars). Those with access to ARPAnet can get the X system free via anonymous ftp from a number of sources [YOU89].

The X Window System was designed at MIT's laboratory for Computer Science for project Athena, primarily by Robert Scheifler, Ron Newman and Jim Gettys, to fulfill that projects need for a distributed, hardware independent user interface platform. The name X, as well as some initial design ideas, were derived from an earlier window system named W, developed by Brian Reed and Paul Asente at Stanford University. Currently, the X Window System is supported by a consortium of hardware and software vendors who support and control the standard specification of the X Window System.

4.2.2 The User

The user of the GRASP/Ada projects application tools will be a programmer or computing specialist who is a moderate to heavy computer user. The user's task will be to use the graphical tools provided by the GRASP/Ada research project to maintain and update application code.

4.2.3 Design Method

A combined software engineering paradigm of fourth generation techniques and prototyping will be used to develop the GRASP/Ada user interface. This combined paradigm approach has two essential advantages. It lends itself well to the use of the X Window System and the X toolkit, and it allows a working prototype to be constructed quickly and continually upgraded as the GRASP/Ada project's application tools are refined. This paradigm also fits nicely into the design methodology outlined by Gould and Lewis in their article [GOU85]. Their recommended design principles were an early focus on users and tasks, empirical measurement, and iterative design.

4.2.4 Design Goals

Focusing on the user and his task, the following primary goals for the GRASP/Ada user interface have been established: (1) *craftsmanship*, (2) *consistency*, (3) *control*, (4) *communication*, and (5) *cognitive layout*. Other user interface design goals such as forgiveness, stability, clarity and simplicity will be adhered to where possible.

Although many perceptions exist, no one user interface design policy has been proven superior for all users. One conclusion that can be drawn, however, is that *craftsmanship* is more important than interface style or design philosophy [WHI88]; a precisely functioning system exerts an enormous effect on usability. Effective applications are *consistent* and more easily learned because a user can transfer those skills from one application to another. Within the GRASP/Ada user interface, there will exist one coherent way for the user to implement actions regardless of the graphical application tool that is being used. As a user advances in skill, *control* often becomes more important as he needs less of the protection of a beginning computer user. Since our user will be more advanced, as many aspects of the GRASP/Ada user interface as practical will lend themselves to alteration to suit the particular user. Communication between the system and the user is the basis for control. Keeping the user informed with feedback and dialogue also exerts an enormous effect on usability. The user of the GRASP/Ada user interface will be kept informed of the progress of each operation, e.g., when completed or what problem prevents execution. Cognitive layout facilitates a match between the user's visual expectations and the actual operations of the window system. Although multiple windows increase the perceived viewing space, they will not necessarily increase the perceived visual scope if the user sees no relationship or pattern that spans the display [NOR86].

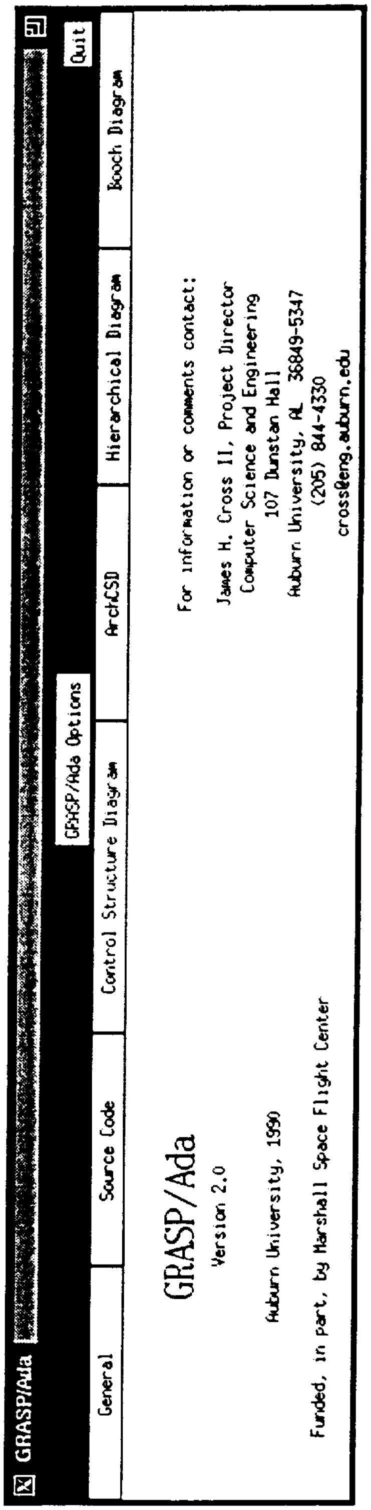
4.2.5 Design Decisions/Implementation

The major design decisions/directions taken to implement the design goals are briefly described include the following. Craftsmanship will be accomplished through continuous refinement with user feedback and the use of modern user interface toolsets. Consistency will be maintained through the use of identical commands throughout all applications within the GRASP/Ada user interface for similar actions. All commands available for a particular application may be found in its header frame in the form of buttons. Control over such aspects of the "look" of the user interface as color, sound, and window size will be provided in the form of alterable default files. Communication in the form of messages will be presented in a message window located across the bottom of the GRASP/Ada system window or as appropriate in a pop-up window. A cognitive layout that increases the visual scope of the user will be achieved through proper spatial and temporal grouping of all active windows for applications within the GRASP/Ada user interface. The basic form of each application window will be a frame header containing all options located across the top of the window and a work area below the frame header where all sub-windows when invoked will appear.

The current state of the GRASP/Ada user interface is reflected in Figures 14 - 16. The GRASP/Ada system window (Figure 14) provides buttons for each of the major functions of the system. In Version 2.0, the buttons for **General**, **Source Code**, and **Control Structure Diagram** are functional. The buttons for **ArchCSD**, **Hierarchical Diagram**, and **Booch Diagram** will be functional in Version 3.0. The user may open one or more source code windows to display and edit text files (Figure 15) and/or one more CSD windows to generate and display the CSD from the indicated source file (Figure 16). The user will have the capability to relocate, resize, and scroll the windows created for each view. The system window tracks and coordinates all other windows in an effort to increase the visual scope of the user.

4.2.6 Porting Phase 1 Components to X Windows

One of the major tasks involved in porting the CSD generator to the X Windows environment was converting the specially designed CSD font to an X compatible format. X Windows uses a special font format called SNF and a font editor capable of producing SNF fonts was unavailable. A program was written to convert the CSD font produced on the SUN SPARCstation to the SNF format.



GRASP/Ada

Version 2.0

Auburn University, 1990

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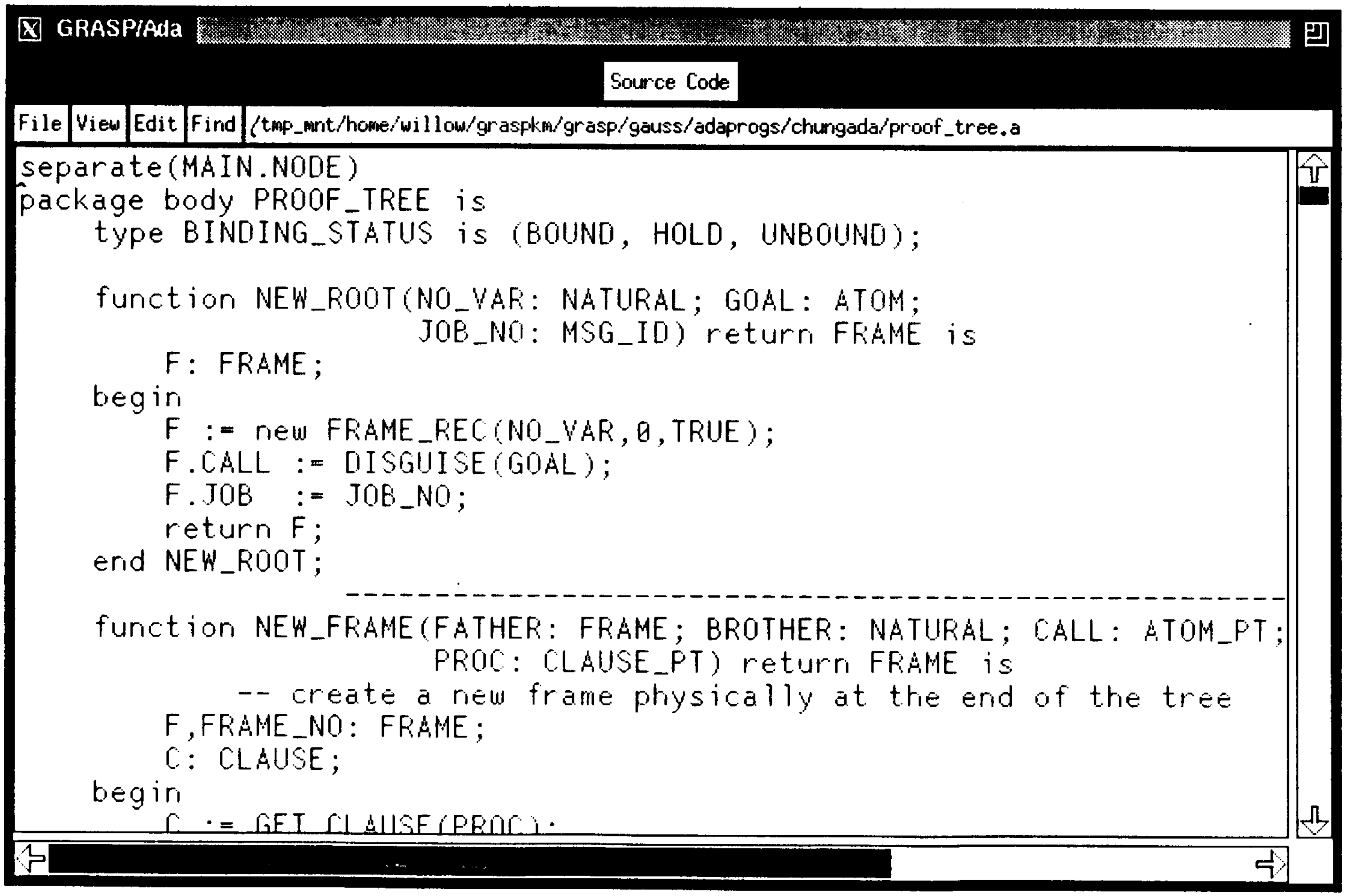
Figure 14. GRASP/Ada System Window

