Reverse Engineering C++ Software Systems by Detecting Design Patterns

By

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A thesis submitted to the Faculty of Graduate Studies and
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degree of

Master of Applied Science

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Abstract

Reverse engineering plays an important role in the comprehension and evolution of software systems. Detecting design patterns in software systems is the first major step toward understanding software systems at a pattern level in order to gain insight into their structure and behavior.

This thesis proposes a rule-based approach to detecting design patterns in software systems. A model for the formal description of design patterns is proposed based on both static and dynamic characteristics of design patterns. It is represented as logic rules in a rule base, while the design information extracted from source code is represented as logic facts in a fact base. The fact and rule base are integrated as a knowledge base. By querying this knowledge base, we can detect patterns enclosed in source code. The features of logic programming make the implementation of the approach simple, flexible and extensible.

Two case studies have been carried out in this thesis. The results and their comparisons indicate the effectiveness and improvement of our approach in this area.

As design patterns have been widely used in software development, a pattern-level view of software systems will be more helpful for software maintainers and developers.

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Chapter 1 Introduction

1.1 Introduction

Reverse engineering (cf. figure 1-1) is “the process of analyzing a software system to identify the system’s components and their interrelationships and create representations of the system in another form at a higher level of abstraction” [Chi90]. It is a process of examination, rather than change or replication. The aim of reverse engineering is to provide an overview of legacy software systems. It is the first major step towards understanding the evolution of a software system. Reverse engineering is a necessary component of software maintenance in that it enables us to understand the information embedded in the code.

The task of reverse engineering is to identify and recover requirements and design specifications. This high-level design information helps in understanding a software system. In general, such high-level information extracted from source code includes [Lu00]:

- System structure- its components and their interrelationships, as expressed by their interfaces
- Functionality – which operations are performed by which components
- Dynamic behavior – a systematic understanding about how input is transformed to output
- Rationale – design involves decision making between a number of alternatives at each design step in the design
- Construction – modules, documentation, test suites, etc.

Reverse engineering plays an important role in software maintenance; it is the foundation of re-engineering. Re-engineering is the examination and alteration of a software system to reconstitute it in a new form and the subsequent implementation of the new form [Chi90]. Re-engineering (cf. Figure 1-1) includes some form of reverse engineering (to achieve a more abstraction description) followed by some form of forward engineering or restructuring.

The following are some of the research techniques [Hon01, Sys00, Rea00, Ros99, Mul98, Cha98, Jer97, Che97, Ga96, Gan96, Bus96, Myl94, Che94, Wil93, Ben92, Har90 Raj90] applied in reverse engineering [Lu00]:

- Program understanding – The objective of program understanding is to extract information useful for comprehension from source code and represent it in such a

way that conforms to human cognitive habits. Program understanding can be conducted in a formal or an ad hoc manner.

- Specification recovery – Specification recovery is a bottom-up process in which a description of the functional and nonfunctional requirements of a software system is extracted from source code.
- Design recovery- Design recovery is a process whereby design information is recovered from the code. Its objective is to extract design information from source code. There are two strategies to achieve this.
 - Fundamental method. The source code is represented in such a way that a maintainer can conduct abstraction. In this method, the computer retrieves information that is entirely embedded in the source code.
 - Knowledge-based method. In this method the tool's aim is to make the abstraction automatically or semi-automatically. The source code is analyzed by using information from a knowledge base.

The most popular approaches in design recovery are as follows:

1. Code views – A part of or the entire source code is represented in a certain way to speed the comprehension of software systems. The information included in the representations is the same as the source code. E.g., call graphs, data flow, definition-use graphs and/or control dependencies.
2. Reformatting and Markup Languages – Reformatting changes the structure of the source code without changing its functions in order to improve readability. Markup languages are languages for annotations of

source code simply to improve the source code's appearance by the means of bold-faced key words, slanted comments, etc.

3. Hypertext-This is used to help browse the source code.
 4. Source code analysis with program transformation and abstraction rules-
Source code is analyzed using the concrete rules of program transformation and abstraction; these are defined according to concrete source code language. A sophisticated abstraction can be obtained from source code by searching for certain types of knowledge in a database using these rules.
 5. Data-Centered and control-centered program understanding – Data-centered methods focus on data and data relationships whereas control-centered methods focus on the control structure of a program, such as call graphs, control flow graphs and paths.
 6. Program slicing – a large program is decomposed into some functional self-contained slices (program fragments) in which only the statements useful for understanding the program are kept.
- Architecture recovery – Architecture gives a global picture of the whole software system. Architecture recovery aims to extract the system architecture from the legacy source code and available documentation.
 - Business rules extraction – The business rules for an organization are extracted from legacy software systems.
 - Cognitive processes in human program understanding- this research issue focuses on the process in which a human reader understands the source code, through

cooperating with computer technology. The study of human cognitive processes can improve reverse engineering by making the approach and tools more supportive to human understanding.

- Intermediate representation of source code – Source code is preprocessed and is represented as an intermediate representation that stores the same information as the source code. Querying this intermediate representation to get high-level view of a software system will be faster than querying the source code directly. It can be used to improve the efficiency of the re-engineering of large systems. In this research direction there are two main topics as follows:

- Data and knowledge-based representation

The source code information is stored in data and a knowledge-based representation so that the design information can be extracted by querying the knowledge base. Relevant artificial intelligence technologies are used to facilitate and optimize the process of reverse engineering.

- Graph based representation

The source code information is represented in a certain form of graph to provide a more perceptive overview, e.g., ASG (Abstract Syntax Graph).

- Discovery of reusable components – This technique focuses on identifying and extracting existing reusable components from legacy software systems.
- Knowledge-based analysis – knowledge-based analysis in reverse engineering enables re-engineering tools to become so smart that frequently used domain knowledge can be recovered automatically.

The subject of this thesis belongs to the ‘design recovery’ group. The aim is to detect design patterns in software systems. The model presented in this thesis is a rule-based approach.

1.2 Thesis Motivation

During the development process, software systems often have incomplete, incorrect or even nonexistent design documentation due to short time to market, staff mobility and costs. After their delivery some software systems have evolved due to requirement change, error correction, business rule changes, and structural re-organization. In these cases, the original design documentation may not always reflect the updated information contained in the current code. Therefore the source code is the only highly reliable source for obtaining the precise design information.

In general, UML class diagrams could be used to represent design information extracted from source code. A class diagram can show the classes and their interrelationships that are included in source code. This is really helpful for understanding the software system. However, as the software systems grow larger it is very hard to get a high-level view of software systems from the several hundreds of classes and their interrelationships.

A higher-level abstraction is needed to simplify the complexity of class diagrams. One such high-level abstraction is the design pattern. Design patterns can be viewed as micro-architectures for solving particular design problems because they reflect the structure and behavior of a set of classes in a software system. A design pattern records the experts’ experience in solving a recurring problem using a general way so that

software developers can easily make a good design and make software development more efficient and time-saving.

Looking for patterns in the source code makes it easier to fully understand the way the software system is structured. A design pattern specifies the role of each class in the pattern, the relationships among the classes and interactions among instances of classes.

By using design patterns when extracting design information we can understand a piece of code at pattern level, a higher abstraction level than the design and implementation level, but lower than the architecture level.

Therefore, design patterns provide good insight into the structure and behavior of a software system.

1.3 Thesis Objectives

This research is motivated by the need for a high-level abstraction to simplify the complexity of software systems for better comprehension within reverse engineering. Design patterns represent a high-level abstraction. In order to acquire such a high-level abstraction from the source code, we need an approach to effectively identify design patterns from the design information extracted from the source code.

The objectives of this thesis are summarized as follows:

- To examine the entire source code for complete program information.
- To define a model for a formal description of design patterns.
- To propose an approach to effectively identify design patterns according to this model.
- To apply this approach to some case studies and validate it.

- To analyze the results obtained from the case studies.

1.4 Thesis Contributions

This thesis proposes a simple model and tool for the extraction of design patterns from C++ code.

1. The model follows a rule-based approach. This approach exploits two major concepts of logic programming:
 - Flexibility – comes from the underlying principle of logic programming, that is, it is possible to change the rule base without affecting the inference engine acting on the rules.
 - Declarative nature of programming in logic-like languages (e.g. Prolog)- this helps to avoid the specification of a lot of execution control constraints.
2. The model examines both static and dynamic information from the source code. In this case, the tool will only work on a code that is compilable and executable
3. A formal approach is developed for the detection of relationships among software components. The set of algorithms from this approach is used to extract design information.
4. The extraction of design information is separated from design pattern recovery in order to facilitate flexibility. This way, the design pattern recovery is language-independent while the information extraction is language-dependent. The positive thing here is that the tool can be extended to capture other programming languages (e.g. Java) without significantly affecting the design of the design pattern recovery section. In addition a user of the tool could decide to introduce

new rules into the rule base while keeping the fact base intact, this can happen as long as the relationships detection algorithms syntax is respected.

5. The parser that is developed for the static analysis captures the entire source code. In our opinion, this is better than just capturing the header files alone. The header files do not represent the complete information in the code.
6. A prototype tool DPET (Design Pattern Extraction Tool) is implemented by the rule-based approach proposed in this thesis.
7. In addition, the intermediate results (i.e. fact base) could be used to visualize the class diagram representing the static information of the system under review (cf. Appendix D)

1.5 Thesis Organization

The rest of this thesis is structured as follows:

Chapter 2 provides background information about software design patterns. It describes briefly the concepts of pattern, design pattern, object-oriented program and UML.

Chapter 3 states the problem to be solved in this thesis followed by a review of the state of the art of related work in this research direction. Chapter 4 proposes a model to formalize design patterns in Prolog presentation in terms of static and dynamic characteristics of design patterns. It describes a set of detection algorithms based on design information and pattern detection algorithms. Chapter 5 describes a prototype tool *DPET* implemented according to the model proposed in Chapter 4, the architecture of the tool and the process of extraction. Two case studies are provided in Chapter 6 to validate our approach. Chapter 7 summarizes the conclusions and points to the direction future research should be heading.

Chapter 2 Background

This chapter provides background information related to this thesis. The concepts from design patterns to object-oriented programming are presented briefly, in order to make the thesis self-contained.

2.1 Design Patterns

2.1.1 Patterns

From kids to adults we all have learned a lot about how we do things from our parents, teachers and friends, etc. If we want to do many things, we know how to do it according to schemes. For instance, if you want to drive a car, you have to operate it according to some schemes or rules. Otherwise if you don't you may have a bad experience in driving, or even maybe unable to start the car. After several years of driving you may become an expert and the scheme of driving a car have become a mental pattern. This mental pattern has been engraved firmly in your mind, later on you don't have to think of how to drive a car, it becomes reactionary, and you can even teach others to drive. You have learned to do it according to both your own experience and others' experience. Such schemes of how to do things are introduced in the software engineering and are called software patterns.

The simplest definition of a pattern is “a solution to a problem in a context”[Gam95]. The mental pattern in the above example is just a solution to the problem of how to drive a car in the context of safe driving. The term “pattern” adopted in software engineering comes from the work of Christopher Alexander, an architect who was exploring patterns in architecture. Through his work he recorded design principles in

architecture in order to prevent future architects from making mistakes. He categorized architectural design patterns so that other architects could acquire his knowledge. The definition of a pattern given by Alexander is as follows: “Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice [Ale79].”

A pattern can be viewed as a prose format for recording solutions that have worked well in the past and can be applied again in similar situations in the future [Bec96]. The need for the introduction of patterns in software originates from the need of the engineering discipline to mature, and to provide guidelines for describing successful solutions to known problems.

A pattern is a way to provide information on the form of a problem statement, constraints on the problem and presentation of a widely accepted solution to the problem and then a discussion of the consequences of that solution. Patterns are expressed textually in an informal manner, their description of a name, a problem and its associated context, a discussion and a solution. A description of a design pattern includes not only the static structure based on classes and objects involved in the pattern and their relationships, but also the behavioral pattern dynamics based on the exchanged messages. In order to be considered a pattern the solution must be verified as a recurring solution to a recurring problem.

2.1.2 Classification of Software Patterns

In general the software community focuses mainly on design patterns, which are described by [Bec96, Gam95, Pre94]. However, patterns can be found in all aspects of software such as development organization, software process, project planning, requirements engineering, and software configuration. There are many different classifications of software patterns; one possible classification of patterns is as follows [App00]:

- Design patterns: the patterns in software engineering.
- Analysis patterns: the patterns that describe recurring and reusable analysis models.
- Organization patterns: the patterns that describe software process design.
- Other domain-specific patterns.

Reihle and Zullighoven [Rei96] propose a different classification of patterns; the three types of patterns they define are as follows:

- Conceptual patterns, which are described by means of the terms and concepts from an application domain, which are geared towards a restricted application domain.
- Design patterns, which are described by means of software design constructs, e.g., objects, classes, inheritance, aggregation, and reuse relationship. Design patterns complement the conceptual space opened by the conceptual patterns.
- Programming patterns, which are described by means of programming language constructs.

2.1.3 Design Patterns in Design Level

Design patterns can be divided further into three categories of patterns based on the level of abstractions [Bec96]:

- Architectural patterns, Are high-level strategies that are concerned with large-scale components and global properties and mechanism of a system. Architectural patterns have implications affecting the overall structure and organization of a software system.
- Design patterns, Are medium-level strategies that are concerned with the structure and behavior of components, and their relationships. Design patterns do not influence the overall system structure, but instead define micro-architectures of subsystems and components. Design patterns in this classification correspond to design patterns in the classification by [Rei96], and to GOF patterns, i.e., patterns described by [Gam95].
- Idioms, are paradigm-specific and language-specific programming techniques that fill in low-level internal and external details of a component's structure or behavior. Jim O. Coplien describes idioms in C++ [Cop92].

The difference between these three categories of design patterns is their corresponding levels of abstraction and detail.

2.2 Design Patterns in This Thesis

This thesis is based on medium-level software design patterns as mentioned above, that is, the GOF design patterns categorized in [Gam95]. The GOF design patterns

concerned with the structure and behavior of components and their interrelationships. Design patterns have no impact on the whole system structure, but define micro-architectures of subsystems and components. They specifically deal with common problems in OO design [Gam95], which are the problems that are often encountered again and again in OO design. Design patterns provide general solutions to these common problems.

2.2.1 The GOF Patterns and Catalog

The catalog mentioned in [Gam95] consists of 23 design patterns that are called GOF (Gang Of Four) patterns and introduces an informal way to describe them. According to the terminology proposed by [Gam95], the design patterns can be classified into creational, structural and behavioral depending on their purpose and scope. Creational patterns concern object creation, where as structural patterns capture class or object composition. Behavioral patterns deal with the way in which classes and objects distribute responsibility and interact.

2.2.2 General Pattern Description

The GOF patterns are described in a consistent form and in natural language. The general form is as follows:

- **Pattern name:** The short name to refer to the pattern and the problem it solves.
- **Intent:** Brief description of what issue the pattern addresses.
- **Also known as:** Other names for the pattern, if there are any.
- **Motivation:** An example design problem that is solved with the pattern at hand.
- **Applicability:** the context in which the pattern can be applied.

- **Structure:** A graphical scheme of the pattern, usually shown by a UML class diagram.
- **Participants:** Description of the sets of participants in the pattern and their responsibilities.
- **Collaborations:** The way in which the participants interact to solve the problem.
- **Consequences:** The results of applying this pattern, and the trade-offs.
- **Implementation:** how to implement this pattern.
- **Sample Code:** Sample code fragments of implementing the pattern in OO language.
- **Known Uses:** Good examples of real software systems that used the pattern.
- **Related Patterns:** The patterns that are closely related to this pattern.

2.2.3 Usage of the Catalog and the Patterns

Design patterns originally have been used in software development. When we design object-oriented software, we want to make a solid design so as to reuse it for other software later on. When looking for patterns in the catalog for a new design you will have to decide what pattern to apply. First of all you should have a thorough knowledge of the problem you are trying to solve. Then, you should know what kind of patterns in the pattern family could be applied to deal with it. In order to do that, checking the general description of design patterns is the first step towards an application of the patterns. The Intent section indicates what that pattern does. The Motivation and Applicability part of the pattern description indicates what the meaning of the pattern is. When you cannot find the information you want, the Related Patterns section might give some hints for other choices.

2.3 History of Software Patterns

The concept of “pattern” originates from the idea of Christopher Alexander, an architect, who wrote several books about patterns in urban planning and building architecture were published between 1964 and 1979. The most famous being is *The Timeless Way of Building* [Ale79].

In 1987 Ward Cunningham and Kent Beck first used some of Alexander’s ideas to develop a small pattern language for guiding novice Smalltalk programmers. The result of their work was presented in the paper *Using Pattern Language for Object-Oriented Programs* at OOPSLA in 1987.

In the following years, Jim Coplien began to study language-specific C++ patterns so-called idioms. The book *Advanced C++ Programming Styles and Idioms* [Cop92] was published in 1992.

In 1990 members of GOF started work on compiling the catalog of patterns. At the OOPSLA workshop given by Bruce Andersen, in 1991, great progress was achieved since many of the pattern notables took part in the workshop, e.g., Jim Coplien, Doug Lea, Desmond D’Souza, Norm Kenth, Wolfgang Pree, and members of the GOF.

In August of 1993, Kent Beck and Grady Booch sponsored a mountain retreat to Colorado, the first meeting of what is now called the Hillside Group. Another pattern workshop was held at OOPLA in 1993, and in 1994, shortly after the book by GOF, *Design patterns: Elements of Reusable Objects* [Gam95], was published. The book is a milestone in software engineering and has had an enormous impact on software development.

