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Canada
A DESIGN TOOL FOR OBJECT-ORIENTED DEVELOPMENT

Hanwei Ding

A thesis in The Department of Computer Science

Presented in Partial Fulfillment of the Requirements For the Degree of Master of Computer Science Concordia University Montréal, Québec, Canada

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Abstract

A Design Tool For Object-Oriented Development

Hanwei Ding

This thesis presents a supportive tool for object-oriented design and system evolution. As the design is the most important and effort consuming phase in object-oriented software development, our tool aims at providing automated support to empower the designers as much as possible during the design process. This is done by providing the designers with multiple views of the design, the facility to update the design easily, the ability to check the completeness and consistency of the design, and the ability to generate a printed report of the design. Maintenance is the most costly phase in system evolution; our tool provides directly assistance to the maintainers during system evolution by supporting automation in capturing and altering the design.

A carefully defined, consistently formatted user interface is developed with Motif as part of the tool, and as the medium for human interaction with the function modules of the tool. We considered the interface part to be the most significant and necessary part of the tool design, and emphasis is put on it to achieve the ease of use of the tool.

Some directions of further work about the tool, which will brighten the future of the tool, are also described.
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I would like to thank my husband Boqian Cheng for his encouragement and moral support.

Finally, I would like to dedicate this work to my parents who always stood behind me with great patience and encouragement.
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Chapter 1

Introduction

1.1 Why object-oriented design?

One major trend in the history of software engineering is the shift in focus from programming-in-the-small to programming-in-the-large. This trend changed the software engineer’s way of thinking and eventually led to a new paradigm: object-oriented technology.

In the late 80’s, almost every software developer experienced this “object-oriented” storm which touched every field of software engineering. Object-oriented technology provides a different approach to the software system. It relies on the three developing phases – analysis, design and implementation – to carry out the major characteristics of object-orientation: data abstraction, information hiding, dynamic binding and inheritance.

Conventional functional approaches require the designer to first ask what the system does: the functional aspects. This is probably adequate if the target system solves a fixed problem once and for all. But changes happen over time. What the system will do in its first release is probably going to be a little different from what it
was expected to do at requirement time, and very different from it will be expected to do several years later.

However, the categories of objects on which the system acts will probably be quite stable. A document processing system will always work on documents, chapters, sections paragraphs, and so on. Thus it is wiser in the long term to rely on categories of objects as a basis for decomposition than on functionality. The object-oriented design technique is defined in such a way that the principle of modular decomposition of the system is according to the classes of objects which the system manipulates[19].

Compared to the traditional functional design, object-oriented design aims for more robust software that can be easily reused, modified, maintained and extended. The greatest strength of this approach to development is that it offers a mechanism that captures a model of the real world which leads to greatly improved understandability and maintainability of systems.

But current approaches to object-orientation lack complete and standardized representations, and lack a complexity management mechanism to permit viewing the design at varying levels of details or from various perspectives. Some weaknesses of current object-oriented analysis and design lie in: identifying interfaces, application and system classes; identifying and representing different kinds of relationships; maintaining consistent and correct semantics for such relationships; representing dynamic views, and maintaining consistent levels of abstraction[20][1].

Although object-oriented design is criticized by different groups, no one has said that object-oriented design should be abandoned. One way to make it do the job better is to provide better techniques and better supporting tools.

1.2 Why is a tool needed?

When large systems are developed, all information should be recorded properly. A good tool will help to automate a large amount of such work, and provides efficient support to the life cycle of software development. Developing a large system is difficult and expensive, and maintaining it is even more difficult. As the existing knowledge changes over time, more detailed knowledge is required and more information will be
added or existing information will be removed during the evolution of change. Tools empower the designer, freeing him or her to concentrate upon the truly creatively aspects of the designing and maintaining.

The object-oriented programming revolution has spawned a whole new industry devoted to object-oriented analysis and design tools and the corresponding methodologies they support. As in conventional structural design, there are different tools to support each phase of the software life cycle, i.e., analysis, design and implementation. But current tools are intolerant of changes[16]. When a client has used a system and changed the requirements after certain time, the maintenance programmers will respond to change the code to meet the new requirements. But in most cases, they forget to update the design. After evolving like this for a long time, this system will not be recognizable from the design, and the inconsistency between requirements, design and implementation will make the system extremely difficult to change and maintain.

To our knowledge, there are no convenient tools to help to capture the change of design during system evolution. No facilities are provided for integrating design changes with existing partial implementations. Since reuse is a fundamental aspects of object-oriented technology, better tools are needed to support re-analysis, re-design and re-implementation. Particularly, a good tool which is convenient to use and efficiently supportive for updating the design during system evolution is needed, and this latter issue is made the focus of this thesis.

The design tool described in this thesis is a software system which provides facilities for creating, examining, checking and modifying design. The tool provides a user friendly interface. It allows the user to display the design in different forms, as text or table. The user can select the level of detail to view the design when it is displayed in tabular form. The tool also allows the user to check the consistency and completeness of design, and it can generate high-quality printable output of the design.

Such a design helps to fill the process information gap and re-orient existing design to support software evolution more effectively. The designer and maintainer can simply use it as required. It supports system collection and maintains and coordinates
design information.

It is clear that the designer's work load will be greatly reduced with the help of such a tool during software creation and maintenance.

1.3 The structure of the thesis

The rest of the thesis is organized as follows: Chapter 2 introduces a survey of background in object-oriented design. Various methods for object-oriented analysis and design and some supporting tools are overviewed; Chapter 3 outlines the issues that were considered during the design of the tool. The goal and objectives, design format, representation forms of the design and design decisions made for the tool are exploited and illustrated; Chapter 4 discusses the design and implementation of the Design Tool. The central data structure, the abstract syntax tree, the parser module and the user interface and major functional modules are presented. Chapter 5 describes a walk-through of the Design Tool with an example given in previous chapter. Some windows with displayed tables of a design which are constructed by the tool are described, and an example of a printable report of a design which is generated by the tool is also given. Chapter 6 gives conclusion of the study and suggests for further related works.
Chapter 2

Principles of Objected Oriented Design

In this chapter, we review various methods that have been proposed for object oriented analysis and design. These methods formed the basis for the approach to design which underlies our design tool. Some of the tools that have been developed to support object oriented program development are described in the second section.

2.1 Object-Oriented Analysis and Design

Although object oriented programming was introduced in the late sixties [21], the first references to object oriented technology appeared in the early eighties. In this section, we introduce some of the terminology that has evolved around object oriented technology, and we discuss some of the design methodologies that have been proposed.

2.1.1 General Concepts

Object-oriented technology, since it was proposed, has experienced more than a decade's practice, and has steadily gained ground in the world of software development. Although the term object-oriented has become a buzzword that means different
things to different people: it has been used synonymously with modularity, information hiding, encapsulation and data abstraction, but it always refers to a system design philosophy which is fundamentally different from the functional design.

System development is the process of producing descriptions of models. The development of a large complex system involves steps of decomposition of the system into desired model descriptions. The functional approach emphasizes the functional aspect of the system, which concerns what the system does. Therefore the decomposition of a system with a functional design is based on the model which forms the functionality of the system. This top-down functional approach is good if the target system solves a fixed problem once and for all. But such case does not happen regularly, the functional properties of a system do change over time. In a long view, what the system is to do in its first release is probably different from what it is expected to do at the requirement time, and very different from what it is expected to do a long time later. The easily changeable property of the functional aspect of a system limits the maintainability of the system. However, the categories of objects on which the system acts are quite stable. An operating system will always work on devices, memories, processing units, and so on. Therefore it is wiser in the long term to rely on the categories of objects as the basis for system decomposition. The object-oriented design technique is defined in such a way that the principle of modular decomposition of the system is based on the classes of objects which the system manipulates. This approach reveals what the system is, not what it does. The objects of a system, which are the building blocks in the system development, are therefore made central issue of the object-oriented design.

But what is an object? An object usually reflects the entity in the real world, like a car, a tree, a computer, etc. "An object is an entity able to save a state (information) and which offers a number of operations (behavior) to either examine or affect this state" [15]. In other words, an object encapsulates both functions and data which are conceptually related to each other. Encapsulation therefore is considered as one of the important characteristic of the object, while information hiding, introduced by Parnas[22], is another characteristic that is considered as central to the nature of the object.
Other concepts[25] of object-orientation are listed as follows:

**Abstract data type** — An abstraction that describes a set of objects in terms of an encapsulated or hidden data structure and operations on that structure.

**Class** — An abstraction of a set of objects that specifies the common static and behavioral characteristics of the objects, including the public and private nature of the state and behavior.

**Generic definition** — The ability to parameterize a class, like the *template* concept in C++.

**Inheritance** — (a). *Single*: A relationship between classes whereby one class acquires the structure of other classes in a strict hierarchy from a single parent.

(b). *Multiple*: A relationship between classes whereby one class acquires the structure of other classes in a lattice with multiple parents.

**Instance** — One object in the set of objects described by a class abstraction.

**Instantiation** — The creation of a new instance object of a class or a new specific class from a generic class.

**Message** — A request for an object to carry out the sequence of action in one of the operations of its class.

**Method** — An operation defined in a class abstraction that carries out a sequence of actions in the class.

**Operation** — A class-level abstraction describing a sequence of messages or actions that access or change the state of an instance of the class.

**Overloading** — A simple form of *polymorphism*; the ability to attach more than one meaning to the same name in the same scope as differentiated by type or some other class characteristic.
Polymorphism  The ability of an entity to refer at runtime to instances of various class. Hence, the actual operation performed on receipt of a message depends on the class of the instance.

Currently there are many methods proposed by different developers for object-oriented development. The following section gives an overview of some of the methods that we have referred to as the state-of-the-art object-oriented technology.

2.1.2 Overview of Object-Oriented Design Methods

Booch’s design method[6][5] is built upon the object model. The concept of an object is introduced that has state, behavior, and identity, and with two kinds of hierarchy relationships: using and containing. A class is defined as a set of objects that share common structure and a common behavior which has four kinds of hierarchy relationships: inheritance, using, instantiation and metaclass. The key abstractions are the classes and objects that form the vocabulary of the problem domain, and classification is applied in the process of abstraction.

A set of notations are defined for the design which include four basic diagrams (class, object, module, and process) and two supplementary diagrams (state transition and timing). Each of these notations is defined as follows:

• A class diagram is used to show the existence of classes and their relationships in the logical design of a system; a class diagram represents all or part of the class structure of a system.

• An object diagram is used to show the existence of objects and their relationships in the logical design of a system; an object diagram represents all or part of the object structure of a system and primarily illustrates the semantics of key mechanisms in the logical design. A single object diagram represents a snapshot in time of an otherwise transitory event or configuration of objects.

• A module diagram is used to show the allocation of classes and objects to modules in the physical design of a system; a module diagram represents all or part of the module architecture of a system.
• A process diagram is used to show the allocation of processes to processors in the physical design of a system; a process diagram represents all or part of the process architecture of a system.

• A state transition diagram is used to show the state space of an instance of a given class, the events that cause a transition from one state to another, and the actions that result from a state change.

• A timing diagram is used to show the dynamic interactions among various objects in an object diagram.

In addition to the above diagrams, a textual representation notation is also defined. This so-called template notation captures all the important aspects of a class which is less readable but more detailed than the diagram. During the design process, the diagrams and templates evolve as new design decisions are made and more detail is established.

Unlike structured design, the process of the object-oriented design is neither top-down nor bottom-up; rather it can be best described as round-trip gestalt design, which emphasizes the incremental and iterative development of a system. A process of the object-oriented design is described by Booch as follows:

• The first step in the process of the design involves the identification of the classes and objects at a given level of abstractions and the invention of important mechanisms.

• The second step involves the identification of the semantics of these classes and objects; the important activity in this step is for the developer to act as a detached outsider, viewing each class from the perspective of its interface.

• The third step involves the identification of the relationships among these classes and objects; in this step, the ways in which things interact within the system are established, with regard to the static as well as the dynamic semantics of the key abstractions and important mechanisms.
• The fourth step involves the implementation of these classes and objects; the important activities in this step involve choosing a representation for each class and object, and allocating classes and objects to modules, and programs to processes; this step is not necessarily the last step, for its completion usually requires that we repeat the entire process, but at a lower level of abstraction.

The method proposed by Wirfs-Brock et al.[27], has been given the name responsibility-driven design. As usual, a set of basic concepts of the design are defined. In addition to the concepts described previously, such as object, class, inheritance, and polymorphism, the following concepts are defined:

Object accessing -- one object accesses another object by sending it a message, which consists of the name of an operation and any required arguments. A method is the step-by-step algorithm executed in response to the method received, and whose formal specification is called signature.

Contract -- the ways in which a given client can interact with a given server, i.e. the list of requests that a client can make of a server.

responsibility — responsibilities include two key items: the knowledge an object maintains, and the actions an object can perform. They are all the services an object provides for all the contracts it supports.

Collaborations — collaborations represent requests from a client to a server in fulfillment of a client responsibility. Therefore an object can fulfill a particular responsibility itself, or it may require the assistance of other objects.

Subsystems — groups of classes, or groups of classes and other subsystems, that collaborate among themselves to support a set of contracts. And a class is part of a subsystem only if it exists solely to fulfill the goals of that subsystem.

Protocol — a set of signatures to which a class will respond.

The process of design involves six activates, which are described as follows:
• Finding classes by carefully and repeatedly examining the requirements specification, using abstract and modeling as the helping tools to find the candidate classes, and identifying candidate superclasses by grouping classes that share common attributes.

• Assigning responsibilities by determining the responsibilities of the system as a whole, and then assigning each of these responsibilities to a specific class; looking for relationships between classes to find additional responsibilities.

• Identifying collaborations between classes by analyzing the interactions of each class and then examining the responsibilities for dependencies: if a class is responsible for a specific action, but does not possess all the knowledge needed to accomplish that action, a collaboration is identified between the class and another class(es) that possess the knowledge; identifying additional collaborations by looking for the relationships between classes.

• Constructing hierarchies examining the relationships between class and identifying the contracts of the classes using the following guidelines:
  
  ▶ model the “kind-of” hierarchy.
  
  ▶ factor common responsibilities as high as possible.
  
  ▶ ensure that no abstract class inherits from concrete classes.
  
  ▶ eliminate classes that do not add functionality.

• Identifying subsystems by examining the responsibilities and collaborations of the classes. Strongly interdependency between two classes is the major reason to group the two classes into one subsystem.

• Creating protocols of a class by refining the responsibilities of the class and providing the formal specification of the class interfaces.

The tools used in the design process are class and subsystem cards, hierarchy graph, Venn diagram, collaboration graph and walk-through. The result of the design process is a design document which includes: a graph of the class hierarchies, a graph of the
paths of collaboration for each subsystem, a specification of each class, a specification of each subsystem and a specification of the contracts supported by each class and subsystem.

The Object Modeling Technique (OMT) presented by Rumbaugh et al.[23] is a method for collecting and representing information about requirement and design. The OMT method introduces three kinds of models to describe the system. They are object model, dynamic model and functional model. Each model is applicable during all stages of the development and acquires implementation details as development progresses. The three models and their representation notations are described as follows:

Object model: the purpose of object modeling is to describe the objects in a system. The object model describes the structure of the objects—their identity, their relationships to other objects, their attributes, and the operations they preserve. This model provides the essential framework into which the dynamic and functional models can be placed, since the objects are the units into which the world is divided, and the molecules of the whole system.

The object model is represented graphically with object diagrams containing object associated with other classes. There are two types of object diagrams: class diagrams and instance diagrams. A class diagram is a schema for describing object classes (a group of objects with similar properties (attributes) and common behavior (operations)). The class name, its attributes and operations are displayed in the class diagram. Also clear emphasis is placed on the associations between objects. One-to-one and one-to-many relationships can be represented in the diagram. An instance diagram describes how a particular set of objects relate to each other. It is used mainly to show examples of a class diagram to help to clarify the complexity of the class diagram.