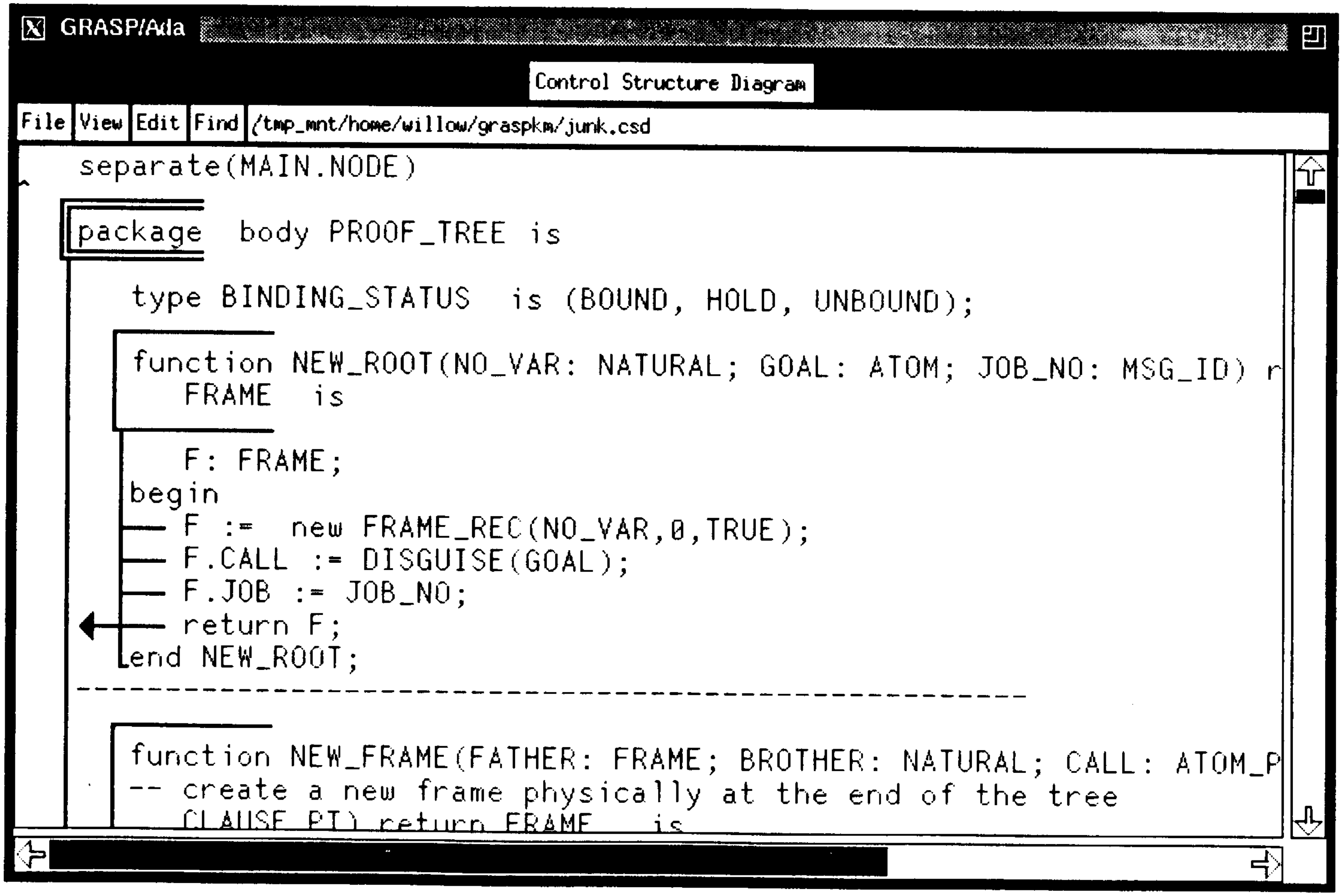


/tmp_mnt/home/willow/graspkm/grasp/gauss/adaprogs/chungada/proof_tree.a

```
separate(MAIN.NODE)
package body PROOF_TREE is
    type BINDING_STATUS is (BOUND, HOLD, UNBOUND);

    function NEW_ROOT(NO_VAR: NATURAL; GOAL: ATOM;
                      JOB_NO: MSG_ID) return FRAME is
        F: FRAME;
    begin
        F := new FRAME_REC(NO_VAR,0,TRUE);
        F.CALL := DISGUISE(GOAL);
        F.JOB  := JOB_NO;
        return F;
    end NEW_ROOT;
                  ----------------------------------------------------
    function NEW_FRAME(FATHER: FRAME; BROTHER: NATURAL; CALL: ATOM_PT;
                       PROC: CLAUSE_PT) return FRAME is
            -- create a new frame physically at the end of the tree
        F,FRAME_NO: FRAME;
        C: CLAUSE;
    begin
        C := GET_CLAUSE(PROC);
```

Figure 15. GRASP/Ada Source Code Window



GRASP/Ada
Control Structure Diagram
File
View
Edit
Find
/tmp_mnt/home/willow/graspkm/junk.csd

```
separate(MAIN.NODE)
package  body PROOF_TREE is

   type BINDING_STATUS  is (BOUND, HOLD, UNBOUND);

   function NEW_ROOT(NO_VAR: NATURAL; GOAL: ATOM; JOB_NO: MSG_ID) r
      FRAME  is

      F: FRAME;
   begin
      F :=  new FRAME_REC(NO_VAR,0,TRUE);
      F.CALL := DISGUISE(GOAL);
      F.JOB := JOB_NO;
      return F;
   end NEW_ROOT;
-----------------------------------------------------

   function NEW_FRAME(FATHER: FRAME; BROTHER: NATURAL; CALL: ATOM_P
   -- create a new frame physically at the end of the tree
      CLAUSE_PT) return FRAME   is
```

Figure 16. GRASP/Ada Control Structure Diagram Window

CSD Font Background. The reader may wonder why yet another CSD font was required, and the answer has to do with the bewildering number of font formats available for today's common output devices. The earliest versions of the CSD intended for the CSD symbols to be represented using the extended graphics characters in the IBM PC ASCII character set. However, this reliance on the character set of a specific machine was not favored as it drastically limited the design of CSD characters and was not portable. The use of customized fonts was identified as a superior approach which would allow the GRASP/Ada team total freedom in the design of CSD characters. Unfortunately, this meant having to design custom CSD fonts for each desired output device and introduced the problem of keeping consistent these numerous CSD fonts which often had widely different character resolutions and horizontal/vertical proportions.

Phase I of the GRASP/Ada research project involved the design and implementation of a CSD generator for the VAX 11/780 platform. The available output devices were the VT220 series terminal, the DEC LN03 laser printer, and the HP LaserJet II laser printer, and each output device had its own font format. The VT220 terminals required a screen font with characters six pixels wide by ten pixels deep, encoded in a font format using sixels (a DEC convention referring to a number of pixels). The DEC LN03 laser printer also required a sixel-based font format but with a much higher resolution. As sixel-based font editors were not available to us, the GRASP/Ada team wrote its own customizable font editor for producing VT220 and LN03 fonts. The HP LaserJet II required its own special font format using a 25 pixel by 51 pixel character matrix, and this font was created using a font editor for the IBM PC.

Porting the CSD generator to the SUN SPARCstation environment introduced a new output device, the SUN SPARCstation display. This output device made use of fonts encoded in a format called vfont, with a vfont font editor provided as part of the system software. The GRASP/Ada team used this editor to produce a vfont version of the CSD font.

At this point, four different CSD fonts were in existence, the two sixel-based fonts, the LaserJet font, and the SUN SPARCstation font. Other fonts, in still more formats, were under consideration, including fonts for the IBM PC, Apple Macintosh, and Printronix P300 line printer. Each font would have to be individually created because the widely varying resolutions and differing horizontal/vertical proportions among the different output devices made automatic font translation impractical. It would be preferable to work with a CSD font for one device and automatically generate the fonts for other devices, but the automatic translation would lead to less than desirable results. Furthermore, font creation often requires a certain amount of minor character manipulation to produce aesthetically pleasing results on lower resolution devices. Because of this, any design change in a CSD character promoted a flurry of smaller redesigns for each of the supported fonts, a time-consuming problem. It was clear that something would have to be done about the rapidly multiplying font problem in order to maintain consistency among the various output devices.

CSD Font For X Windows. The solution lay, in part, in the port of the CSD generator to the X Windows environment. X windows is a device-independent window manager that was slow to gain acceptance because of its processor-intensive graphics manipulation but is rapidly becoming an industry standard due to the advent of suitable hardware. Fonts in X Windows use a format called SNF and are device-independent, as the burden of displaying SNF fonts on the output device is left to the implementor of X Windows for that output device. By producing the CSD font in SNF format and using X Windows routines for all I/O, the CSD generator would be compatible with all machines that supported X Windows.

The GRASP/Ada team was unable to locate either an SNF font editor or documentation describing the SNF font format. A utility to create SNF fonts from fonts in BDF format was available on the SUN SPARCstation, but a BDF font editor could not be found (BDF is not a "machine-ready" font format, but rather a textual format for describing fonts). However, documentation describing the BDF font format was available, so we proceeded as follows. First, the vfont format was chosen as the "working" font format as a font editor for that format was available on the SPARCstation. This font was updated to reflect all of the CSD modifications and extensions needed for the Phase II GRASP/Ada CSD generator. Second, a conversion program was written to translate CSD vfont fonts to BDF fonts. A typical 256 character SUN font translated to a BDF file of almost 6000 lines. Third, the BDFTOSNF utility was used to create an SNF CSD font for X Windows. This font was then available for installation and use by the GRASP/Ada CSD generator.

CSD Fonts For PostScript Printers. While X Windows has been establishing itself as the output format for display screens, PostScript has become the de facto output format standard for printers. PostScript is an interpreted language for graphics and type that is device and resolution independent. The versatile operators in the language allow many effects to be performed with text, including rotation, shading, and scaling. Its major disadvantages are speed and costs. Because it is interpreted and uses a great deal of memory, PostScript is notoriously slow on most printers, and licensed versions of PostScript are usually expensive. However, faster processors, more on-board memory for printers, and better PostScript implementations have minimized the speed problem, and lower-cost PostScript clones are becoming commonplace. In addition, some attempts have been made at using PostScript for producing text on computer displays, most notably the NEXT computer which uses a screen format called Display PostScript. This would enable the same operations to produce output for both display screens and printers and would greatly reduce the amount of effort needed to write applications programs. At the present time, however, the optimal implementation of the GRASP/Ada tool has utilized the X Windows format for screen display and PostScript for hardcopy.

4.3 Hardware Requirements

The intended platform for development and distribution will be a Sun/SPARC workstation. The advanced graphics capability of this system was a primary consideration. Other options included the VAX 11-780 and a PC environment.

4.4 System Software Requirements

The system software constitutes the software platform on which the individual GRASP components are based. This platform currently consists of the X Windows facilities, discussed above in conjunction with the user interface, and the VADS Ada system with its DIANA interface. A discussion of DIANA and the VADS implementation follows.

4.4.1 DIANA - An Intermediate Representation for Ada

DIANA, Descriptive Intermediate Attributed Notation for Ada, is an intermediate representation language for Ada source code. DIANA is called a "language" because its definition [GOO83] is described in a BNF-like notation known as Interface Description Language (IDL) [NES81, GOO83, McK86]; in reality, DIANA is an abstract data type whose model is that of an abstract syntax tree supplemented with semantic links, creating a DIANA net. A DIANA net consists of typed nodes decorated with four types of attributes: (1) syntactic (links to other nodes producing the tree), (2) semantic (producing a directed graph), (3) lexical, and (4) code generation-specific. An instance of DIANA with only lexical and syntactic attributes comes close to a comparable abstract syntax tree except that some similar nodes (e.g. nodes referencing identifiers) are typed differently so that each type may contain different semantic attributes. In addition, a storable form of DIANA is defined to facilitate reuse of specific instances of the data type. [GOO83, ROS85]

Figure 17 partially illustrates the contents of a DIANA subnet corresponding to a segment of Ada code. Consider the following segment:

```
type MYFLOAT is digits 6 range -1.0..1.0;
subtype MYFLOAT2 is MYFLOAT digits 2;
X : MYFLOAT2;
```