2.4 Object Oriented Programming Concepts

The term “Object Oriented” means that software is organized as a collection of discrete objects that incorporate both data structure and behavior [Rum91]. Object oriented programming originates as a discipline for imperative programming. With imperative programs growing bigger, the conventional programming is getting more unmanageable because there are some unavoidable drawbacks. E.g., a global variable can be accessed and updated anywhere and at anytime in a program.

An object is a software bundle of related variables and operations. Software objects are often used to model real-world objects you find in everyday life. An object model captures the static structure of a system by showing the objects in the system, relationships between objects, and the attributes and operations that characterize each class of objects.

Objects are instances of a particular class and classes are organized in a hierarchy of subclasses and super-classes; an object will inherit the attributes and behaviors of all its super-classes.

2.4.1 Objects and Classes

A class describes the underlying structure of a group of objects. It could be said that a class is a blueprint, and an object is a house. An object belonging to a class is also called an *instance* of that class.

A class specifies the data items of each object and contains the operations or methods that can be performed on each object within that class (in object-oriented languages that lack generic functions). Collaborating objects compose an object-oriented

program, in which each object has a specific behavior and state; this behavior may depend on the state of the object. The class can be compared to a mold for producing specific objects. The things that an object in that class can do are called operations. Operations, like functions, live inside an object. Some operations that can be invoked by other objects are called *public* operations, while other operations that can be used only by the object itself are referred to as *private* operations.

Object-oriented languages create new objects in one of two ways; some languages, like Smalltalk, have classes that are full objects in their own right. In these languages, an operation applied to a class object (called a class method) creates a new object of the class. Other languages, such as C++ and Eiffel, do not have class objects. These languages have special operations that are responsible for creating new objects.

There are some classes without instances and they just capture common behavior for consistency of the class hierarchy and reuse. They are called abstract classes as opposed to concrete classes of which instances can be instantiated.

2.4.2 Message Exchanging

As mentioned above, object-oriented programs consist of objects. There must be some way to communicate among objects; operations are responsible for it. By sending each other messages, objects invoke an operation of another object, which is called `SendMessage` in this thesis, or its own operation, which is called `SelfMessage` in this thesis. The message might be a call for information, or a question like changing the state of objects. In order to do so, an object has to know about other objects to which messages are sent. An object “knows” another object when one is the instance variable of another, or one can create another by sending a construction message (“new” in C++ term) to the

latter's class. Depending on a possible result of a message send, the object to which the message is sent might change its state or send more requests to other objects.

2.4.3 Inheritance

Car and aircraft are both part of a bigger community called MobileVehicle. Both are used as vehicles that can load persons or things and move from one place to another place. However both are different in many specific aspects, e.g., a car moves on roads while an aircraft flies in the sky. The class MobileVehicle can be used as a superclass that captures common behavior among families of both objects; cars and aircrafts can be used as subclasses to capture their own specific behavior. In this way, the classes of Cars and Aircrafts are subclasses of MobileVehicle, and both inherit the behavior of MobileVehicle. In some object-oriented languages, classes can have multiple super-classes from which behavior is inherited. This is called multiple-inheritance.

In order to provide a difference in behavior for the same request, subclasses might define a new operation with the same name instead of using the inherited one. We call this *overriding*.

In case the overriding procedure needs the original operation to do its job, the original operation can be called upon by sending a message to a superclass.

In typed object-oriented language classes there may be overloaded operations. These are operations with the same name, but they differ in the type of their arguments. This concept is called *overloading*.

2.4.4 Polymorphism

Polymorphism means “many forms.” In object-oriented programming it enables one operation to operate differently on different types of objects, providing a useful abstraction that enables users of that operation to treat dissimilar objects in a similar manner.

There may be times when you want to treat different objects in similar ways. For example, a *Car* class might be passed to an operation named *move*, which is responsible for moving the car in a certain direction at a certain speed. An *aircraft* class also has a *move* operation, but both don't move in the same way. For example, an aircraft is propelled through the air by propellers installed on the wings of the aircrafts. On the other hand, cars move in a very different manner from aircraft. Their wheels “push” them by creating directional friction against the road. Internally, the processes are very different in propelling each vehicle.

With object-oriented programming, being able to create abstractions that hide such differences is part of what makes them so powerful. With an abstraction such as the *move* operation, you could make an aircraft move the same way that you could make a car move, without having to worry about the details that are “hidden” beneath the abstraction. The command `move (car1, 100, "east")` would make a truck go 100 Km per hour in an eastbound direction just as `move (aircraft1, 100, "east")` would make an aircraft move in the same direction at the same speed. Consider the example shown in the following code listing.

```

1 class MotorVehicle {
2 //MotorVehicle's general properties and operations
3 }
4
5 class Car based on MotorVehicle {
6 //Car's properties and operations
7 }
8
9 class Aircraft based on MotorVehicle {
10 //Aircraft's properties and operations
11 }
12
13 Operation move (MotorVehicle theVehicle, integer theSpeed,
direction theDirection) {
14 if theVehicle is an aircraft then
15 move it like an aircraft
16 if theVehicle is a car then
17 move it like a car
18 }
19 void main(){
20 aircraft1 = new Aircraft;
21 car1 = new Car;
22 move(aircraft1, 100, "east");
23 move(car1, 100, "east");
24 }

```

This code defines a MotorVehicle class. It then creates two subclasses of MotorVehicle: Car and Aircraft. These two subclasses inherit the properties and operations of the MotorVehicle parent class. A move operation is also declared. This operation must be passed three parameters when it is called: a mobile vehicle object, an

integer specifying the speed, and the direction. The move operation performs different routines to set the speed and direction of the different kinds of MotorVehicles. Finally, the code example creates two objects: aircraft1 (an Aircraft) and car1 (a Car). These are two different classes of objects, though both share an ancestor class of MotorVehicle. The code then uses the same operation to move both types of objects, even though the operation treats the two objects differently. To a user of the move operation, the implementation details are hidden. Moving an aircraft is the same as moving a car. This is called polymorphism.

2.5 UML Models

Unified Modeling Language (UML) [Rat99, BRJ99] is a popular design notation defined by Object Management Group (OMG) for object-oriented-design. The **OMG** specification states:

"The Unified Modeling Language (UML) is a graphical language for visualizing, specifying, constructing, and documenting the artifacts of a software-intensive system. The UML offers a standard way to write a system's blueprints, including conceptual things such as business processes and system functions as well as concrete things such as programming language statements, database schemas, and reusable software components."

The UML is important part of developing object-oriented-software and the software development process. The UML uses mostly graphical notations to express the design of software projects. Using the UML helps project teams communicate, explore potential designs, and validate the architectural design of the software.

Each UML diagram is designed to allow developers and customers to view a software system from different perspectives and in varying degrees of abstraction. As described in [Uml03] the following UML diagrams commonly created in visual modeling tools include:

- **Use Case Diagram** displays the relationship among actors and use cases.
- **Class Diagram** models class structure and contents using design elements such as classes, packages and objects. It also displays relationships such as containment, inheritance, associations and others.
- **Interaction Diagrams**
 - **Sequence Diagram** displays the time sequence of the objects participating in the interaction. This consists of the vertical dimension (time) and horizontal dimension (different objects).
 - **Collaboration Diagram** displays an interaction organized around the objects and their links to one another. Numbers are used to show the sequences of messages.
- **State Diagram** displays the sequences of states that an object of an interaction goes through during its life in response to received stimuli, together with its responses and actions.
- **Activity Diagram** displays a special state diagram where most of the states are action states and most of the transitions are triggered by completion of the actions in the source states. This diagram focuses on flows driven by internal processing.
- **Physical Diagrams**
 - **Component Diagram** displays the high level packaged structure of the code itself. Dependencies among components are shown, including source code

components, binary code components, and executable components. Some components exist at compile time, at link time, at run times, as well as at more than one time.

- **Deployment Diagram** displays the configuration of run-time processing elements and the software components, processes, and objects that live on them. Software component instances represent run-time manifestations of code units.

All static and dynamic Interaction diagrams provided in this thesis are conformed to UML. For detailed description of these notations, please refer to [Boo99, Rat99].

Chapter 3 Related Works and Thesis Problem Statement

This research is motivated by the need for a higher-level abstraction for better understanding of software systems than design level. Design patterns represent an ideal choice because they define the micro-architecture of subsystems and components and can give a clearer overview of software systems. Hence, a pattern-level view of software systems is needed in reverse engineering.

In this chapter, the related works in this area are reviewed, followed by the problem definition, and a discussion on this problem is given in the last section of this chapter.

3.1 The Related Works

To date, there have been many attempts [Nie02, Wuy01, Cag00, Cin00, Kel99, Ton99, Ant98, See98, Ban98, Shu96, Kra96, Bro96, Lan95] made to get high-level abstraction of software systems and detect design patterns.

From the view of applications, they can be divided into the following two approaches:

1. Manual pattern detection

The pattern detection is performed manually, step by step. It can only be applied in a limited range because it is very difficult and even impossible to perform this task manually for large-sized software systems.

2. Automatic pattern detection

The automatic pattern detection includes full automation and semi-automation. The source code information and the pattern definitions are

always represented in a certain format (form), and certain query mechanisms are implemented to search for design patterns.

- Data format-based representation for pattern detection

The source code information and pattern definitions are stored in data format-based representation so that the design patterns can be detected by querying this data format base in a certain way.

- Graph-based representation for pattern detection

The source code information and pattern definitions are represented in the form of graph so as to detect design patterns by using graph query mechanisms.

- Metrics-based representation for pattern detection

The software metrics and other constraints like the structural characteristics of patterns are used to represent the source code and pattern definitions. Design patterns can be detected based on these.

- Logic-based representation for pattern detection

The source code information is represented as logic facts and the pattern definitions as logic rules. Design patterns can be detected by querying this logic base.

These approaches are reviewed as follows:

3.1.1 Manual Pattern Detection

Shull et al. [Shu96] have developed an inductive method to help discover custom domain-specific design patterns in existing OO software systems, which is called BACKDOOR (Backwards Architecting Concerned with Knowledge Discovery of OO

Relationships). Creating a pattern knowledge base for a development organization as shown in Figure 3-1 motivates their research.

Figure 3-1 The cycle between DO and PKB

This goal can be achieved by multiple iterations through a feedback cycle between the Domain Organization (DO) and Pattern Knowledge Base (PKB).

Their research aim is to discover design patterns, which is called reverse architecting design patterns, not to recover existing design patterns as we do in this thesis.

BACKDOOR consists of six steps, which are really iterated within and across steps. It starts by reviewing the problem specification and design documents, then develop and refine the model of the system, finally, identify potential candidates for patterns based on inheritance and communication links between classes.

Shull et al. work gives some hints about how to extract design patterns from the source code, but the whole process is performed manually. It will become a very tough task when a big-sized software system is analyzed.

3.1.2 Automatic Pattern Detection

The automatic pattern detection discussed in this section encompasses full automation and semi-automation.

3.1.2.1 Data format-based presentation for pattern detection

[Kel99, Sch99] Keller and Schauer et al. present an environment called SPOOL for the reverse engineering of design components based on the structural descriptions of design patterns. This process of pattern detection encompasses the following parts: source code capturing, design repository, pattern-based design recovery and design representation. Source code is parsed by a C++ parser then the source code elements are represented by an ASCII-based representation UML/CDIF as an intermediate representation. The source code model and the abstract design components that are recovered are stored in a design repository, a data format base. The abstract design components are actually the structural descriptions of design patterns. A query mechanism that can recognize the structural descriptions in the source code models are implemented to extract design patterns from this database. The detected patterns are visualized through design representation to provide an intuitive impression for human analysis and better understanding the software system.

In their approach the representations of design patterns are only based on the structural characteristics of design patterns. Both the structural and behavioral characteristics are considered in our approach. Their approach doesn't propose a generic pattern detection algorithm like ours does. They do not report on how to deal with relationships among classes, which has a great impact on identifying design patterns.

3.1.2.2 Graph-based presentation for pattern detection

Niere et al. [Nie02] propose an approach to solving the implementation variants problem by defining sub-patterns using a formal description ASG (Abstract Syntax Graph) to describe design patterns.

The parsed program information is obtained from JavaCC parser and converted into ASG objects as an intermediate representation. The design patterns and sub-patterns are defined as rules. These rules are used to search for pattern instances from ASG objects that are obtained from source code by switching between bottom-up and top-down search strategy.

In their approach to deal with implementation variants they defined many subpatterns to reflect the relationships among classes such as association, aggregation and so on. In order to overcome the problem of many definitions of slightly different variants of subpatterns a general rule has been used to replace several slightly different subpattern rules. This consists of the common parts of those replaced rules, but it leads to more false positives. Therefore, a balance between the number of general rules and the number of detected false positives has to be determined by the reverse engineer. In our approach, the parser has been developed to directly deal with implementation variants of sub-patterns (i.e., relationships among classes).

3.1.2.3 Metrics-based representation for pattern detection

Antoniol et al [Ant98] describe a multi-stage filtering process to detect design patterns, in which multiple metrics of patterns and design patterns are described through their structural characteristics, e.g. the number of classes, the number of inheritances, and the number of references, etc. At each stage different metrics and other constraints like

delegation (a kind of class relationship) are used to reduce the search space. The reason for using metrics in pattern definitions is to reflect the quality of source code in software metrics. For the recovery of design patterns, this may lead to many false positives due to the quantitative definition of design patterns. In the Chapter 6 case study, in this thesis, a comparison table of extraction results between their approach and ours is provided to show that our approach does reduce the false positives for the same pieces of sample code.

3. 1. 2. 4 Logic-based pattern detection

Kramer et al. [Kra96] propose an approach based on Prolog queries. The Prolog descriptions of several patterns are provided, and the parser *Paradigm Plus* is used to parse C++ header files. However, the front-end parser could not parse C++ definition file and has not defined a complete Prolog representation to describe design patterns. Therefore, some key characteristics of design patterns get lost, and it leads to a lot of false positives, e.g. *delegation*, a kind of class relationship and a special form of association. In [Kra96] *delegation* relationships are replaced by association relationships, so more false positives have been raised.

K. Mens and R. Wuyts et al. [Me01, Men01, Wuy98, Wuy01] adopt a declarative meta-programming approach to explicitly codify programming patterns in software development process. They reify the structure of object-oriented programs in terms of logic clauses, and declare programming patterns as logic rules on top of these clauses. By querying the logic system, these rules allow for checking, enforcing and searching for occurrences of patterns in the software. The approach uses Prolog query to identify

design patterns in terms of a description of design patterns based on the structure of an OO program.

In their approach, the basic program information is directly represented as logic facts. This may make the logical programs become too big for large-sized software systems. Consequently, the rules become quickly impossible to manage. In our case, we separate relationship detection algorithms from pattern detection. Doing so can reduce the search space from both the fact base and the rule base. In addition, dynamic characteristics of design patterns are not discussed in their papers though it is important in identifying some behavioral design patterns.

In [Ric99] Richner et al. propose a logic-based approach to get high-level view of software systems, by creating high-level abstractions to produce views based on the combination of user-defined queries. Static and dynamic characteristics of software systems are represented as logic facts. By making different queries on the facts, the user can decide what kind of views will be produced. In [Ric99], the approach is similar to ours since both static and dynamic information of Object-Oriented software systems have been taken into account and both are based on the logic programming language *Prolog*. Their goal is to achieve a high-level view of software systems at the design level, but we focus on getting higher-level abstraction at the pattern level. They did not consider getting pattern level abstraction like ours and did not construct a model for the formal descriptions of design patterns.

Eden, Gil and Yehudai et al. [Ede97, Ede98, Ede99] have developed and used a declarative pattern specification language of design patterns-LePUS to formalize the design patterns. This formal specification of design patterns can be used as a tool in

support of the implementation and recognition of design patterns. It is helpful extracting design information using design patterns, but some rules in the formal specification are not suitable for identifying design patterns from source code. For instance, the *Observer* patterns mentioned in [Ede99] is formalized using class hierarchy and invocation of methods. However, the behavior of the sets of classes in *Observer* is hard to be captured merely depending on the static information directly obtained from source code. From our point of view, some behavioral design patterns like *Observer* can be effectively identified based on dynamic information of software systems.

3.2 Problem Definition in This Thesis

In order to get a pattern-level view of software systems detecting design patterns in software systems is a must. This is exactly the problem we focus on in this thesis.

The related works mentioned above are also concerned with it to a certain extent. However, there are some points that needed to be improved upon in their different approaches.

- Shuell et al [Shu96] propose to discover design patterns in software systems manually. But manual pattern detection has turned out to be impossible for large-sized software systems.
- Keller and Schauer et al.[Kel99,Sch99] extract design components based on the structural descriptions of design patterns. However, some design patterns can be effectively identified by looking at the behavioral characteristics of design patterns.

- In the approach proposed by Antoniol et al [Ant98], the metrics used can lead to many false positives due to the quantitative definition of design patterns.
- The front-end parser used by Kramer et al. [Kra96] could not parse C++ definition file, and has not defined a complete Prolog representation to describe design patterns.
- In the approach proposed by K. Mens and R. Wuyts et al. [Me01, Men01, Wuy98, Wuy01], the program information is directly represented as logic facts. This may make the logical programs too big to manage for large-sized software systems.
- Richner et al. [Ric99] focus on getting high-level view of software systems at design level, not at pattern level.
- In the formal specification of design patterns proposed by Eden, Gil and Yehudai et al. [Ede97, Ede98, Ede99], some rules are not suitable for identifying behavioral design patterns, like *Observer* from source code.

To avoid these drawbacks a rule-based approach is proposed to detect design patterns in this thesis. The model of formal descriptions of design patterns is presented and is based on both static and dynamic characteristics of design patterns. In addition, the parser developed in this thesis can analyze the entire C++ code and not the header file alone. This approach is described in details in Chapter 4 and Chapter 5 presents the prototype. Two major case studies are reported in Chapter 6.