Dynamic model: the changes over time to the objects and their relationships of a system are represented by the dynamic model. The dynamic model of a system describes the flow of control, the interactions, and the sequencing of operations
in the system of concurrently-active objects. The major dynamic modeling concepts are *events*, which represent external stimuli, and *states*, which represent values of the objects.

An event is a one-way transmission of information from one object to another, and can be grouped into an *event class* and given a name to indicate the common structure and behavior. The time at which an event occurs is an implicit attribute of all events. A *state* is an abstraction of the attribute values and links of an object. Sets of values are grouped together into a state according to the properties that affect the gross behavior of the object. The state diagram is the graphical representation of finite state machines, and is a notation familiar to most software developers.

**Functional model:** the functional model describes the aspects of a system concerned with transformations of values—functions, mappings, constraints, and functional dependencies. It captures what a system does, without regard for how or when it is done.

The functional model is represented with data flow diagrams. The data flow diagrams show the dependencies between values and the computation of output values from input values and functions without regard for when or if the functions are executed.

The output from analysis is a specification of three models that captures the three aspects of the system: the objects and their relationships, the dynamic flow of control, and the functional transformation of data subject to constraints. The overall architecture of the system is determined during the system design where the system is organized into subsystem, concurrency is organized by grouping objects into concurrent tasks, and overall decisions are made about interprocess communication, data storage, and implementation of the dynamic model. The full definitions of the classes and associations, as well as the interface and algorithms of the methods used to implement the operations are determined in the object design phase. This phase adds internal objects for implementation and optimizes data structures and algorithms.

Jacobson's method[15] is given the name use case driven approach. The term
use case was introduced by Jacobson; it plays an important role in the modeling of the dynamic behavior of a system. Usually, the entire behavior of a system is described by describing the behavior model by model in the system. Jacobson’s method describes a system as a black box by describing a number of aspects of the system with each of these aspects corresponding to a behaviorally related sequence called use cases. The use case model consists of two items: the actor and the use case. The actors model anything that needs information exchange with the system, thus define the roles that the users of the system can play. The actors are the major tool for finding the use cases. A use case is a specific way of using the system by using some part of the functionality. Each use case constitutes a complete course of events initiated by an actor and it specifies the interaction that takes place between an actor and the system. The use case model forms a thread running through all the phases of the system development.

The system development involves two separate but interacting processes: system analysis and system construction. The analysis process aims at defining and specifying the system to be built and no requirements from the actual implementation environment are to be taken into account. The analysis process produces two models: the requirement model which specifies all the functionality that the system should be able to perform through the use cases in the use case model; and the analysis model which forms the basis for the system’s structure and specifies all the logical objects to be included in the system and how they are related and grouped. The requirement model uses actors and use cases to describe in detail each and every way of using the system, from a user’s perspective. The analysis model aims at forming a logical and maintainable structure in the system. Three object types are used to construct the analysis model: interface objects, entity objects and control objects. The interface objects model all the functionality that concerns the system interfaces; the entity objects model all functionality that handles the actual information kept in the system for a long period of time and the control objects model such functionality that is not naturally tied to any of other objects (often mainly behavior). These object types are identified when the use cases are analyzed and broken down. Subsystems which are formed by grouping the objects are used to structure the system in large
The construction process consists of two phases: design and implementation. The results of these two phases are two models called design model and implementation model respectively. Three steps are involved in the process of producing the design model: initially, the actual implementation environment is identified, such as how the processes should be handled, the constraints from the programming language, etc. This step aims at drawing conclusion on how these circumstance should be handled in the system; secondly, the conclusion drawn in the first step is incorporated into the design to develop a first approach to a design model. The analysis model is used as a base and is translated into design objects in the design model that fits the current implementation environment; finally, the object interfaces are constructed by describing how the objects interact in each specific use case. Therefore the design model is formalized to describe all stimuli sent between objects and to define what each operation will do to each object. From the design model, every detailed specification of all objects, including their operations and attributes are obtained. The implementation activity then implements each specific object with the selected programming language.

Champeaux and Lea et al.[11] state that “Object-oriented design is best characterized as a transformational process”. The transformational process starts with a declarative, non-computational specification, and then applies methods and strategies that result in an implementable software design. The process is divided into three major phases: class design, system design and program design. The class design defines the representational and algorithmic properties of the classes obeying the declarative constraints specified with the object-oriented analysis; the system design maps objects to processors, processes, storage, and communication channels; the program design reconciles the functionality and resource mapping in order to meet the the performance requirements when expressed using the target implementation languages, tools, configurations, etc.

Buhr and Casselman[7] present a new design concept for systems with distributed control, called causality flow, a new notation for this control, called timethreads, and a design process based on the notation called “designing with timethreads”.

15
“Causality flow” means the chains of causes and effects rippling through a system as a whole that triggered by the occurrence of stimuli from its environment. “Timethreads” is a visual notation for describing causality-flow scenarios. This notation provides high level abstraction which can be used as a reasoning tool to help drive the requirements-to-preliminary-design process, not just as a means of recording scenarios for a more-or-less completed design. For the purposes of “designing with timethreads”, a notation role architecture is introduced to express the system organization at a high level of abstraction. Timethreads and role architectures have no built-in assumptions about software or other implementation techniques. In addition, Timethreads are self-similar at different levels of details, which means that they use the same notation and may show similar patterns. The details at different levels will be different, but there is nothing in the general “look” of timethreads at different levels to identify the level. This feature enables the timethreads to span a wide design range from requirements definition to detailed design.

Coleman et al.[9] introduce a notation called Objectcharts for specifying object classes. An objectchart diagram is an extended form of a Statechart. The Objectchart transitions correspond to the state-changing methods that the class provides as well as those that the class requires of other classes. Object attributes and observer methods annotate the Objectchart states.

Haythorn[13] indicates that it “is probably a marketing mistake” that “discussions of the benefits of object-oriented programming often emphasize reuse rather than extensible, maintainable systems”. He argues that reuse applies to individual classes and pays off several years down the road, while maintainability applies to the whole system and pays off sooner. Since we are really concerned with building systems, maintainability is a more important goal than reuse, and clear guidelines for system design which focuses on the maintainability should be obtained.

Monarchi and Puhl[20] evaluate current research on object-oriented analysis and design (OOAD). Various OOAD techniques (i.e. processes or methods) and representations are compared, and some strong and weak areas in OOAD are identified. They state that the strengths of current OOAD research lie in: identifying semantic classes, attributes and behavior of a class; placing the methods to a class; identifying
and representing generalization and aggregation structures; and representing static views of the system and classes (i.e. structures). Some weaknesses in current OOAD research identified by [20] are: the way to identify interface, application and system classes; the way to determine when an attribute, relationship or behavior should be a class; where to place the classes; the way to identify and represent other kinds of relationships than the inheritance and part-of; the way to maintain consistent and correct semantics for relationships; the way to represent dynamic views (i.e. message passing, control, etc.); the way to integrate static and dynamic models; and the way to maintain consistent levels of abstraction/granularity.

2.2 Supporting Tools for Object-Oriented Design

A lot of effort has been put on the development of the supporting tools for object-oriented development since the OO technology was proposed. Beck and Cunningham[4] have introduced index cards which are used as a simple tool for teaching object-oriented concepts to designers. This index card has been used by the responsibility-driven designers to capture initial classes, responsibilities, and collaborations, as well as recording inheritance relationships and common responsibilities defined by superclasses[26]. Index cards are helpful because they are compact, easy to manipulate, and easy to modify and discard with small amount of classes. They can be easily arranged on a tabletop and a reasonable number of them can be viewed at same time. However, with large, complex systems, such tools for recording design information will be clumsy and inefficient. Especially during the system evolution, updating the design will become a heavy burden to the maintainers.

Some developers have suggested the idea of design record for reducing software lifecycle costs[2]. A design record is a collection of information, often in an on-line repository, to support software evolution, which also provides a view of information (i.e., interactive screen of information) about the system or its evolution. By collecting a great deal information about the software design, much information is available and helpful to the software developers and maintainers. Capturing designs or design decisions was one of the primary motivators for the design record since the design
decisions made throughout the life of a system are critical in defining the architecture of the system, and they provide clues to the maintenance programmers of the "why" of existing code. A design record helps to fill the process information gap and re-orient existing information to support software evolution more effectively. It supports system collects, maintains and coordinates design record information. However, the major problems with such design record tool are that it is high-cost to keep documents up to date as the system is maintained with on-line editing, and collecting massive information does not equate to maintenance effectiveness. In order to efficiently support the developing and maintaining process, the design record should meet the following criteria:

- The maintenance process step supported by a design record should be a cost driver for software maintenance.

- Design record information should be collectible as automatically as possible as a part of an instrumented process. This reduces the burden on the maintainers for making the design record a reality.

- Design record information should be updateable as automatically as possible. This helps to ensure that the information can be kept current without burdening the maintainers.

The above overview reveals for us that the many methods proposed by different people of object-oriented analysis, design and supporting share various similarities. These methods all involve building models based on the object, separate static features from dynamic ones, and all provide diagrams as well as text to represent the models. Meanwhile, these methods all assume a fairly "classsical" process in which analysis and design precede implementation and maintenance. The reality is that almost all successful software evolve overtime which indicates that the analysis and design phases are always overlap. A good design method should reflect this overlap.
Chapter 3

Tool Design

In this chapter, we outline the issues that were considered during the design of the tool. The first section describes the goal and the objectives of the Design Tool, and the features of the target tool are listed. The second section presents the design format that is the theoretical basis for the tool, specifying what kind of design the tool will handle. The next section presents the search of suitable representation forms which will be used for display of the design in the tool. And finally, details of design decisions made for the tool are described.

3.1 Objectives And Expectations

As mentioned in Chapter 1, one typical situation in software design and maintenance can be described as follow:

Before a system is shipped for first release, the requirements, design and the code developed by analysts, designers, and implementors are made fully consistent with each other. But some time later, when the client has used the system and modified the requirements, the system maintainers have responded by changing the code to meet the new requirements, while the design of the system usually has not been updated to meet the changes in requirements and implementation. When this gap is increased beyond a certain extent, the system will become a complex entity which is
unmaintainable and unrecognizable.

One major reason for this scenario is that design is not kept “light-weight”: updating design during the system evolution is a heavy burden for designers and maintainers and may also be extremely costly. In order to keep consistency between requirements, design and implementation, the design must be light-weight[12] — easy to capture and easy to modify. If there is a computer-aided design tool that can be used by designers and maintainers, the tool should contribute to the speed, flexibility and ease of the design process and software evolution. The primary goal of our design tool is to provide a facility for designers to explore and modify their designs as easily as possible and as quickly as possible.

Some design tools are used to record decisions made during the design process, as well as other design information. In this way, the tool maintains a complete record of the design. But these tools are not effective on the following reasons:

- It depends largely on the developer’s self-discipline to capture design information and keep it up to date. This is time consuming, costly, and therefore often neglected.

- To keep the design up to date is expensive, because it it not sufficient merely to add new information, it is also necessary to purge information that is no longer relevant. There is a need for mechanisms to keep the design current at reasonable cost, but on-line editing of the design does not satisfy this requirement.

A more advanced design tool is needed, which should provide facilities for creating, examining, checking, and modifying designs very easily.

The objectives of our design tool are as follows. It should:

- Provide automated assistance for object oriented program development, with particularly strong support for the design phase.

- Support evolutionary development. We consider a software product to be a continuously evolving entity; changes affect all phases of development. At all times, the documentation of each phase should be consistent with the other phases.
Help the designer to complete the design as quickly and easily as possible. The tool can do this by providing a variety of related functions that automate the tedious chores of design.

We conclude this section with a brief outline of the features that we believe a design tool should provide. Each of these features is described in subsequent sections of the thesis. The tool should:

- provide the facilities to read, write, and display designs;
- provide multiple views of a design and provide facilities to change the design based on the view;
- provide the facility to check the consistency and completeness of the design upon request;
- provide the facility to generate high-quality printable reports for design archiving;
- respond to queries about the design, especially “what if?” queries;
- provide traceability to both requirements and code.
- designs provided by the tool can be implemented in any target language. The tool is biased, however, towards strongly-typed, class-based languages, such as C++, Eiffel, and Dee. It would be straightforward to extend the tool to write class skeletons in any of these languages, but the present version of the tool does not do this.

3.2 Design Format

Rumbaugh suggests that a design should incorporate three distinct models of the target system[23]:
• The functional model describes the computations performed. A computation may be carried out by a single object or by an ensemble of objects working in harmony.

• The data or object model describes the way in which data is represented and managed within the system. In an object-oriented system, each object encapsulates a component of the data; objects may be parts of other objects.

• The dynamic model describes the flow of control within an object and between objects.

Our design notation does not explicitly differentiate between these models. It is organized around the object model. A system is composed of objects, so our design is essentially represented as a collection of class interfaces. The functional model can be extracted from the object model by examining descriptions of methods of the classes.

The dynamic model cannot, in general, be extracted from object/class interfaces, therefore it must be described separately. Although state-charts are popular for dynamic modeling, other methods may be more suitable for object-oriented systems, like time-threads and use cases. Our tool currently does not support the dynamic modeling of a system, and this is made an issue for future consideration.

A design, then, is a collection of class descriptions. Classes may be independent, but are usually components of subsystems, frameworks, and inheritance graphs.

Classes can be described at different levels of detail. The minimal description of a class could provide just its name. A full description includes the relation of the class to other classes, the instance variables, and a description of each method of the class. A method has a name and a signature, and may also have a specification and a list of methods that it may invoke. Obviously, the amount of useful feedback that the tool can provide to the designer should increase with the amount of information that the designer provides. Nevertheless, the tool’s ability to process partial designs is crucial to its flexibility.

Our tool is based on a model of object-oriented computation, and assumes the following properties of a design:
• The design consists of a number of classes. Each class provides a number of methods, or services.

• There are currently two relations on classes: client/server (uses) and parent/child (inherits). The model may later be extended to provide other relations between classes.

• If class C uses class S, the client, C, needs one or more of the services provided by the server, S.

• There may be cycles in the uses relation: X may use Y and Y may use X.

• If class C inherits from class P, the child, C, provides all of the services of the parent, P, and may provide additional services.

• There are no cycles in the inherits relation.

• A class can provide three kinds of service:
  
  ▶ a constructor creates a new object of the class.
  
  ▶ an observer returns an attribute of the current object (for example, the age of a person).
  
  ▶ a mutator changes the value of the current object (for example, changing the balance of an account).

• If the services provided by a class include one or more mutators, the class and its instances are called mutable. If no mutators are provided, the class and its instances are called immutable.

3.3 Design Display Forms

The principal purpose of the tool is to display the design in ways that permits the designer to explore and modify it as easily as possible. Consequently, the tool should provide different kinds of display.
Before we move to different kinds of display form, we introduce an example that we will use in the coming sections.

### 3.3.1 Example: a Heating System

**Specification**

The problem of the simulation of a simple central heating system can be described as follow:

> There are several rooms in the house. The central heating system consists of a furnace which heats the water. The water runs through each room to pass the heat. There are a valve, a radiator and a thermostat which work in each room. The process can be described as: the furnace heats the water; the water heats radiators; the radiator heats rooms; the valve is set to on/off to control the heat into the room; the thermostat reflects the temperature in the room; and the rooms radiate heat into the environment. There can be from 1 to 8 rooms.

The user controls only the external temperature. If the external temperature is close to zero, the radiators go on and off and the temperatures oscillate. If it is very cold outside, say –20 degrees, the furnace runs all the time and the rooms reach an equilibrium temperature below their thermostat settings.
<table>
<thead>
<tr>
<th>object</th>
<th>attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>room</td>
<td>temperature, valve, radiator, thermostat, $K(\text{room, env.})$</td>
</tr>
<tr>
<td>valve</td>
<td>switch (on/off)</td>
</tr>
<tr>
<td>radiator</td>
<td>temperature, $K(\text{radiator, room})$, $K(\text{water, radiator})$, switch(on/off)</td>
</tr>
<tr>
<td>thermostat</td>
<td>temperature-set, tolerance</td>
</tr>
<tr>
<td>furnace</td>
<td>switch (on/off), $K(\text{furnace, water})$</td>
</tr>
<tr>
<td>water</td>
<td>temperature, pressure</td>
</tr>
<tr>
<td>environment</td>
<td>temperature</td>
</tr>
</tbody>
</table>

Table 1: Possible objects caught in heating system

The result of the simulation can be viewed in three different ways: analog, bar-chart, and analog graph.