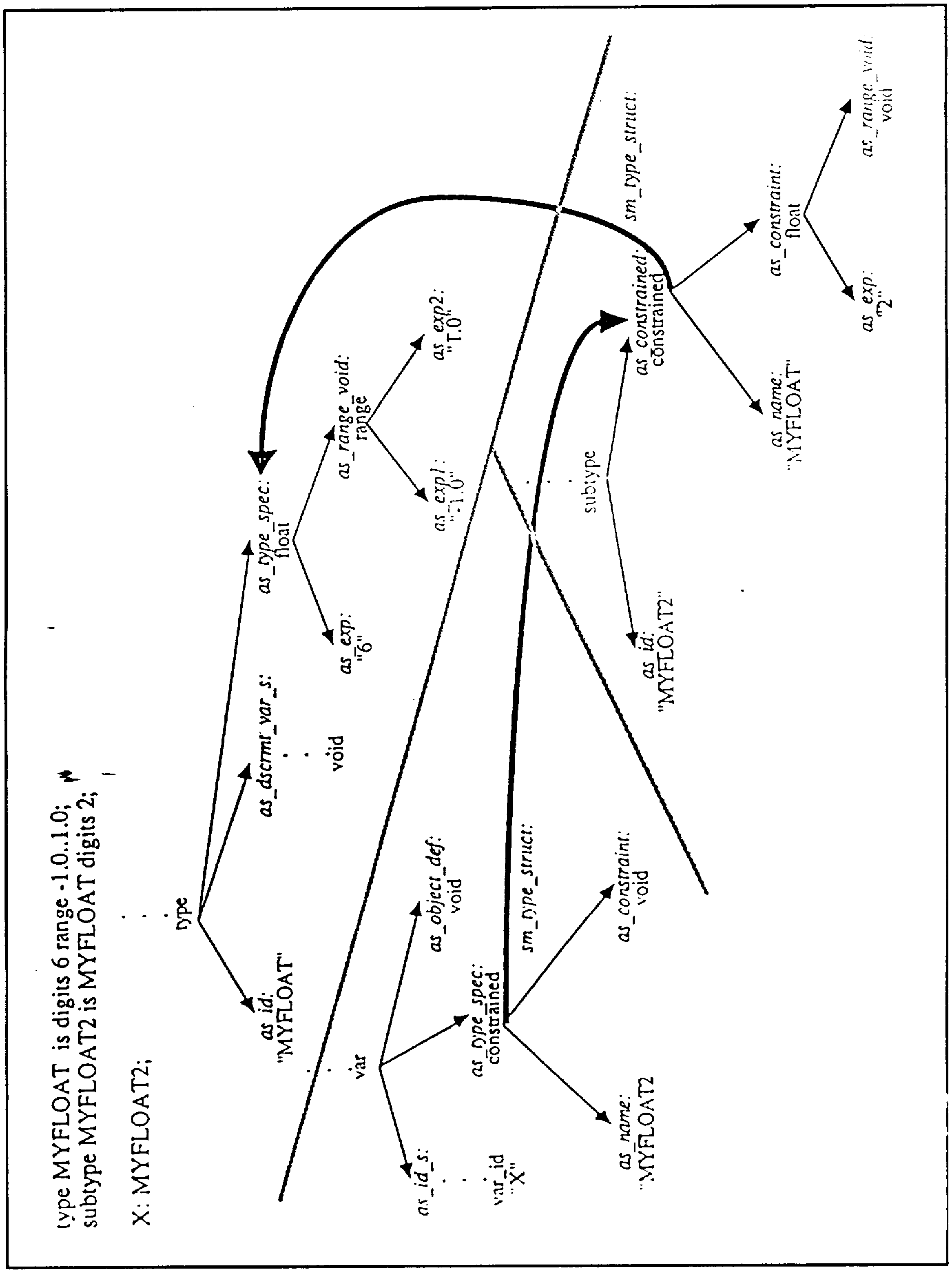


Figure 17. Example of DIANA Subnet

The figure illustrates in part the concurring DIANA subnet. For convenience, the diagram is split into three sections paralleling the subnet for each line in the above code. These three subnets are part of a larger DIANA net for the enclosing compilation unit. The subnet for the variable declaration has its basic abstract syntax tree form (syntactic attribute names prefixed by *as_*), supplemented by a semantic attribute (named *sm_type_struct*) pointing back to a subnet containing the subtype structure of MYFLOAT2. This subnet, in turn, has its own semantic attribute (again named *sm_type_struct*) pointing back to the underlying type structure. This figure, adapted from [GOO83], is incomplete in that many more semantic attributes exist which may point to distant subnets when evaluated.

Background. DIANA was first developed in 1981 by the cooperative effort of teams from the University of Karlsruhe (West Germany), Carnegie Mellon University, Intermetrics, and Softech. The design was based on previous intermediate languages TCOL and AIDA [BRO80, DAU80, PER80, GOO83, McK86]. A revision effort headed by Arthur Evans, Jr. and Kenneth J. Butler at Tartan Laboratories under the auspices of the Ada Joint Program Office produced a revision of DIANA based on the 1982 version of the Ada definition. This edition contained an Ada package specification for the DIANA data type [GOO83]. A third revision was drafted in 1986 by Carl F. Schaefer and Kathryn L. McKinley of Intermetrics for the Naval Research Laboratories; however, no example Ada package specification for the DIANA type was provided [GOO83, McK86, SMI88]. The MITRE Corporation derived two package specifications in its effort to evaluate the 1986 version of DIANA [SMI88].

The original purpose of the DIANA data type was to serve as a basis for communication between early and late stages of compilers; in fact, [SMI88] mentions several compilers which are DIANA-based including VERDIX, Rational, and others. However, [GOO83] claims the suitability of DIANA for other tools as well. Several of these tools are mentioned below along with discussions of their DIANA implementations.

[ROS85] is concerned with the use of DIANA data type templates to create source "transformation tools". However, the article was useful in that it demonstrates the necessary contents of a DIANA support toolset. As described by Rosenblum, the necessary tools include a parser to translate Ada source into an abstract syntax tree, a "tree normalizer" to convert the AST to a full DIANA net, a prettyprinter to revert the DIANA net to Ada source, a "tree dumper" to convert the internal DIANA to external (ASCII) DIANA, and a "tree reader" to perform the inverse function. The tools described in [ROS85] were based on the 1983 version of DIANA.

[SMI88] describes the MITRE effort in evaluating the 1986 version of DIANA. This involved the translation of the IDL specification for DIANA into a data type and structure specification plus operations on that type using the IDL Toolkit developed at the University of North Carolina [WAR85, SNO86, SMI88, SHA89]. Also required were the development of a parser and a set of packages to connect the semantic links of the underlying DIANA tree.

[MEN89] describes the Stanford implementation of Anna, a superset language of Ada containing formal annotations. The manual describes the tools which comprise the Anna toolset and outlines scenarios for their use. Most of these tools work with

DIANA nets in varying stages of development. The DIANA implementation is based on the 1983 version of DIANA and on the work described in [ROS85].

The major tool dealing with DIANA is, in fact, the package **ast_v.a** which provides the definition of the DIANA type, of constituent types, and of the operations on those types. In addition to the node types mentioned in [GOO83], there are node types which are specific to Anna and are not defined in standard DIANA. There is a parser which translates Anna source code (or presumably pure Ada code) into a DIANA abstract syntax tree with possible Anna-specific nodes. A semantic processor adds the semantic links, changing the tree into a directed graph. A transformer translates the Anna-specific subnets into pure Ada-based DIANA. There are other support tools such as a DIANA reader/dumper, a DIANA-to-Anna (or Ada) prettyprinter, and a parser generator complete with an Anna grammar. An interesting problem which could have arisen with the use of this toolset would be the possible overhead resulting from the fact that the toolset implements a superset of Ada (e.g. the use of the transformer). Another problem which would certainly have proven troublesome is the incompleteness in the implementation of Ada semantics.

Verdix VADS DIANA. The DIANA interface used by the VERDIX VADS compiler was selected for use in the GRASP project. This interface consists of seven Ada specification packages atop a largely C-based implementation. This interface provides the type declarations for DIANA nodes with discriminants to distinguish node types. Also included are facilities to produce a dependency graph for a given unit, to produce a topological sort of that graph corresponding to a given compilation order, and to access the DIANA net for each unit in that sort. A generic tree walking algorithm with two formal subprogram parameters corresponding to preorder processing and postorder processing routines for each node can be tailored to gather what information is needed from each net.

The VERDIX version of DIANA differs slightly from the [GOO83] version, the difference supposedly being for performance reasons. Among the most detrimental changes was the trimming of the nets for storage efficiency. It was hoped that the reduced net would be sufficient for purposes of the project; however, the full DIANA net (produced only by the **-F** option of the compiler) was required. The full net is usually significantly larger than the reduced net; this will probably prove to be an inconvenience to those involved in the tool's development as well as its users. In addition, VERDIX added symbol table nodes for quicker access to the meanings of the symbols. Earlier examination of the utility of the symbol table nodes proved inconclusive; however, further discussions with the technical representative at VERDIX may yet prove fruitful. There are characteristics of DIANA which constrict its ease of use. For instance, the designers of DIANA forbade the alteration of nets created in previous compilations [GOO83, McK86]. By every indication, VERDIX has followed this policy with its DIANA implementation.

In order to produce a subprogram invocation graph by mere traversal of the DIANA net, it is necessary for there to be a pointer path between the node representing the invocation of a subprogram and the node representing the body of that subprogram. Unfortunately, no such path exists in general. There are links from both the invocation and the body to the original specification of the subprogram, but no direct path is possible from invocation to body. Because of this disconnection, it is difficult to determine calling hierarchies by mere traversal of DIANA nets.

In order to build the calling hierarchy, it is necessary to provide a means to "connect" the invocation of a subprogram to the body of that subprogram. The approach has been to construct a directed graph where vertices represent subprograms and arcs represent the calling hierarchy among subprograms. The creation of a vertex in the directed graph corresponds to the encounter of a new subprogram specification within some DIANA net. The creation of an arc corresponds to encountering a call by one subprogram to another, where the head and tail of the arc represent the called subprogram and the caller respectively. The routines provided by the DIANA interface, namely **get_compilation_order**, plus the Ada requirement that the specification of a subprogram be compiled before any call to that subprogram, ensure that there are no "dangling arcs." This approach is currently being implemented.

4.4.2 Library Management

Any tool that aspires to be part of a comprehensive software development environment must contend with database issues. This is especially true of a tool which would be part of an APSE, considering Ada's separate compilation requirements. Ideally, an APSE database would maintain relationships of various sorts among the program components of Ada systems. Such a database would also maintain other artifacts pertaining to the Ada system such as text documentation, testing procedures, and graphical representations as well as the connections to their program components.

The entity-relationship database model is recommended for APSE databases [McD84, LYO86]. Such a choice is quite appropriate given the variety of relationships among units of an Ada program. For each unit (whether such a unit is embedded within another or not), the library will contain, among other things, the name of the unit, its intermediate representation, a file name and position where the unit can be located, a timestamp, and any graphical representation heretofore created corresponding particularly to that unit. Each unit can be related by various forms of hierarchy, and this relationship will be reflected the library structure as well.

The purpose of a "GRASP library" is to maintain the information on an Ada system needed to produce appropriate graphical representations. The extent to which this goal can be realized depends on the effective granularity which can be achieved practically in the GRASP library. The granularity not only refers to the refinement of entities in such a library but also the relationships which can be practically determined. It is envisioned that the GRASP library would act as a supplement to DIANA in the areas of deficiency mentioned earlier and will most likely build on (and be limited by) the facilities provided by VADS.

4.4.3 Graphics Tools Requirements

Tools will be required to produce icons appropriate for the diagrams produced by the GRASP tool. The X Windows graphics facilities will be used as the icon construction tool.

4.5 Status of the GRASP/Ada Prototype

Figure 18 shows the current the architecture of the GRASP/Ada prototype. The user interface, built around X Windows, provides access to all GRASP components. CSDgen, ArchCSDgen, SCgen, and ODgen generate CSDs, architectural CSDs, structure charts, and object diagrams respectively, from Ada source code. CSDgen and ArchCSDgen are based on a parser and scanner built using BISON and LEX. SCgen and ODgen are being built around the DIANA interface to Verdix VADS. All of the components ultimately rely on the UNIX file system.

The user interface and CSDgen are fully operational and available on a limited basis for initial evaluation. ArchCSDgen is in the late stages of implementation, but will not be fully integrated with the user interface until Phase 3. SCgen and ODgen will be implemented and integrated during Phase 3.