3.3 Summary

Design patterns can be taken as micro-architectures for solving particular design problems because design patterns reflect the structure and behavior of a set of classes in a software system. Especially when the design documentation is poorly recorded, reverse engineering software systems can detect design patterns to achieve a high-level view of software systems because design patterns reflect interrelationships among a set of classes. Of course, not all software systems contain design patterns in their source code, e.g. some legacy code developed before emergence of the concept of design patterns. However, because design patterns record experts' experience and enable novices to create supreme design, they have been widely used in software development process for reuse. The detection of design patterns in software systems would be very helpful for software maintenance.

Chapter 4 An Approach to Design Pattern Detection

4.1 Introduction

As mentioned in Chapter 3, the problem to be solved in this thesis is how to detect design patterns in software systems. There are three factors that have a huge impact on this issue:

- The front-end parser for extracting program information
- The detection algorithms for recovering design information
- The pattern detection algorithms for identifying design patterns.

The precision of program information provided by the front-end parser directly influences the result of extraction. A parser that can scan both header files and definition files in C++ code is what is needed since it can provide complete program information about source code.

Design information, such as classes and their interrelationships, is the foundation of identifying design patterns. Because UML relationships are defined from the perspective of design, some relationships may map too many implementation forms in the source code. Sometimes this may cause many false pattern instances, and even ruin the process of pattern detection. So a refinement of these relationships is needed and is actually equivalent to finding effective detection algorithms for recovering design information.

Pattern detection plays an essential role in identifying design patterns. Pattern detection algorithm should be effective for all kinds of GOF design patterns.

According to the factors above the following work has been conducted,

- A C++ parser has been developed. It is able to examine the entire source code, i.e., header and definition files.
- A set of detection algorithms based on the relationships among the different components of the software system has been developed.
- A model for formal description of design patterns has been proposed. Design patterns based on static and dynamic information are modeled in a logic language.
- A rule-based approach for pattern detection is adopted.

The logic language has the following advantages:

- The absence of control structures in logic language results in a simple, easy to learn and easy to use language.
- Using a logic programming language to express queries has advantages in that, although the queries are very powerful the language is easy to understand and use.
- The logic language is open in such a way that everyone can easily add information to the unification process, which makes the DPET tool more flexible (The DPET tool is described in Chapter 5). This is exactly suitable for development of design patterns because more patterns would be discovered continuously. It would be easy to add new rules to the rule base for identifying design patterns.

The major disadvantage of logic programming languages is the slow execution time. This depends on the complexity of the query that needs to be solved. When a large software system that often includes several hundred classes is analyzed, if the relationships among them are complex the execution time will be long. In order to avoid this, we separate design information detection from design pattern recovery in the

implementation. The algorithms for detecting the relationships among classes are implemented in C++, rather than logic language *Prolog*.

In this approach design patterns are modeled based on static and dynamic information in logic language.

Static information about design patterns can be obtained more easily than dynamic information. Sometimes, however, dynamic information about design patterns is the key to identifying behavioral design patterns. For instance, the *Observer* design pattern is hard to identify merely in terms of a structural-based model (i.e. static information), which leads to so many false positives that it may ruin the detection. What we can know about dynamic information from the structure-based model is which object invokes another object between two operations. It is hard and even impossible to obtain the information about the sequence of messages exchanged among multiple objects merely by analyzing the source code statically, because of some of the features of OO programming like polymorphism.

4.2 Formal Description of Components and Relationships

In our model the design information extracted from a software system consists of components and the relationships among them.

Components are of two kinds, static components and dynamic components. Static components consist of classes and operations while dynamic components are composed of objects, that is, the instances of classes during run time.

Relationships consist of static relationships and dynamic relationships. Static relationships include Inheritance, Aggregation, Using, Association, and Delegation.

Dynamic relationships include CreationLink, SendMessage, and SelfMessage.

DIS: Design Information in Software; C: Components; SC: Static Components; DC: Dynamic Components; R: Relationships; SR: Static Relationships; DR: Dynamic Relationships;
$DIS \supset \{C, R\};$ $C \supset \{SC, DC\};$ $SC \supset \{\text{Classes (abstract class, concrete class), Operations (abstract and concrete operations)}\},$ $DC \supset \{\text{Objects (instances of classes)}\};$ $R \supset \{SR, DR\};$ $SR \supset \{\text{Inheritance, Aggregation, Using, Association, Delegation}\};$ $DR \supset \{\text{CreationLink, SelfMessage, SendMessage}\};$

Table 4.1 The Composition of the model for formal description of design patterns

As for a design pattern its static characteristics focus on a set of static components including classes, operations, and static relationships; while its dynamic characteristics (behavior) focus on a set of dynamic components including objects and dynamic relationships, i.e., messages exchange between them.

The definition of relationships and their detection algorithms are as follows.

4.2.1 Relationships

4.2.1.1 Static Relationships

The definitions of static relationships in this section are based on the definitions in [Boo94].

- **Inheritance:**

Inheritance is the mechanism that allows a class to inherit properties of another class. If class A inherits from class B, then B is called superclass of A. A is called

subclass of B. Objects of a subclass can be used where objects of the corresponding superclass are expected. This is due to the fact that objects of the subclass share the same behavior as objects of the superclass. Objects of the inheriting class have access to attributes and operations of the inherited class without the need to redefine them.

Multiple inheritances mean that one subclass can have *more than one* superclass. This enables the subclass to inherit properties of more than one superclass and to "merge" their properties.

- **Implementation:** Finding inheritance by examining the declarations or definitions of classes according to the detection algorithm in Table 4.2

Table 4.2 Detection algorithm of <i>Inheritance</i> in C++ pseudo code.	
These relationships are identified according to declaration of the following forms, these declarations are usually found in the header files:	
class Class_A: Class_B	
class Class_A: public Class_B	
class Class_A: protected Class_B	
class Class_A: private Class_B	
class Class_A: virtual Class_B	/*Virtual inheritance*/
If (Class_B: public/protect/private Class_A{...})	/*Single inheritance*/
Class_B inherits from Class_A.	
Multiple inheritance:	
If (Class_C: public/protect/private Class_A, Class_B{...})	/*Multiple inheritance*/
Class_C inherits from Class_A and Class_B.	
Note that multiple inheritance and virtual inheritance are also taken into account in the tool DPET.	

- **Aggregation:**

Aggregation asserts a direction to the whole/part relationship. It can be divided into two kinds of containment [Boo94]. One is *containment by value*, a kind of physical containment meaning where the object does not exist independently of its enclosing instance. Another less direct kind of aggregation is also possible, called containment by reference. For example, Class_A has a data member b that is a pointer to Class_B with the following declaration:

```
class Class_A{
    Class_B * b;
    //....
};
```

In this case the enclosing class still denotes the whole and an instance of the enclosed class is still one of its parts, although that part must now be accessed indirectly. Hence, the lifetime of each of these two objects are not so tightly coupled as before: we may create and destroy instances of each class independently.

- **Implementation:** Typically the aggregation relationship is detected by looking for data-member declarations in classes that are of other user-defined class types as shown in Table 4.3.

Table 4.3 Detection algorithm of <i>Aggregation</i> in C++ pseudo code.
<ul style="list-style-type: none"> • Class_A has Class_B by value. <pre>class Class_A{ Class_B b; // an instance of Class_B is part of Class_A Class_C c[m]; //an array of instances of Class_C is part of Class_A //... };</pre>

- Class_A has Class_B by reference

```
class Class_A{
    Class_B b*; // a dynamic instance of Class_B is part of Class_A
    Static Class_C *c[m]; //a dynamic array of instances of Class_C is part of Class_A
    //...
```

```
Class_A (); //constructor for Class_A
```

```
Class_A::Class_A {
```

```
Class_B b = new Class_B; // dynamically creating b;
```

```
Class_C c[] = new Class_C; //dynamically creating c[];
```

- Template A has Class_B

```
template <Class_B> A; // template instantiation
```

```
If ( A has B by value || A has B by reference || A has B in template )
```

```
A aggregates B.
```

- **Composition:**

We did not take composition relationships, separately, into account when we carried out the recovery of design pattern. Composition is a specific kind of aggregation and the difference between aggregation and composition is only focused on meaning of code. It is hard and even impossible to discern their difference from the syntax of the code without human involvement when using an automated tool.

- **Using Relationships**

“Using” relationships among classes parallel the peer-to-peer links among the corresponding instances of these classes. Whereas an association denotes a bi-directional semantic connection, a “using” relationship is a possible refinement of an association, whereby we assert which abstraction is the client and which is the supplier of certain services [Boo94].

In general, a using relationship is a unidirectional association with the “using” refining the association. Strict “using” relationships are occasionally too confining because they only allow the client the public interface of the supplier. Sometimes, for tactical reasons, we must break the encapsulation of these abstractions, which is the very purpose of the friend concept in C++.

- **Implementation:** This relationship is generally implemented through method parameters and therefore detected by examining method parameter types as shown in Table 4.4.

Table 4.4 Detection algorithm of <i>Using</i> relationship in C++ pseudo code
<p>- Friend member function using relationship</p> <pre> Class Class_A { //... friend return_type Class_B::Op(...); /*An operation Op of Class_B has friend relationship with Class_A*/ //... }; </pre> <p>-Friend class Using</p> <p>they are identified according to declarations of the following forms:</p> <pre> class Class_A { friend class Class_B; /*Class_B has relationship with Class_A*/ //... }; </pre> <p>- Formal parameter to method</p> <pre> Class_A:: Op(Class_B b, ...) { /*An instance of Class_B is the argument of an operation Op of Class_A*/ //... } or Class_A::Op(Class_B &b, ...) { /*A reference of Class_B is the argument of </pre>

```

                                an operation Op of Class_A*/
//...
} or
Class_A::Op(Class_B *b, ...) { /*A pointer of Class_B is the argument of
                                an operation Op of Class_A*/
//...
}
If the above cases happen, A uses B.

```

- **Association:**

An association is often replaced by cyclic aggregation or cyclic “using” relationships [Boo94]. More often than not, however, an association (which by definition implies bidirectional navigation) is refined during design to be a single aggregation or “using” relationship, thus denoting a constraint upon the direction of the association.

Multiplicity: One-to-one; One-to-many, Many-to-many;

- **Implementation:** Cyclic aggregation or cyclic using relationships as shown in Table 4.5.

Table 4.5 Detection algorithm of <i>Association</i> in pseudo code.
<pre> If (A uses B && B uses A) (A aggregates B && B aggregates A) A associates with B. </pre>

- **Delegation:**

A specific application of an object composition is a delegation, an object that is receiving messages, a delegator, delegates these requests (received messages) to a

delegatee object. Often combined with inheritance, delegation is heavily used in design patterns.

Delegation is a way of making composition as powerful for reuse as inheritance. In delegation two objects are involved in handling a request; a receiving object delegates operations to its delegatee. This is analogous to subclasses deferring requests to parent classes.

Figure 4-1 UML class diagram of *Delegation* relationship

- **Implementation:** From the above figure 4-1, we can see that there are two classes. One class “Handle” contains a pointer of class “Body” as its attribute. The member function `op()` of class “Handle” is implemented by the member function `op()` in class “Body”. This is a kind of object composition by a pointer and actually a Handle/Body idiom in C++, which has been widely used in C++ coding. The handle represents an abstraction and it is visible to the client, while the invisible body provides the implementation. The handle-body technique results in another design pattern, called the “Bridge design pattern”. Many design patterns have this kind of interclass relationship such as “Adapter”, “Proxy”, “Composite” and so on.

Table 4.6 Detecting *Delegation* algorithm in C++ pseudo code.

- Delegation by pointer

```
Class_A{
    Class_B *b;      /*A pointer of Class_B is data member of Class_A*/
    //...
}
Class_A::Op(){
    b->Op();          /* an operation Op of Class_A calls an operation Op of Class_B*/
    //...
}
```

There is a delegation relationship between A and B.

- Delegation pass by reference(it is used by Visitor design pattern)

```
Class_A::Op(Class_B &b,...){ /*A reference of Class_B is the argument of
                                an operation Op of Class_A.*/
    b.Op();                  /*The operation Op of Class_A calls
                                an operation Op of Class_B*/
    //...
}
```

If the above cases happen, A and B has a delegation relationship.

4.2.1.2 Dynamic relationships:

- **CreationLink:**

During run time, one object may create other objects, e.g., the instance of Class *Factory* in *Abstract Factory* design pattern is responsible for creating all the instances of other classes.

- **Implementation:** The instance of Class A creates an instance(s) of class B.

Though we cannot know when the instance of a class is created from source code, we can get CreationLink relationships merely from source code as shown in Table 4.7.

Table 4.7 Detecting *CreationLink* algorithm in C++ pseudo code

```

If ( A ← B::Op() &&
    B::Op() {
    A (derived) Ptr = new A(derived); return Ptr;
    or return new A(derived);.....} )
CreationLink(B,A(derived));

A ← B::Op() : the return type of B:Op() is A.

```

- ***SendMessage:***

This relationship can be only acquired by dynamic analysis because the sequence number of sending messages can be known only when executing the program. Through static analysis the function calls between two functions (methods) may be obtained, but no object information is available for use. In comparison with sequence diagrams, a call graph is easier to construct by profiling the source code. Call graphs, however, only provides us with the information on function calls between two objects, but we cannot be aware of the sequence of messages exchanged among objects. Therefore, an appropriate dynamic analysis tool may be required to offer a variety of sequence diagrams.

Table 4.8 Detecting *SendMessage* algorithm in pseudo code

```

If ( ObjectA sends a message to ObjectB and
    the sequence number of the message is known )
ObjectA sends a Message to ObjectB in Sequence Number.

```

- *SelfMessage*

This is a case where one object sends a message to itself instead of other objects.

Table 4.9 Detecting <i>SelfMessage</i> algorithm in C++ pseudo code

If(Class_A::Op() { Class_A::anotherOp(); })

The Object sends a message to itself, that is, one operation in Class_A invoke another operation in the same class.

4.3 Prolog Representation of the Formal Description

In this section, we present a Prolog representation of the formal description given in section 4.2.

4.3.1 Components

A program is defined as a collection of components and the relationships among them. Components consist of static components, dynamic components and relationships that consist of static relationships and dynamic relationships.

4.3.1.1 Static Components:

- *Class*

class(ClassType, ClassName)

If a software component is class, and class ClassName is of type ClassType.

Note: ClassType includes concrete classes and abstract classes
--

- **Operation**

operation(Category,Kind,Class,Name,VisibilityScope,Params,ReturnType)

There is an operation with various properties in Class.

Category: virtual, pure virtual, concrete;
--

Kind: selector or modifier;

Class: class name enclosing the operation;
--

Name: operation name;

Visibility Scope: public, protect, and private;

Params: parameters of the operation;

ReturnType: The return type of the operation.

4.3.1.2 Dynamic Components:

- **Object**

object(ClassType, InstanceName)

A component of InstanceName is an object and it is the instance of a ClassType class.

4.3.2 Relationships

Relations consist of static relationships and dynamic relationships (behavior).

4.3.2.1 Static relationships

Static relationships include inheritance class hierarchy, aggregation, using, association, and delegation.

- **Inheritance**

inheritance(SuperClass, SubClass)

SubClass inherits from SuperClass in class hierarchy.

- **Aggregation**

aggregation(Aggregator, Aggregatee, Multiplicity).
--

Aggregator aggregates Aggregatee with Cardinality. Multiplicity: one-to-one, one-to-many, many-to-many

- **Using**

using(ClassNameA, ClassNameB)

ClassA uses ClassB.

- **Association**

association(ClassNameA, ClassNameB)

ClassA associates with ClassB.

- **Delegation**

Delegation(ClassNameA, ClassNameB)

ClassA delegates ClassB;

4.3.2.2 Dynamic Relationships:

- **CreationLink**

creationlink(ClassNameA, ClassNameB)

The instance of class A is created by an operation of class B

- ***SendMessage***

sendmessage (ObjectA, ObjectB, MessageA, SequenceNumber)
Message A is sent from ObjectA to ObjectB in the order of sequence number. Note that the sequence number is the sequence of message exchange.

- ***SelfMessage***

selfmessage (Object, Message, SequenceNumber)
Object sends a Message to itself. Note that the sequence number is the sequence of message exchange.

4.4 Formal Description of Design Patterns

This section describes the model of a formal description of design patterns in Prolog. The following typical patterns from GOF design patterns are selected as examples,

- Creational design patterns: Factory Method.
- Structural design patterns: Adapter, Composite, Decorator, Proxy, and Bridge.
- Behavioral design patterns: Strategy, Observer, Chain of Responsibility, and Visitor.

All the models consist of components and relationships defined in our model in section 4.2. Different kinds of design patterns may have different compositions of the model. For example, Structural design patterns contain strong structural characteristics, so the models for identifying them are just based on static information. But it is not the case to some creational design patterns. Some creational design patterns, like the Factory Method, cannot be identified merely based on static information. Instead, dynamic information like `CreationLink`, along with static information can be used to detect Factory Method design patterns from C++ code. For behavioral design patterns, some, such as Chain of Responsibility and Observer are easier to identify if their models are based on dynamic information because they are of strong behavioral characteristics. Meanwhile, in order to address the key role of dynamic information in identifying behavioral design patterns theObserver pattern's structure-base model based on static information is introduced for comparison with the behavioral-based model based on dynamic information. The impact of both cases is discussed later in this section.