Figure 1 is a diagram of a simulated domestic heating system.

Analysis

Using the method provided by [27], we first collect the objects of the system (since it’s not a big system, no subsystem level decomposition is needed).

Possible objects may used in design of the system are:

room, valve, radiator, thermostat, furnace, water, environment.

Now we can list the attributes of each object obtained as shown in Table 1.

The $K(\text{room, env.})$ in Table 1 indicates that the temperature of a room is affected by the temperature of the environment, and this relationship can be represented by a constant value $K$ which is an attribute of the room. Therefore, during the computation of a room, the effect of the environment to the room will be taken in consideration through the value of this $K(\text{room, env.})$ attribute. Other Ks in the table have similar meanings.

Since object value only has attribute switch (on/off), we may make it an attribute of object room. Actually, radiator and thermostat can also be considered as attributes of room but, since they will take more complicated responsibilities and have additional attributes of their own, we leave them as independent objects. The object environment is taken in consideration by the room through the constant value
<table>
<thead>
<tr>
<th>object</th>
<th>attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>room</td>
<td>temperature, valve, radiator, thermostat, K(room,env.)</td>
</tr>
<tr>
<td>radiator</td>
<td>temperature, K(radiator,room), K(water,radiator), switch(on/off)</td>
</tr>
<tr>
<td>thermostat</td>
<td>temperature-set, tolerance</td>
</tr>
<tr>
<td>furnace</td>
<td>switch (on/off), K(furnace,water)</td>
</tr>
<tr>
<td>water</td>
<td>temperature, pressure</td>
</tr>
<tr>
<td>view</td>
<td>room temperature, time period</td>
</tr>
</tbody>
</table>

Table 2: Obtained objects of heating system

K(room, env.) and therefore can be eliminated from the list of objects. Meanwhile, the object view is added into the list which is responsible to display the result of the simulation.

Table 2 lists new objects and their attributes after we have made the above changes.

The next step is to assign proper responsibilities to each object that we have found. The Responsibilities of an object are all the services it provides for all the contracts (requests made by a client to a server) it supports. They include two key items: the knowledge an object maintains and the actions an object can perform. Responsibilities are meant to convey a sense of the purpose of an object and the role it will play in the system.

Followings are the responsibilities that we have identified for each object:

**room**

Read room temperature, take into consideration the effect of the environment, send messages to radiator and thermostat for their control.

**radiator**

Acts as server of room. When the room temperature is above the setting temperature, set radiator/valve off, or when the room temperature is lower than certain value and while the switch is off, set it on.

**thermostat**

When temperature setting is within tolerance, set the valve on or off according
to the temperature-setting and current temperature.

furnace
When water temperature is over certain value, set the switch off, or when heat is needed, set it on.

water
Maintain the temperature and pressure of the water.

view
Display the result of the simulation in three different ways: analog, barchart, and analog graph.

With the above analysis result at hand, we can start our object oriented design of the heating system.

Design
The system architecture is described in Figure 2.

![Diagram](image)

Figure 2: Architecture of the heating system

But Figure 2 does not give enough information about the system. In particular, it does not provide the information about how the components of the system communicate with each other, and what the control sequences in the process and among objects look like. We use Buhr’s timethreads notation to add in this part.
Figure 3: Timethread of the heating system

As mentioned in Chapter 2, timethreads notation is a design approach which jointly manipulates causality-flow scenarios and schematic components of organizations to make design decisions[8][7]. A timethread of the heating system is given in Figure 3, which indicates that when the heating system starts, first the furnace is heated and then the water; later, the radiator is heated through the water and change in the thermostat is made accordingly; finally the room is heated, and some heat is lost in the environment.

Figure 2 shows the Model component of an Model-View-Control system; Figure 4 shows the entire system.

Finally, we conclude the design by giving a list of class specifications based on [27]. These are given in Appendix A.

Figure 4: MVC view of architecture of the heating system
3.3.2 Textual Form

Textual form is the basic form provided for any kind of document, since text can be formal or informal, and can be handled by both human and computer. If we define the syntax of a design document, then the document can be read easily by a parser based on that syntax. For our design format, we define the syntax for the design which will be handled by our design tool.

The syntactic conventions that we use for design documents are listed below.

- Use lower-case characters for keywords. The only allowed keywords are: system, class, inherits, uses, var, method and end.

- A design may contain comments. Each comment begins with two dashes ("--") and continues to the end of the line containing the dashes. A group of lines beginning with two dashes is considered to be a single comment.

- The description of a system begins with the keyword system, followed immediately by the name of the system.

- A system has at least one class, and each class has a unique name inside the scope of the system; the description of a class begins with the keyword class, followed immediately by the name of the class.

- Inside a class, there is at most one inherits-list; the description of the inherits-list begins with the keyword inherits, followed immediately by one or more class names; if there is more than one class name in the list, class names are separated by commas or spaces.

- Inside a class, there is at most one uses-list; the description of the uses-list begins with the keyword uses, followed immediately by one or more class names; if there is more than one class name in the list, class names are separated by comma or space.

- Inside a class, there are zero or more var-lists; the description of each var-list begins with the keyword var, followed immediately by a name: type pair; the
name indicates the variable name and type indicates a class name; name and type are connected by a colon (";").

- A class may contain zero or more methods. Each method is introduced by the keyword method and has a name that must be unique within the class. A method also has an optional argument list and an optional return type. The argument list is a list of name:type pairs enclosed in parentheses. The return type follows the argument list and is separated from it by a comma.

Example: method get (index: Int): String

- Inside a method, there are zero or more uses-lists; the description of each uses-list begins with the keyword uses, followed immediately by a name::type pair; the name in the pair indicates the method(service) being used, and the type is a class name in which the method(service) is provided; name and type are connected by a double colon (::).

- Each class is ended with the keyword end and followed by the class name.

- Comments are only allowed at certain places: after system name, after class name, after variable name and after method name.

Now we can generate the source text for the heating system according to the design in Section 3.3.1.

system HeatingSystem
-- an OO design for a domestic heating system

class HeatSim
-- ancestors Program StdErrors
inherits StdError:: Program
uses Bool Textin Buffer ViewDigital ViewBarChart Float Water
    View Furnace Int ViewGraph Iterator Room List String
    Keyboard Window
method entry
end HeatSim

class View

-- An instance of a View class can display changing values of
-- several floating-point variables. This class, View, is
-- abstract: it defines the minimal protocol for a class that
-- provides views. A view has several channels, each
-- corresponding to a particular variable. Channels are
-- initialized and updated independently in any sequence. The
-- display is updated as a unit.
method init (channel:Int value:Float)
-- Initialize the given channel with the given value.
method set_val (channel:Int value:Float)
-- Update the given channel with the given value.
method set_title (channel:Int title:String)
-- Provide the given channel with the given title.
method calibrate (value:Float str_value:String)
-- A calibration point is used to label the axis of a graph or to
-- perform a similar service for another display mode. This
-- method uses the given value to position the calibration mark
-- and writes the string at that position.
method update
-- Update the display for all channels.
method message (txt:String)
-- Display a message other than channel data
method close
-- Null method to close display. Descendant classes which require
-- a closing action should redefine this method.
end View

......

class Water
-- Simulates the water in a heating system. The only interesting
-- attribute of the water is its temperature.
var temp:Float
method make (water_temp:Float)
   -- Set the initial temperature of the water.
method change_temp (new_temp:Float)
   -- Set temperature of water to given value.
end Water

Although text is easy for the computer to handle and process, text is not always
the ideal medium for presenting information to people. Readers must derive the
information they need sentence by sentence, and deriving information from large
blocks of text is sometimes inefficient. There are ways of presenting text, however,
that allow people to extract the information they need very efficiently. To overcome
the shortcomings of plain text displays, our tool can also present information in the
form of tables.

3.3.3 Tabular Form

Tables are formal structures that can be processed easily and efficiently by computers.
Tables can also be viewed as a form of picture, and it is well-known that people assimilate
pictorial information very efficiently. A person can quickly obtain information
from a table by scanning its rows and columns. Tables therefore provide information
directly and in a straightforward manner. Besides, tables have several advantages
when they are used in a human-computer interface:

- tables are easy to create;
- large tables, like spreadsheets, are easy to navigate by simple scrolling operations;
- tables make efficient use of precious screen space; microscopic fonts are not
  required; and
small changes to the design tend to cause small changes to the tables.

Questions need to be answered before we start to build tables for the design.

▷ We know that the design is composed of classes of a system (the object-model), but what should the table look like so it can make the information contained by the design well organized and fully contained?

▷ One obvious way to display aspects of a large system in tabular form is to provide multi-level tables. But what levels should be provided, and how should the user select them?

▷ Finally, what are the attributes of each table at different levels?

The following considerations about tables refer to the questions above.

1. There are at least two kinds of tables. One is a system-level table which lists all the classes in a system and their descriptions. So when we get the table, we know what classes are in the system and what are they by one quick glance at the table; another is a class-level table which lists information about all the methods in the class, so we can get detailed information about any specific class that we choose.

2. The attributes of a system-level table should contain at least class name, its description, a list of inherit class names, and a list of the class names it uses. Thus the classes of a system and their relationship with other classes are obvious at a glance.

3. The attributes of a class-level table should at least consist of the method name, its description, its return type, its argument-list and list of the method::class pairs which the method uses.

4. There should be a system name and its description in the system-level table, so we know which system we are looking at.

5. There should be a class name and its description in the class-level table, so we know which class we are looking at without making any confusion.
<table>
<thead>
<tr>
<th>Class name</th>
<th>Inherits Class</th>
<th>Uses Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>View</td>
<td></td>
<td></td>
<td>An instance of a View class can display changing values of several floating-point variables. This class, View, is abstract: it defines the minimal protocol for a class that provides views. A view has several channels, each corresponding to a particular variable. Channels are initialized and updated independently in any sequence. The display is updated as a unit.</td>
</tr>
<tr>
<td>ViewDigital</td>
<td>View</td>
<td></td>
<td>Implements a View by displaying floating-point variables as strings.</td>
</tr>
<tr>
<td>ViewBarChart</td>
<td>View</td>
<td></td>
<td>Implements a View using horizontal bar charts.</td>
</tr>
<tr>
<td>ViewGraph</td>
<td>View</td>
<td></td>
<td>Implement a view by displaying variables on an X-Y graph.</td>
</tr>
</tbody>
</table>

Table 3: System-level table for the heating system
<table>
<thead>
<tr>
<th>Class name</th>
<th>Inherits Class</th>
<th>Uses Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace</td>
<td></td>
<td></td>
<td>Simulates the furnace in a simple central heating system. The furnace provides heat to the water if any heat is needed. If no heat is needed, the water cools down.</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td>Simulates the water in a heating system. The only interesting attribute of the water is its temperature.</td>
</tr>
<tr>
<td>Room</td>
<td>Heatable, Any</td>
<td></td>
<td>Simulates a room which obtains heat from a radiator and loses heat to the environment. Room inherits from Any in order that we can declare an array of Rooms.</td>
</tr>
<tr>
<td>Radiator</td>
<td>Heatable</td>
<td></td>
<td>Simulates a radiator which receives heat from the water supply and provides heat to a room. The object simulated is actually a rather complicated radiator, complete with thermostat and valve. You could make the simulation more realistic by splitting this class up into three components: a thermostat which switches on or off depending on the room temperature; a valve which is controlled by the thermostat; and a radiator which is controlled by the valve.</td>
</tr>
</tbody>
</table>

Table 4: System-level table for the heating system (continued)
<table>
<thead>
<tr>
<th>Class name</th>
<th>Inherits Class</th>
<th>Uses Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heatable</td>
<td></td>
<td></td>
<td>An abstract class which captures the basic property of a heatable object. A heatable object is connected to a source, from which it gains heat, and a sink, to which it loses heat. The object has a temperature and coupling coefficients to its source and sink.</td>
</tr>
</tbody>
</table>

Table 5: System-level table for the heating system *(continued)*

According to the above considerations, we can build tables for the heating system based on the design we developed in Section 3.3.1.

### 3.3.4 Diagram Form

Many of the popular design techniques are based on pictorial notations. Pictures are useful because they efficiently communicate information about the overall structure of a system. Pictures are an efficient form of information description, especially when they are associated with a more formal representation in another medium. Diagrams can be derived from text and are useful in providing quick confirmation that the expected relationships are present. The essential characteristic of a diagram is that it can be sketched quickly: this is why we use diagrams as aids to thinking and designing.

But pictures also lose some of their effectiveness when they become constrained—all structure charts tend to look the same—or cluttered with a plethora of symbols. Or when they are hard to draw. Diagrams are not an efficient way of communicating with a computer. Although computers can generate a visual representation of data that may help a person, they are not yet capable of extracting useful information from a rough sketch. This ineffectiveness of diagrams is particularly limiting if diagrams are the only, or even the dominant, way of representing designs.
<table>
<thead>
<tr>
<th>MethodName</th>
<th>ReturnType</th>
<th>Parameter</th>
<th>Uses</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>init</td>
<td>Int, Float</td>
<td></td>
<td></td>
<td>Initialize the given channel with the given value</td>
</tr>
<tr>
<td>set_val</td>
<td>Int, Float</td>
<td></td>
<td></td>
<td>update the given channel with the given value</td>
</tr>
<tr>
<td>set_title</td>
<td>Int, String</td>
<td></td>
<td></td>
<td>Provide the given channel with the given value</td>
</tr>
<tr>
<td>calibrate</td>
<td>Float, String</td>
<td></td>
<td></td>
<td>A calibrate point is used to label the axis of a graph or to perform a similar service for another display mode. This method uses the given value to position the calibrate mark and writes the string at the position.</td>
</tr>
<tr>
<td>update</td>
<td></td>
<td></td>
<td></td>
<td>update the display for all channels.</td>
</tr>
<tr>
<td>message</td>
<td>String</td>
<td></td>
<td></td>
<td>Display a message other than channel data</td>
</tr>
<tr>
<td>close</td>
<td></td>
<td></td>
<td></td>
<td>Null method to close display. Descendant classes which require a closing action should redefine this method</td>
</tr>
</tbody>
</table>

Table 6: Class-level table for the class View

<table>
<thead>
<tr>
<th>MethodName</th>
<th>ReturnType</th>
<th>Parameter</th>
<th>Uses</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>make</td>
<td>Float</td>
<td></td>
<td></td>
<td>Set the initial temperature of the water.</td>
</tr>
<tr>
<td>change_temp</td>
<td>Float</td>
<td></td>
<td></td>
<td>Set temperature of water to given value</td>
</tr>
</tbody>
</table>

Table 7: Class-level table for the class Water

37
Figure 5: Organization of the tool

In our tool, the diagram form for display design is not provided in the first version, so we do not discuss it further in this thesis.

3.4 Design of the Tool

The issues discussed in this section include the functional structure of the tool; the most suitable data structure for the data repository (which turns out to be an abstract syntax tree); techniques for constructing and processing the abstract syntax tree; and the major services provided by the tool. In addition, we discuss the design of the user interface, including window layouts. We conclude with a brief discussion of the choice of implementation language and software libraries that we used to build the tool.

Due to the different aspects of the user-interface and its importance, user-interface will be described in a separate section later.