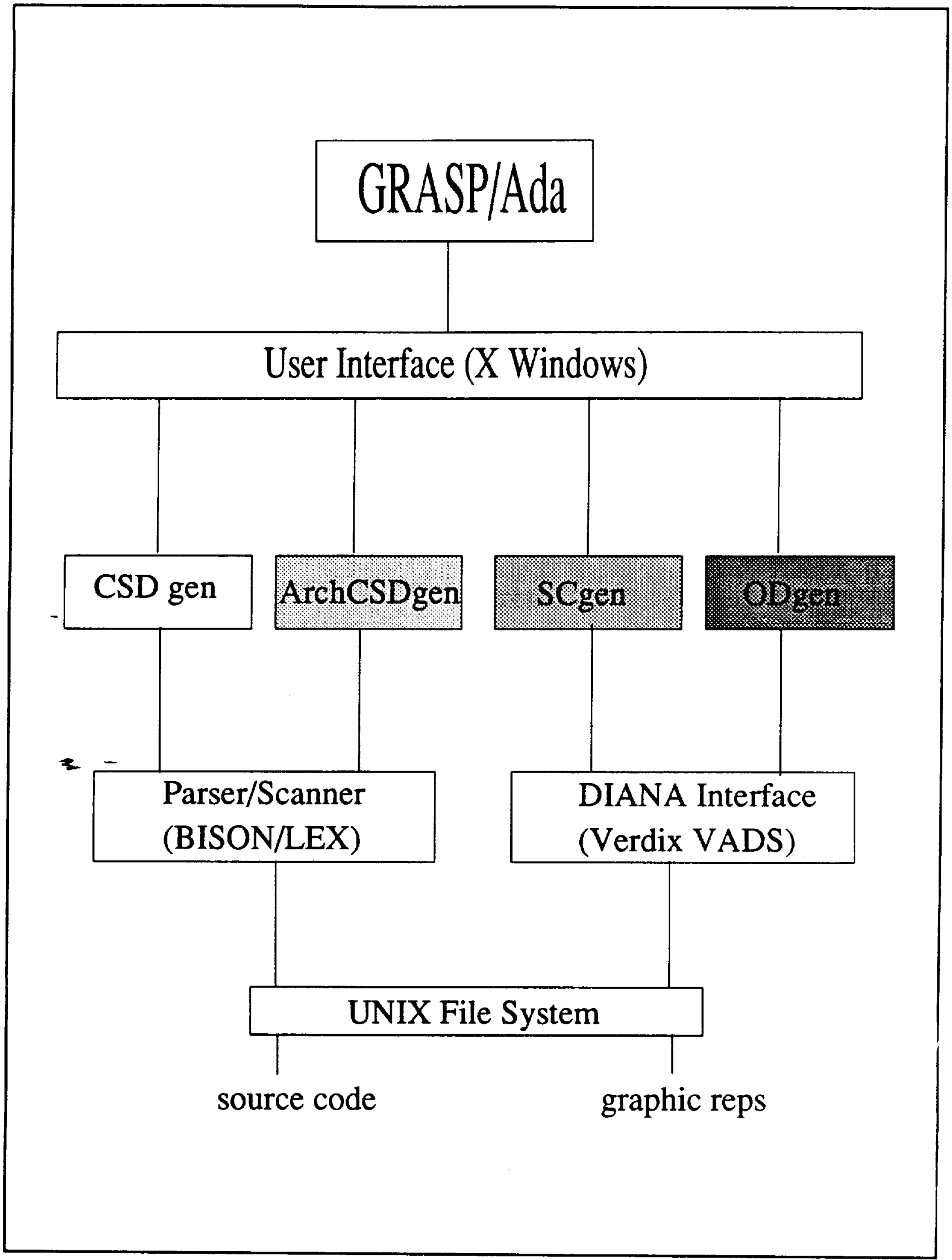


Figure 18. GRASP/Ada System Architecture

5.0 FUTURE WORK

Phases 1 and 2 of this task included (1) the study, formulation and evaluation of graphical representations for Ada software, (2) development of a prototype reverse engineering tool that provides support for generation of both algorithmic and limited hierarchical diagrams, and (3) the investigation of the generation of additional graphical representations to provide task, package, and data flow views of Ada software.

The goals of Phase 3 are the following: (1) to continue the examination, formulation and evaluation of graphical representations for Ada software, (2) to continue the development of the Phase 2 prototype reverse engineering tool to include support for generation of both algorithmic diagrams and architectural diagrams that capture hierarchical organization as well as task, package, and data flow information, and (3) to investigate the generation of additional graphical representations which result from (1). The subtasks outlined in the research approach below are expected to provide a basis for a methodology for graphically-oriented reverse engineering of Ada software.

5.1 Research Approach

This phase of the research includes the following subtasks.

1. Formalize a set of graphical representations that directly support Ada software at the system level of abstraction.

A small, but representative, Ada program will be utilized to formulate and evaluate a set of graphical representations. Specifically, the feasibility of reverse engineering the diagrams from Ada source code will be evaluated. These graphical representations are expected to undergo continual refinement as the automated tools that support them are developed.

2. *Design and implement a prototype software tool for generating architectural diagrams (ADs) [to include structure charts, package diagrams, and task interaction diagrams] from Ada source code.*

The present prototype which has focused on CSDs and architectural CSDs will be extended to include additional architectural diagrams. This subtask will include (1) development of procedures for identifying and recording module interconnections, (2) development of algorithms for architectural diagram layout, and (3) development of methods for displaying/printing architectural diagrams on hardware available for this research. The tool will be used on representative Ada software. The generated set of graphical representations will be evaluated for completeness, correctness, and general utility as an approach to reverse engineering.

3. *Investigate the migration of the graphical representations generated by the reverse engineering prototype tool toward forward engineering methods.*

Of particular importance here is the ability to edit the diagrams directly rather than regenerate them from Ada source code each time a change is made. The feasibility of extending an existing text editor with the capability of interactively generating diagrams as the source code is entered or modified will be determined.

4. *Investigate additional automatically generated graphical representations of Ada software such as a data flow view, and investigate the application of artificial intelligence (AI) and expert systems to the generation of system level diagrams.*

A general data flow view of the software is expected to be the most difficult to generate strictly from source code. The use of expert systems and rule-based systems will be investigated as an approach to analysis of Ada software. In particular, AI-assisted identification of components and layout of the graphical representations described above will be investigated.

5. *Investigate the integration of the prototype with existing CASE tools.*

It is important to leverage the functionality of existing tools to achieve an overall automated support environment. While this research has focused on reverse engineering, other tools have been developed which address additional aspects of the software life cycle. Of particular interest here is Interactive Development Environments' (IDE) CASE tool which supports Object-Oriented Structured Design (OOSD).

5.2 Proposed Research Schedule

The Gantt chart in Figure 19 provides the sequence of activities to be accomplished during Phase 3 of this project. The rows in the chart correspond to each of the subtasks described above.

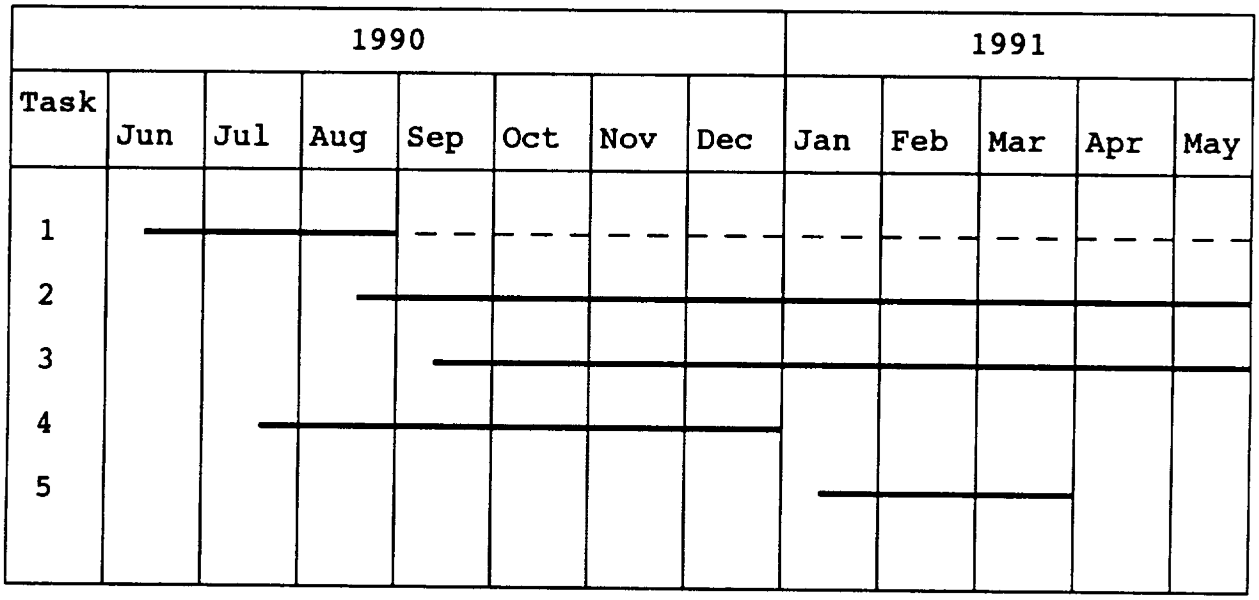


Figure 19. Phase 3 Gantt Chart

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Appendix A

"Reverse Engineering and Design Recovery : A Taxonomy"

by

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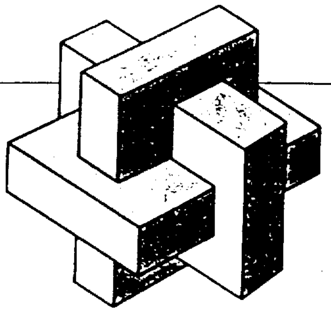

Reverse Engineering and Design Recovery: A Taxonomy

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James H. Cross II, *Auburn University*

Reverse engineering is evolving as a major link in the software life cycle, but its growth is hampered by confusion over terminology. This article defines key terms.

The availability of computer-aided systems-engineering environments has redefined how many organizations approach system development. To meet their true potential, CASE environments are being applied to the problems of maintaining and enhancing existing systems. The key lies in applying reverse-engineering approaches to software systems. However, an impediment to success is the considerable confusion over the terminology used in both technical and marketplace discussions.

It is in the reverse-engineering arena, where the software maintenance and development communities meet, that various terms for technologies to analyze and understand existing systems have been frequently misused or applied in conflicting ways.

In this article, we define and relate six terms: forward engineering, reverse engineering, redocumentation, design recovery, restructuring, and reengineering. Our objective is not to create new terms but to rationalize the terms already in use. The resulting definitions apply to the underlying engineering processes, regardless of the degree of automation applied.

Hardware origins

The term "reverse engineering" has its origin in the analysis of hardware — where the practice of deciphering designs from finished products is commonplace. Reverse engineering is regularly applied to improve your own products, as well as to analyze a competitor's products or those of an adversary in a military or national-security situation.

In a landmark paper on the topic, M.G. Rekoff defines reverse engineering as "the process of developing a set of specifications for a complex hardware system by an orderly examination of specimens of that system."[1] He describes such a process

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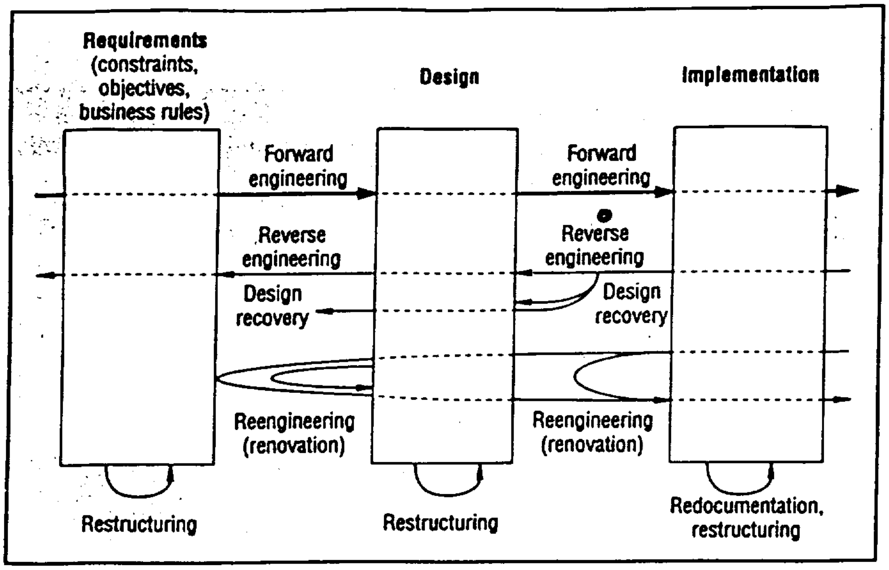

Figure 1. Relationship between terms. Reverse engineering and related processes are transformations between or within abstraction levels, represented here in terms of life-cycle phases.

as being conducted by someone other than the developer, "without the benefit of any of the original drawings ... for the purpose of making a clone of the original hardware system...."