4.4.1 The Models of Creational Design Patterns

4.4.1.1 Factory Method

The Factory Method defines an interface for creating an object, but allows subclasses to decide which class to instantiate. Actually, Factory Method lets a class defer instantiation of subclasses. Factory Method design pattern is based on both static and dynamic information. Factory Method can be applied to defer the instantiation of classes, that is, the task of creating objects to be forwarded to the subclass whose superclass includes the operations responsible for creating objects. Sometimes the superclass provides a default operation for instantiation of classes, rather than do nothing.

Figure 4-2 is a UML class diagram of Factory Method design pattern. Its structure is composed of two class hierarchies. Using the sign “new “ in C++ code, the CreationLink relationship defined in section 4.2.2.2.1 can be found to show a link between Product class and Creator class, and another link between ConcreteProduct class and ConcreteCreator class. This way, Factory Method design patterns can be extracted from source code effectively. The detailed extraction process will be described in Chapter 5.

Figure 4-2 UML class diagram of *Factory Method* design patterns

4.4.1.1.1 The mapping between the model of Factory Method and its *Prolog* representation

The mapping between the model of Factory Method and its *Prolog* representation is as follows,

Elements in the model	Prolog representation
Static Components	
Classes	fm_classes
Operations	fm_ops
Static Relationships	fm_stcrelations
Inheritance	inheritance
Dynamic Relationships	fm_dynrelations
CreationLink	creationlink

Using Figure 4-2 and the table above, the model of Factory Method in Prolog is as follows:

Prolog Representation
SC: Static Components; SR: Static Relationships;
DC: Dynamic Components; DR: Dynamic Relationships; /*...*/: Comments
<pre> factormethod(Product, ConcrProduct, Creator, ConcrCreator):- fm_classes(Product,ConcrProduct,Creator,ConcrCreator), /*SC: classes*/ fm_ops(Creator,ConcrCreator, FactoryMethod), /*SC: Operations*/ fm_stcrelations(Creator,ConcrCreator,Product,ConcrProduct), /*SR*/ fm_dynrelations(Product,ConcrProduct,Creator,ConcrCreator). /*DR*/ fm_classes(Product,ConcrProduct,Creator,ConcrCreator):- /*SC: Classes*/ class(abstrclass,Product), /*Product is an abstract class*/ class(concrclass, ConcrProduct),/*ConcrProduct is an concrete class*/ class(_,Creator), /*Creator is a class*/ class(concrclass,ConcrCreator). /*ConcrCreator is a Concrete class*/ </pre>


```

fm_ops(Creator,ConcrCreator, FactoryMethod):-      /*SC: Operations*/
operation(virtual,_,_,Creator, FactoryMethod,_,_),/*FactoryMethod is a
                                                    virtual operation in Creator class.*/
operation(_,_,_,ConcrCreator,FactoryMethod,_,_). /*Override FactoryMethod of
                                                    Creator class in ConcrCreator class*/

fm_stcrelations(Creator,ConcrCreator,Product,ConcrProduct):- /*SR*/
inheritance(Creator, ConcrCreator),               /*Inheritance*/
inheritance(Product, ConcrProduct).                /*Inheritance*/

fm_dynrelations(Product,ConcrProduct,Creator,ConcrCreator):- /*DR*/
creationlink(Creator, Product),                    /*CreationLink*/
creationlink(ConcrCreator, ConcrProduct).          /*CreationLink*/

```

4.4.2 The Models of Structural Design Patterns

4.4.2.1 Adapter design pattern:

Figure 4-3 UML class diagram of *Adapter* design patterns

The Adapter pattern converts the interface of a class into another interface so as to make those classes work together which originally cannot be compatible. When an existing class is expected to use, but its interface cannot match the interface in need, the Adapter pattern can be applied to solve this problem. As shown in Figure 4-3, Class Adapter in the pattern inherits Class Target while it delegates the operation *request()* from Class Adaptee. These two relationships in the structure of the pattern is the key to identifying the Adapter design pattern and they are reflected well in the Adapter model as shown below.

4.4.2.1.1 The mapping between the model of Adapter and its *Prolog* representation

The mapping between the model of Adapter and its *Prolog* representation is as follows,

Elements in the model	Prolog representation
Static Components	
Classes	adapter_classes
Operations	adapter_ops
Static Relationships	adapter_stcrelations
Inheritance	inheritance
Delegation	delegation

Using Figure 4-3 and the table above, the model of the *Adapter* pattern in *Prolog* is as follows:

Note: in this table,	
SC: Static Components;	SR: Static Relationships;
DC: Dynamic Components;	DR: Dynamic Relationships; /*...*/: Comments
Prolog Representation	

```

adapter(Target, Adapter, Adaptee) :-
    adapter_classes(Target, Adapter, Adaptee), /*SC: Classes*/
    adapter_ops(Adapter, Adaptee, Target, Request, SpecRequest), /*SC: Operations*/
    adapter_stcrelations(Target, Adapter, Adaptee). /*SR*/

Adapter_classes:- /*SC: Classes*/
    class(_, Target), /*Target is a class*/
    class(_, Adapter), /*Adapter is a class*/
    class(_, Adaptee). /*Adaptee is a class*/

Adapter_ops(Adapter, Adaptee, Target, Request, SpecRequest):- /*SC:Operation*/
    operation(_, _, Adaptee, SpecRequest, _, _, _),
    operation(_, _, Target, Request, _, _, _),
    operation(_, _, Adapter, Request, _, _, _).

Adapter_stcrelations(Target, Adapter, Adaptee):- /*SR*/
    inheritance(Target, Adapter), /*Inheritance*/
    delegation(Adapter, Adaptee). /*Delegation*/

```

4.4.2.2 Composite design pattern:

Figure 4-4 UML class diagram of *Composite* design patterns

Composite patterns can be used for clients to treat individual objects (components) and their composite (collection) identically so that clients ignore the difference between compositions of objects and individual objects. From Figure 4-4, we can see that there is a loop between Component and Composite. On one hand, Composite inherits from Component; on the other hand Composite aggregates Component. That is, between parent and child classes, Composite pattern requires a part-whole relationship, and this aggregation relationship has a cardinality of one to many. There is a loop existing between a child class and a parent class and this is the key to detecting Composite patterns. When this key is found in class hierarchies it indicates a high possibility of the presence of a Composite pattern. This key has been already included in the model as logic rules,

```
inheritance(Compos,Cpnt)
```

```
aggregation(Compos,Cpnt,one-to-many)
```

4.4.2.2.1 The mapping between the model of Composite and its *Prolog* representation

The mapping between the model of Composite and its *Prolog* representation is as follows,

Elements in the model	Prolog representation
Static Components	
Classes	comp_classes
Operations	comp_ops
Static Relationships	comp_strelations
Inheritance	inheritance
Aggregation	aggregation
Delegation	delegation

The model of the Composite Design pattern in Prolog is as follows:

Note: in this table,

SC: Static Components; SR: Static Relationships;

DC: Dynamic Components; DR: Dynamic Relationships; Comments: /*Comments*/

Prolog Representation

Composite(Cpnt, Leaf, Compos):-

Comp_classes(Cpnt, Compos, Leaf), /*SC: Classes*/

comp_ops(Cpnt, Leaf, Compos), /*SC: Operations*/

comp_stcrelations(Cpnt, Compos, Leaf). /*SR*/

Comp_classes(Cpnt, Compos, Leaf):- /*SC: Classes*/

class(_, Cpnt), /*Cpnt is a class*/

class(concrclass, Leaf), /*Leaf is a concrete class*/

class(concrclass, Compos). /*Compos is a concrete class*/

comp_ops(Cpnt, Leaf, Compos):- /*SC: Operations*/

operation(_, _, Cpnt, Op, _, _, _). /*Op is an operation of Cpnt class*/

operation(_, _, Leaf, Op, _, _, _). /*Op is an operation of Leaf class*/

operation(_, _, Compos, Op, _, _, _). /*Op is an operation of Compos class*/

operation(_, _, Cpnt, Add, _, _, _). /*Add is an operation of Cpnt class*/

operation(_, _, Cpnt, Remove, _, _, _). /*Remove is an operation of Cpnt class*/

operation(_, _, Cpnt, GetCh, _, _, _). /*GetCh is an operation of Cpnt class*/

operation(_, _, Compos, Add, _, _, _). /*Add is an operation of Compos class*/

operation(_, _, Compos, Remove, _, _, _). /*Remove is an operation of Compos

class*/

operation(_, _, Compos, GetCh, _, _, _). /*GetCh is an operation of Compos*/

```

comp_stcrelations(Cpnt,Compos,Leaf):-
inheritance(Leaf,Cpnt), /*Inheritance*/
inheritance(Leaf,Compos), /*Inheritance*/
inheritance(Compos,Cpnt), /*Inheritance*/
aggregation(Compos,Cpnt,one-to-many), /*Aggregation*/
delegation(Cpnt,Compos). /*Delegation*/

```

4.4.2.3 Decorator Design Pattern:

Figure 4-5 UML class Diagram of *Decorator* design patterns

The Decorator pattern is used to dynamically attach additional responsibilities to an object. Decorators provide a flexible alternative to subclassing for extending functionality. As shown in Figure 4-5 the basic structure is similar to that of the Composite pattern, but the difference between the Decorator pattern and the Composite pattern is seen in the aggregation relationship between the child class and the parent

class. In the Composite pattern the cardinality in the aggregation between Component class and Composite class is one to many, but the aggregation between Component class and Decorator class in the Decorator pattern is one to one. This difference in their structure can be used to identify the Decorator patterns in a code.

4.4.2.3.1 The mapping between the model of Decorator and its *Prolog* representation

The mapping between the model of Decorator and its *Prolog* representation is as follows,

Elements in the model	Prolog representation
Static Components	
Classes	dec_classes
Operations	dec_ops
Static Relationships	dec_stcrelations
Inheritance	inheritance
Aggregation	aggregation
Delegation	delegation

Using Figure 4-5 and the table above, the model of the Decorator Design Pattern in Prolog is as follows:

Note: in this table, SC: Static Components; SR: Static Relationships; DC: Dynamic Components; DR: Dynamic Relationships; /*...*/: Comments
Prolog Representation
<pre>decorator(Cpnt,ConcrCpnt,Deco,ConcrDecoA,ConcrDecoB):- dec_classes(Cpnt,ConcrCpnt,Deco,ConcrDecoA,ConcrDecoB), /*SC: Classes*/ dec_ops(Cpnt,ConcrCpnt,Deco,ConcrDecoA,ConcrDecoB), /*SC: Operations*/ dec_stcrelations(Cpnt,ConcrCpnt,Deco,ConcrDecoA,ConcrDecoB). /*SR*/</pre>

```

dec_classes(Cpnt,ConcrCpnt,Deco,ConcrDecoA,ConcrDecoB):-/*SC: Classes*/
class(_,Cpnt),/*Cpnt is a class*/
class(concrclass,ConcrCpnt),/*ConcrCpnt is a concrete class*/
class(_,Deco),/*Deco is a class*/
class(concrclass,ConcrDecoA),/*ConcrDecoA is a concrclass*/
class(concrclass,ConcrDecoB)./*ConcrDecoB is a concrclass*/

dec_ops(Cpnt,ConcrCpnt,Deco,ConcrDecoA,ConcrDecoB):- /*SC:Operations*/
operation(_,_,Cpnt,Op,_,_,_),/*Op is an operation of Cpnt class*/
operation(_,_,ConcrCpnt,Op,_,_,_),/*Op is an operation of ConcrCpnt class*/
operation(_,_,Deco,Op,_,_,_),/*Op is an operation of Deco class*/
operation(_,_,ConcrDecoA,Op,_,_,_),/*Op is an operation of ConcrDecoA*/
operation(_,_,ConcrDecoB,Op,_,_,_)./*Op is an operation of ConcrDecoB*/

dec_stcrelations(Cpnt,ConcrCpnt,Deco,ConcrDecoA,ConcrDecoB):- /*SR*/
inheritance(Cpnt,ConcrCpnt),/*Inheritance*/
inheritance(Cpnt,Deco),/*Inheritance*/
inheritance(Deco,ConcrDeco),/*Inheritance*/
inheritance(Deco,ConcrDecoA),/*Inheritance*/
inheritance(Deco,ConcrDecoB),/*Inheritance*/
aggregation(Deco,Cpnt,one-to-one),/*Aggregation*/
delegation(Cpnt,Deco)./*Delegation*/

```

4.4.2.4 Proxy design pattern:

Figure 4-6 UML class diagram of *Proxy* design patterns

The Proxy design pattern is used as a surrogate for another object in order to control access to it. The reason why a Proxy is used to control access to an object is to defer the full cost of its creation and initialization until it is actually needed. The key to identifying the Proxy design pattern is Delegation relationship between Proxy and RealSubject; Proxy is the delegator while RealSubject is delegatee. It is reflected in the model as follows:

`delegation (RealSubj , Proxy) .`

4.4.2.4.1 The mapping between the model of Proxy and its *Prolog* representation

The mapping between the model of Proxy and its *Prolog* representation is as follows:

Elements in the model	Prolog representation
Static Components	
Classes	proxy_classes
Operations	proxy_ops
Static Relationships	proxy_stcrelations
Inheritance	inheritance
Delegation	delegation

Using Figure 4-6 and the table above, the model of the Proxy design pattern is as follows:

<p>Note: in this table,</p> <p>SC: Static Components; SR: Static Relationships;</p> <p>DC: Dynamic Components; DR: Dynamic Relationships ; /*...*/:Comments</p>
Prolog Representation
<pre> Proxy(Subj,RealSubj,Proxy):- Proxy_classes(Subj,RealSubj,Proxy),/*SC: Classes*/ proxy_ops(Subj,Op,RealSubj,Proxy),/*SC: Operations*/ proxy_stcrelations(Subj,RealSubj,Proxy)./*SR*/ </pre>
<pre> Proxy_classes(Subj,RealSubj,Proxy):- /*SC: Classes*/ class(_,Subj), /*Subj is a class*/ class(_,RealSubj), /*RealSubj is a class*/ class(_,Proxy). /*Proxy is a class*/ </pre>
<pre> proxy_ops(Subj,Op,RealSubj,Proxy):- /*SC: Operations*/ operation(_,_,Subj,Op,_,_,_), /*Op is an operation of Subj class*/ operation(_,_,RealSubj,Op,_,_,_),/*Op is an operation of RealSubj class*/ operation(_,_,Proxy,Op,_,_,_). /*Op is an operation of Proxy class*/ </pre>
<pre> proxy_stcrelations(Subj,RealSubj,Proxy):- /*SR*/ inheritance(RealSubj,Subj), /*Inheritance*/ inheritance(Proxy,Subj), /*Inheritance*/ delegation(RealSubj,Proxy). /*Delegation*/ </pre>

4.4.2.5 Bridge design pattern:

Bridge design pattern bridges the abstraction and its implementation and let them vary independently. In doing so we can avoid a permanent binding between an abstraction and its implementation. The key to identifying Bridge design pattern is the delegation relationship between Abstraction and Implementor as well as inheritance in class hierarchy.

Figure 4-7 UML class diagram of *Bridge* design patterns

4.4.2.5.1 The mapping between the model of Bridge and its *Prolog* representation

The mapping between the model of Bridge and its *Prolog* representation is as follows:

Elements in the model	Prolog representation
Static Components	
Classes	bridge_classes
Operations	bridge_ops
Static Relationships	bridge_stcrelations
Inheritance	inheritance
Delegation	delegation

Using Figure 4-7 and the table above, the model of the Bridge design pattern in Prolog is as follows:

Note: in this table,
SC: Static Components; SR: Static Relationships;
DC: Dynamic Components; DR: Dynamic Relationships ; /*...*/:Comments
Prolog Representation

```

bridge(Abstr,RefAbstr,Impl,ConcrImplA,ConcrImplB):-
bridge_classes(Abstr,RefAbstr,Impl,ConcrImplA,ConcrImplB),/*SC: Classes*/
bridge_ops(Abstr,Op,Impl,OpImpl,ConcrImplA,ConcrImplB),/*SC: Operations*/
bridge_stcrelations(Abstr,RefAbstr,Impl). /*SR*/

bridge_classes(Abstr,RefAbstr,Impl,
                ConcrImplA,ConcrImplB):- /*SC:Classes*/
class(_,Abstr), /*Abstr is a class*/
class(concrclass,RefAbstr),/*RefAbstr is a concrete class*/
class(_,Impl), /*Impl is a class*/
class(concrclass,ConcImplA),/*ConcrImplA is a concrete class*/
class(concrclass,ConcImplB)./*ConcrImplB is a concrete class*/

bridge_ops(Abstr,Op,Impl,OpImpl,ConcrImpl):-
operation(_,_,Abstr,Op,_,_,_), /*Op is an operation of Abstr class*/
operation(_,_,Impl,OpImpl,_,_,_),/*OpImpl is an operation of Impl class*/
operation(_,_,ConcrImpl,OpImpl,_,_,_)./*OpImpl is an operation of
                                   ConcrImpl class*/

bridge_stcrelations(Abstr,RefAbstr,Impl):- /*SR*/
inheritance(Abstr,RefAbstr),/*Inheritance*/
delegation(Abstr,Impl)./*Delegation*/

```

4.4.3 The Models of Behavioral Design Patterns

4.4.3.1 Strategy Design Pattern:

The strategy design pattern provides a common interface, a strategy class to encapsulate a group of algorithms so that they can be varied independently from clients that uses it. As shown in Figure 4-8, each algorithm can be varied independently of its context, this make the Strategy class easier to switch, understand, and extend.

Figure 4-8 UML class diagram of *Strategy* design patterns

The key to identifying Strategy design patterns is the aggregation relationships between context and strategy and the inheritance relationships between Strategy and ConcreteStrategy, as well as AlgorithmInterface overridden by each subclass of Strategy. This key is reflected in Operation of Static Component and the Static Relationships in the model below.