3.4.1 Organization of the Tool

Functionality and structure of the tool

As mentioned in Section 3.1, major functions of our tool are the ability to create, examine, check and modify the design, and to produce high-quality printable reports
for the design. Based on this, we can divide the functionality of the tool into four service modules: a text-editor for creating and modifying the design, a viewer for examining and displaying the design, a checker for checking the consistency and completeness of the design, and a printer for producing high-quality output of the design. All these facilities are provided to users by a carefully designed, user-friendly interface. The window-based interface is composed of different levels of windows which are equipped with various, but consistently formatted, pull-down menus and push buttons. All major functions can be activated by using the mouse only. However, all the functional modules can not be active without the data which are represented as the abstract syntax tree (AST). Every part of the tool has an intimate relationship with the AST. Whenever the user wants to modify, view, check or print a design, the tool needs to get data from the AST, then invokes the corresponding module for the user. The generation of the AST is the responsibility of the parser, which takes a file of source-text as input and constructs the AST. The parser is the first step in activating any functions in the tool. It reads source text, scans it, checks the syntax, and generates the AST.

Therefore the organization of the tool is composed of four parts: data structure, parser, functional modules and user-interface. These are shown in Figure 5.
Data Structure

The abstract syntax tree is required to store all the information about a design. Since a design is basically a list of class descriptions of a system, the AST should be able to hold arbitrary number of classes, and in turn, hold arbitrary number of variables and methods inside a class, as the design format specified in Section 3.2. Using a pictorial description, AST will look something like in Figure 6.

Parser

The parsing component will have three parts: one for scanning the input file and obtaining tokens for grammar checker, one for checking the syntax of input file and report syntax error, and the third one which is responsible for grabbing the data parsed and generating the AST. Once the syntax of the input file – source text – is determined, the scanner and the parser will be determined accordingly. The data grabber/clutter part will be fixed on the decision of AST.

Major functional modules

Text Editor

Text editor is the basic and conventional tool for creating and modifying text. The tool will provide a fully functional editor which allows the user to open and save files which contain design document, browse the design in text form, and modify it with convenient edit tool, like search, cut, paste, copy, etc., which are provided in the tool.

We assume that the design documents are files that with extension .d, so whenever the user wants to select a file for open or save, the tool will provide a file list, and only those files with extension .d appear on the list for selection.

Viewer

The viewer is a module which provides a tabular display of the system’s design on a window. The tabular form is discussed in Section 3.3.3. The module will
provide different tables on user’s request. The user can choose to view system-level table by select a file which contains the design from a list of files provided. After the file has been parsed by the parser, and the AST has been generated, the module displays the system-level table like Table 3 in page 33. The user is allowed to choose to view a class-level table when a system-level table has been displayed – therefore, a system has been selected – otherwise, a warning message will be issued. If the class name selected does not belong to the system, a warning message will also be given.

The two kinds of tables will be displayed on the same window, therefore, only one table can be viewed at a time.

A ScreenClear function will be included in this module.

Checker

The ability to check the consistency and completeness of a design is a significant feature provided by our tool.

Consistency and Completeness mean every class and method used in the design is completely defined. Each class, whenever is inherited, is used, or is used as type of a variable, as return type of a method should be defined in the scope of the system, or in a standard library of the design whose source text is contained in a file named the same as the file containing the design, but with extension .lib.

Our checker will allow the user to select a file from a file list provided, and to invoke the checking by pressing a button. As in the case for Viewer, our parser will first parse the file and generate the AST which will be used by the Checker to perform checking. The check result will be given to the user which is either the information about undefined class names and method names or a succeed message.

For the convenience of the user, the consistency checker can be activated both as an independent action from a viewing window or from within the editor.
**Printer**

The printer is a module for generating output files of design in a form suitable for printing. We have found that \LaTeX\ to be very suitable for this purpose: it is straightforward to generate \LaTeX\ code, and the printed output is pleasing to the eyes. Although the development of a design is best done interactively, leisurely study of hard-copy often reveals area for improvement.

This module will allow the user to select a file from a file list provided by the tool, and start the process by a simple mouse click on a button. After the selected file has been parsed by our parser, and AST has been generated there after, the module creates a new file if there is no such file (or rewrite if there exists). The name of the new file is the same as the input file except that its extension is `.tex`. The printer then writes to this file with \LaTeX\ form of the design. When successfully finishing the generating of the output file, the module will give a message to the user indicating the name of the generated file.

### 3.4.2 User-interface

**Basic considerations**

As mentioned in Section 3.1, the goal of our design tool is to provide a facility for designer to explore and modify the design as easily as possible. There are two parts that contribute to this goal: one is the functional modules as discussed before; the other is user-interface. Without interface, user and functional modules which are provided for achieving the goal are on two sides of a river. A carefully defined, and user friendly interface will sharply narrow the distance between what the user wants and what he/she will get. That is why we consider the interface part to be the significant and necessary part of our tool.

The most fundamental principle in user interface design is user compatibility, i.e. to know well about the user\[18\]. The users of our tool are the designers and maintainers of object-oriented software who have the knowledge about the design and the ability to create and modify the design. Meanwhile, some principles\[18\][\!\!24\] are selected as guidelines in our design of the interface. They are listed as follow:
1. **Ease of use:** This characteristic makes the system acceptable and enjoyable to the user. Therefore, in our system, each window, button, menu and dialog and color or font used in the interface should be carefully organized so that the maximum of their potential self-explanation can be achieved, and the system is made explicit in both *what* and *how*. Conveniently obtained on-line help should be provided when it is necessary.

2. **Consistency:** Consistency allows people to reason by analogy and predict how to do things they have never done before, thus minimizing the need to consult a manual. It improves both performance and user satisfaction, as it imparts a sense of mastery to the user. We emphasize consistency within the system: the labeling and graphic conventions should be kept consistent as well as format in all displays; identical terminology should be used in prompts, menus and help screens, and consistent commands should be employed throughout.

3. **Simplicity:** One common mistake in interface design is to try to provide all the functionality in a complex interface which results in overwhelming and confusing details to the new user and tedious to navigate for the expert. One of our goals is to provide a rich complex functionality through a simple interface. The interface should not confuse the user by providing too much information on one screen or by presenting too many complicated functions in one step. This can be achieved through *layers* of the interface.

4. **Duration:** The system should tolerate common and unavoidable human errors. The system should offer simple error handling as much as possible. If an error is made, the system should detect the error and offer simple, comprehensible mechanisms for handling the error. The system should let the user feel confident that the system is robust enough to handle any kind of input, including errors.

5. **Familiarity:** Based on the natural human tendency to learn and reason by analogy, familiarity can greatly facilitate the learning of a new interface. Therefore, concepts, terminology and spatial arrangements that are familiar to the user will be used in the interface. Ambiguous words and description should be avoided.
as much as possible.

Features of window layouts

According to the guidelines given above, we design the window layouts in the tool to contain the following features:

1. Each window only provides the necessary information for current/present actions, all other information which may be used later will be hidden from current appearance of the window, therefore the chance to make the user confused is largely eliminated. Advanced functions are presented to the user by multiple levels of window.

2. All the windows are carefully organized to give a simple appearance to the user. They are so straightforward that, with the exception of the MainWindow, no help windows are needed, although there are spaces for placing the Help button which may be needed when the system is extended in the future and more functions are added. Users can get information about the functions and usages of each window from the appearance of the window itself.

3. All the windows are consistent in their button placements: the Quit button on each working window is always on the left corner of the button or menu fields; the Help button on each window (if there exists) is always on the right corner of the button or menu fields; and the functional buttons on each working window are always on the middle of the button or menu fields.

4. All the Information Dialogs look the same: one message field and a button field; the button field only contains one button for the user to confirm the message and dismiss the dialog.

5. Whenever the user makes a mistake in input through either selection or typing, the system will give a message dialog corresponding to that error. Additionally, when the user want to exit the tool, a confirming message is provided. Protection is also made for the editor where designs are to be modified, and changes
should be saved before the updating information could be lost. Warning dialogs are used to remind the user a specific situation.

Structure of Window Layouts

**ToolMainWindow**

Since there are four major functional modules in the tool, and the user should be allowed to perform any of the four actions sequentially or in parallel, the tool interface should provide a top level window which incorporates the above actions and allow the users to select any one of them. This is the window we named *ToolMainWindow*. Each action is represented in this window by a push button. When the button is pressed, a corresponding new window is popped up for further action. As for Design, a new window named *DesignWindow* is popped up; for View, there is a *ViewWindow*; for Check there is *CheckWindow*; and for Output, there is an *OutputWindow*. Besides, inside the *ToolMainWindow*, a Help button is necessary and important which will pop up a *HelpWindow* and give descriptive information about the tool and its use. Also a Quit button for exiting the tool is provided.

**HelpWindow**

The *HelpWindow* should give the user all the information about the tool. The information that the window gives are displayed text, and the user is allowed to scroll the window when it is necessary. When the user finishes reading the text, the window can be dismissed by clicking on a button. The window should be retrieved by selecting the Help button in *ToolMainWindow* again.

**DesignWindow**

The *DesignWindow* is popped up to carry out the task of creating and modifying design upon user's request. There are two parts which form the layout of this window. On the top part, there is a message wrapped in a frame which gives description of this window, therefore the help message is provided directly; on the bottom part is the action field which consists of several buttons: a Quit button for exiting this window, a button named Edit for popping up a text
editor, etc. When new functions, such as a Query window for a new way of creating and modifying the design, is to be added to the system, a new button with a name, such as Query (or another proper name) can be added to this part without difficulty.

**ViewWindow**

The **ViewWindow** is popped up to carry out the task of displaying the design upon user's request. Like the **DesignWindow**, this window is composed of a message field for the description of this window and an action field equipped with several buttons. As usual, a Quit button is provided. Tabular display is one of the major features of our tool. Accordingly, a button named Table is presented for popping up a view-table window. When new functions of display of design are to be added to the tool, such as graphic display, new buttons, such as a Graph button, can be added to this field.

**CheckWindow**

The **CheckWindow** is popped up to carry out the task of checking the consistency and completeness of the design upon user's request. This window consists of three parts: on the top is the message field like the **DesignWindow** or the **ViewWindow**, in the middle there is a selection part which provides a file list for selection by mouse or by typing; in this field, the current directory is the default value, and switching to other directories is possible; on the bottom there is an action field which is composed of several buttons, such as a Quit button, a ChangeDir button, and a Check button for the check function on the system selected by the user. If an illegal file name is typed for selection or other error happens in the input file, a warning message is popped up to inform the user. After the information dialog has been dismissed, the user can continue with a new selection.

**PrintWindow**

The **PrintWindow** is popped up upon user's request to carry out the task of generating printable report of a design. Like the **CheckWindow**, it is composed of three parts: on the top is the message field for description of this window;
in the middle is the selection field which allows user to choose a system for printing by selecting a file from the file list provided or by typing in a file name on a given place; on the bottom is the action field with several buttons, such as a Quit button, a ChangeDir button and a Print button.

Implementation Language

We chose C as the implementation language and Motif as the toolkit for building user-interface. Although C has some drawbacks, it is the obvious language to use for software that will run under UNIX and will use X windows. There is a good debugging tool (dbx) available, and the interfaces to Motif and X are specified as C prototypes. It would have been possible to use another language, such as Pascal, but development within a mixed language system would probably have presented many problems.

Motif is a toolkit developed by the Open Software Foundation. It provides a set of guidelines that specifies how a user interface for graphical computers should look and feel — how an application appears on the screen (the look) and how the user interacts with it (the feel)[14]. The Motif interface was intentionally modeled after IBM's Common User Access (CUA) specification, which defines the interface for OS/2 and Microsoft Windows. Its GUI was implemented by OSF using X as the window system and the X-toolkit(Xt) Intrinsic as the platform for the Application Programmer's Interface. Consequently, Motif is both portable and robust. Xt provides an object-oriented framework for creating reusable, configurable user-interface components called widgets. Motif provides widgets for such common user-interface elements as labels, buttons menus, dialog boxes, scollbars, and text-entry or display areas. We chose Motif because it is efficient, powerful, and popular, and because we like the pleasing layouts it provides.
Chapter 4

Tool Implementation

In this chapter, we discuss the design and implementation of the Design Tool. The tool is organized around a central data structure, the Abstract Syntax Tree or AST, that we describe in the first section. The AST is created as a side-effect of scanning and parsing the text of an object oriented design, as described in the second section. In the final section, we describe the user interface of the Design Tool: its overall structure, the windows and dialog boxes it uses, and the major functions used.

4.1 Abstract Syntax Tree

The Abstract Syntax Tree (AST) is the center part of our tool system. A proper definition of AST is crucial to all of the other parts of the system. Based on the design decision made in section 3.4.1, the AST can be built using C structures:

- A *system* is defined as a C structure which has several fields: a system name, its description, and a list of class definitions which belong to the system.

- A *class* is defined as a C structure which contains several fields: a class name, its description, the inherits class list, the uses class list, variable list, a list of method definitions and a pointer to the next class definition.
A method definition is a C structure which consists of the method name, its description, its return type, a list of argument (name:type) pair, a list of uses (method:::class) pair and a pointer to the next method definition.

The definitions of a system, a class and a method are given in Figure 7.

typedef struct TMethod {
    TLabel       label;    /* name and description */
    TTOPair      typeOrig; /* type */
    TNTPairDict  *paraList; /* para::type pair */
    TNTPairDict  *usesList; /* method::class pair */
    struct TMethod *next;
} TMethod;

typedef struct TClass {
    TLabel          label;    /* name and description */
    TINherits      *inherits; /* inherits class list */
    TQStringDict   *usesList; /* uses class list */
    TVar           *varList;  /* var list */
    TMethod        *methodList; /* method list */
    struct TClass  *next;
} TClass;

typedef struct TSystem {
    TLabel          label;    /* name and description */
    TClass          *classList; /* class list */
    struct TSystem *next;
} TSystem;

Figure 7: AST of a system, a class and a method

Appendix B gives the complete declaration of the AST with explanations.
4.2 Parser

Our parser module is actually composed of three parts as mentioned in Section 3.4.1: a scanner for scanning the input file and generating tokens; a parser which uses the tokens to check the syntax of the input stream and report errors if there are any; and constructors which work inside the parser to generate the AST.

4.2.1 Scanner

```c
switch(c) {
  case ' -: /*--handle comment-----*/
    if (follow(' -')) { /* '---' are found */
      while (c != EOF) {
        c = ngetc(); /* continue to get next char */
        *tp++ = c;
        if (c == '\n') /* until end of a line */
          break;
      }
    *--tp = '\0'; /* leave out the char '\n' */
    yylval.str = token;
    return COMMENT;
  }
}
```

Figure 8: C code of scanner for handling comment

Input streams in UNIX are byte streams. Converting the byte stream into a token stream is the task of a lexical analyzer, called a scanner. The scanner in our system is hand-coded and written in C (lex.c). Its major part is a procedure call `yylex` with `int` as its return type. The function of `yylex` is to examine the input stream and group individual characters into several distinct tokens, and return them through an external variable named `yyval` to pass the token value from the lexical analyzer to the parser. The names “yylex” and “yyval” are chosen for compatibility with Yacc, as described in the next section. We know from Section 3.3.2 that the keywords defined for the source text of design are `system`, `class`, `method`, `inherits`, `uses`, `var`,

50
end. Besides, comments are defined as starting with double dashes and continuing until the end of the line. Therefore, `yylex` goes through each character in the input stream and compares each string obtained to the predefined keyword and also makes a copy of the word into `yyval`. If a match in the comparison is found, a corresponding keyword is returned, otherwise the string is returned as the semantic value of an identifier. Figure 8 gives the part of code for handling comments.

### 4.2.2 Parser

The function of the parser is to determine if a given source text is syntactically correct and to perform actions on correct text. The parser organizes the tokens it reads according to the rules of a grammar. When the parser has a sequence of tokens that corresponds to a rule, an associated action is executed. The actions can make use of the values of tokens to generate output or pass the values to other routines in the program.