In applying these concepts to software systems, we find that many of these approaches apply to gaining a basic understanding of a system and its structure. However, while the hardware objective traditionally is to duplicate the system, the software objective is most often to gain a sufficient design-level understanding to aid maintenance, strengthen enhancement, or support replacement.

Software maintenance

The ANSI definition of software maintenance is the "modification of a software product after delivery to correct faults, to improve performance or other attributes, or to adapt the product to a changed environment," according to ANSI/IEEE Std 729-1983.

Usually, the system's maintainers were not its designers, so they must expend many resources to examine and learn about the system. Reverse-engineering tools can facilitate this practice. In this context, reverse engineering is the part of the maintenance process that helps you understand the system so you can make appropriate changes. Restructuring and reverse engineering also fall within the global definition of software maintenance. However, each of these three processes also has a place within the contexts of building new systems and evolutionary development.

Life cycles and abstractions

To adequately describe the notion of software forward and reverse engineering, we must first clarify three dependent concepts: the existence of a life-cycle model, the presence of a subject system, and the identification of abstraction levels.

We assume that an orderly life-cycle model exists for the software-development process. The model may be represented as the traditional waterfall, as a spiral, or in some other form that generally can be represented as a directed graph. While we expect there to be iteration within stages of the life cycle, and perhaps even recursion, its general directed-graph nature lets us sensibly define forward (downward) and backward (upward) activities.

The subject system may be a single program or code fragment, or it may be a complex set of interacting programs, job-control instructions, signal interfaces, and data files. In forward engineering, the subject system is the result of the development process. It may not yet exist, or its existing components may not yet be united to form a system. In reverse engineering, the subject system is generally the starting point of the exercise.

In a life-cycle model, the early stages deal with more general, implementation-independent concepts; later stages emphasize implementation details. The transition of increasing detail through the forward progress of the life cycle maps well to the concept of abstraction levels. Earlier stages of systems planning and requirements definition involve expressing higher level abstractions of the system being designed when compared to the implementation itself.

These abstractions are more closely related to the business rules of the enterprise. They are often expressed in user terminology that has a one-to-many relationship to specific features of the finished system. In the same sense, a blueprint is a higher level abstraction of the building it represents, and it may document only one of the many models (electrical, water, heating/ventilation/air conditioning, and egress) that must come together.

It is important to distinguish between *levels* of abstraction, a concept that crosses conceptual stages of design, and *degrees* of abstraction within a single stage. Spanning life-cycle phases involves a transition from higher abstraction levels in early stages to lower abstraction levels in later stages. While you can represent information in any life-cycle stage in detailed form (lower degree of abstraction) or in more summarized or global forms (higher degree of abstraction), these definitions emphasize the concept of *levels* of abstraction between life-cycle phases.

Definitions

For simplicity, we describe key terms using only three identified life-cycle stages with clearly different abstraction levels, as Figure 1 shows:

- requirements (specification of the problem being solved, including objectives, constraints, and business rules),
- design (specification of the solution), and
- implementation (coding, testing, and delivery of the operational system).

Forward engineering. Forward engineering is the traditional process of moving from high-level abstractions and logical, implementation-independent designs to the physical implementation of a system.

While it may seem unnecessary — in view of the long-standing use of design and development terminology — to introduce a new term, the adjective "forward" has come to be used where it is necessary to distinguish this process from reverse engineering. Forward engineering follows a sequence of going from requirements through designing its implementation.

Reverse engineering. Reverse engineering is the process of analyzing a subject system to

- identify the system's components and their interrelationships and
- create representations of the system in another form or at a higher level of abstraction.

Reverse engineering generally involves extracting design artifacts and building or synthesizing abstractions that are less implementation-dependent. While reverse engineering often involves an existing functional system as its subject, this is *not* a requirement. You can perform reverse engineering starting from any level of abstraction or at any stage of the life cycle.

Reverse engineering in and of itself does *not* involve changing the subject system or creating a new system based on the reverse-engineered subject system. It is a process of *examination*, not a process of change or replication.

In spanning the life-cycle stages, reverse engineering covers a broad range starting from the existing implementation, recapturing or recreating the design, and deciphering the requirements actually implemented by the subject system.

There are many subareas of reverse engineering. Two subareas that are widely referred to are redocumentation and design recovery.

Redocumentation. Redocumentation is the creation or revision of a semantically equivalent representation within the same relative abstraction level. The resulting forms of representation are usually considered alternate views (for example, dataflow, data structure, and control flow) intended for a human audience.

Redocumentation is the simplest and oldest form of reverse engineering, and many consider it to be an unintrusive, weak form of restructuring. The "re-" prefix implies that the intent is to recover documentation about the subject system that existed or should have existed.

Some common tools used to perform redocumentation are pretty printers (which display a code listing in an improved form), diagram generators (which create diagrams directly from code, reflecting control flow or code structure), and cross-reference listing generators. A key goal of these tools is to provide easier ways to visualize relationships among program components so you can recognize and follow paths clearly.

Design recovery. Design recovery is a subset of reverse engineering in which domain knowledge, external information, and deduction or fuzzy reasoning are added to the observations of the subject system to identify meaningful higher level abstractions beyond those obtained directly by examining the system itself.

Reverse engineering in and of itself does not involve changing the subject system. It is a process of examination, not change or replication.

Design recovery is distinguished by the sources and span of information it should handle. According to Ted Biggerstaff: "Design recovery recreates design abstractions from a combination of code, existing design documentation (if available), personal experience, and general knowledge about problem and application domains ... Design recovery must reproduce all of the information required for a person to fully understand what a program does, how it does it, why it does it, and so forth. Thus, it deals with a far wider range of information than found in conventional software-engineering representations or code."[2]

Restructuring. Restructuring is the transformation from one representation form to another at the same relative abstraction level, while preserving the subject system's external behavior (functionality and semantics).

A restructuring transformation is often one of appearance, such as altering code to improve its structure in the traditional sense of structured design. The term "restructuring" came into popular use from the code-to-code transform that recasts a program from an unstructured ("spaghetti") form to a structured (goto-less) form. However, the term has a broader meaning that recognizes the application of similar transformations and recasting techniques in reshaping data models, design plans, and requirements structures. Data normalization, for example, is a data-to-data restructuring transform to improve a logical data model in the database design process.

Many types of restructuring can be performed with a knowledge of structural form but without an understanding of meaning. For example, you can convert a set of If statements into a Case structure, or vice versa, without knowing the program's purpose or anything about its problem domain.

While restructuring creates new versions that implement or propose change to the subject system, it does not normally involve modifications because of new requirements. However, it may lead to better observations of the subject system that suggest changes that would improve aspects of the system. Restructuring is often used as a form of preventive maintenance to improve the physical state of the subject system with respect to some preferred standard. It may also involve adjusting the subject system to meet new environmental constraints that do not involve reassessment at higher abstraction levels.

Reengineering. Reengineering, also known as both renovation and reclamation, is the examination and alteration of a subject system to reconstitute it in a new form and the subsequent implementation of the new form.

Reengineering generally includes some form of reverse engineering (to achieve a more abstract description) followed by some form of forward engineering or restructuring. This may include modifications with respect to new requirements not met by the original system. For exam-

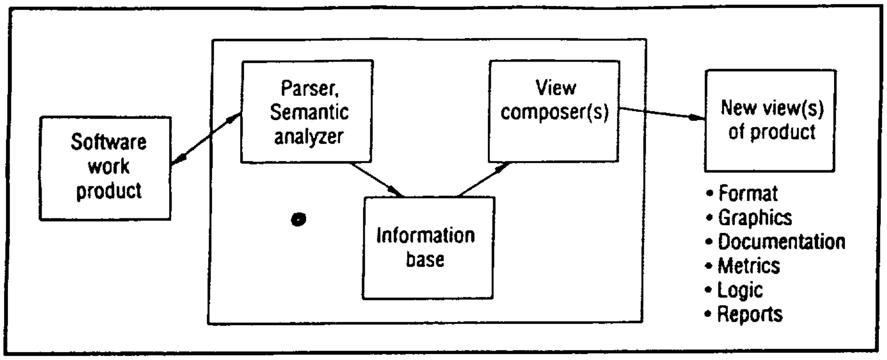

Figure 2. Model of tools architecture. Most tools for reverse engineering, restructuring, and reengineering use the same basic architecture. The new views on the right may themselves be software work products, which are shown on the left. (Model provided by Robert Arnold of the Software Productivity Consortium.)

ple, during the reengineering of information-management systems, an organization generally reassesses how the system implements high-level business rules and makes modifications to conform to changes in the business for the future.

There is some confusion of terms, particularly between reengineering and restructuring. The IBM user group Guide, for example, defines "application reengineering" as "the process of modifying the internal mechanisms of a system or program or the data structures of a system without changing the functionality (system capabilities as perceived by the user). In other words, it is altering the *how* without affecting the *what.*"[3] This is closest to our definition of restructuring. However, two paragraphs later, the sane publication says, "It is rare that an application is reengineered without additional functionality being added." This supports our more general definition of reengineering.

While reengineering involves both forward engineering and reverse engineering, it is *not* a supertype of the two. Reengineering uses the forward- and reverse-engineering technologies available, but to date it has not been the principal driver of their progress. Both technologies are evolving rapidly, independent of their application within reengineering.

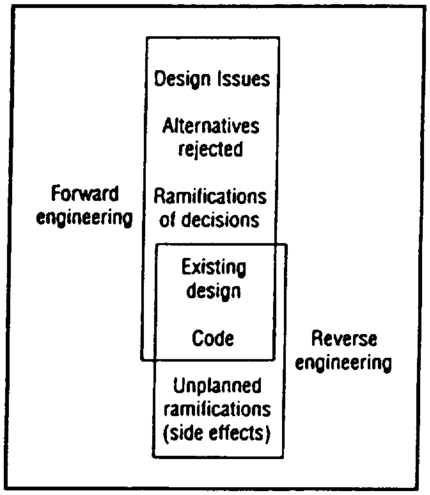

Figure 3. Differences between viewpoints. Although reverse engineering can help capture lost information, some types of information are not shared between forward- and reverse-engineering processes. However, reverse engineering can provide observations that are unobtainable in forward engineering.

Objectives

What are we trying to accomplish with reverse engineering? The primary purpose of reverse engineering a software system is to increase the overall comprehensibility of the system for both maintenance and new development. Beyond the definitions above, there are six key objectives that will guide its direction as the technology matures:

• Cope with complexity. We must develop methods to better deal with the shear volume and complexity of systems. A key to controlling these attributes is automated support. Reverse-engineering methods and tools, combined with CASE environments, will provide a way to extract relevant information so decision makers can control the process and the product in systems evolution. Figure 2 shows a model of the structure of most tools for reverse engineering, reengineering, and restructuring.

• Generate alternate views. Graphical representations have long been accepted as comprehension aids. However, creating and maintaining them continues to be a bottleneck in the process. Reverse-engineering tools facilitate the generation or regeneration of graphical representations from other forms. While many designers work from a single, primary perspective (like dataflow diagrams), reverse-engineering tools can generate additional views from other perspectives (like control-flow diagrams, structure charts, and entity-relationship diagrams) to aid the review and verification process. You can also create alternate forms of nongraphical representations with reverse-engineering tools to form an important part of system documentation.