4.4.3.1.1 The mapping between the model of Strategy and its *Prolog* representation

The mapping between the model of Strategy and its *Prolog* representation is as follows:

Elements in the model	Prolog representation
Static Components	
Classes	str_classes
Operations	srt_ops
Static Relationships	str_stcrelations
Inheritance	inheritance

Using Figure 4-8 and the table above, the model of the Strategy design pattern in Prolog is as follows:

Note: in this table,
 SC: Static Components; SR: Static Relationships;

DC: Dynamic Components; DR: Dynamic Relationships ; /*...*/: Comments
Prolog Representation
<pre> Strategy(Context,Strategy,ConcrStrategyA, ConcrStrategyB,ConcrStrategyC):- str_classes(Context,Strategy,ConcrStrategyA, ConcrStrategyB,ConcrStrategyC),/*SC: Classes*/ str_ops(Context,Strategy,ConcrStrategyA, ConcrStrategyB, ConcrStrategyC),/*SC: Operations*/ str_stcrelations(Context,Strategy,ConcrStrategyA, ConcrStrategyB,ConcrStrategyC)./*SR*/ </pre>
<pre> str_classes(Context,Strategy,ConcrStrategyA, ConcrStrategyB, ConcrStrategyC):- class(_,Context),/*Context is a class*/ class(_,Strategy),/*Strategy is a class*/ class(concrclass,ConcrStrategyA),/*ConcrStrategyA is a concrete class*/ class(concrclass,ConcrStrategyB),/*ConcrStrategyB is a concrete class*/ class(concrclass,ConcrStrategyC)./*ConcrStrategyC is a concrete class*/ </pre>
<pre> str_ops(Context,Strategy,ConcrStrategyA, ConcrStrategyB,ConcrStrategyC):- /*SC: Operations*/ operation(_,_,Strategy,AlgInt,_,_,_),/*AlgInt is an operation of Strategy*/ operation(_,_,ConcStrategyA,AlgInt,_,_,_),/*AlgInt is an operation of ConStrategyA*/ operation(_,_,ConcStrategyB,AlgInt,_,_,_),/*AlgInt is an operation of ConStrategyB*/ operation(_,_,ConcStrategyC,AlgInt,_,_,_),/*AlgInt is an operation of ConStrategyC*/ operation(_,_,Context,ContextInt,_,_,_)./*ContextInt is an operation of Context*/ </pre>

```

str_strelations (Strategy, ConcrStrategyA,
                ConcrStrategyB, ConcrStrategyC, Context) :- /*SR*/
inheritance (Strategy, ConcrStrategyA) , /*Inheritance*/
inheritance (Strategy, ConcrStrategyB) , /*Inheritance*/
inheritance (Strategy, ConcrStrategyC) , /*Inheritance*/
aggregation (Context, Strategy, one_to_one) . /*Aggregation*/

```

Though the Strategy design pattern belongs to the Behavioral design pattern its dynamic characteristics are too vague to be used as an identification of this pattern. So the static structure of it becomes our choice instead of dynamic behavior.

4.4.3.2 Observer design pattern

Figure 4-9 UML class diagram of *Observer* design patterns

The Observer design pattern defines a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically.

Here we provide two kinds of models for Observer design patterns, one is based on static characteristics (i.e., structure) of the pattern and the other is based on dynamic characteristics (i.e. behavior) of the pattern.

4.4.3.2.1 The mapping between the structure-based model of Observer and its

***Prolog* representation**

The mapping between the structure-based model of Observer and its *Prolog* representation is as follows:

Elements in the model	Prolog representation
Static Components	
Classes	obs_classes
Operations	obs_ops
Static Relationships	obs_stcrelations
Inheritance	inheritance

- Using Figure 4-9 and the table above, the structure-based model of the Observer design pattern only in terms of static information:

Note: in this table, SC: Static Components; SR: Static Relationships; DC: Dynamic Components; DR: Dynamic Relationships ; /*...*/: Comments
Prolog Representation
<pre> observer (Subject,ConcrSubject,Observer,ConcrObsvr) :- obs_classes (Subject,ConcrSubject,Observer,ConcrObsvr) , /*SC: Classes*/ obs_ops (Subject,ConcrSubject,Observer,ConcrObsvr) , /*SC: Operations*/ obs_stcrelations (Subject,ConcrSubject,Observer,ConcrObsvr) ./*SR*/ </pre>

<pre> obs_classes (Subject,ConcrSubject,Observer,ConcrObsvr):- /*SC: Classes*/ class(abstrclass,Subject), /*Subject is an abstract class*/ class(concrclass,ConcrSubject),/*ConcrSubject is a concrete class*/ class(abstrclass,Observer), /*Observer is an abstract class*/ class(concrclass,ConcrObsvr). /*ConcrObsvr is a concrete class*/ </pre>
<pre> obs_ops (Subject,ConcrSubject,Observer,ConcrObsvr):- /*SC: Operations*/ operation(_,_,Subject,Attach,_,_,_),/*Attach is an operation of Subject*/ operation(_,_,Subject,Detach,_,_,_),/*Detach is an operation of Subject*/ operation(_,_,Subject,Notify,_,_,_),/*Notify is an operation of Subject*/ operation(_,_,ConcrSubject,GetState,_,_,_),/*GetState is an operation of ConcrSubject*/ operation(_,_,ConcrSubject,SetState,_,_,_),/*SetState is an operation of ConcrSubject*/ operation(_,_,Observer,Update,_,_,_),/*Update is an operation of Observer*/ operation(_,_,ConcrObsvr,Update,_,_,_)./*Update is an operation of ConcrObsvr*/ </pre>
<pre> obs_stcrelations (Subject,ConcrSubject,Observer,ConcrObsvr):- /*SR*/ inheritance (Subject,ConcrSubject), /*Inheritance*/ inheritance (Observer,ConcrObsvr)./*Inheritance*/ </pre>

- The Behavioral-based model of Observer design patterns in Prolog

Figure 4-10 UML sequence diagram of *Observer* design patterns

4.4.3.2.2 The mapping between the behavioral-based model of Observer and its *Prolog* representation

The mapping between the behavioral-based model of Observer and its *Prolog* representation is as follows,

Elements in the model	Prolog representation
Dynamic Components	obs_dyncomps
Object	object
Dynamic Relationships	obs_dynrelations
SendMessage	sendmessage
SelfMessage	selfmessage

The following is the alternative behavioral-based model of the Observer design pattern:

<p>Note: in this table,</p> <p>SC: Static Components; SR: Static Relationships;</p> <p>DC: Dynamic Components; DR: Dynamic Relationships ;</p> <p>Comments:/*Comments*/</p>
Prolog representation
<pre> observer(Subject,ConcrSubject,Observer,ConcrObsvrA,ConcrObsvrB, AconcrSubj,AconcrObsvrA,AconcrObsvrB,Sn):- /*Sn:Sequence Number of messages*/ obs_stccomps(Subject,ConcrSubject,Observer,ConcrObsvr), /*SC: Classes*/ obs_dyncomps(ConcrSubject,ConcrObsvr, AconcrSubj,AconcrObsvrA,AconcrObsvrB),/*DC*/ obs_dynrelations(AconcrSubj,AconcrObsvrA,AconcrObsvrB,Sn)./*DR*/ </pre>
<pre> obs_stccomps(Subject,ConcrSubject,Observer,ConcrObsvrA,ConcrObsvrB):- /*SC: Classes*/ class(abstrclass,Subject), /*Subject is an abstract class*/ class(concrclass,ConcrSubject),/*ConcrSubject is a concrete class*/ class(abstrclass,Observer), /*Observer is an abstract class*/ class(concrclass,ConcrObsvrA), /*ConcrObsvrA is a concrete class*/ class(concrclass,ConcrObsvrB). /*ConcrObsvrB is a concrete class*/ </pre>
<pre> obs_dyncomps(ConcrSubj,ConcrObsvrA,ConcrObsvrB, AconcrSubj,AconcrObsvrA,AconcrObsvrB):- /*DC*/ object(AconcrSubj, ConcrSubj), /*AconcrSubj is an object of ConcrSubj class*/ object(AconcrObsvrA,ConcrObsvrA),/*AconcrObsvrA is an object of ConcrObsvrA*/ object(AconcrObsvrB,ConcrObsvrB)./*AconcrObsvrB is an object of ConcrObsvrB*/ </pre>

```

obs_dynrelations (AconcrSubj, AconcrObsvrA, AconcrObsvrB, Sn) :- /*DR*/
    sendmessage (AconcrObsvrA, AconcrSubj, SetState, Sn), /*SendMessage*/
    selfmessage (AconcrSubj, Notify, Sn+1), /*SelfMessage*/
    sendmessage (AconcrSubj, AconcrObsvrA, Update, Sn+2), /*SendMessage*/
    sendmessage (AconcrObsvrA, AconcrSubj, GetState, Sn+3), /*SendMessage*/
    sendmessage (AconcrSubj, AconcrObsvrB, Update, Sn+4), /*SendMessage*/
    sendmessage (AconcrObsvrB, AconcrSubj, GetState, Sn+5). /*SendMessage*/

```

Observer design patterns are of strong dynamic characteristics. Suppose that dynamic information such as SendMessage and Object is available, it would be easy to identify Observer design patterns with high precision.

In contrast, in the aspect of static components and relationships of an Observer pattern there are only two class hierarchies that are key to identifying the pattern that would result in many false instances of the pattern. In our case study, after the structural-based model is used to identify Observer design patterns, many false instances were generated. This is because in the Observer pattern the structural characteristics that can be used as the key for identifying is not so strong that a set of classes that have the same class hierarchies can have different behavior.

4.4.3.3 Chain of Responsibility

Chain of Responsibility aims to “avoid coupling between the sender of a request and its receiver by giving more than one object a chance to handle the request.”[Gam95]. It makes use of some mechanisms like polymorphism to form a chain among objects. A request from senders will be passed along the chain until an object handles it.

As shown in Figure 4-11 it has strong dynamic characteristics. When a message is exchanged by several objects one by one it implies that a chain is formed. By finding

such a chain in related dynamic information Chain of Responsibility design patterns can be identified easily.

Figure 4-11 UML sequence diagram of *Chain of Responsibility* design patterns

Here is the model based on dynamic characteristics called behavioral-based model.

4.4.3.3.1 The mapping between the model of Chain of Responsibility and its *Prolog* representation

The mapping between the model of Chain of Responsibility and its *Prolog* representation is as follows:

Elements in the model	Prolog representation
Dynamic Components	cor_dyncomps
Object	object
Dynamic Relationships	cor_dynrelations
SendMessage	sendmessage

Using Figure 4-11 and the table above, the behavioral-based model of Chain of Responsibility in Prolog is as follows:

<p>Note: in this table,</p> <p>SC: Static Components; SR: Static Relationships;</p> <p>DC: Dynamic Components; DR: Dynamic Relationships ; /*...*/: Comments</p>
Prolog Representation
<pre> cor(ClassA,ClassB,ClassC,ObjectA,ObjectB,ObjectC,Sn):- /* Sn is sequence number of messages */ cor_stccomps(ClassA,ClassB,ClassC), /*SC*/ cor_dyncomps(ObjectA, ObjectB,ObjectC), /*DC*/ cor_dynrelations(ObjectA, ObjectB,ObjectC,Sn)./*DR*/ </pre>
<pre> cor_stccomps(ClassA,ClassB,ClassC):- /*SC*/ class(_,ClassA), /*ClassA is a class*/ class(_,ClassB), /*ClassB is a class*/ class(_,ClassC). /*ClassC is a class*/ </pre>
<pre> cor_dyncomps(ObjectA, ObjectB,ObjectC):- /*DC: Objects*/ object(ObjectA, ClassA), /*ObjectA is an object of ClassA*/ object(ObjectB, ClassB). /*ObjectB is an object of ClassB*/ object(ObjectC, ClassC). /*ObjectC is an object of ClassC*/ </pre>
<pre> cor_dynrelations(ObjectA,ObjectB,ObjectC,Sn):- sendmessage(ObjectA, ObjectB, aMessage, Sn), /*SendMessage*/ sendmessage(ObjectB, ObjectC, aMessage, Sn+1). /*SendMessage*/ </pre>

The Chain of Responsibility pattern has strong dynamic characteristics; the soul of this pattern is its behavior rather than its structure. If this pattern is identified merely based on static information it is likely that some implementation variants of the pattern are lost. For example, in [Gam95], the chain is formed by polymorphism, but in [Coo98], it is implemented by directly defining a Chain interface explicitly responsible for passing

the message among objects. The structure of both is different but their behavior is the same.

4.4.3.4 Visitor

Visitor represents an operation to be performed on the elements of an objects structure. Visitor design pattern allows the definition of a new operation without changing the classes of the elements on which it operates [Gam95].

Figure 4-12 UML class diagram of *Visitor* design patterns

As shown in Figure 4-12 the Visitor class declares a Visit operation for each class of ConcreteElement and uses them as the argument of the operation. In this way each ConcreteElement class can use Visit operation of Visitor class just like their own if there is an Accept operation with Visitor as an argument in each class of ConcreteElement.

As defined in section 4.3, Visitor uses each class of ConcreteElement via the arguments of Visit operation. Meanwhile, each class of ConcreteElement delegates Visitor's operations via Accept operation with Visitor as an argument, so there are delegation relationships between Visitor and each class of ConcreteElement. These relationships are very useful for identifying this pattern and reflected it in the model below.

4.4.3.4.1 The mapping between the model of Visitor and its *Prolog* representation

The mapping between the model of Visitor and its *Prolog* representation is as follows:

Elements in the model	Prolog representation
Static Components	
Classes	vstr_classes
Operations	vstr_ops
Static Relationships	vstr_stcrelations
Inheritance	inheritance
Using	using
Delegation	delegation

Using Figure 4-12 and the table above, the model of the Visitor design pattern in Prolog:

Note: in this table,
SC: Static Components; SR: Static Relationships;
DC: Dynamic Components; DR: Dynamic Relationships ; /*...*/:Comments
Prolog Representation


```

Visitor(Visitor,ConcrVisitor1,ConcrVisitor2,
        Element,ConcrElementA,ConcrElementB):-
vstr_classes(Visitor,ConcrVisitor1,ConcrVisitor2,
              Element,ConcrElementA,ConcrElementB),/*SC: Classes*/
vstr_ops(Visitor,ConcrVisitor1,ConcrVisitor2,
          Element,ConcrElementA,ConcrElementB),/*SC: Operations*/
vstr_strelations(Visitor,ConcrVisitor1,ConcrVisitor2,
                  Element,ConcrElementA,ConcrElementB)./*SR*/

vstr_classes(Visitor,ConcrVisitor1,ConcrVisitor2,
              Element,ConcrElementA,ConcrElementB):- /*SC: Classes*/
class(_,Visitor), /*Visitor is a class*/
class(concrclass,ConcrVisitor1),/*ConcrVisitor1 is a concrete class*/
class(concrclass,ConcrVisitor2),/*ConcrVisitor2 is a concrete class*/
class(_,Element),/*Element is a class*/
class(concrclass,ConcrElementA),/*ConcrElementA is a concrete class*/
class(concrclass,ConcrElementB)./*ConcrElementB is a concrete class*/

```

```

vstr_ops(Visitor,ConcrVisitor1,ConcrVisitor2,
        Element,ConcrElementA,ConcrElementB):- /*SC: Operations*/
operation(_,_,Visitor,VisitorConcrElementA,_,_,_),/*VisitorConElement is an
                                                operation of Visitor class*/
operation(_,_,Visitor,VisitorConcrElementB,_,_,_),/*VstConcrElementB is an
                                                operation of Visitor class*/
operation(_,_,Element,Accept,_,_,_),/*Accept is an operation of Element*/
operation(_,_,ConcrElementA,Accept,_,_,_),/*Accept is an operation of
                                                ConcrElement class*/
operation(_,_,ConcrElementA,OperationA,_,_,_),/*OperationA is an operation
                                                of ConcrElementA class*/
operation(_,_,ConcrElementB,Accept,_,_,_),/*Accept is an operation of
                                                ConcrElementB class*/
operation(_,_,ConcrElementB,OperationB,_,_,_)./*OperationB is an operation
                                                of ConcrElementB class*/

vstr_stcrelations(Visitor,ConcrVisitor1,ConcrVisitor2,
        Element,ConcrElementA,ConcrElementB):-
inheritance(Visitor,ConcrVisitor1),/*Inheritance*/
inheritance(Visitor,ConcrVisitor2),/*Inheritance*/
inheritance(Element,ConcrElementA),/*Inheritance*/
inheritance(Element,ConcrElementB),/*Inheritance*/
using(ConcrElementA,Visitor),/*Using*/
using(ConcrElementB,Visitor),/*Using*/
using(ConcrVisitor1,ConcrElementA),/*Using*/
using(ConcrVisitor2,ConcrElementB),/*Using*/
delegation(ConcrElementA,Visitor),/*Delegation*/
delegation(ConcrElementB,Visitor)./*Delegation*/

```

4.5 Summary

In this chapter we propose a rule-based approach to the problem of reverse engineering C++ software systems by detecting design patterns. In this approach, design patterns based on static and dynamic information are modeled in logic language. All models are composed of components and relationships. Components and relationships are divided into static and dynamic ones respectively. The formal descriptions of some typical patterns in GOF design patterns are presented in details.

In the models for formal descriptions of design patterns, creational design patterns, like Factory Method, are described based on static and dynamic characteristics. Structural design patterns like Adapter are described based on static characteristics because they are of strong structural characteristics. Some behavioral design patterns like strategy are described based on static characteristics and others like Chain of Responsibility and Observer are described based on dynamic characteristics because of their strong behavioral characteristics.