Our parser is generated by `YACC`[17] — Yet Another Compiler-Compiler which is provided in UNIX. `Yacc` provides a general tool for imposing structure on the input to a computer program. The Yacc programmer prepares a specification of the input process, which includes rules describing the input structure, code to be invoked when these rules are recognized, and low-level routines to do the basic input. Yacc then generates a parser, which is a function named `yyparse`, and which calls the low-level input routine (the `yylex`) to pick up the basic items (the `tokens`) from the input stream. The tokens are organized according to the input structure rules; when one of these rules has been recognized, a corresponding action is invoked. Yacc generates its actions and output subroutines in C.

According to the syntax defined in Section 3.3.2, we prepared the specification of the input text. The specification is in the form of grammar rules with a set of actions. This is the file `parse.y`. The part of the rules for `system` written in Yacc is given in Figure 9.

This rule indicates that a system comes in the form that starts with keyword `system`, then a name for this system (the IDENTIFIER), then an optional comment,
system
  : SYSTEM IDENTIFIER {
    settingSysName($2);
  }
  
  opt_comment {
    addComm(aSYSTEM);
  }
  
  opt_class_list
;

Figure 9: Grammar rule for system

and finally a list of classes.

4.2.3 Constructing the AST

The actions we specified in parse.y are a list of C routines which we defined separately in a file named dataGrab.c. When one of the grammar rules has been recognized by the parser, a corresponding action is invoked immediately. As in Figure 9, when in the source text something matches the rule SYSTEM IDENTIFIER, the action settingSysName($2) is invoked which saves the value of $2 (the semantic value passed by IDENTIFIER) to a proper C structure we defined for holding the system.

We declared several global variables in a file named tempData.h to hold the AST of a system being parsed. These variables are generated through the C routines which define the actions in the parser, and are used throughout the tool code. They will be initialized (by calling initStruct) and regenerated whenever a new source text is input for parsing. Actually, among these variables, only the TSystem typed variable aSystem, which contains all the semantic values of the system being parsed, is used after the parser phase. All other variables, like aClass, aMethod etc., are used only during the parse phase to help to catch information for generating the AST of the system.

Figure 10 gives the code of the operations settingSysname in the grammar rule of Figure 9. In some cases, one system depends on another. For example, many systems
/* create the TSystem typed pointer "aSystem" */
/* and copy the given string to its "name"filed */
/*------------------------------------------------*/
void
settingSysName(str)
TString str;
{
    TSystem *tmp, *sysptr;
    
    tmp = (TSystem *)malloc(sizeof(TSystem));
    initSystem(tmp);
    tmp->label.name = (TString)strdup(str);
    tmp->next = NULL;
    /* always append the new created system to the tail */
    /* of the system list */
    sysptr = aSystem;
    if (sysptr) { /* check to see if this is the first one */
        while (sysptr->next) /* go to the tail */
            sysptr = sysptr->next;
        sysptr->next = tmp;
    }
    else {
        aSystem = tmp;
    }
}

Figure 10: Operations of settingSysName

depend on a standard library. In these cases, the Design Tool parses the classes of the system first, and then the library classes, storing the entire system in a single AST. The system and its library are then checked for consistency as if they were a single unit. The newly created system of the library classes is always appended to the tail of the existing aSystem to indicating the close relationship of the two systems.
4.3 User Interface and Functional Modules

In our tool, the user-interface is closely related to the functional modules. For example, the DesignWindow-Edit is activated by calling the module of editor; the ViewWindow-Table is activated through calling the module of viewer, and so on. Therefore, we present the interface part and the functional module part together in this section. We will go through the functionality of major working windows provided by our tool, and describe the implementation issues in the following sequence:

1. *The structure of the block widgets* — this gives the idea how we get the window layout in Motif, therefore the corresponding code for building the window is straightforward.

2. *The appearance of the window* — this gives the actual layout of the window on screen, and therefore describes the appearance of the tool.

3. *Explanation of coding* — this will include descriptions of some important routines in implementation, such as window creations, local variables and major computations, and so on.

Besides major working windows, a group of miscellaneous functions which play important roles in the functionality of the system will be described.

4.3.1 Major Windows

**ToolMainWindow**

The structure of widgets in the ToolMainWindow is portrayed in Figure 11, and Figure 12 gives the window layout.

This part also contains the main program of the system. It creates the toplevel shell and builds a number of different widgets on the top of the shell. The window is composed of two parts: on the top there is a message field, which is built with a label widget, that gives a welcome message; on the bottom, there is an action field, which consists of six buttons named Quit, Design, View, Check, Output and Help. The
The Help button is made to be kept always on the right corner of the action field when the window is resized. When any of the buttons is pressed, a corresponding function, called the callback routine of this button, is invoked to carry out the action. The callback routine for Quit is quitCb which is defined in the same file scope; callback routines for Design, View, Check and Output are designCb, viewCb, checkCb and outputCb which are defined in files designw.c, vieww.c, checkw.c and outputw.c respectively; the callback routine for Help is helpCb which is defined in another file named helpw.c.

The function of QuitCb is to create a warning dialog when the Quit button is pressed. The warning dialog consists of two fields: a message field and an action field. It differs from other information dialog in that it has two buttons, Yes and No, instead of one. This warning dialog is created through calling convenient Motif function for creating warning dialog with specified button labels and warning message. When the user presses the Yes button, a further callback routine named exitTool which is defined in the same file scope is invoked to destroy the toplevel shell and exit the tool; if the user presses the No button, a corresponding callback routine named notExitTool which is defined in the same file scope is invoked to remove the warning dialog from the screen and leave all other windows unchanged. This warning dialog is defined as a static widget, therefore once it is created, it will be used throughout the life time of
Figure 12: ToolMainWindow

the system until the user exits the tool. It will be popped up on the screen whenever the Quit button is pressed in the ToolMainWindow, and will be removed from the screen when the No button is pressed. The warning dialog is shown in Figure 13.

HelpWindow

The structure of widgets in HelpWindow is given in Figure 14, and Figure 15 shows the layout of this window.

The shell of HelpWindow is created based on the parent of the Help button (by Motif convention), and is defined as static. Based on the shell, all other widgets of HelpWindow are defined. They are a PanedWindow, two Forms, a Label for display the image i, a Text widget for display help message, and two Push Buttons: one is Ok for dismissing the window and one is a nonactive button named More. The image i is contained in file info.xbm, and is loaded into the system during the creation of the Label. The help message is initially contained in a String array named helpText, and converted into a string array of type char [], then loaded into the system during the creation of the Text widget.

Like the warning dialog for exiting the tool, HelpWindow needs to be create only
at the first time when the user presses the Help button in ToolMainWindow. Once it has been created, it will be directly popped up on the screen when the user presses the Help button. And it will be removed from the screen when the user presses the Ok button through the callback routine of the Ok button which is the miscellaneous function named popdownWidget.

**DesignWindow**

The structure of widgets in DesignWindow is given in Figure 16, and Figure 17 shows the layout of this window.
As every popped up window must have a shell, the shell of the DesignWindow is created based on the parent of the button Design of the ToolMainWindow. This DesignWindow consists of two parts: a message field for displaying the information of the design window, and an action field which contains buttons. The message is initially stored in a String array designMsg, and then loaded into the system during the creation of a Label. Since using a Label widget to display message is simpler and more direct than using a Text widget, a Label widget is used in this window for message display. A Frame widget is used with the Label widget to get a better appearance. There are four buttons in the action field, named Quit, Edit, Query and Help. The Help button is not necessary for the current version, therefore is made nonactive (say not sensitive in Motif) though it still appears in the window. It can be made active when necessary. It is made to be kept always on the right corner of the action field when the window is resized. Like HelpWindow, this window is declared as static, therefore once it is created, the only action to invoke it is to pop up its shell.

When the Quit button is pressed, a miscellaneous function named popdownWidget
Figure 16: Structure of DesignWindow

is called to remove the shell, so the DesignWindow will disappear from the screen. The callback routine for the button Edit is designEditCb defined in file edit.c. This function is responsible for creating the DesignWindow—Edit which provides the place for user to create or modify the design. The callback routine for the button Query is designQueryCb whose implementation is left to the future, and the button is made inaccessible from the window at present time.

DesignWindow—Edit

Figure 18 gives the structure of the widgets in the editor, and its window layout is shown in Figure 19.

The shell which is the base of all other widgets in the window is created as the child of the parent of the push button Edit in the DesignWindow. The DesignWindow—Edit is composed of five parts which can be viewed from both the structure of widgets and the appearance of the window layout: on the top of the window there is a menu bar with six pull down menus which are labeled Quit, File, Edit, Search, Option and Help respectively. Each pull down menu has a list of one or more menus which can be selected and invoked to perform a specific action; following the menu bar is the place for input of searching and replacing strings. This part is created on a horizontal RowColumn with two pairs of Label and TextField widgets. The Labels are used for
displaying the string "Search Pattern" and "Replace Pattern". The TextFields are used by the user to input the patterns for searching and replacing; the next part in the DesignWindow-Edit is one of the message fields which is built on a horizontal RowColumn widget with a Label and TextField. This part is used for indicating the file name of a design whose source text is currently being loaded into the editor for editing; after that in DesignWindow-Edit is the working area of this window: the editing field, which is built with a ScrolledText widget. The size of the editing area is fixed at the time when the window is popped up on the screen, while the window can be resized and the user can scroll this editing area up and down and left and right with the scrollbar provided; finally, on the bottom is another message field which displays the information when one of the menu items in the pull down menus is invoked, such as it gives the number of bytes read during a file opening, or it displays the number of occurrences found when the user does a searching with a given pattern, etc.

Callback Routines
Each pull down menus in the menu bar is associated with a callback routine which will be invoked when any of the menu items in the pull down menu is selected. There is one menu Quit in the pull down menu Quit with callback routine editQuitCb which is defined in the same file scope to pop down the shell of DesignWindow - Edit. There are two menus in pull down menu File: Open and Save; four menus in pull down menu Edit: Cut, Copy, Paste and Clear; four menu in Search: Find Next, Show All, Replace Text and Clear; and two menus in pull down menu Option: ScreenPrint and ConsistCheck. The callback routines for the pulldown menus File, Edit, Search and Option are the functions fileCb, editCb, searchCb and editOptionCb which are defined in the same file scope. The Help menu is placed always on the right corner of the menu bar as the Quit is placed on the left corner of the menu bar. The callback routine for Help is defined as editHelpCb and its implementation is left to future work when it is necessary.

fileCb for pulldown menu File
The callback routine fileCb is invoked when any of the two menu items in pull-down menu File is selected. The routine’s major function is to create a corresponding file selection dialog for the menu item Open or Save. The file selection
dialog is created by calling a convenient Motif function with some modifications in file searching procedure and button labels. The new file searching procedure is a miscellaneous function named mySearchProc which searches the current directory for those files with extension .d or .lib. Open is the new button label for the default button Ok in the file selection dialog popped up when the user selects Open menu. Accordingly, Save is the new label in the dialog for menu Save. The label of original button Filter is changed to ChangDir for better understanding. The button Cancel is left unchanged.

There are callback routines for each buttons in the file selection dialog. The callback routine for Cancel is the function popdownWidget which is responsible for making the dialog disappear from the screen when the button Cancel is pressed. The callback routines for the button Open and Save in two dialogs are the same function file_select_cb. The responsibilities of this routine include the
operations of obtaining the file name from the selection field in the dialog, and performing the action of file opening or file saving accordingly. If no file name is provided in the selection field, or a given file can not be opened, a corresponding message is displayed in the message field on the bottom of *Design Window—Edit*. When the operation of reading text from a file (for menu *Open*) to the editing area, or writing the text in the *Text* widget (for *Save*) to a file is accomplished, a message for indicating the number of bytes read or written and the full name of the file is displayed in *Design Window—Edit*. Meanwhile, when a file is loaded, the file name appears on the message field up the editing area in *Design Window—Edit*. An example with the file select dialog popped up is show in Figure 20.

*editCb* for pulldown menu *Edit*

The callback routine *editCb* is invoked when any of the four menu items in
the pulldown menu Edit is selected. The procedure uses a variable event to capture the user’s selection, which may be made either by clicking the mouse or by pressing a key. The selection is highlighted in the text. If the user selects the menu Cut, the procedure responds by cutting the selection from the text; if menu item Copy is selected, the procedure copies the user’s selection into a clipboard preserved by Motif; if menu item Paste is chosen, the procedure pastes the content in the clipboard to the place where current cursor is. If no selection is made by the user before one of these options is selected, a message which says “There is no selection.” is displayed on the message field of DesignWindow-Edit. If the user selects the menu item Clear, the procedure simply deletes the content in the clipboard and removes the highlight made by the user during the selection operation.

searchCb for pulldown menu Search

This routine is invoked when any of the four menu items in pulldown menu Search is selected. If the user selects the item Clear, the routine simply removes all the highlights in the text. For the other three menu items, the routine first checks if there is any text in the editing area. If there is none, a message which says “No text to search” is displayed on the message field on the bottom of DesignWindow-Edit, and the the procedure returns. Otherwise, the routine continues by checking if a search pattern is given in the window, if none, the routine gives a message and returns. When both text and a search pattern are available, and if the menu item Find Next is selected, the routine starts searching from current cursor position until a pattern is found in the text; if no matching pattern is found, a new search from position 0 of the text is invoked until a pattern is found in the text. Whenever the pattern is found or not found in the text, a corresponding message is given on the bottom of the DesignWindow-Edit. If the menu item Show All or Replace Text is selected, the procedure searches all the text, and highlights the found pattern(s) (for Show All), or replaces the found pattern(s) (for Replace Text), then displays a corresponding message for indicating the number of patterns found in the window of DesignWindow-Edit.
editOptionCb for pulldown menu Option

This routine is invoked when the user select the menu items in pulldown menu Option. There are two menu items in this pulldown menu: ScreenPrint and ConsistCheck, but only the latter one is implemented in the first version of the tool. When ConsistCheck is selected by the user, editOptionCb responds by first checking if a design source text has been currently loaded into the editing area. If there is current design, it continues by calling a function named checkFunc, which is defined in file checkw.c, and in the meantime passing the file name to this function. The function checkFunc is responsible for doing the consistency check of the design. If there is no file name available, a message which says “Choose a file” is given in the DesignWindow Edit.

ViewWindow

Figure 21 gives the structure of the widgets of the ViewWindow, and the window layout is shown in Figure 22.

Like the DesignWindow, the shell of this window is created as the child of the parent of the button View in ToolMainWindow. There are two parts in the ViewWindow: a message field for displaying information about this window which is built with a Frame and a Label, and an action field equipped with several buttons. The buttons
in the window are Quit, Table, Graph, Query and Help. The callback routine of Quit button is the common function popdownWidget which is responsible for removing the shell of this window, thus making the window disappear from the screen. The callback routine for button Table is the function viewTableCb which is defined in file vtable.c and is to be described in the next subsection. As in all other windows, the Help button is kept always on the right corner of the action field, and Quit button is kept on the left corner. The implementation of the callback routines for Graph and Query are left to future work, and the buttons are made inaccessible from the window for the current version. The button Help is also made inaccessible because no help is needed and therefore is not provided for current version.

ViewWindow—Table

The structure of the widgets in this window is given in Figure 23, and Figure 24 shows the layout of the window.
The shell of \textit{ViewWindow-Table} is created as a child of the parent of the button \textbf{Table} in \textit{ViewWindow}. The body of this \textit{ViewWindow-Table} is composed of four parts as shown in the layout of the window. Like the \textit{DesignWindow-Edit}, on the top of the window, there is a menu bar which consists of four pulldown menus. From left to right, these pulldown menus are \texttt{Quit}, \texttt{TableView}, \texttt{Option} and \texttt{Help}. Following the convention of the window layout in the system, the \texttt{Help} is kept far away on the right corner of the menu bar. Beneath the menu bar, there is a message field which is built with two \texttt{TextField} widgets. This message field (we call it \textit{top message field} in order to distinguish it from another message field on the bottom of the window) is used for displaying the information about a table, such as a system name for a system-level table, or a class name for a class-level table. The next part in the window is the drawing area which is used for displaying tables. Finally, on the bottom of the window is another message field for indicating the name of the file which holds the source text of the design whose table is currently being displayed (for system-level table), or the name of the system of whom the class-level table is currently being displayed.