• Recover lost information. The continuing evolution of large, long-lived systems leads to lost information about the system design. Modifications are frequently not reflected in documentation, particularly at a higher level than the code itself. While it is no substitute for preserving design history in the first place, reverse engineering — particularly design recovery — is our way to salvage whatever we can from the existing systems. It lets us get a handle on systems when we don't understand what they do or how their individual programs interact as a system.

• Detect side effects. Both haphazard initial design and successive modifications can lead to unintended ramifications and side effects that impede a system's performance in subtle ways. As Figure 3 shows, reverse engineering can provide observations beyond those we can obtain with a forward-engineering perspective, and it can help detect anomalies and problems before users report them as bugs.

• Synthesize higher abstractions. Reverse engineering requires methods and techniques for creating alternate views that transcend to higher abstraction levels. There is debate in the software community as to how completely the process can be automated. Clearly, expert-system technology will play a major role in achieving the full potential of generating high-level abstractions.

• Facilitate reuse. A significant issue in the movement toward software reusability is the large body of existing software assets. Reverse engineering can help detect candidates for reusable software components from present systems.

Economics

The cost of understanding software, while rarely seen as a direct cost, is nonetheless very real. It is manifested in the time required to comprehend software, which includes the time lost to misunderstanding. By reducing the time required to grasp the essence of software artifacts in each life-cycle phase, reverse engineering may greatly reduce the overall cost of software.

In commenting on this article, Walt Scacchi of the University of Southern California made the following important observations: "Many claim that conventional software maintenance practices account for 50 to 90 percent of total life-cycle costs. Software reverse-engineering technologies are targeted to the problems that give rise to such a disproportionate distribution of software costs. Thus, if reverse engineering succeeds, the total system expense may be reduced/mitigated, or greater value may be added to current efforts, both of which represent desirable outcomes, especially if one quantifies the level of dollars spent. Reverse engineering may need to only realize a small impact to generate sizable savings."

Scacchi also pointed out that "software forward engineering and reverse engineering are *not* separate concerns, and thus should be viewed as opportunity for convergence and complement, as well as an expansion of the repertoire of tools and techniques that should be available to the modern software engineer. I, for one, believe that the next generation of software-engineering technologies will be applicable in both the forward and reverse directions. Such a view also may therefore imply yet another channel for getting advanced software-environment/CASE technologies into more people's hands — sell them on reverse engineering (based on current software-maintenance cost patterns) as a way to then introduce better forward engineering tools and techniques."

We have tried to provide a framework for examining reverse-engineering technologies by synthesizing the basic definitions of related terms and identifying common objectives.

Reverse engineering is rapidly becoming a recognized and important component of future CASE environments. Because the entire life cycle is naturally an iterative activity, reverse-engineering tools can provide a major link in the overall process of development and maintenance. As these tools mature, they will be applied to artifacts in all phases of the life cycle. They will be a permanent part of the process, ultimately used to verify all completed systems against their intended designs, even with fully automated generation.

Reverse engineering, used with evolving software development technologies, will provide significant incremental enhancements to our productivity. ❖

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Appendix B

"Control Structure Diagrams For Ada"

by

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To appear in *Journal of Pascal, Ada & Modula 2*.

Control Structure Diagrams for Ada

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ABSTRACT

The Control Structure Diagram (CSD) is a graphical notation intended to increase the comprehensibility of software written in block-structured languages such as Ada, Pascal, and Modula 2, or their associated PDLs. The CSD provides for the explicit depiction of control constructs and control flow by extending the traditional textual representation of PDL or source code with intuitive graphical constructs which are easily adapted to a specific language or PDL. The CSD can be used as a natural extension to popular architectural level representations such as data flow diagrams, Booch diagrams, and structure charts. The CSD constructs for Ada are described in the context of a simple task example. The CSD is currently supported by a fully operational prototype graphical prettyprinter.

Introduction

Advances in hardware, particularly high-density bit-mapped monitors, have led to a renewed interest in graphical representation of software. Much of the research activity in the area of software visualization and computer-aided software engineering (CASE) tools has focused on architectural-level charts and diagrams. However, the complex nature of the control constructs and the subsequent control flow defined by program design languages (PDLs), which are based on programming languages such as Ada, Pascal, and Modula 2.

make detailed design specifications attractive candidates for graphical representation. And since the source code itself will be read many times during the course of initial development, testing and maintenance, it too should benefit from the use of an appropriate graphical notation. The control structure diagram (CSD) is a notation intended specifically for the graphical representation of detailed designs as well as actual source code. The primary purpose of the CSD is to reduce the time required to comprehend software by clearly depicting the control constructs and control flow at all relevant levels of abstraction, whether at the design level or within the source code itself. The CSD is a natural extension to existing architectural graphical representations such as data flow diagrams, structure charts, and Booch diagrams.

The CSD, which was initially created for Pascal/PDL [1], has been extended significantly so that the graphical constructs of the CSD map directly to the constructs of Ada. The rich set of control constructs in Ada (e.g. task rendezvous) and the wide acceptance of Ada/PDL by the software engineering community as a detailed design language made Ada a natural choice for the basis of a graphical notation. A major objective in the philosophy that guided the development of the CSD was that the graphical constructs supplement the code and/or PDL without disrupting their familiar appearance. That is, the CSD should appear to be a natural extension to the Ada constructs and, similarly, the Ada source code should appear to be a natural extension of the diagram. This has resulted in a concise, compact graphical notation which attempts to combine the best features of previous diagrams with those of well-established PDLs. A CSD generator was developed to automate the process of producing the CSD from Ada source code.

Background

Graphical representations have long been recognized as having an important impact in communicating from the perspective of both the "writer" and the "reader." For software, this includes communicating requirements between users and designers and communicating design specifications between designers and implementors. However, there are additional areas where the potential of graphical notations have not been fully exploited. These include communicating the semantics of the actual implementation represented by the source code to personnel for the purposes of testing and maintenance, each of which are major resource sinks in the software life cycle. In particular, Shelby [2] found that code reading was the most cost effective method of detecting errors during the verification process when compared to functional testing and structural testing. And Standish [3] reported that program understanding may represent as much as 90% of the cost of maintenance. Hence, improved comprehension efficiency resulting from the integration of graphical notations and source code could have a significant impact on the overall cost of software production.

Since the flowchart was introduced in the mid-50's, numerous notations for representing algorithms have been proposed and utilized. Several authors have published notable books and papers that address the details of many of these [4, 5, 6]. Tripp, for example, describes 18 distinct notations that have been introduced since 1977 and Aoyama et.al. describes the popular diagrams used in Japan. In general, these diagrams have been strongly influenced by structured programming and thus contain control constructs for sequence, selection, and iteration. In addition, several contain explicit EXIT structures to allow single entry / multiple exit control flow through a block of code, as well as

PARALLEL or concurrency constructs. However, none the diagrams cited explicitly contains all of the control constructs found in Ada.

Graphical notations for representing software at the algorithmic level have been neglected, for the most part, by business and industry in the U.S. in favor of non-graphical PDL. A lack of automated support and the results of several studies conducted in the seventies which found no significant difference in the comprehension of algorithms represented by flowcharts and pseudo-code [7] have been a major factors in this underutilization. However, automation is now available in the form of numerous CASE tools and recent empirical studies reported by Aoyami [6] and Scanlan [8] have concluded that graphical notations may indeed improve the comprehensibility and overall productivity of software. Scanlan's study involved a well-controlled experiment in which deeply nested if-then-else constructs, represented in structured flowcharts and pseudo-code, were read by intermediate-level students. Scores for the flowchart were significantly higher than those of the PDL. The statistical studies reported by Aoyami et.al. involved several tree-structured diagrams (e.g., PAD, YACC II, and SPD) widely used in Japan which, in combination with their environments, have led to significant gains in productivity. The results of these recent studies suggest that the use of a graphical notation with appropriate automated support for Ada/PDL and Ada should provide significant increases productivity over current non-graphical approaches.

The Control Structure Diagram Illustrated

Figure 1 (a) contains an Ada task body CONTROLLER adapted from [9], which loops through a priority list attempting to accept selectively a REQUEST with priority P. Upon on acceptance, some action is taken, followed by an exit from the priority list loop to restart the loop with the first priority. In typical Ada task fashion, the priority list loop is contained in an outer infinite loop. This short example contains two threads of control: the rendezvous, which enters and exists at the accept statement, and the thread within the task body. In addition, the priority list loop contains two exits: the normal exit at the beginning of the loop when the priority list has been exhausted, and an explicit exit invoked within the select statement. While the concurrency and multiple exits are useful in modeling the solution, they do increase the effort required of the reader to comprehend the code.

Figure 1 (b) shows the corresponding CSD generated by the graphical prettyprinter. In this example, the intuitive graphical constructs of the CSD clearly depict the point of rendezvous, the two nested loops, the select statement guarding the accept statement for the task, the unconditional exit from the inner loop, and the overall control flow of the task. When reading the code without the diagram, as shown in Figure 1 (a), the control constructs and control paths are much less visible although the same structural and control information is available. As additional levels of nesting and increased physical separation of sequential components occur in code, the visibility of control constructs and control paths becomes increasingly obscure, and the effort required of the reader dramatically increases in the absence of the CSD.

Now that the CSD has been briefly introduced, the various CSD constructs for Ada are presented in Figures 2. Since the CSD is designed to supplement the semantics of the underlying Ada, each of the CSD constructs is self-explanatory and are presented without further description.

Automated Support -- The CSD Graphical Prettyprinter

Automated support is a requirement, at least in the in professional ranks, for widespread utilization of any graphical representation. Without automated support, diagrams are difficult to construct and maintain from the standpoint of "living" formal documentation, although software practitioners may use several types of diagrams informally during design and even implementation. Automated support comes in many forms ranging from general purpose "drawing aids" to automatic generation and maintenance based on changes to source code. The CSD for Ada is currently supported by an operational prototype graphical prettyprinter which accepts Ada source code as input and generates the CSD in a manner similar to text-based prettyprinters. The prototype was implemented under DEC's VAX VMS using a scanner/parser generator and an Ada grammar. The user interface was built using DEC's VAX Curses, and to provide the user with interactive viewing of the CSD, a special version of DEC's EVE editor was generated. Custom fonts for the CSD graphics characters were built for both the VT220 terminal and the HP Laser Jet printer. Using font-oriented graphics characters diagrams rather than bit-mapped images provided for a high degree of efficiency in generating the diagrams. The prototype is currently being ported to the Sun-4 workstation under UNIX and X Windows, where enhancements will include an option to collapse the diagram around any control constructs and an option to generate an intermediate level architectural diagram which indicates control structure among subprograms and tasks.

Conclusions and Future Directions

A new graphical tool which maps directly to Ada was formally defined and automated. The CSD offers advantages over previously available diagrams in that it is combines the best features PDL and code with simple intuitive graphical constructs. The potential of the CSD can be best realized during detailed design, implementation, verification and maintenance. The CSD can be used as a natural extension to popular architectural level representations such as data flow diagrams, Booch diagrams, and structure charts.

Our current reverse engineering project, GRASP/Ada [10], is focused on the generation of multi-level and multi-view graphical representations from Ada source code. As indicated in GRASP/Ada overview shown in Figure 3, the CSD represents the code/PDL level diagram generated by the system. Our present efforts are concentrated on the extraction of architectural and system level diagrams such as structure charts, Booch diagrams, and data flow diagrams. The reverse engineering of graphical representations is destined to become an integral component of CASE tools, which until recently have focused on forward engineering. The development of tools that provide for interactive automatic updating of charts and diagrams will serve to improve the overall comprehensibility of software and, as a result, improve reliability and reduce the cost of software.