Chapter 5 Design Pattern Extraction Tool (DPET)

5.1 Introduction

DPET consists of three processes, extraction process, knowledge base process, and pattern detection process.

- Extraction process is made up of a parser, a profiling tool, static and dynamic information repository, and an extractor.
- Knowledge base process is made up of a rule base and a fact base.
- Pattern detection process is made up of a Prolog inference engine.

5.2 The Architecture of DPET

Figure 5-1 The architecture of the tool DPET

The Design Pattern Extraction Tool (DPET) has been implemented using the approach proposed in Chapter 4. As shown in Figure 5-1, DPET consists of the front-end parser, the profiling tool, the fact and rule base, and the *Prolog* inference engine.

5.2.1 The Parser

A parser for extracting static information from C++ code has been revised based on a C++ parser for measuring software metrics developed by Tim Littlefair[Lit01], which is heavily dependent on ANTLR (ANOther Tool for Language Recognition), a predict LL(k) parser generator [Par93].

ANTLR constructs human-readable recursive-descent parsers in C or C++ from pred-LL(k) grammars, namely LL(k) grammars, for $k > 1$ that support predicates.

Our choice is based on the following properties of ANTLR:

- $k > 1$ lookahead,
- Semantic predicates (the ability to have semantic information direct the parsing)
- Syntactic predicates (selective backtracking).

The pred-LL(k) parsers are stronger than LR(k) parsers for two reasons. First, semantic predicates may be used to parse context sensitive languages. Second, pred-LL(k) parsers have access to arbitrary lookahead. Further, embedding actions in an LR grammar can introduce ambiguities, thus reducing the strength of LR.

Ultimately, the true test of language tool's usefulness lies with the vast industrial use. ANTLR is widely used in the commercial and academic communities. Thousands of people in virtually all industrialized nations have acquired the software since the original 1.00 release in 1992. Several universities currently teach courses with ANTLR. Many commercial programs use ANTLR [Ant03].

5.2.2 The Profiling Tool

GNU *gprof* [Gpr02], a tool for profiling programs, is used to generate dynamic information about source code.

Profiling is a dynamic analysis technique that can provide valuable information about how a program spends its time and which functions called which other functions (Call Graph) while executing. It looks into each function and inserts code at the head and tail of each one in order to collect timing information. Since the profiler uses information collected during the actual execution of the program it can be used on programs that are too large or too complex to analyze by reading the source. That is, profiling technique can provide dynamic information about programs even if we know little about the programs in advance. However, how the program is run will affect the information that shows up in the profile data. If some features of the program are not used while it is being profiled, no profile information will be generated for that feature.

5.2.3 The Extractor

The goal of the extractor is to detect relationships among components from program information extracted from source code. The extractor uses the relationship detection algorithms defined in section 4.2.1. The relationships will be used to identify design patterns together with components.

5.2.4 The Knowledge Base

The knowledge base consists of two bases, the fact base and the rule base. The design information extracted from source code is stored in the fact base while the model of design patterns is stored in the rule base.

5.2.5 Prolog Inference Engine

By running the Prolog inference engine to query the knowledge base design patterns can be detected.

5.3 The Extraction Process

The extraction process of design patterns is introduced briefly in the above section. In order to make it clearer, two pieces of sample code are used to show the whole extraction process. The first code fragment adopted from [Gam95] is used to describe the process of extracting the Proxy design pattern. The second code adopted from our case study-1 is used to describe the process of extracting the Adapter design pattern. Appendix A gives a complete extraction description including the original data of the intermediate result.

5.3.1 Extraction Description of Proxy Design Patterns

• Extraction Process

(1) Source code is parsed to extract static information using C++ parser

The following sample code fragment is adopted from the “Proxy” sample code in [Gam95]. The *Graphic* class defines the interface for graphical objects.

The *Image* class implements the *Graphic* interface to display image files. *Image* overrides *HandleMouse* to let users resize the image interactively.

ImageProxy has the same interface as *Image*.

```
1. class Graphic {                                     //abstract class Graphic
2. public:
3. virtual ~Graphic();
4. virtual void Draw(const Point& at) = 0;             // pure virtual operation
5. virtual void HandleMouse(Event& event) = 0;         //pure virtual operation
6. virtual const Point& GetExtent() = 0;               //pure virtual operation
7. virtual void Load(istream& from) = 0;              //pure virtual operation
```

```

8. virtual void Save(ostream& to) = 0;    //pure virtual operation
9. protected:
10.    Graphic();
11.    };
12.    class Image : public Graphic { //class Image inherits class Graphic
13.    public:
14.        Image(const char* file);
15.        virtual ~Image();
16.        virtual void Draw(const Point& at);
17.        virtual void HandleMouse(Event& event);
18.        virtual const Point& GetExtent();
19.        virtual void Load(istream& from);
20.        virtual void Save(ostream& to);
21.    private:
22.        // ...
23.    };
24.    class ImageProxy : public Graphic { //class ImageProxy inherits
    Graphic
25.    public:
26.        ImageProxy(const char* imageFile);
27.        virtual ~ImageProxy();
28.        virtual void Draw(const Point& at);
29.        virtual void HandleMouse(Event& event);
30.        virtual const Point& GetExtent();
31.        virtual void Load(istream& from);
32.        virtual void Save(ostream& to);
33.    protected:
34.        Image* GetImage(); //GetImage() return a pointer of Image
35.    private:
36.        Image* __image; //Image's instance as data member of class
    ImageProxy
37.        Point __extent;
38.        char* __fileName;
39.    };
40.    ImageProxy::ImageProxy (const char* fileName) {
41.        __fileName = strdup(fileName);
42.        __extent = Point::Zero;
43.        __image = 0;
44.    }
45.    Image* ImageProxy::GetImage() { //The return type of GetImage() is
    Image
46.        if (__image == 0) {
47.            __image = new Image(__fileName);
48.        }
49.        return __image;
50.    }
51.    const Point& ImageProxy::GetExtent () {
52.        if (__extent == Point::Zero) {
53.            __extent = GetImage()->GetExtent(); //GetImage() return a pointer of
    Image.
54.        }
55.        return __extent;
56.    }
57.    void ImageProxy::Draw (const Point& at) {
58.        GetImage()->Draw(at); //GetImage() return a pointer of Image.
59.    }
60.    void ImageProxy::HandleMouse (Event& event) {

```



```

61.  GetImage()->HandleMouse(event); //GetImage() return a pointer of
                                     Image.
62.  }
63.  void ImageProxy::Save (ostream& to) {
64.  to << _extent << _fileName;
65.  }
66.  void ImageProxy::Load (istream& from) {
67.  from >> _extent >> _fileName;
68.  }
69.  class TextDocument {
70.  public:
71.  TextDocument();
72.  void Insert(Graphic*);
73.  // ...
74.  };
75.  void dummy () {
76.  TextDocument* text = new TextDocument;
77.  // ...
78.  text->Insert(new ImageProxy("anImageFileName"));
79.  }

```

Note that the lines that are related to pattern detection in code have been commented. The above program information is exactly needed to extract for “Proxy” pattern detection.

Table 5.1 The sample code fragment of Proxy design patterns

(2) The static information parsed is stored in the below data format:

The data formats used in the extraction of this sample code is shown below. Please refer to Appendix B for a complete data formats and Appendix A for the program information extracted from the above code.

- *Data format for Classes:*
CCCC_Module@ModuleName@ModuleType
CCCC_ModExt@ModuleName@ModuleType@
 FileName@Line@Definition/Declaration@Properties@Metrics
 - *ModuleType: Class and Struct*
 - *Meaning:* At the Line of the Filename file, there is a Definition/Declaration of ModuleName module of ModuleType (class/struct) type with Properties and Metrics.
- *Data format for Operations:*
CCCC_Member@ModuleName@OperationName@ReturnType@Parameter@
CCCC_MemExt@ModuleName@OperationName@ReturnType@Parameter@
 FileName@Line@Declaration/Definition@OperationType@Metrics
 - *Meaning:* At the Line of the FileName file, there is a Definition/Declaration of OperationName of OperationType in ModuleName with ReturnType, Parameter

and Metrics.
<ul style="list-style-type: none"> • <i>Data format for basic relationships among classes (pass by reference, has by value, inheritance) and class attribute: data member in class.</i> CCCC_UseRel@ModuleName1@ModuleName2@(Pointer/Reference)@ CCCC_UseExt@ModuleName1@ModuleName2@(Pointer/Reference) @FileName@Line@BasicRelationships@Properties@Metrics <ul style="list-style-type: none"> ▪ Meaning: At the Line of the FileName file, there is a basic Relationship between ModuleName1 and ModuleName2 with Properties and Metrics.
<ul style="list-style-type: none"> • <i>Data Format for Delegation Instances:</i> CCCC_Delegation@Reference/Pointer@CalledOperation@CallingModule@ CallingOperation@ <ul style="list-style-type: none"> ▪ Meaning: The CallingOperation of the CallingModule calls the CalledOperation with the Refence/Pointer.

(3) The design information (e.g., classes and their interrelationships) is extracted from the static information using the Extractor, and stored in the fact base of the knowledge base.

- **Knowledge base process**

(1) The facts stored in the fact base as follows:

```
class(abstrclass,graphic).
class(concrclass,image).
class(concrclass,imageProxy).
operation(,,graphic,draw,,,_).
operation(,,graphic,getExtent,,,_).
operation(,,graphic,handleMouse,,,_).
operation(,,image,draw,,,_).
operation(,,image,getExtent,,,_).
operation(,,image,handleMouse,,,_).
operation(,,imageProxy,draw,,,_).
operation(,,imageProxy,getExtent,,,_).
operation(,,imageProxy,getImage,,,_).
operation(,,imageProxy,handleMouse,,,_).
inheritance(graphic,image).
inheritance(graphic,imageProxy).
delegation(imageProxy,image).
```

(2) The rules for identifying the “Proxy” design pattern is stored in the rule base of the knowledge base based on the model of formal descriptions of design patterns.

```
proxy(Subj,RealSubj,Proxy,N):- //N is the number of pattern instances
    proxy_relations(Subj,RealSubj,Proxy),
    proxy_classes(Subj,RealSubj,Proxy),
    proxy_operations(Subj,Op,RealSubj,Proxy),
    increment(N).

proxy_classes(Subj,RealSubj,Proxy):-
```

```

class (_, Subj) ,
class (concrclass, RealSubj) ,
class (concrclass, Proxy) ,
!.

proxy_relations (Subj, RealSubj, Proxy) :-
    inheritance (Subj, RealSubj) ,
    inheritance (Subj, Proxy) ,
    delegation (RealSubj, Proxy) .

proxy_operations (Subj, Op, RealSubj, Proxy) :-
    operation (_, _, Subj, Op, _, _, _) ,
    operation (_, _, RealSubj, Op, _, _, _) ,
    operation (_, _, Proxy, Op, _, _, _) ,
    !.

```

Note: cut "!" is used here for eliminating unnecessary backtracking.

- **Pattern Detection Process**

The design pattern can be detected by querying the knowledge base.

The following results are obtained after running *SWI-Prolog* inference engine to identify design patterns:

```

Subject = Graphic
RealSubject= Image
Proxy= ImageProxy

```

It indicates that there is a “Proxy” design pattern in the code that consists of Graphic class, Image class and ImageProxy class as shown in Figure 5-2.

Figure 5-2 UML representation of the “Proxy” design pattern

5.3.2 Extraction Description of Adapter Design Patterns

- **Extraction Process**

(1) Source code is parsed to extract static information using C++ parser.

The following sample code fragment is from LQNS that is applied in case study-1 later. *ActivityList* class is an interface; *SequentialActivityList* class inherits from it and overrides *owner* operation by delegating *owner* operation of *Activity* class.

```

class ActivityList //class ActivityList
{
friend class Activity;
public:
virtual const Component * owner() const; // virtual operation
//...
private:
//...
const Activity * originator;
};
class SequentialActivityList:public ActivityList
  
```

```

{
public:
virtual const Component * owner() const; //virtual operation
//...
protected:
Activity * myActivity; //Activity's instance as data member of
                        SequentialActivityList
};
const Component * SequentialActivityList::owner() const
{
return myActivity->owner(); //SequentialActivityList delegates
                        Activity's owner() operation.
}

class Activity : public Phase //Activity inherits Phase
{
public:
//...
virtual const Component * owner() const; //virtual operation
private:
//...
};
const Component *
Activity::owner() const
{
return myTask;
}

```

Note that the lines that are related to pattern detection in the code have been bolded with comments. The above program information is exactly needed to extract for "Adapter" pattern detection.

Table 5.2 The sample code fragment of Adapter Design patterns

(2) The static information parsed is stored in the below data formats:

The data formats used in the extraction of this sample code is shown below. Please refer to Appendix B for a complete data formats and Appendix A for the program information extracted from the above code.

- *Data format for Classes:*
CCCC_Module@ModuleName@ModuleType
CCCC_ModExt@ModuleName@ModuleType@
 FileName@Line@Definition/Declaration@Properties@Metrics
 - *ModuleType: Class and Struct*
 - *Meaning: At the Line of the Filename file, there is a definition/declaration of ModuleName module of ModuleType (class/struct) type with Properties and Metrics.*
- *Data format for Operations:*

<p>CCCC_Member@ModuleName@OperationName@ReturnType@Parameter@ CCCC_MemExt@ModuleName@OperationName@ReturnType@Parameter@ FileName@Line@Declaration/Definition@OperationType@Metrics</p> <ul style="list-style-type: none"> ▪ Meaning: At the Line of the FileName file, there is an Definition/Declaration of OperationName of OperationType in ModuleName with ReturnType, Parameter and Metrics.
<ul style="list-style-type: none"> • Data format for basic relationships among classes (pass by reference, has by value, inheritance) and class attribute: data member in class. <p>CCCC_UseRel@ModuleName1@ModuleName2@(Pointer/Reference)@ CCCC_UseExt@ModuleName1@ModuleName2@(Pointer/Reference) @FileName@Line@BasicRelationships@Properties@Metrics</p> <ul style="list-style-type: none"> ▪ Meaning: At the Line of the FileName file, there is a basic Relationship between ModuleName1 and ModuleName2 with Properties and Metrics
<ul style="list-style-type: none"> • Data Format for Delegation Instances: <p>CCCC_Delegation@Reference/Pointer@CalledOperation@CallingModule@ CallingOperation@</p> <ul style="list-style-type: none"> ▪ Meaning: The CallingOperation of the CallingModule calls the CalledOperation with the Refence/Pointer.

(3) The design information (e.g., classes and their interrelationships) is extracted from the static information using the Extractor, and stored in the fact base of the knowledge base.

- **Knowledge base process**

(1) The facts stored in the fact base as follows:

```

class(concreclass,activityList).
class(concrclass,sequentialActivityList).
class(concrclass,activity).
operation(,,activityList,owner,,,_).
operation(,,activity,owner,,,_).
operation(,,sequentialActivityList,owner,,,_).
inheritance(activityList,sequentialActivityList).
delegation(sequentialActivityList,activity).

```

(2) The rules for identifying the “Proxy” design pattern is stored in the rule base of the knowledge base based on the model of formal description of design patterns.

```

adapter(Target,Adapter,Adaptee,N):-//N is the number of pattern
instances
    adapter_relations(Target,Adapter,Adaptee),
    adapter_classes(Target,Adapter,Adaptee),
    adapter_operations(Adapter,Adaptee,Target,Request,SpecRequest),
    increment(N).

adapter_classes(Target,Adapter,Adaptee):-
    class(_,Target),

```

```

class(concrrclass,Adapter),
class(concrrclass,Adaptee),
!.

adapter_operations(Adapter,Adaptee,Target,Request,SpecRequest):-
    operation(_,_,Adaptee,SpecRequest,_,_,_),
    operation(_,_,Target,Request,_,_,_),
    operation(_,_,Adapter,Request,_,_,_),
    !.

adapter_relations(Target,Adapter,Adaptee):-
    inheritance(Target,Adapter),
    delegation(Adapter,Adaptee).

```

Note: cut “!” is used here for avoiding unnecessary backtracking.

• Pattern Detection Process

The design pattern can be detected by querying the knowledge base.

The results after running *SWI-Prolog* inference engine to identify design patterns:

Target = activityList

Adapter= sequentialActivityList

Adaptee= activity

It indicates that there is an “Adapter” design pattern in the code, which consists of activityList class, sequentialActivityList class and activity class as shown in Figure 5-3.

Figure 5-3 UML representation of the “Adapter” design pattern

5.3.3 Extraction Description of Dynamic Information using Profiling

GNU *gprof*, a tool for profiling programs is used to capture dynamic information. The sample code adopted from [Gam95] for the Chain of Responsibility design pattern has been profiled by GNU *gprof*. The call graphs about the sample code have been obtained.

In order to profile a program the following steps are taken:

- (1) Compile and link the program with profiling enabled.

To compile and link a source file for profiling, specify the `-pg` option when running the compiler.

Here are examples:

```
g++ -pg chain.C -o chain (chain.C is shown in Table 5.3)
```

- (2) Execute the program to generate a profile data file.

```
chain
```

Once the program is compiled for profiling run it in order to generate the information that *gprof* needs. Simply run the program as usual using the normal arguments, file names, etc. The program should run normally producing the same output as usual. It will, however, run somewhat slower than normal because of the time spent collecting and the writing the profile data.

The program will write the profile data into a file called `gmon.out` just before exiting.

- (3) Run *gprof* to analyze the profile data.


```
gprof -c -z chain gmon.out
```

After you have a profile data file 'gmon.out', run *gprof* to interpret the information in it. The *gprof* program prints a flat profile and a call graph on standard output.

Typically redirect the output of *gprof* into a file with '>'.