\textbf{Callback routines}

Each pulldown menu in the menu bar is associated with a callback routine.
which will be invoked when any of the menu items in the pulldown menu is selected. As in DesignWindow-Edit, there is one menu items, Quit, in the pulldown menu Quit whose callback routine is utQuitCb. This routine simply pops down (removes and can be retrieved later) the shell of ViewWindow-Table when Quit is selected. There are two menu items, System and Class, in the pulldown menu TableView. The callback routine for this pulldown menu is the function tableCb which is defined in the same file scope. There is one menu item, ScreenClear, in the pulldown menu option whose callback routine is tableOptionCb. The responsibility of ScreenClear is to clear the drawing area and the message fields. Therefore the callback routine tableOptionCb simply sets the text of all the TextFields to NULL, and calls the function clearDrawArea to remove anything in the drawing area.

Callback tableCb for pulldown menu TableView

The routine tableCb is invoked when any of the two menu items, System and Class, in the pulldown menu TableView is selected. If the user selects the item System which means a system-level table of a design needs to be displayed for
Figure 25: ViewWindow—Table with Class selected in pulldown menu TableView

the user, the procedure responses by popping up a file selection dialog for the user from which a file that contains the source text of the design can be selected. This dialog is created by calling a convenient Motif function with some changes in the file searching procedure and button labels. As all other file selection dialogs used in the tool, this dialog uses the function mySearchProc to search for displaying only those files with extension .d or .lib in the current working directory. Besides, the label of the OK button is changed to View, and the Help button is not necessary, therefore is made inaccessible. As usual, the label of the button Filter is changed to ChangDir, and Cancel button is left unchanged. The callback routine for Cancel is popdownWidget, which is responsible for
removing the dialog from the screen when Cancel is pressed. The callback routine for the button View in the dialog is the function sysTableCb. As usual, this file selection dialog is declared static.

If the user selects the menu item Class in the pulldown menu TableView to view a class-level table of a design, the routine tableCb first checks if there is a design available, i.e. if there has been a file selected from the file selection dialog which is popped up by choosing the menu item System. Before a class-level table can be displayed, a design must have been loaded into the tool. A variable “currentSys” is used to hold the abstract syntax tree of the design which is the most recently loaded into the tool. The variable is initialized to NULL when the system starts, and is checked before a class-level table is to be drawn. If the value of “currentSys” is NULL, i.e. no design loaded into the tool, tableCb is responsible for popping up an information dialog which informs the user to select a design through the menu item System, and then the routine tableCb returns. The information dialog is created by calling a miscellaneous function createInfoDialog. Otherwise, if a design is available, tableCb creates a selection dialog in which a list of class names of the design is displayed. This selection dialog is created by calling a convenient Motif function with some changes in button labels: the label of button OK is changed to View; the Cancel button is set on the left corner of the action field of the dialog; since further help text is not necessary, the Help button is made inaccessible. The list of class names is
obtained from the AST of the design, and is loaded into the dialog before the
dialog is managed and popped up to the screen. The dialog is declared static,
therefore it needs to be created only once. But the list of class names of the
design must be prepared each time when the selection dialog is to be popped up
due to the difference of the classes in different designs. There are two buttons
accessible in this selection dialog: Cancel and View. The callback routine for
Cancel is popdownWidget which removes the dialog when Cancel is pressed.
The callback routine for View is the function clsTableCb. Besides the callback
clsTableCb for button View, another callback routine noMatchClassCb is also
provided for the button View. This noMatchClassCb is to be invoked when
the user presses the View button, but the selection made by the user does not
match any one in the list displayed in the dialog. The no match callback function
simply pops up an information dialog to inform the user that the selection is
improper. This information dialog is also created by calling errHugoDialog
and setting a corresponding message in its message field before managing it and
popping it up. An example with the menu item Class being selected is shown
in Figure 25. Figure 26 gives the layout of an information dialog.

**Callback sysTableCb of View in the file selection dialog**

The callback routine sysTableCb is invoked when the user presses the View
button in the file selection dialog which is popped up by the selection of item
System in menu TableView. The responsibilities of sysTableCb include:

- obtaining the file name from the selection field of the dialog;
- calling the parser to parse the file and generate the Abstract Syntax Tree
  for the design;
- popping up an information dialog when the AST is not generated due to
  some reason such as file can not be opened or the parsing fails, or
- (when parsing succeeds) drawing the system-level table of the design as well
  as displaying the messages on the message fields in ViewWindow Table.

The parsing is invoked by calling the function ast, and the generated Abstract
Syntax Tree is held in a global variable aSystem in file tempData.h. As before, the information dialog is created with createInfoDialog. The drawing of the table is accomplished by calling a function drawSystemTable.

In drawSystemTable, some local variables are defined for representing the positions of lines and text of a table, and a new C structure TMultiStr is defined for holding multiple lines of a string. There are two fields in this C structure: a char array for holding a string and an int for holding the length of the string. Variables which are declared as arrays of such type are used frequently in building a table. Several library routines in Xlib[3] are called to accomplish the task of drawing, such as XDrawLine, XDrawRectangle and XDrawString. Since the window is allowed to be resized, a pixel map is created to store a copy of the table in the drawing area. When the window is resized or when the user scrolls the window by the provided scrollbar, the drawSystemTable is responsible to handle the expose event by redrawing the table. This is accomplished by adding to the window an "exposeCallback", the function redraw, which copies the table from the pixel map to the drawing area.

In a system-level table, the system name of a design is displayed in the top message field of the window. If there is a description (comments) about the system in the design, it is to be displayed on the top of the drawing area. The length of one line for displaying the system description is prefixed by the program as indicated by the variable scwd (the value of this variable represents the number of pixels). The description is actually a group of characters including double dashes ("--") and carriage returns ("\n"). Before this string is to be displayed, all the double dashes and carriage returns are removed by calling a miscellaneous function rmLnDash. The length of the new string is compared with the value of scwd to see if the string can be held completely in one line. In our tool, one character takes about 6 pixels based on the font we chosen. If one line is not long enough to hold the string of system description, new lines are added and carriage returns are inserted into the string accordingly, by calling the function addRetn, until the string of the system description is completely drawn.
From Section 3.3.3, we know there are four columns in a system-level table. From left to right, the columns are labeled **Class Name**, **Inherits Class**, **Uses Class** and **Description**. The width of each column is prefixed in the program, but leaving the height (number of lines) of a row adjustable for holding different length of strings in a row. The strings for labeling each column are drawn in a line under the system description, and their positions are calculated according to the width of each column. The content of the table is drawn from row to row, and is done by first drawing a rectangle and then drawing a string inside the rectangle. As mentioned before, the width of each column is prefixed, while the number of lines in a row depends on the length of the strings which are to be displayed in this row. The number of lines in a row is initialized to 1 before drawing, and the actual number of lines in a row is computed as follow:

- starting from the class name, the procedure compares the length of the string (the class name) to the prefixed width of first column. If one line is not long enough to hold the string, new lines are added and carriage returns are inserted into the string accordingly until the string of the class name can be held completely in first column. A variable *cuhi* is used to store the minimal number of lines in a row needed for the class name;

- similar calculations are made for “Inherits Class”. All the names of “inherits class” are concatenated together into one string, and commas are inserted between any two names. The length of this new string is compared to the width of the second column. If one line is not long enough to hold the string, new lines are added, and carriage returns are inserted into the string accordingly, until the string can be held completely in the second column. The variable used for holding the minimal number of lines needed in a row is *cahi*;

- similar computations are made for “Uses Class” and “Description” of the class, and the number of lines needed to hold the strings are stored in variables *cuhi* and *cdhi* respectively;

- then the four integers are compared to find the biggest one among them
which is to be the actual number of lines used in drawing this row.

Finally, four rectangles and four strings are drawn at their calculated positions.

Callback \texttt{clsTableCb} of \texttt{View} in the class selection dialog

The callback \texttt{clsTableCb} is invoked when the user presses the \texttt{View} button in the selection dialog popped up by choosing the item \texttt{Class} in pulldown menu \texttt{TableView}. This routine is responsible for filling the message fields of the window and draw a class-level table on the drawing area by calling function \texttt{drawClassTable}. The name of the class whose class-level table is to be drawn is displayed on the top message field, and the system name of a design to which the class belongs is displayed in the message field on the bottom of the window.

The function \texttt{drawClassTable} is similar to the function \texttt{drawSystemTable}, except that there are five instead of four columns in the class-level table. These columns are labeled \texttt{Method Name}, \texttt{Return Type}, \texttt{Parameter}, \texttt{Uses Methods} and \texttt{Description} (comments for the method).

\textbf{CheckWindow}

The structure of the widgets in the \texttt{CheckWindow} is given in Figure 27, and Figure 28 shows the layout of the window.

This window is popped up when the button \texttt{Check} is pressed in the \texttt{ToolMainWindow}. From the layout of the window (Figure 28), we can see the body of this
window is composed of three parts: on the top there is a message part which is used for displaying information about this window; in the middle there is a file selection part where a list of files with extension .d and .lib are displayed and a selection field is provided under the file list; on the bottom there is an action part equipped with four buttons. The message part is created with a Label widget, and the text for display is loaded during the creation of the Label. The file selection part and the action part are created together by calling a convenient Motif function for creating file selection dialog. Function mySearchProc is used for file searching, and some changes in button labels are made. The label of the button OK is changed to Check, and Cancel button is set to the left corner of the action part, and Help button is made inaccessible since no further help text is needed for the current version. As usual, the callback for Cancel is popdownWidget. The callback for button Check is the function doCheckCb.

The routine doCheckCb is responsible for obtaining the file name from the selection
Figure 29: The information dialog which is popped up when the checking succeeds
field in the CheckWindow, then passing the file name to a function named checkFunc.
The function checkFunc calls the function ast to parse the given file. If parsing fails, a
subsequent information dialog is popped up on the screen to inform the user, and
the checking process is terminated. If the parsing succeeds, checkFunc assumes there
is a standard library for the selected design. The AST for the library is generated
inside the function checkFunc and the AST is stored together with the AST of the
design in the global variable aSystem. The design selected by the user and the library
are checked together as one unit by calling the function doCheckStuff.

The function doCheckStuff is a routine that prepares for the actual check by ini-
tializing the data structure for holding the undefined class and method names, calls
the function consistCheck to check the consistency and completeness of the selected
design, and finally gives the check result on a popup window. If the design passes
the consistency check, an information dialog is popped up to inform the user of the
success of the checking (an example of this is given in Figure 29). If the consist-
tency check of the selected design fails, doCheckStuff is responsible for outputting the
checking result in a popup window. The unsuccessful checking result is a list of class
names and method names which are not defined but are used in the design. The list
of class and method names is generated by the function consistCheck, and stored in
a global variable nonDefine which is defined in file nonDefineData.h. The popup
window is composed of three parts: a message part on the top of the window which
is built with a Label widget and is used for displaying the message of "Consistency
Figure 30: The output window which is popped up when the checking fails

Check Output”; a Text in the middle of the window which is used to display the list of undefined names; and on the bottom, there is an action part with a button OK in it. The callback routine for OK is the function popdownWindow which is responsible for removing the result window from the screen. The function consistCheck is defined in file consistCheck.c.

Inside the file consistCheck.c, a function initNonDefine is also defined which simply sets the variable nonDefine to NULL. This function is always called before checking to prepare the data structure for holding the new undefined names which are to be generated during the coming checking.

As we have seen, the global variable aSystem defined in file tempData.h is used to hold the AST of a design. The standard library of the design is stored in the place pointed by the next field of the variable aSystem. The two systems (the design and the library) are to be used together in consistency checking. The function consistCheck checks the following parts of a class C in the system of a design:

• each class that C inherits must be defined in the design or in the library of the design;
• each class used by $C$ must be defined in the design or in the library;

• each type used in the variable declarations of $C$ must be defined in the design or in the library;

• the return type as well as each parameter type in a method protocol in the class $C$ must be defined in the design or in the library; and

• for each "method::name" pair inside a method of the class $C$, the "method" must be defined in the class “name”, and obviously the class “name” must be defined in the design or in the library.

The undefined class names and “method::name” pairs are stored in a global variable nonDefine and duplicated names and pairs are eliminated from nonDefine. As an example, the part of code for checking the inherited class name is given in Figure 33 at the end of this Chapter.

OutputWindow

The structure of the widgets in this window is the same as that of the CheckWindow, and is shown in Figure 26, and Figure 31 shows the layout of the window.

This window is popped up when the button Output in the ToolMainWindow is selected by the user. The layout of this window is very similar to that of the CheckWindow except that the message on the top of the window is different and the label of the button OK is Print instead of Check. The procedure of creating OutoutWindow is exactly the same as that of creating CheckWindow. The callback routine for the button Print is the function printCb defined in file print.c.

The purpose of printCb is to generate for the user a file in LATEX form which is the printable report of a design. The routine printCb gets the file name from the selection field of OutputWindow, then passes the file name to the function ast for parsing. If the parsing fails, an information dialog is popped up to inform the user and printCb returns. Otherwise, the output process moves on to get an output file name which is the same as the name of the selected file containing source text of the design but with extension .tex. The file name obtained is passed to the function thereIs, which
Figure 31: *OutputWindow*

looks for a file of the same name in the current working directory. If such a file exists, it is deleted. In either case, the function ensures that an empty file with the given name is available for writing. The following contents are written to the file:

- The function *printCb* first writes to the file a text which is the header of a \LaTeX{} file and contains the information of textwidth, textheight and topmargin, and so on. The text is stored in a local variable *textBegin*.

- Then *printCb* writes to the file the name of the system of the design and the description of the system, in \LaTeX{} form.

- After that, it writes to the file in \LaTeX{} form the information about each class in the system of the design. The information written includes:
  
  ▶ the class name, its description;
  
  ▶ the list of names of inherited class;
Figure 32: The information dialog which is popped up to indicate the generated file

- the list of class names used by the class;
- variables defined in the class, and
- the information about each method defined in the class, i.e. the method protocol and its description.

- Finally, printCb writes to the file a text stored in a local variable textEnd which is the end part of a \LaTeX\ file containing \texttt{\textbackslash end\{document\}}.

After all the content has been written to the file, printCb closes the file and pops up an information dialog to inform the user the generated file. One such example is given in Figure 32.

4.3.2 Miscellaneous Functions

The functions described here are routines called miscellaneous functions which are frequently used for the creations of different windows, and are grouped into a file named \texttt{misc\_Func\_c}.