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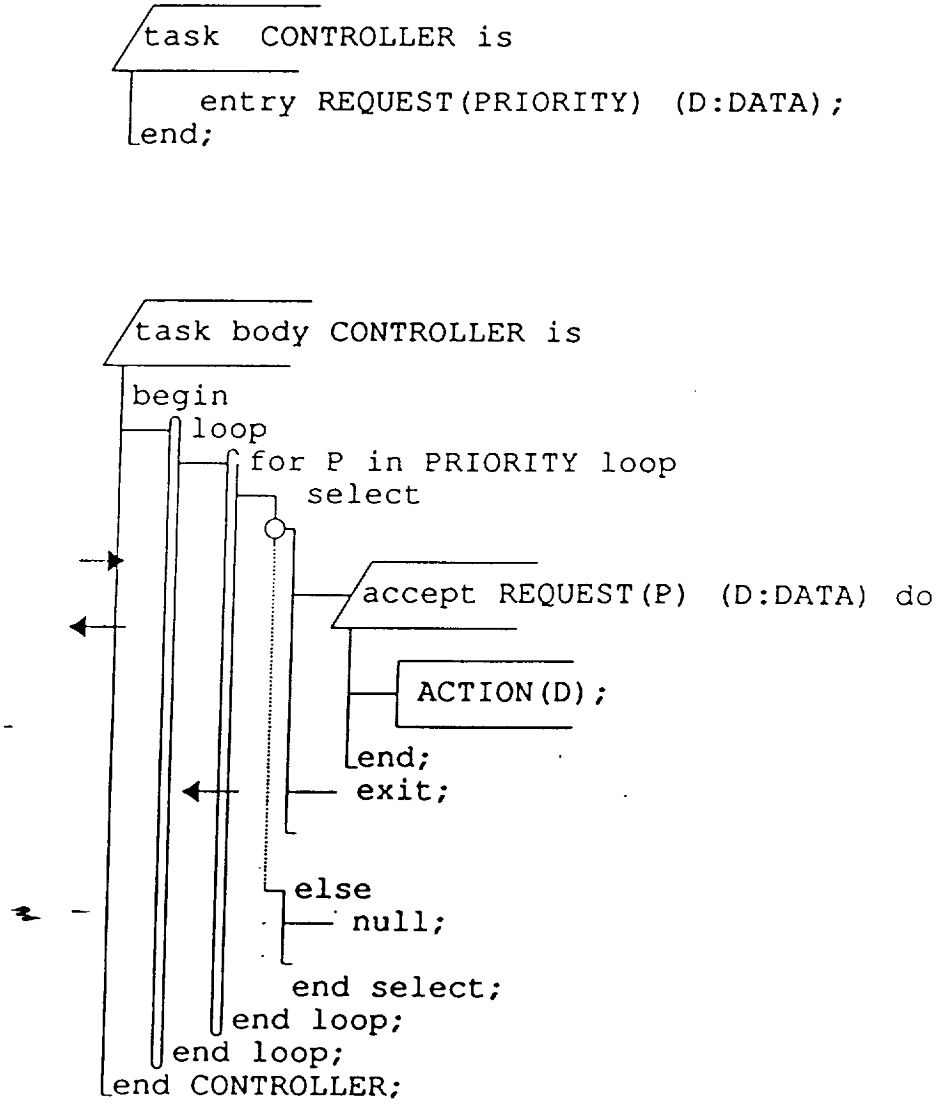
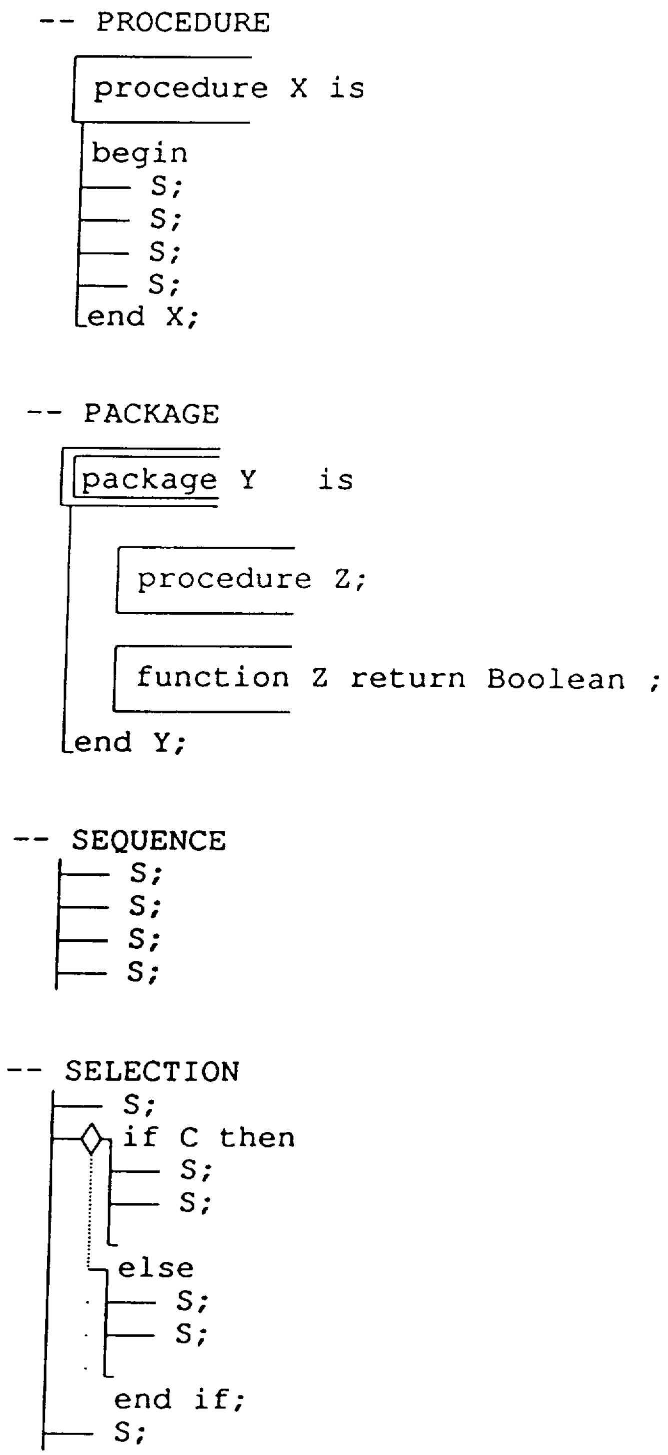
```
task  CONTROLLER is

   entry REQUEST(PRIORITY) (D:DATA);
end;



task body CONTROLLER is

begin
   loop
      for P in PRIORITY loop
         select

            accept REQUEST(P) (D:DATA) do

               ACTION(D);

            end;
            exit;

         else
            null;

         end select;
      end loop;
   end loop;
end CONTROLLER;
```

Figure 1(a). Ada Source Code for Task CONTROLLER.



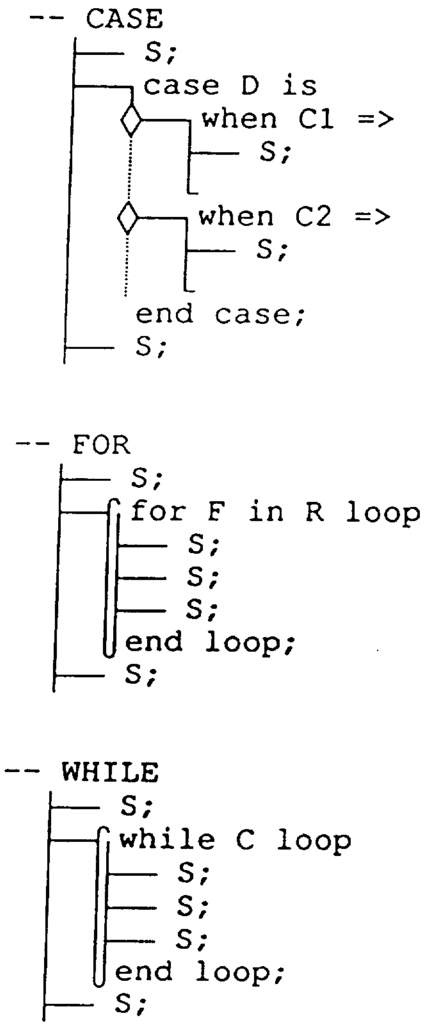
```
task  CONTROLLER is
     entry REQUEST(PRIORITY)  (D:DATA);
end;


task body CONTROLLER is
begin
     loop
          for P in PRIORITY loop
               select
                    accept REQUEST(P)  (D:DATA) do
                         ACTION(D);
                    end;
                    exit;
               else
                    null;
               end select;
          end loop;
     end loop;
end CONTROLLER;
```

Figure 1(b). Control Structure Diagram of Ada Source Code for Task CONTROLLER.



```
-- PROCEDURE
procedure X is
begin
   S;
   S;
   S;
   S;
end X;

-- PACKAGE
package Y   is

   procedure Z;

   function Z return Boolean ;

end Y;

-- SEQUENCE
   S;
   S;
   S;
   S;

-- SELECTION
   S;
if C then
      S;
      S;
else
      S;
      S;
end if;
   S;
```

Figure 2. Control Structure Diagram Constructs For Ada.

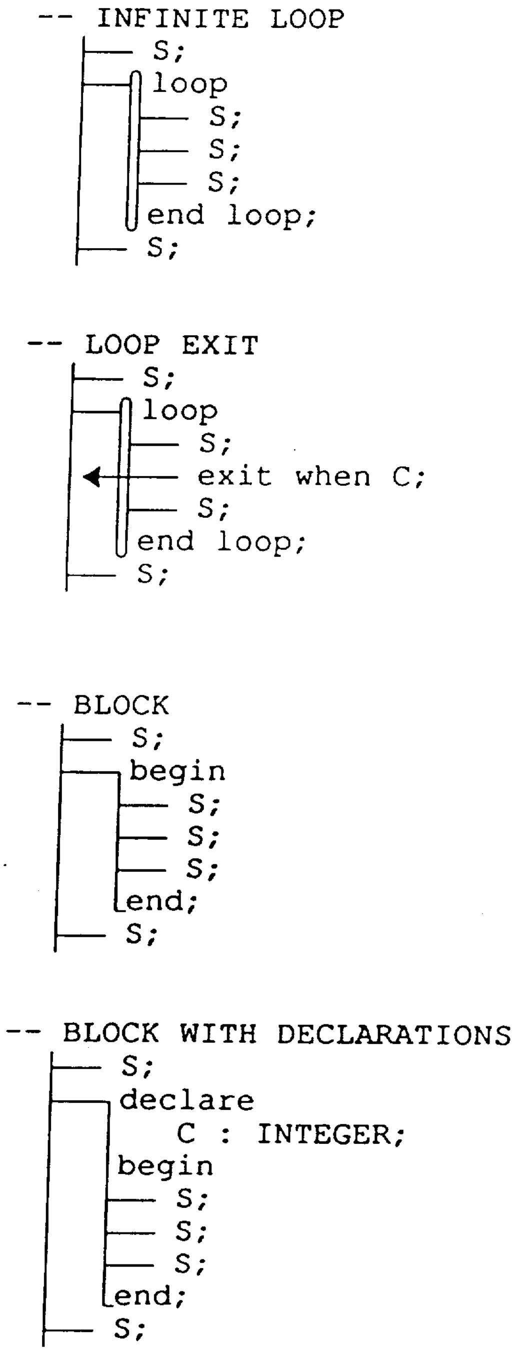


```
-- CASE
S;
case D is
   when C1 =>
      S;
   when C2 =>
      S;
end case;
S;
```

```
-- FOR
S;
for F in R loop
   S;
   S;
   S;
end loop;
S;
```

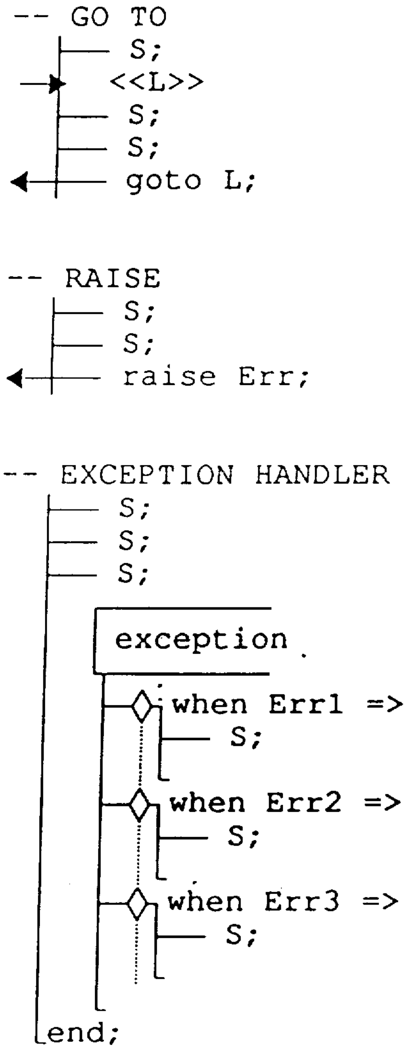
```
-- WHILE
S;
while C loop
   S;
   S;
   S;
end loop;
S;
```

Figure 2 (continued). Control Structure Diagram Constructs For Ada.