Run *gprof* like this:

```
gprof options [executable-file [profile-data-files...]] [> outfile]
```

Here square brackets indicate optional arguments.

The following sample code is adopted from [Gam95], which originally is a piece of code fragment and cannot be executed; to execute it some modifications are made. This example illustrates how a chain of responsibility can handle requests for an on-line help system. The user can obtain help information on any part of the graphical interface just by clicking on it. The help that's provided depends on the part of the interface that's selected and its context. The button in a dialog box offers information, if specific help information exists for that part of the interface. If not a more general help message-dialog box should be displayed. If there is no help information from a dialog box a more general dialog box should appear—application offers help information to its users. In this way the help request can be passed along the chain formed by button, dialog, and application objects.

```
1. #include<iostream>
2. class Application;
3. class Dialog;
4. class HelpHandler;
5. typedef int Topic;
6. const Topic NO_HELP_TOPIC = -1;
7. class HelpHandler {
8. public:
```

```

9.  HelpHandler(HelpHandler* = 0, Topic = NO_HELP_TOPIC);
10.  virtual bool HasHelp();
11.  virtual void SetHandler(HelpHandler*, Topic);
12.  virtual void HandleHelp();
13.  private:
14.  HelpHandler* __successor;
15.  Topic __topic;
16.  };
17.  void HelpHandler::SetHandler(HelpHandler* h, Topic t){
18.  __successor=h;
19.  __topic=t;
20.  }
21.  HelpHandler::HelpHandler (
22.  HelpHandler* h, Topic t
23.  ) : __successor(h), __topic(t) { }
24.  bool HelpHandler::HasHelp () {
25.  return __topic != NO_HELP_TOPIC;
26.  }
27.  void HelpHandler::HandleHelp () {
28.  if (__successor != 0) {
29.  cout<<"Go to chain!"<<endl;
30.  __successor->HandleHelp();
31.  }
32.  }
33.  class Widget : public HelpHandler {
34.  protected:
35.  Widget(Widget* parent, Topic t = NO_HELP_TOPIC);
36.  private:
37.  Widget* __parent;
38.  };
39.  Widget::Widget (Widget* w, Topic t) : HelpHandler(w, t) {
40.  __parent = w;
41.  }
42.  class Button : public Widget {
43.  public:
44.  Button(Widget* d, Topic t = NO_HELP_TOPIC);
45.  virtual void HandleHelp();
46.  // Widget operations that Button overrides...
47.  };
48.  Button::Button (Widget* h, Topic t) : Widget(h, t) { }
49.  void Button::HandleHelp () {
50.  if (HasHelp()) {
51.  cout<<"offer help on the button!"<<endl;
52.  } else {
53.  HelpHandler::HandleHelp();
54.  }
55.  }
56.  class Dialog : public Widget {
57.  public:
58.  Dialog(HelpHandler* h, Topic t = NO_HELP_TOPIC);
59.  virtual void HandleHelp();
60.
61.  // Widget operations that Dialog overrides...
62.  // ...
63.  };
64.  Dialog::Dialog (HelpHandler* h, Topic t) : Widget(0) {
65.  SetHandler(h, t);

```

```

66.     }
67.     void Dialog::HandleHelp () {
68.         if (HasHelp()) {
69.             cout<<"offer help on the dialog!"<<endl;
70.         } else {
71.             HelpHandler::HandleHelp();
72.         }
73.     }
74.     class Application : public HelpHandler {
75.     public:
76.         Application(Topic t) : HelpHandler(0, t) { }
77.         virtual void HandleHelp();
78.         // application-specific operations...
79.     };
80.     void Application::HandleHelp () {
81.         cout<<"show a list of help topics!"<<endl;
82.     }
83.     int main() {
84.         const Topic PRINT_TOPIC = 1;
85.         const Topic PAPER_ORIENTATION_TOPIC = 2;
86.         const Topic APPLICATION_TOPIC = 3;
87.         Application* application = new Application(APPLICATION_TOPIC);
88.         Dialog* dialog = new Dialog(application, NO_HELP_TOPIC);
89.         Button* button = new Button(dialog.NO_HELP_TOPIC);
90.         button->HandleHelp();
91.     }

```

Table 5.3 the sample code of Chain and Responsibility patterns (chain.C)

The Output is obtained after running *gprof* command. The related part of the call graph is shown below for giving an overview. Please see Appendix C for details.

```

/*
 * Copyright (c) 1993 by Sun Microsystems, Inc.
 */
#pragma ident "@(#)gprof.calig.blurb      1.8   93/06/07 SMI"
call graph profile:
granularity: each sample hit covers 4 byte(s) for 100.00% of 0.01 seconds

```

index	%time	self	descendents	called/total called+self called/total	parents name index children
		0.00	0.00	1/1	main [16]
[11]	0.0	0.00	0.00	1	HandleHelp_Button [11]
		0.00	0.00	1/1	HasHelp_HelpHandler [12]
[12]	0.0	0.00	0.00	1	HandleHelp_Button [11]
		0.00	0.00	1	HasHelp_HelpHandler [12]
[13]	0.0	0.00	0.00	1	__Dialog:HelpHandler [316]
		0.00	0.00	1	SetHandler 11HelpHandler:HelpHandler [13]
[16]	0.0	0.00	0.00	1	_start [798]
		0.00	0.00	1	main [16]

		0.00	0.00	1/1	__Application [314]
		0.00	0.00	1/1	__Dialog:HelpHandler [316]
		0.00	0.00	1/1	__Button:Widget [315]
		0.00	0.00	1/1	HandleHelp__Button [11]

		0.00	0.00	1/3	__Application [314]
		0.00	0.00	2/3	__Widget:Widget [308]
[306]	0.0	0.00	0.00	3	__HelpHandler:HelpHandler [306]

		0.00	0.00	1/2	__Button:Widget [315]
		0.00	0.00	1/2	__Dialog:HelpHandler [316]
[308]	0.0	0.00	0.00	2	__Widget:Widget [308]
		0.00	0.00	2/3	__HelpHandler:HelpHandler [306]

		0.00	0.00	1/1	main [16]
[314]	0.0	0.00	0.00	1	__Application [314]
		0.00	0.00	1/3	__HelpHandler:HelpHandler [306]

		0.00	0.00	1/1	main [16]
[315]	0.0	0.00	0.00	1	__Button:Widget [315]
		0.00	0.00	1/2	__Widget:Widget [308]

		0.00	0.00	1/1	main [16]
[316]	0.0	0.00	0.00	1	__Dialog:HelpHandler [316]
		0.00	0.00	1/2	__Widget:Widget [308]
		0.00	0.00	1/1	SetHandler__HelpHandler:HelpHandler[13]

Index by function name					
[8] .udiv	[323] _getegid	[332] _setorientation			
[11] HandleHelp__Button	[324] _geteuid	[307] _smallloc			
[12] HasHelp__HelpHand	[325] _getgid	[333] _thr_main			
[13] SetHandler__HelpH	[326] _getuid	[334] _write			
[314] __Application	[327] _ioctl	[335] _wrtchk			
[306] __HelpHandler:H	[328] _isatty	[336] _xflsbuf			
[315] __Button:Widget	[311] _lseek64	[6] atexit			
[316] __Dialog:HelpHan	[3] _malloc_unlocked	[14] check_nlspace_env			
[308] __Widget:Widget	[4] _morecore	[5] cleanfree			
Object modules					
1: chain					

From the above call graph we can see the parents and children of each operation used during run time, that is, which operation calls for which other operation. But in the call graph there is no information about the calling order among operations. The sequence of objects sending messages cannot be induced, this is important in identifying some behavioral design patterns.

5.4 Summary

In DPET, the extraction process of design information is language- specific. This is because different object-oriented languages have different implementations for the relationships. For example, in C++ there is a pointer of a class as a data member of another class to form an aggregation relationship between two classes. But in Java there is no pointer at all. So the relationships detection algorithm has to be updated according to different implementations among OO languages.

Meanwhile, the pattern detection process is language-independent because logic language *Prolog* has been adopted to represent the model of formal descriptions of design patterns. *Prolog* representation is language-independent and the design pattern extraction may be applied to other language such as Java or Smalltalk, etc. without changing the rules of design patterns.

In addition to this new rules may be added into the model in the future. Logic language makes this easy to achieve this.

Chapter 6 Case Study

6.1 Introduction

In order to validate our approach we have applied DPET to the two case studies.

The first case study is the extraction of design patterns from LQNS (Layered Queuing Network Solver), a C++ source code. LQNS is a tool for the evaluation of software performance that was developed by Woodside et al [Fra99, Fra96] at the department of Systems and Computer Engineering, Carleton University. LQNS provides a language for modeling layered systems. LQNS has been selected for this research project for two reasons. Firstly, we can easily access its complete source code and its design documentation. This enables us to compare the pattern instances extracted by the *DPET* with design documentation to make sure whether the results are correct. Secondly, LQNS is a large-sized software system that implies that our approach can be applied to large-sized software systems in public domain.

The second case study is based on the extraction of design patterns from three pieces of C++ source code: libg++, galib, and groff. Libg++(version 2.7.2) is a well-known C++ library of foundation class and is part of the GNU Free Software Foundation C++ development environment. Galib (release 2.4), developed at the Massachusetts Institute of Technology, is a C++ Genetic Algorithm Library to solve optimizations problems. Groff (version 1.10) is the GNU Free Software Foundation version of Unix groff utility. Because these three pieces of software were used in [Ant98] to validate the that particular proposed approach we selected them for our case studies in order to

compare the results of our approach with those obtained by the Multi-stage filtering approach (MsA) from [Ant98].

6.2 Case Study-1

In this case study the tool *DPET* has been used to extract design patterns from the source code of LQNS. There are total nine kinds of patterns to be detected that are selected from creational, structural and behavioral design patterns respectively. The design information obtained by this case study is compared with the design documentation to make a conclusion.

The following table shows that LQNS has 279 classes and complex relationships between classes.

LOC	21,182	Associations	16
Classes	279	Using	700
Operations	1,911	Delegations	28
Aggregations	142	Detection Time (sec)	131

Table 6.1 LQNS code characteristics and detection time

6.2.1 The Results of Case Study-1

We tried to extract GOF design pattern instances from LQNS source code. Table 6.2 shows the results of extraction. The number of real patterns in LQNS code has been obtained by checking both the design documentation and the source code of LQNS.

Code	LQNS			
Pattern	Pattern instances	Real patterns	False Positives	Precision
Factory Method	0	0	0	-
Adapter	12	8	4	67%
Proxy	1	1	0	100%
Bridge	0	0	0	-
Composite	0	0	0	-
Decorator	0	0	0	-
Strategy	0	0	0	-
Visitor	0	0	0	-
Observer	7	-	7	—
Time (sec)	131			

Table 6.2 Results of pattern detection in LQNS using our tool *DPET*

6.2.2 Discussion on Case Study-1

The extraction process took 131 seconds and it produced (Table 6.1) 279 classes, 1,911 operations, 142 aggregations, 16 associations, 193 inheritances, and 700 using relationships. When comparing the results with the design documentation and the source code there were twelve instances of adapter patterns compared to eight real patterns giving four false positive patterns. The precision is sixty seven percent. The second pattern extracted was the proxy pattern. In this case there is 100% precision. We intentionally tried to only use structure-based model (Static Component & Static Relationships) to identify behavioral design patterns *Observer*. It resulted in 7 false positives of Observer pattern instances. The reason why we got them is that some behavioral design patterns like Observer and Mediator have strong dynamic characteristics as well as weak static characteristics. This is because they are responsible for the behavior of decoupling senders and receivers. Without dynamic information we

may get many false positives. It would be effective to reduce the false positives and augment the precision of retrieval if true behavioral characteristics are identified.

6.3 Case Study-2

In order to show what we have achieved in comparison with the approach proposed in [Ant98] we apply DPET to three pieces of software systems – libg++, galib and groff. The results of comparison are provided and discussed below.

6.3.1 The Results of Case Study-2

	Libg++	Galib	groff
LOC	10680	12556	26677
Classes	55	69	290
Operations	348	655	2549
Aggregations	22	29	61
Associations	4	4	0
Inheritances	16	42	91
Using	66	168	243
Delegations	1	10	16
Remarks: * The relationships among classes are kind of different from the ones defined by UML. From the above table we can see that there are no associations in “groff” code. Here association means cyclic aggregation or cyclic “using” relationships. No association indicates that there are no cyclic aggregation and cyclic using relationships.			

Table 6.3 Code characteristics of three pieces of software

Table 6.3 shows the extraction results of design information from the three software systems. The LOC for the three pieces of software are 10,680, 12,556 and 26,677 respectively. The number of classes is 55, 69 and 290, and the number of operations are

348, 655 and 2,549 respectively. The different relationships (aggregations, associations, etc.) are also shown in the table.

Table 6.4 shows the results of pattern detection using our tool DPET. There are 10 adapter pattern instances detected in galib, 1 adapter pattern instance detected in libg++, 12 adapter pattern instances as well as 1 Proxy pattern instance detected in LQNS. No pattern instances are detected in groff.

Code	Galib		Libg++		Groff		LQNS	
Pattern	PI	Real	PI	Real	PI	Real	PI	Real
Adapter	10	6	1	1	3	0	12	8
Proxy	0	0	0	0	0	0	1	1
Bridge	0	0	0	0	0	0	0	0
Composite	0	0	0	0	0	0	0	0
Decorator	0	0	0	0	0	0	0	0
Notes:								
PI- Pattern Instances retrieved by the tool DPET.								
Real- Real Patterns in source code.								

Table 6.4 Results of pattern instance detection using our tool *DPET*

Table 6.5 shows the results of the extraction of design patterns using the approach proposed by Antoniol. 33 adapter pattern instances are detected in galib. There is 1 adapter pattern instance detected in libg++. In groff, 4 adapter pattern instances are detected.

Code	Galib		Libg++		Groff	
Pattern	PI	Real	PI	Real	PI	Real
Adapter	33	6	1	1	4	0
Proxy	0	0	0	0	0	0
Bridge	0	0	0	0	0	0
Composite	0	0	0	0	0	0

Decorator	0	0	0	0	0	0
-----------	---	---	---	---	---	---

Notes:

PI-Pattern Instances retrieved by the approach proposed by Antoniol et al.

Real- Real Patterns in source code.

Table 6.5 Results of pattern detection using the approach proposed by Antoniol.

Table 6.6 shows the comparison of the pattern instances extracted from the three pieces of software below.

Code	Galib			Libg++			Groff		
Pattern	PI by MsA	PI by DPET	Real	PI by MsA	PI by DPET	Real	PI by MsA	PI by DPET	Real
Adapter	33	10	6	1	1	1	4	3	0
Proxy	0	0	0	0	0	0	0	0	0
Bridge	0	0	0	0	0	0	0	0	0
Composite	0	0	0	0	0	0	0	0	0
Decorator	0	0	0	0	0	0	0	0	0

*Precision

Precision	Galib	Libg++	Groff
DPET	60%	100%	3 false positives
MsA	18%	100%	4 false positives

Notes:

PI-Pattern Instance

MsA-the tool using Multi-stage Approach proposed by Antoniol in [AFC98].

DPET- the tool “Design Pattern Extraction Tool”.

PI by DPET – the number of pattern instances retrieved by DPET.

PI by MsA – the number of pattern instances retrieved by MsA in [AFC98].

*Precision is the ratio of the number of relevant items retrieved over the total number of all items retrieved.

Table 6.6 Comparison of pattern instances obtained by DPET and MsA

6.3.2 Discussion on Case Study-2

From Table 6.6, we can see that the precision has been increased from 18% to 60% when retrieving pattern instances from *galib* source code using DPET. Because the *libg++* has only one Adapter pattern, so the precision of both DPET and MsA reaches 100%. For *groff* code there are no real patterns enclosed in the source code. DPET only has three false positives, one less than four in MsA. Thus it seems that our approach could reduce the number of false positives and augments the precision of extraction of design patterns. So far it is hard to find a piece of source code that contains rich patterns in the reality so that we can apply it to validate our approach and obtain more reasonable and convictive precision of detection.

In *groff* the reason for 3 false positives is that the three pattern instances have the same static structure as the model of Adapter patterns, but the developer did not use them as adapter patterns. If we add a constraint, which in fact is the operation of delegator that has the same name as that of the operation of delegate these false positives will be eliminated. But in fact, it is very likely for developers to use different operation names of delegator and delegatee when implementing adapter design patterns. If we add this constraint in our model such adapter patterns with different operation name of delegator and delegatee will be lost. This has greater negative impact on program understanding than not using this constraint.

6.4 Relationship between Detection Times

In the whole process of extraction the detection time of each piece of code is shown in table 6.7.

	Libg++	galib	LQNS	groff
LOC	10680	12556	21182	26677
Classes	55	69	279	290
Operations	348	655	1911	2549
Aggregations	22	29	142	61
Associations	4	4	16	0
Inheritances	16	42	193	91
Using	66	168	700	243
Delegations	1	10	28	16
*DPET Time(sec)	25	64	103	81

Table 6.7 Code characteristics and detection time of each software system

From the Table 6.7 we can see that the detection time is increasing with the LOC (Lines of Code) increasing. But the comparison of groff and LQNS is an exception. Groff has 26677 lines of code, greater than 21182 lines of code in LQNS, but the detection time of groff (81sec) is less than that of LQNS (103 sec). This may be due to the fact that relationships among classes in LQNS are much more complicated than those of groff. We try to investigate this claim in table 6.8. For instance, LQNS has 142 aggregation relationships, 193 inheritance and 700 using relationships while groff only has 61, 91, and 243 respectively. So DPET has to take more time to analyze these relationships.