\texttt{popup\_Window}

The most frequently used routine is the \texttt{popupWindow} which simply calls \texttt{XToolkit} library \texttt{Xi\_Pop\_down} to pop down the given widget.
isGood

The purpose of the function isGood is to check if the given file has extension .d (files containing the source texts of the designs) or .lib (the file containing the source text of the standard library). It obtains the extension of the given file (i.e. the string after the first dot in the file name), and compares the string to d and lib. If a match is found, an integer value 1 is returned to the calling routine, otherwise 0 is returned.

mySearchProc

The function mySearchProc is the new file searching procedure used during the creation of all the file selection dialogs in the tool. This function obtains the path of the current working directory from the search_data (provided by Motif) of the file selection dialog, reads all the files in the directory to a buffer, then calls the function isGood to select only those files with extension .d or .lib for display.

bigger

The function bigger compares two given integers and returns the bigger one to the calling routine.

rmRnDash

The purpose of the this function is to remove the carriage returns ("\n") and double dashes ("--") in the given string. It goes through each character in the given string, and whenever a carriage return or a pair of double dashes is found, it simply removes them.

addRetn

This routine is used frequently in drawing tables of a design. The purpose of addRetn is to split the given string into multi-line strings according to some calculation, then store the resulted strings in a variable multiStr which is an array of the type TMultiStr. Meanwhile, the number of lines needed for holding this string in a row is calculated accordingly and stored in a variable norow. The number of characters
that will fit on a line is obtained by dividing the length of the line by the width of each character. The length of the line, in pixels, is known, and the Design Tool uses a font in which each character is 6 pixels wide. The given string, which may be a long string and has no carriage returns, is split into multiple lines and each split one-line string and its length are stored in the variable multiStr. In case one word is split into two lines, a dash ("–") is inserted at the end of the first part of the word. Finally, the split string and the number of lines it takes are returned to the calling routine by the variables multiStr and norow.

thereIs

The purpose of the function thereIs is to check if there is a file existing in the current working directory which matches the given file name. The function obtains the path of the current working directory by calling a UNIX system call[10] getwd, and reads all the files in the directory to a buffer, then compares each file name with the given string until a match is found (1 is returned) or the end of the file list is reached (0 is returned).

createInfoDialog

Information dialogs are used very often in the tool which are popped up to inform the user a specific status of a process, such as when a design has been checked successfully. As mentioned in the previous subsection, all the information dialogs are created by calling this createInfoDialog. This function calls the convenient Motif function to create a information dialog as a child of the given widget. During the creation, the OK button and Help button are not managed and therefore disappear from the action field of the dialog. The label of the Cancel button is changed to OK and the callback routine for this button is popdownWidget which is responsible for removing the dialog from the screen when OK is pressed. Finally, the shell of the created dialog is passed back to the calling routine.
writetofile

This function is used by printC\& during the generation of the LaTeX file for a design. It simply call the C library fwrite to write a given string to a opened file.

checkspecial

This function is used frequently by printC\& during the generation of the LaTeX file for a design. The purpose of this file is to preprocess all the special characters in the given string. These characters, which need special handling in LaTeX are " " , "%", "&", "$", "#", "{", "}" , "-", "~" and ". If any of the first seven characters is found, a backslash is inserted before it. Otherwise, a special handling is needed, such as for "\", a string "$\backslash$" is used to replace it, for "~", a string "$\cdot\{\}$" is used instead, and for "-", a string "$\cdot\{\}$" is used for replacing. Finally, the new string is returned to the calling routine.

isExist

The purpose of this function is to check if the given name already exists in the given list. This function is used by consistCheck to eliminate the duplicated names found in the variable nonDefine which is used to hold the undefined class and method names. The "name" is a string, and the "list" is a pointer to the type TStringDict. If the "name" is found in the "list", 1 is returned, otherwise, 0 is returned.
/* check inherits class names */
inhs = currCls->inherits;
while (inhs) {
tmpSys = aSystem;
while (tmpSys) {
otherCls = tmpSys->classList;
name = (char *)strdup(inhs->name);
found = FALSE;
while (otherCls) {
    if (strcmp(name, otherCls->label.name) == 0) {
        found = TRUE;
        break;
    }
    otherCls = otherCls->next;
}
if (found)
    break;
tmpSys = tmpSys->next;
}
if (!found) { /* the name not defined */
    if (!isExist(name, nonDefine)) {
        tmp = (TStringDict *)malloc(sizeof(TStringDict));
tmp->name = (char *)strdup(name);
tmp->next = nonDefine;
    nonDefine = tmp;
    }
}
inhs = inhs->next;
}

Figure 33: Code for checking inherited class name
Chapter 5

A Walk-Through of The Design Tool

In this chapter, we describe a walk-through of the Design Tool with the example which we described in Section 3.3.1, the Heating System. Therefore the tables in the View Window and the text in the Edit Window can be used to compare with the tables and text which we developed in Section 3.3. Major functions of the tool are described with corresponding pictures of the tool we dumped from X window environment. An example of a printable report which is generated by the Design Tool is also given at the end of this chapter.

Common Features of Windows and Dialog Boxes

The following are features common to all the windows and dialog boxes except the main window of the Design Tool (with the exception of the first one):

- Every window can be resized by placing the mouse pointer on the small square which is on the right top of the window frame, pressing the left button of the mouse, and dragging the mouse to the desired size then releasing the mouse button (The ToolMainWindow can be resized in the same way).
• The selection of an item in every selection dialog box (including file selection dialog and general selection dialog) can be made either by mouse or by keyboard input. Mouse selection is done by placing the mouse pointer to the desired name in the list provided by the dialog, clicking the left button of the mouse, and then using the mouse to click on the action button, such as View or Open and so on, to finish the action of selection. The keyboard input can be done by typing the desired name on the selection field which is usually on the bottom part of the dialog, then pressing the Return key to invoke the selection action.

• The newly popped up window is always appears on the top of the screen. When a window is popped up on the screen, it always appears on the place where it is removed (popped down) last time from the screen, except on the first time that it is created, at what time it appears on the left up corner of the screen.

• There is at most one window of each type exists in the tool, and when the user presses some button to invoke the popping up of the corresponding window, the popped up window will appear on the top of the screen therefore it can be seen as a whole by the user, no matter whether it has been created and hidden by other windows, or it has been removed from the screen after it has been created, or it has not been created.

**ToolMain Window**

The tool is activated by typing the command oodtool inside the X window or the Motif window environment, and the main window of the tool, the ToolMain Window (Figure 12), is popped up on the top of the screen. The ToolMainWindow is the only place to get access to the help, in the Help Window which provides the on-line help to the tool, and the working windows which provide the four major functions, i.e. editing, viewing, checking and outputting. It is also the only place to properly exit from the Design Tool. The Help Window, which is shown in Figure 15, is invoked by pressing the Help button on the right corner of the action field of the main window. It can be dismissed by selecting the OK button in the window, and can be retrieved later by selecting the Help button in the ToolMainWindow again. If we want to exit
the tool, the Quit button should be pressed, and when a warning dialog (Figure 13) is popped up, the Yes button in the dialog should be selected. Once we select the button Yes in the warning dialog, all the windows of the tool are deleted from the screen. Otherwise, if the button No is selected, only the warning dialog is removed from the screen, and everything else in the tool are left unchanged.

**DesignWindow–Edit**

Suppose we want to activate the editing function to view the source text of a design or to modify a design, the button Design in the ToolMainWindow should be selected by a mouse clicking on the button. As the result, the DesignWindow (Figure 17) is popped up on the top of the screen. We can quit the DesignWindow by selecting the Quit button in the DesignWindow, and can retrieve it by selecting the Design button again. The access to the Edit Window of the Design Tool can be achieved by selecting the Edit button in the DesignWindow. The Edit Window, named DesignWindow–Edit, is popped up on the top of the screen with an empty editing area in the middle of the window (Figure 19). Exiting from this window can be done by selecting the Quit menu in the pull down menu Quit on the left corner of the menu bar. Suppose we want to edit the source text of the design of the Heating System, we can do so by selecting the Open menu in the second pull down menu File on the menu bar, and when a file selection dialog is popped up on the screen, selecting the file demo.d in the file list (Figure 20). As the result of such selection, the source text of the design of the Heating System is loaded into the editing area of the window and ready for viewing and editing. Meanwhile, the file name demo.d is displayed in the message field on the top of the editing area. We can scroll the scrollbars up or down, and right or left to view the different part of the text in the editing area, as well as resize the the whole window to make the editing area larger or smaller. For editing, we can make some selection of the text by mouse dragging, and the selected text is highlighted in the editing area. Then we can do Cut, Copy and Paste to the selected text by choosing the corresponding menu in the pull down menu Edit of the menu bar. The Cut action simply cuts the selected text, which is also highlighted, from the editing area. Copy will copy the selected text into a clipboard which is preserved by the tool and used as
Figure 34: DesignWindow Edit with Search invoked
a temporary buffer. The Paste action pastes the content in the clipboard to the place where the current cursor is. The menu Clear of the pull down menu Edit deletes the content of the clipboard. This window also allows the user to do searching and replacing on the text. Searching is done by input the search pattern on the left text field directly beneath the menu bar. If we want to search for the string view in the text, we can do so by typing the view in the searching place, and then selecting the menu item Find Next in the pull down menu Search to search the string one by one in the text, or selecting the Show All to get all the string views highlighted in the text (an example of this is shown in Figure 34). The number of occurrences which match the search pattern is displayed on the message field on the bottom of the window. The Replacing can be done by first typing the searching pattern, such as view, in the left text field and replace pattern, such as View, in the right text field directly beneath the menu bar, then selecting the menu item Replace & Text. As the result, all the string views will be replaced by the string Views. The highlights of text which are made during the selection can be removed by selecting the menu item Clear in the pull down menu Search. After some changes have been made to the source text of the design, we can save the changes in the design by selecting the Save menu in the pull down menu File, and after a file selection dialog is popped up on the screen, selecting the right file name by mouse click or typing the desired file name through the keyboard. Then the updated content in the editing area is saved to the file which we chose. If some changes are made to the design, and the changes are not saved to a file when we try to exit the DesignWindow-Edit, a warning dialog is popped up on the screen to remind that the changes have not been saved, and could be lost if we exit the window. Similar things happen when we make some modifications to the design, then try to open a new file before the modifications we made are saved to a file. Another function which does not belong to the scope of editing but presents the convenience of checking to the designers is also provided in this window. This is the function ConsistencyCheck in the pull down menu Option. Once we have loaded a file into the editing area, or when we have finished the updating of the design in the editing area, we can check the consistency of the design by selecting the menu ConsistencyCheck. There is one thing needs to be mentioned here: when the source text
of a design has been changed in the editing area, only when we save the source text
of the design into the same file which previously contains the old source text of the
design, the consistency check will be done on the updated design, otherwise, the check
is done on the old one. Therefore, the Design Tool provides protection by checking
the editor to see if some modifications have been made, but have not been saved. If
this happens, the tool pops up a warning dialog to remind us about this situation.

**ViewWindow-Table**

If we want to view the tables of a design, we can do so by selecting the *View* button
in the *ToolMainwindow*, and when the *ViewWindow* (Figure 22) is popped up on
the screen, choosing the *Table* button. Then the view table window, *ViewWindow-
Table*, is popped up on the screen with an empty and white drawing area in the middle
of the window (Figure 24). Since the default window size is too small to view any
particular tables, we can enlarge the window size by mouse to get a bigger drawing
area. Suppose we want to view the tables of the design of the Heating System, we
then need to do the selection by choosing the menu *System* in the pull down menu
*TableView*, and when a file selection dialog is popped up on the screen, selecting
the file name *demo.d* from the file list. As the result, the system-level table of the
design of the Heating System is displayed in the drawing area of the window, with
the system name of the design *HeatingSystem* displayed on the message field on the
top, and the file name *demo.d* displayed on the message field on the bottom of the
window. We can scroll the scrollbars up or down, and right or left to view different
part of the table in the window. The complete system-level table of the Heating
System is given in Figure 35 and Figure 36. If we want to view a class-level table of
one of the classes in the design of the Heating System, we can do so by choosing the
menu *Class* in the pull down menu *TableView*. A selection dialog is then popped
up on the screen with a list of class names which belong to the design of the Heating
System (Figure 25). Suppose we want to view the table for the class *View*, a selection
of the name *View* in the class list of the selection dialog should be made by mouse
or by keyboard input. The class-level table of the class *View* is then displayed in the
drawing area of the window, with the class name *View* displayed on the message field
System Description:

A OO design for a domestic heating system.

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Inherits Class</th>
<th>Uses Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HeatSim</td>
<td>StdErrors, Program</td>
<td>Bool, Input, Buffer, ViewDigital, ViewBarChart, Float, Water, View, Furnace, Int, ViewGraph, Iterator, Room, List, String, Keyboard, Window</td>
<td>ancestors: Program, StdErrors</td>
</tr>
<tr>
<td>View</td>
<td></td>
<td></td>
<td>An instance of a View class can display changing values of several floating-point variables. This class, View, is abstract; it defines the minimal protocol for a class that provides views. A view has several channels, each corresponding to a particular variable. Channels are initialized and updated independently in any sequence. The display is updated as a unit.</td>
</tr>
<tr>
<td>ViewDigital</td>
<td>View</td>
<td></td>
<td>Implements a View by displaying floating-point variables as strings.</td>
</tr>
<tr>
<td>ViewBarChart</td>
<td>View</td>
<td></td>
<td>Implements a View using horizontal bar charts.</td>
</tr>
<tr>
<td>ViewGraph</td>
<td>View</td>
<td></td>
<td>Implements a View by displaying variables on an X-Y graph.</td>
</tr>
<tr>
<td>Furnace</td>
<td></td>
<td></td>
<td>Simulates the furnace in a simple central heating system. The furnace provides heat to the water if any heat</td>
</tr>
</tbody>
</table>

Figure 35: The system-level table of the Heating System
<table>
<thead>
<tr>
<th>Object</th>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace</td>
<td></td>
<td>Simulates the furnace in a simple central heating system. The furnace provides heat to the water if any heat is needed. If no heat is needed, the water cools down.</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td>Simulates the water in a heating system. The only interesting attribute of the water is its temperature.</td>
</tr>
<tr>
<td>Room</td>
<td>Heatable</td>
<td>Simulates a room which obtains heat from a radiator and loses heat to the environment. Room inherits from Array in order that we can declare an array of Rooms.</td>
</tr>
<tr>
<td>Radiator</td>
<td>Heatable</td>
<td>Simulates a radiator which receives heat from the water supply and provides heat to a room. The object simulated is actually a rather complicated radiator, complete with thermostat and valve. You could make the simulation more realistic by splitting this class up into three components: a thermostat which switches on or off depending on the room temperature; a valve which is controlled by the thermostat; and a radiator which is controlled by the valve.</td>
</tr>
<tr>
<td>Heatable</td>
<td></td>
<td>An abstract class which captures the basic property of a heatable object. A heatable object is connected to a source, from which it gains heat, and a sink, to which it loses heat. The object has a temperature and coupling coefficients to its source and sink.</td>
</tr>
</tbody>
</table>

Figure 36: The system-level table of the Heating System (continued)
A class instance of the View class can display changing values of several floating-point variables. This class, View, is abstract; it defines the minimal protocol for a class that provides views. A view has several channels, each corresponding to a particular variable. Channels are initialized and updated independently in any sequence. The display is updated as a unit.

<table>
<thead>
<tr>
<th>Method Name</th>
<th>Return Type</th>
<th>Parameter</th>
<th>Uses Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>init</td>
<td>Int, Float</td>
<td></td>
<td></td>
<td>Initialize the given channel with the given value.</td>
</tr>
<tr>
<td>set_val</td>
<td>Int, Float</td>
<td></td>
<td></td>
<td>Update the given channel with the given value.</td>
</tr>
<tr>
<td>set_title</td>
<td>Int, String</td>
<td></td>
<td></td>
<td>Provide the given channel with the given title.</td>
</tr>
<tr>
<td>calibrate</td>
<td>Float, String</td>
<td></td>
<td></td>
<td>A calibration point is used to label the axis of a graph or to perform a similar service for another display mode. This method uses the given value to position the calibration mark and writes the string at that position.</td>
</tr>
<tr>
<td>update</td>
<td></td>
<td></td>
<td></td>
<td>Update the display for all channels.</td>
</tr>
<tr>
<td>message</td>
<td>String</td>
<td></td>
<td></td>
<td>Display a message other than channel data.</td>
</tr>
<tr>
<td>close</td>
<td></td>
<td></td>
<td></td>
<td>Null method to close display. Descendant classes which require a closing action should redefine this method.</td>
</tr>
</tbody>
</table>

Figure 37: The class-level table for the class View
Figure 38: The class-level table for the class *Water*

on the top of the drawing area and the system name of the design *HeatingSystem* displayed on the message field beneath the drawing area. This is shown in Figure 37. Another class-level table for the class *Water* is also given in Figure 38, and these two figures (37, 38) can be compared with Table 6 and 7 in Section 3.3.1. We can clear the drawing area by selecting the menu *ScreenClear* in the pull down menu *Option*. Exiting from this window can be done by selecting the menu *Quit* in the pull down menu *Quit*.