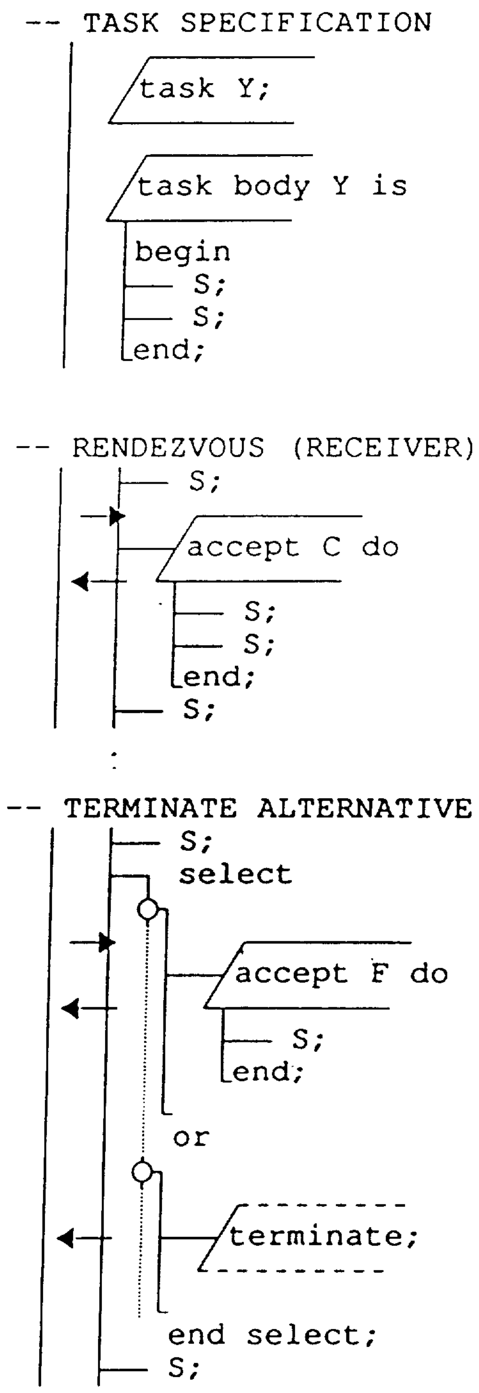
```
-- INFINITE LOOP
  S;
  loop
    S;
    S;
    S;
  end loop;
  S;

-- LOOP EXIT
  S;
  loop
    S;
    exit when C;
    S;
  end loop;
  S;

-- BLOCK
  S;
  begin
    S;
    S;
    S;
  end;
  S;

-- BLOCK WITH DECLARATIONS
  S;
  declare
     C : INTEGER;
  begin
    S;
    S;
    S;
  end;
  S;
```

Figure 2 (continued). Control Structure Diagram Constructs For Ada.



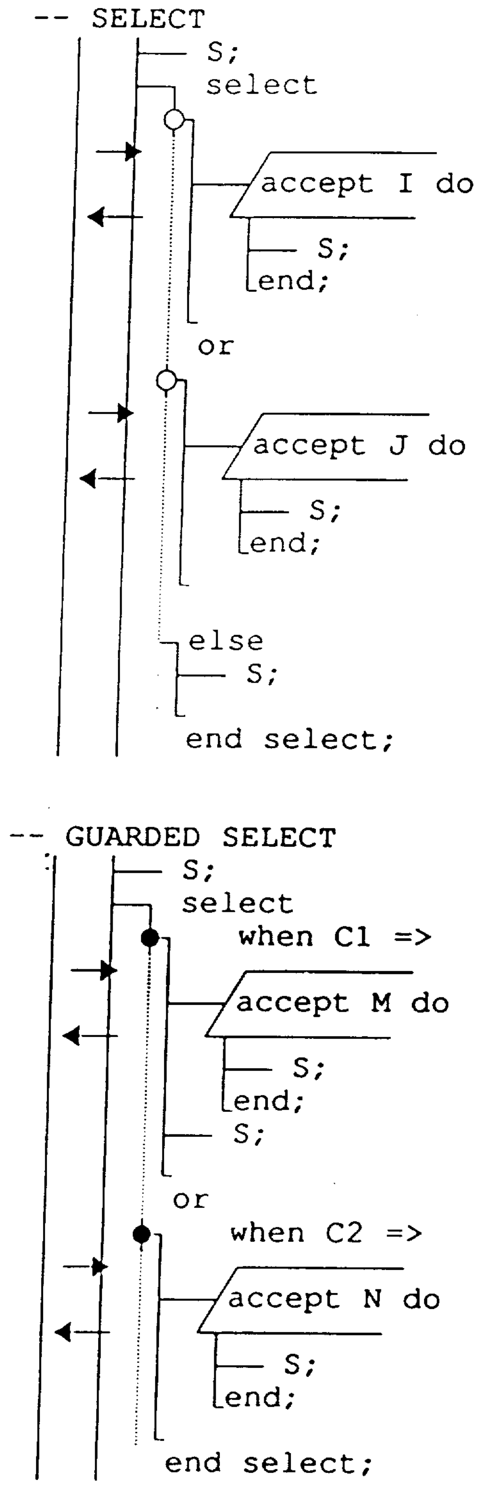
```
-- GO TO
   S;
 <<L>>
   S;
   S;
   goto L;

-- RAISE
   S;
   S;
   raise Err;

-- EXCEPTION HANDLER
   S;
   S;
   S;
 exception
   when Err1 =>
      S;
   when Err2 =>
      S;
   when Err3 =>
      S;
end;
```

Figure 2 (continued). Control Structure Diagram Constructs For Ada.



```
-- TASK SPECIFICATION
task Y;

task body Y is
begin
   S;
   S;
end;

-- RENDEZVOUS (RECEIVER)
   S;
   accept C do
      S;
      S;
   end;
   S;

-- TERMINATE ALTERNATIVE
   S;
   select
      accept F do
         S;
      end;
   or
      terminate;
   end select;
   S;
```

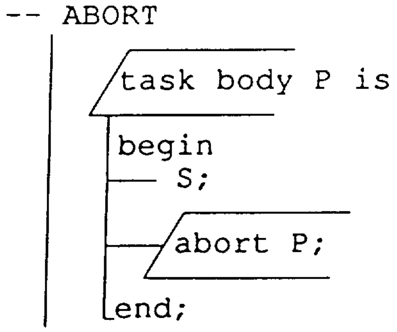
Figure 2 (continued). Control Structure Diagram Constructs For Ada.



```
-- SELECT
   S;
   select
      accept I do
         S;
      end;
   or
      accept J do
         S;
      end;
   else
      S;
   end select;
```

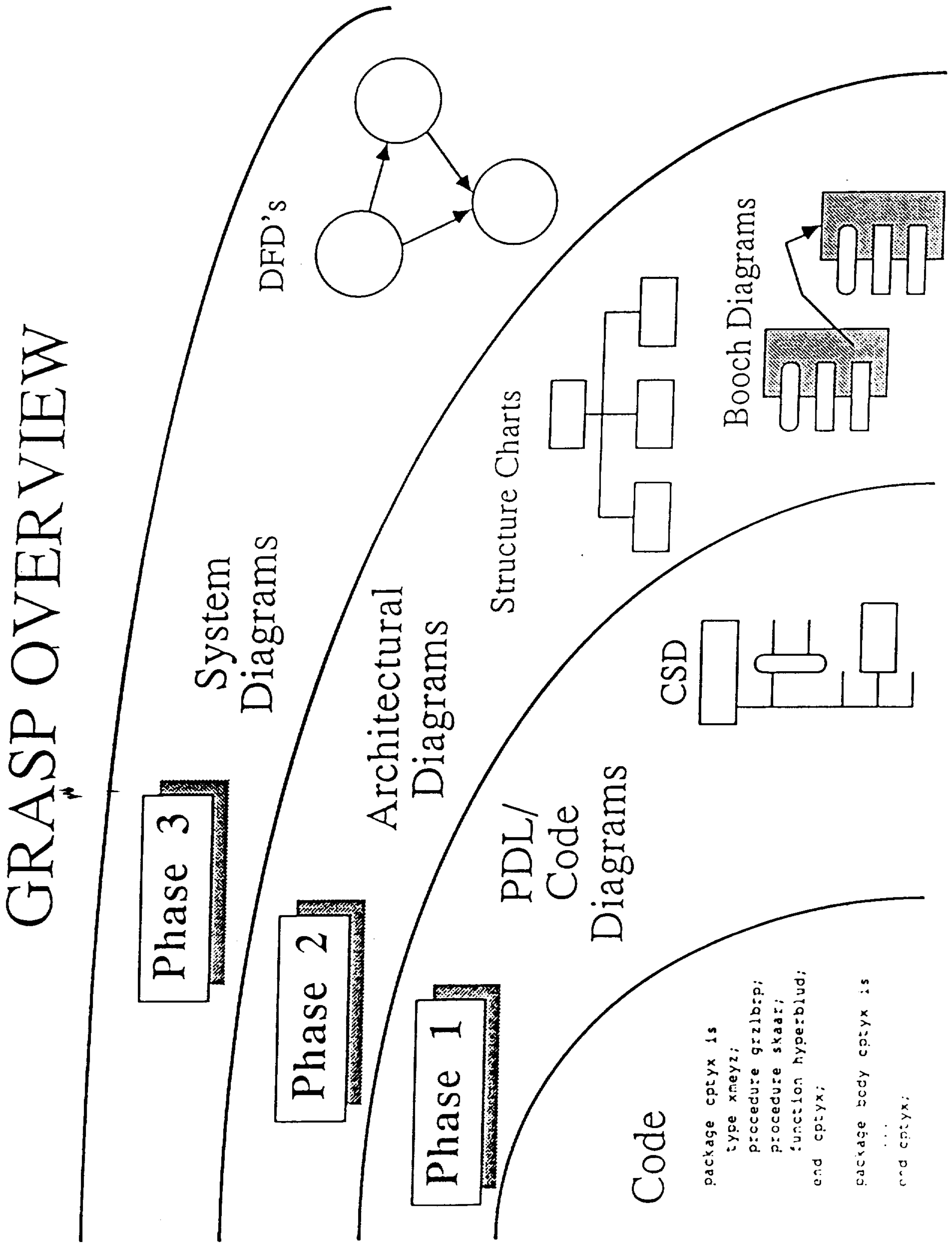
```
-- GUARDED SELECT
   S;
   select
      when C1 =>
      accept M do
         S;
      end;
      S;
   or
      when C2 =>
      accept N do
         S;
      end;
   end select;
```

Figure 2 (continued). Control Structure Diagram Constructs For Ada.



```
-- ABORT
task body P is
begin
   S;
   abort P;
end;
```

Figure 2 (continued). Control Structure Diagram Constructs For Ada.



```
package cptyx is
    type xneyz;
    procedure grzlbrp;
    procedure skaar;
    function hyperblud;
end cptyx;

package body cptyx is
    ...
end cptyx;
```

Figure 3. Overview of the GRASP/Ada Reverse Engineering Project.