**CheckWindow**

As mentioned before, we can do the consistency check of a design either inside the *DesignWindow>Edit*, or through the check window. The *CheckWindow* (Figure 28) can be loaded by selecting the *Check* button in the *ToolMainWindow*. Suppose we want to check the consistency of the design of the Heating System, we need to select the file which contains the source text of the design, i.e. select the file *demo.d* in the
file list. The check action is accomplished by mouse clicking on the button Check. On
the accomplishment of the checking, the CheckWindow is removed from the screen,
and the result of the check is given by either an information dialog for indicating the
success of the checking, or an output window (Figure 30) for listing the undefined
names of classes and methods in the design. For the Heating System, an information
dialog (Figure 29) is popped up on the screen. The files displayed in the file list are
based on the current working directory, and we can change to another directory by
either typing the name of that directory on the selection field, or using mouse to click
on the directory. One thing needs to be mentioned here is that all the file selection
dialogs in the tool only display the files with extension .d or .lib, therefore, in some
case, the file list part in the dialog may not contain any file names. The exiting of
the CheckWindow can be done by selecting the button Quit.

OutputWindow

The printable report of a design can be generated by invoking the output function
of the tool. This is done by selecting the Output button in the ToolMainWindow.
Then the OutputWindow (Figure 31) is popped up on the screen. Suppose we want
to generate the printable report of the design of the Heating System, we begin by
selecting the file demo.d in the file list, then mouse clicking on the button Print. The
generated LATEX file of the design is given the name demo.tex on the current working
directory. Part of this generated file is shown in the following, and the report of the
design, which is obtained by compiling the generated LATEX file and converting it to
the PostScript form, is shown next.

% The first command specifies the style (article) and base font size (12pt).
\documentstyle[12pt]{article}
% Page size and margins: set for 8.5in x 11in paper with 1in margins.
\textwidth 6.5in
\textheight 9in
\topmargin -0.5in
\oddsidemargin 0in

95
% Insert any additional macros etc here.
% Then start the 'document'.
\begin{document}

{\Large \textbf{system}\{\sl HeatingSystem\}}

{\textbf{small}
\begin{flushleft}
an OO design for a domestic heating system\par
\end{flushleft}}

\vskip 30pt plus 12pt minus 6pt
{\textbf{large}
\begin{flushleft}
\textbf{HeatSim}\} \{\sl ancestors Program StdErrors\par
\end{flushleft}}

\vskip 6pt plus 3pt minus 1pt
{\bf inherits}
{\sl StdErrors\}
{\sl Program\}

{\bf uses}
{\sl Bool\}
{\sl Textin\}
{\sl Buffer\}
{\sl ViewDigital\}
{\sl ViewBarChart\}
An instance of a View class can display changing values of several floating-point variables. This class, View, is abstract: it defines the minimal protocol for a class that provides views. A view has several channels, each corresponding to a particular variable. Channels are initialized and updated independently in any sequence. The display is updated as a unit.
\textbf{method}\{\textit{sl init}\}(\{\textit{sl channel}\}, :, \{\textit{sl Int}\}, \{\textit{sl value}\}, :, \{\textit{sl Float}\}), \texttt{par}
\leftskip 24pt \texttt{small}
Initialize the given channel with the given value. \texttt{par}

\vskip 6pt plus 3pt minus 1pt
\textbf{method}\{\textit{sl set\_val}\}(\{\textit{sl channel}\}, :, \{\textit{sl Int}\}, \{\textit{sl value}\}, :, \{\textit{sl Float}\}), \texttt{par}
\leftskip 24pt \texttt{small}
Update the given channel with the given value. \texttt{par}

\vskip 6pt plus 3pt minus 1pt
\textbf{method}\{\textit{sl set\_title}\}(\{\textit{sl channel}\}, :, \{\textit{sl Int}\}, \{\textit{sl title}\}, :, \{\textit{sl String}\}), \texttt{par}
\leftskip 24pt \texttt{small}
Provide the given channel with the given title. \texttt{par}

\vskip 6pt plus 3pt minus 1pt
\textbf{method}\{\textit{sl calibrate}\}(\{\textit{sl value}\}, :, \{\textit{sl Float}\}, \{\textit{sl str\_value}\}, :, \{\textit{sl String}\}), \texttt{par}
\leftskip 24pt \texttt{small}
A calibration point is used to label the axis of a graph or to perform a similar service for another display mode. This method uses the given value to position the calibration mark and writes the string at that position. \texttt{par}

\vskip 6pt plus 3pt minus 1pt
\textbf{method}\{\textit{sl update}\}\texttt{par}
\leftskip 24pt \texttt{small}
Update the display for all channels. \texttt{par}
\textbf{inherits}
The following are the actual printable report of the part of the design, the Heating System, obtained by compiling the above LATEX file.

**system HeatingSystem**

an OO design for a domestic heating system

**class HeatSim**

ancestors Program StdErrors

**inherits StdErrors Program**

**uses** Bool Textin Buffer ViewDigital ViewBarChart Float Water View Furnace Int ViewGraph Iterator Room List String Keyboard Window
method entry

class View

An instance of a View class can display changing values of several floating-point variables. This class, View, is abstract: it defines the minimal protocol for a class that provides views. A view has several channels, each corresponding to a particular variable. Channels are initialized and updated independently in any sequence. The display is updated as a unit.

method init(channel: Int, value: Float)

Initialize the given channel with the given value.

method set_val(channel: Int, value: Float)

Update the given channel with the given value.

method set_title(channel: Int, title: String)

Provide the given channel with the given title.

method calibrate(value: Float, str_value: String)

A calibration point is used to label the axis of a graph or to perform a similar service for another display mode. This method uses the given value to position the calibration mark and writes the string at that position.

method update

Update the display for all channels.

inherits View

method message(txt: String)

Display a message other than channel data
method close

Null method to close display. Descendant classes which require a closing action should redefine this method.
Chapter 6

Conclusion

In this thesis, we presented a supporting tool for object-oriented design and system evolution. As design is the most important and effort consuming phase in object-oriented software development, our tool aims at providing automated support to empower the designers as much as possible during the design process. Maintenance is the most costly phase in system evolution, our tool provides direct assistances to the maintainers during system evolution by supporting automation in capturing and altering the design. Important features of the tool are editing, viewing, consistency checking and the generating of printable report of the design.

The design and implementation of the tool were presented in the thesis. Design format which forms the theoretical basis for the tool was discussed; design display in textual and tabular forms were exploited and illustrated with an example; the abstract syntax tree (AST) which is the base of data in the tool were generated, and a parser module for constructing the AST of a design were presented; functional modules of editor, viewer, checker and printer were built based on the analysis of the tool and theoretical results.

A carefully defined, consistently formatted user interface was developed as part of the tool, and as the media for human interaction with the function modules of the tool. We considered the interface part to be the significant and necessary part of the tool design, and emphasis was put on it to achieve the ease of the use of the tool.
As the first version of the design tool, limitation of the functionality of the tool is unavoidable, and several directions for future work can be suggested to contribute to the improvement of the tool. The following are some suggestions for future work:

- Some new functions can be added to the tool to enlarge the tool's functionality. This may include the ability to provide graphical display (diagram) of the system of a design and a class in the system; the ability to respond to the user's queries, entered by means of menu and simple dialog boxes, some typical queries are: which classes use service C::S? Which services does class C use? If I change C::S, what classes will be affected? etc.; the ability to provide a faster and more convenient way than on-line editing to modify the design, and once a change has been made to a design, the user would soon be informed in a proper way.

- More advanced features can be added to the tool. For example, the tool could suggest a sequence for implementing the design, and could propose test plans for each stage of the implementation.

- The future version of the tool can take into account the dynamic model of a system as a part of the design of the system. This could be done by portraying the dynamic behaviors and causality flows of the system through the notations of use cases and timethreads.

- The tool could be added to with a system interface, therefore it could be incorporated with other automated tools, like a code generator, to form a unified development and maintenance environment for object-oriented software.

- The tool could be extended with generators for various target languages. For example, it could generate class specifications in C++ or Eiffel, leaving only the bodies of the methods to be completed by the implementors.

- An experiment could be conducted to compare this tool with other tools.

Some people, including myself, like the implementation phase of software development. Implementation is enjoyable because progress is visible during the process. Our
tool makes the design enjoyable by allowing the designer to see progress immediately and to monitor it. In this way, the tool supports and encourage design evolution.
References


Appendix A Class Specifications
of the Heating System

<table>
<thead>
<tr>
<th>class</th>
<th>HeatSim</th>
</tr>
</thead>
<tbody>
<tr>
<td>superclass</td>
<td>none</td>
</tr>
<tr>
<td>subclass</td>
<td>none</td>
</tr>
<tr>
<td>description</td>
<td>the main class used to invoke the simulation</td>
</tr>
</tbody>
</table>

| contract | 1. entry |
| description | one method for starting main loop |

<table>
<thead>
<tr>
<th>class</th>
<th>Furnace</th>
</tr>
</thead>
<tbody>
<tr>
<td>superclass</td>
<td>none</td>
</tr>
<tr>
<td>subclass</td>
<td>none</td>
</tr>
<tr>
<td>description</td>
<td>Simulates the furnace in a simple central heating system. The furnace provides heat to the water if any heat is needed. Simulates the furnace in a simple central heating system.</td>
</tr>
</tbody>
</table>

| contract | 1. make(furnace_power:Float sys_water:Water max_water_temp:Float) |
| description | Construct a furnace object, given the water it has to heat, and the maximum temperature of the water. |

<p>| contract | 2. update(heat_needed:Bool env_temp:Float) |
| description | Use the furnace to increase the water temperature if heat is needed and the water is not above its maximum temperature. The water loses a little heat to the environment. |</p>
<table>
<thead>
<tr>
<th>class</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>superclass</td>
<td>Heatable, Any</td>
</tr>
<tr>
<td>subclass</td>
<td>none</td>
</tr>
<tr>
<td>description</td>
<td>Simulates a room which obtains heat from a radiator and loses heat to the environment. Room inherits from Any in order that we can declare an array of Rooms.</td>
</tr>
</tbody>
</table>

| contract   | 1. same(other:Room): Bool |
| description| Return true if self and other refer to the same object. |

| contract   | 2. show : String         |
| description| Return a string representation of the receiver. |

| contract   | 3. change_temp(source_temp:Float sink_temp:Float) |
| description| Change the temperature of the heatable object given the temperatures of the associated source and sink. The new temperature will depend on the relative temperatures of the object, the source, and the sink as well as the thermal coupling coefficients between the objects. |

| description| Constructing a room requires that several important parameters be set. room_from_rad is the thermal coupling for heat flowing from the radiator to the room. room_to_env, rad_from_water, and rad_to_room have similar meanings. The rad_setting is the temperature at which the radiator comes on, but the actual transitions are determined by rad_setting +/- rad_tol. |

| contract   | 5. update (env_temp:Float) |
| description| Update a room given the temperature of the environment. |

<p>| contract   | 6. rad_on : Bool          |
| description| Return true if the radiator belonging to this room is on. |</p>
<table>
<thead>
<tr>
<th>class</th>
<th>View</th>
</tr>
</thead>
<tbody>
<tr>
<td>superclass</td>
<td>none</td>
</tr>
<tr>
<td>subclass</td>
<td>ViewDigital, ViewBarChart, ViewGraph</td>
</tr>
<tr>
<td>description</td>
<td>An instance of a View class can display changing values of several floating-point variables. This class, View, is abstract: it defines the minimal protocol for a class that provides views. A view has several channels, each corresponding to a particular variable. Channels are initialized and updated independently in any sequence. The display is updated as a unit.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>contract</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>init</td>
<td>1. init(channel:Int value:Float)</td>
</tr>
<tr>
<td>description</td>
<td>Initialize the given channel with the given value.</td>
</tr>
<tr>
<td>set.val</td>
<td>2. set.val(channel:Int value:Float)</td>
</tr>
<tr>
<td>description</td>
<td>Update the given channel with the given value.</td>
</tr>
<tr>
<td>set.title</td>
<td>3. set.title(channel:Int title:String)</td>
</tr>
<tr>
<td>description</td>
<td>Provide the given channel with the given title.</td>
</tr>
<tr>
<td>calibrate</td>
<td>4. calibrate(value:Float str.value:String)</td>
</tr>
<tr>
<td>description</td>
<td>A calibration point is used to label the axis of a graph or to perform a similar service for another display mode. This method uses the given value to position the calibration mark and writes the string at that position.</td>
</tr>
<tr>
<td>update</td>
<td>5. update</td>
</tr>
<tr>
<td>description</td>
<td>Update the display for all channels.</td>
</tr>
<tr>
<td>message</td>
<td>6. message(txt:String)</td>
</tr>
<tr>
<td>description</td>
<td>Display a message other than channel data.</td>
</tr>
<tr>
<td>close</td>
<td>7. close</td>
</tr>
<tr>
<td>description</td>
<td>Null method to close display. Descendant classes which require a closing action should redefine this method.</td>
</tr>
<tr>
<td>class</td>
<td>Water</td>
</tr>
<tr>
<td>----------</td>
<td>---------------</td>
</tr>
<tr>
<td>subclass</td>
<td>none</td>
</tr>
<tr>
<td>subclass</td>
<td>none</td>
</tr>
<tr>
<td>description</td>
<td>Simulates the water in a heating system. The only interesting attribute of the water is its temperature.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>contract</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. make (water_temp:Float)</td>
<td>Set the initial temperature of the water.</td>
</tr>
<tr>
<td>2. change_temp(new_temp:Float)</td>
<td>Set temperature of water to given value.</td>
</tr>
</tbody>
</table>
Appendix B Abstract Syntax Tree

The AST is declared in C as a union of "struct" with each "struct" corresponding to a non-terminal of the abstract syntax of the design input language.

```c
#ifndef TOOLSTRUCT_H
#define TOOLSTRUCT_H

#include <stdlib.h>
#include <stdio.h>
#include <strings.h>
#define NIL NULL
#define TRUE 1
#define FALSE 0
#define NOFILENAME 0
#define CANNOTOPEN 1
#define PARSEFAIL 2
#define PARSESUCCEED 3
typedef char* TString;

/* data structure used for holding multi-line string in display */
typedef struct TMultiStr {
    char *str;
    int len;
} TMultiStr;
```

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typedef enum
{
sYSTEM, cCLASS, cMETHOD, cVAR, cUSES, cINHERITS
} TAttrType;

typedef struct TLabel {
    TString name;
    TString comment;
} TLabel;

typedef struct TStringDict {
    TString name;
    struct TStringDict *next;
} TStringDict;

typedef struct TNTPairDict {
    TString name;
    TString type;
    struct TNTPairDict *next;
} TNTPairDict;

typedef struct TTOPair {
    TString type;
    TString origin; /* indicating where the type is declared */
} TTOPair;

typedef struct TVar {
    TLabel label; /* var name and comment */
    TTOPair typeOrig; /* only the 'type' field is used */
    struct TVar *next;
} TVar;

typedef struct TMethod {
struct TMethod {
    TLabel label;  /* method name and comment */
    TTOPair typeOrig;  /* the return type */
    TNPairDict *paraList;  /* para: type pair */
    TNPairDict *usesList;  /* the `method::class' pair */
    struct TMethod *next;
} TMethod;

struct TClass;

typedef struct TInherits {
    TString name;  /* only the 'name' field is used */
    struct TClass *inhNodePtr;  /* pointing the class definition */
                  /* where the inherited class is defined */
    struct TInherits *next;
} TInherits;

typedef struct TClass {
    TLabel label;  /* class name and comment */
    TInherits *inherits;  /* inherits class list */
    TStringDict *usesList;  /* uses class list */
    TVar *varList;  /* var list */
    TMethod *methodList;  /* method list */
    struct TClass *next;
} TClass;

typedef struct TSystem {
    TLabel label;  /* name and description */
    TClass *classList;  /* class list */
    struct TSystem *next;
} TSystem;

#endif

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