In order to further explore the relationship between relationships among classes and detection time we try to remove the detection of each relationship to see what happens. The results are in the Table 6.8. The operating environment for table 6.7 and the suppositions for table 6.7 and 6.8 are given below in section 6.4.1.

	libg++		galib		LQNS		groff	
Normal (Sec)	25	*Rate	64	*Rate	103	*Rate	81	*Rate
Removing Delegation (Sec)	24	4%	63	1%	102	1%	80	1%
Removing Association (Sec)	23	8%	62	3%	99	4%	78	4%
Removing Using Relationship (Sec)	23	8%	60	6%	93	10%	75	7%
Removing Inheritance (Sec)	24	4%	63	1%	102	1%	80	1%
Removing Aggregation (Sec)	23	8%	62	3%	102	1%	79	2%
<p>Normal: the detection time spent in Table 6.7.</p> <p>Removing X: the detection time spent when not detecting X relationship.</p> <p>*Rate: the decreasing rate of the detection time after not detecting X in comparison with the normal detection time, i.e., $\text{Rate} = (\text{NDT} - \text{RDT}) / \text{NDT}$, where</p> <p>NDT = Normal detection time; RDT = the detection time spent when not detecting some relationship.</p> <ul style="list-style-type: none"> Sampling steps for detection time: <p>The program runs five times in each case so that five sets of time values are obtained, and then get the average values.</p>								

Table 6.8 Detection time table after not detecting some relationships

The operating environment of our case study is shown in Table 6.9 for reference and comparison in the future.

Operating Environment: Sun Workstation Sun Blade 100	
Operating System	SunOS 5.8
Physical Memory	128M DIMM
Processor	500-MHz UltraSPARC[tm]-Iie, 64-bit
Cache Memory	256-KB L2 external cache
Disk	15GB

Table 6.9 Operating environment of this experiment

6.4.1 Discussion – Hypotheses on design information detection time

- *Hypothesis 1:* After removing the detection of using relationships the detection time of LQNS relatively decreases by 10% from 103 to 93. Though the LOC of Groff is greater than that of LQNS the number of using relationships of LQNS is almost 3 times as that of Groff (243/700). The using relationships may be a contributing factor to the detection time of LQNS compared to that of groff.
- *Hypothesis 2:* The Lines of Code of galib is 1.2 times that of libg++ but the detection time of galib is 2.7 times compared to libg++. This might imply that the detection time is related with not only LOC, but also the number of some kind of relationships among classes in the software systems.
- *Hypothesis 3:* In each piece of code the number of using relationships is the greatest among a variety of relationships. From table 6.8 we can see that the rate of the detection time changing has been decreased after removing the detection of a using relationship. In comparison with removing the detection of other relationships, using relationships have a great impact on the detection time. On the other hand, the number of delegation relationships is the second least in each piece of code in Table 6.7, removing it has little impact on the detection time. The reason why removing using relationships has the greatest impact on the detection time is because the number of using relationships in each system is the most numerous of all kinds of relationships.
- *Hypothesis 4:* After removing the detection of association relationship its impact on the detection time seems greater than that of removing delegations, even though the number of association relationships is less than that of delegation relationships. This is because the definition of association is cyclic aggregation and using relationships.

Chapter 7 Conclusions & Future Work

This chapter discusses important conclusions that are discussed in this thesis and presents some suggestions for future research.

This thesis presents a rule-based approach in the extraction of design patterns in order to understand software systems at a pattern level. The models for formal descriptions of design patterns proposed are based on static and dynamic characteristics of design patterns. It is stored in a rule base, while design information extracted from source code is stored in the fact base, design patterns are extracted by querying the knowledge base composed of both the fact and rule base.

7.1 Conclusions

Four pieces of software systems have been applied in our case studies. Their results are encouraging and show that DPET can effectively extract design patterns from source code. Furthermore, by comparing these results with the approach proposed by Antoniol et al, our approach does reduce the false instances and augment the precision of pattern detection. We also carried out a study on the relationship between detection time and class relationships and proposed some hypotheses.

The following conclusions are made from this thesis:

- The rule-based approach makes implementation simple, flexible and extendable. This is the most important contribution of this thesis.
- The model for formal descriptions of design patterns is based on static and dynamic characteristics of design patterns. For some behavioral design patterns dynamic information is the only way to identify them.

- Logic-based pattern detection makes this process language-independent. The pattern detection can be applied to other language like Java without modifications.
- Separation of the extraction of design information from the design pattern recovery makes the whole extraction process more effective and overcomes the drawbacks of logic programming - slow execution time.
- The parser we have developed is capable of scanning the entire C++ source code so that some important relationships like delegation can be detected thereby contributing to the effective detection of design patterns.
- The software maintainers can get benefits from DPET performing between automatic and manual mode.
- The case studies on a large-sized software system have shown that our approach can be applied to large-sized software systems.
- In addition, the intermediate results (i.e. fact base) could be used to visualize the class diagram representing the static information of the system under review (cf. Appendix D)

7.2 Future Work

Several issues in which we are still interested in our future work are as follows:

- An approach to automatic instrumentation for obtaining dynamic information is needed to study further. We have tried to get dynamic information of software systems using the profiling technique. Profiling can provide call graphs and performance information in crucial section of the source code. But there is no information of call sequence available from call graph, which is the

key to extracting some behavioral design patterns based on dynamic information. Profiling alone cannot make significant contributions to the extraction of design patterns. Hence, an automatic instrumentation technique is needed for obtaining the call sequence. The basic technique of program instrumentation is to instrument a code at points of interest in the program. During the execution the instrumented code is then executed together with the original program code. It provides the time stamp of each call from which we can get the call sequence by comparing the call graph generated from the profiling tool. Manual instrumentation has very limited application. For large-sized software with several hundred of classes, it would become impossible.

- A graphic interface is needed to display class diagrams of software systems based on the fact base obtained by DPET. In addition, a set of classes composing a design pattern should be showed in certain way like highlight line so as to facilitate the process of reverse engineering. This can give software maintainers an intuitive view of software systems at pattern and design level.
- Further performance analysis is needed to prove the hypotheses presented in section 6.4. In terms of the data from our case studies several hypotheses about the relationship between detection time and class relationships are proposed. They need to be fully proved in the future.

In conclusion, this thesis has presented a comprehensive and simple approach to design pattern detection in order to aid program understanding and software maintenance. We believe that the software maintainers as well software engineers will find this approach useful.

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Appendix A The Detailed Extraction Process of Proxy and Adapter Patterns

A.1 Extraction Description of Proxy design patterns

1. Parsing the code using C++ parser

The following sample code fragment is adopted from the “Proxy” sample code in [Gam95].

```
1. class Graphic {                                     //abstract class Graphic
2. public:
3. virtual ~Graphic();
4. virtual void Draw(const Point& at) = 0;             // pure virtual operation
5. virtual void HandleMouse(Event& event) = 0;         //pure virtual operation
6. virtual const Point& GetExtent() = 0;               //pure virtual operation
7. virtual void Load(istream& from) = 0;               //pure virtual operation
8. virtual void Save(ostream& to) = 0;                 //pure virtual operation
9. protected:
10. Graphic();
11. };
12. class Image : public Graphic { //class Image inherits class Graphic
13. public:
14. Image(const char* file);
15. virtual ~Image();
16. virtual void Draw(const Point& at);
17. virtual void HandleMouse(Event& event);
18. virtual const Point& GetExtent();
19. virtual void Load(istream& from);
20. virtual void Save(ostream& to);
21. private:
22. // ...
23. };
24. class ImageProxy : public Graphic { //class ImageProxy inherits Graphic
25. public:
26. ImageProxy(const char* imageFile);
27. virtual ~ImageProxy();
28. virtual void Draw(const Point& at);
29. virtual void HandleMouse(Event& event);
30. virtual const Point& GetExtent();
31. virtual void Load(istream& from);
32. virtual void Save(ostream& to);
33. protected:
34. Image* GetImage(); //GetImage() return a pointer of Image
35. private:
36. Image* _image; //Image's instance as data member of class ImageProxy
37. Point _extent;
38. char* _fileName;
39. };
40. ImageProxy::ImageProxy (const char* fileName) {
41. _fileName = strdup(fileName);
42. _extent = Point::Zero; // don't know extent yet
43. _image = 0;
44. }
45. Image* ImageProxy::GetImage() {
```

```

46.  if (_image == 0) {
47.  _image = new Image(_fileName);
48.  }
49.  return _image;
50.  }
51.  const Point& ImageProxy::GetExtent () {
52.  if (_extent == Point::Zero) {
53.  _extent = GetImage()->GetExtent(); //GetImage() return a pointer of Image.
54.  }
55.  return _extent;
56.  }
57.  void ImageProxy::Draw (const Point& at) {
58.  GetImage()->Draw(at); //GetImage() return a pointer of Image.
59.  }
60.  void ImageProxy::HandleMouse (Event& event) {
61.  GetImage()->HandleMouse(event); //GetImage() return a pointer of Image.
62.  }
63.  void ImageProxy::Save (ostream& to) {
64.  to << _extent << _fileName;
65.  }
66.  void ImageProxy::Load (istream& from) {
67.  from >> _extent >> _fileName;
68.  }
69.  class TextDocument {
70.  public:
71.  TextDocument();
72.  void Insert(Graphic*);
73.  // ...
74.  };
75.  void dummy () {
76.  TextDocument* text = new TextDocument;
77.  // ...
78.  text->Insert(new ImageProxy("anImageFileName"));
79.  }

```

Comments:

The lines that are related with pattern detection in code have been bolded with comments. In order to better understand them, all comments are put together as follows for giving a whole view of the static information we need to extract from code.

```

// class Image is abstract class
// Draw() is pure virtual operation
// HandleMouse() is pure virtual operation
// GetExtent() is pure virtual operation
// Load() is pure virtual operation
// Save() is pure virtual operation
// class Image inherits class Graphic
// class ImageProxy inherits class Graphic
// GetImage() of class ImageProxy return a pointer of Image
// Image's instance as data member of class ImageProxy
// GetImage() return a pointer of Image.
// So the above should be equivalent of extent = _image->GetExtent();
// ImageProxy delegates Image via GetExtent() operation
// Draw() returns a pointer of Image.

```

```
// So the above should be equivalent of extent = _image->Draw();
// ImagePoxy delegates Image via Draw() operation
// GetImage() return a pointer of Image.
// So the above should be equivalent of extent = _image->HandleMouse();
// ImagePoxy delegates Image via HandleMouse() operation.
The above static information is exactly what we use.
```

2. Storing the program information in “cccc.db” after parsing the code

- *Data format for Classes:*

CCCC_Module@ModuleName@ModuleType

CCCC_ModExt@ModuleName@ModuleType@

FileName@Line@Definition/Declaration@Properties@Metrics

CCCC_Module@Graphic@class@

CCCC_ModExt@Graphic@class@proxy.C@78@definition@F??T2@LOC:4 COM:6 MVG:0@2@d@

CCCC_Module@Image@class@

CCCC_ModExt@Image@class@proxy.C@7@definition@F??T2@LOC:3 COM:0 MVG:0@2@d@

CCCC_ModExt@Image@class@proxy.C@14@declaration@F??T2@LOC:1 COM:2 MVG:0@2@d@

CCCC_ModExt@Image@class@proxy.C@97@definition@F??T0@LOC:4 COM:3 MVG:0@0@d@

CCCC_Module@ImageProxy@class@

CCCC_ModExt@ImageProxy@class@proxy.C@117@definition@F??T0@LOC:8 COM:2

MVG:0@0@d@

- *Data format for Operations:*

CCCC_Member@ModuleName@OperationName@ReturnType@Parameter@

CCCC_MemExt@ModuleName@OperationName@ReturnType@Parameter@

FileName@Line@Declaration/Definition@OperationType@Metrics

CCCC_Member@Graphic@Draw@void@(const Point &@)@

CCCC_MemExt@Graphic@Draw@void@(const Point

&@)@proxy.C@83@declaration@F??T0@LOC:1 COM:2 MVG:0@0@d@

CCCC_Member@Graphic@HandleMouse@void@(Event &event)@

CCCC_MemExt@Graphic@HandleMouse@void@(Event&event)@proxy.C@84@declaration@F??T0@LOC:1 COM:0 MVG:0@0@d@

CCCC_Member@Image@Draw@void@(const Point &@)@

CCCC_MemExt@Image@Draw@void@(const Point &@)@proxy.C@9@declaration@F??T0@LOC:1

COM:0 MVG:0@0@d@

CCCC_Member@Image@Draw@void@(const Point &@)@

CCCC_MemExt@Image@Draw@void@(const Point

&@)@proxy.C@103@declaration@F??T0@LOC:1 COM:2 MVG:0@0@d@

CCCC_Member@Image@HandleMouse@void@(Event &event)@

CCCC_MemExt@Image@HandleMouse@void@(Event

&event)@proxy.C@104@declaration@F??T0@LOC:1 COM:0 MVG:0@0@d@

CCCC_Member@ImageProxy@Draw@void@(const Point &@)@

CCCC_MemExt@ImageProxy@Draw@void@(const Point

&@)@proxy.C@123@declaration@F??T0@LOC:1 COM:2 MVG:0@0@d@

CCCC_MemExt@ImageProxy@Draw@void@(const Point

&@)@proxy.C@163@definition@F??T@LOC:3 COM:2 MVG:0@?@?@

CCCC_Member@ImageProxy@HandleMouse@void@(Event &event)@

CCCC_MemExt@ImageProxy@HandleMouse@void@(Event

&event)@proxy.C@124@declaration@F??T0@LOC:1 COM:0 MVG:0@0@d@

CCCC_MemExt@ImageProxy@HandleMouse@void@(Event

&event)@proxy.C@168@definition@F??T@LOC:3 COM:2 MVG:0@?@?@

- *Data format for basic relationships among classes (pass by reference, has by value, inheritance) and class attribute: data member in class.*

```

CCCC_UseRel@ModuleName1@ModuleName2@(Pointer/Reference)@
CCCC_UseExt@ModuleName1@ModuleName2@(Pointer/Reference)
CCCC_UseRel@Graphic@ImageProxy@@
CCCC_UseExt@Graphic@ImageProxy@@proxy.C@117@inheritance@F??T0@*@@0@I@
CCCC_UseRel@Image@ImageProxy@_image@
CCCC_UseExt@Image@ImageProxy@_image@proxy.C@135@has by reference@F??T2@LOC:0
COM:0 MVG:0@2@h@
CCCC_UseRel@Graphic@Image@@
CCCC_UseExt@Graphic@Image@@proxy.C@97@inheritance@F??T0@*@@0@I@

```

- *Data Format for Delegation Instances:*

```

CCCC_Delegation@Reference/Pointer@CalledOperation@CallingModule@
CallingOperation@
CCCC_Delegation@GetImage@Draw@ImageProxy@Draw@
CCCC_Delegation@GetImage@GetExtent@ImageProxy@GetExtent@
CCCC_Delegation@GetImage@HandleMouse@ImageProxy@HandleMouse@

```

3. Extracting static info(classes and their interrelationships) from *cccc.db* and storing it into “*writepro.pl*” (executing *detect cccc.db*)

- *The facts generated by running “detect cccc.db”*

```

Class(concrclass,graphic).
class(concrclass,image).
class(concrclass,imageProxy).
operation(_,_,graphic,draw,_,_,_).
operation(_,_,graphic,getExtent,_,_,_).
operation(_,_,graphic,handleMouse,_,_,_).
operation(_,_,image,draw,_,_,_).
operation(_,_,image,getExtent,_,_,_).
operation(_,_,image,handleMouse,_,_,_).
operation(_,_,imageProxy,draw,_,_,_).
operation(_,_,imageProxy,getExtent,_,_,_).
operation(_,_,imageProxy,getImage,_,_,_).
operation(_,_,imageProxy,handleMouse,_,_,_).
inheritance(graphic,image).
inheritance(graphic,imageProxy).
delegation(imageProxy,image).

```

- *The rules for identifying the “Proxy” design pattern*

```

proxy(Subj,RealSubj,Proxy,N):- //N is the number of pattern instance
    proxy_stcrelations(Subj,RealSubj,Proxy),
    proxy_classes(Subj,RealSubj,Proxy),
    proxy_ops(Subj,Op,RealSubj,Proxy),
    increment(N).

proxy_classes(Subj,RealSubj,Proxy):-
    class(_,Subj),
    class(_,RealSubj),
    class(_,Proxy),
    !.

proxy_stcrelations(Subj,RealSubj,Proxy):-
    inheritance(Subj,RealSubj),
    inheritance(Subj,Proxy),
    delegation(RealSubj,Proxy).

proxy_ops(Subj,Op,RealSubj,Proxy):-
    operation(_,_,Subj,Op,_,_,_),

```

```

operation (_,_,RealSubj,Op,_,_,_) ,
operation (_,_,Proxy,Op,_,_,_) ,
!.

```

The above diagram is UML representation of the “Proxy” design pattern existing among these three classes.

4. The results after running SWI-Prolog inference engine to identify design patterns:

```

Subject = Graphic
RealSubject= Image
Proxy= ImageProxy

```

A.2 Extraction description for *Adapter* design patterns

1. Parsing source code using C++ parser

The following sample code fragment is from LQNS that is applied in case study-2 later.

```
1.  class ActivityList                                //class ActivityList
2.  {
3.  friend class Activity;
4.  public:
5.  virtual const Component * owner() const; // virtual operation
6.  //...
7.  private:
8.  //...
9.  const Activity * originator;
10. };
11. class SequentialActivityList : public ActivityList
12. //SequentialActivityList inherits ActivityList
13. {
14. public:
15. virtual const Component * owner() const; //virtual operation
16. //...
17. protected:
18. Activity * myActivity;
19. //Activity's instance as data member of SequentialActivityList
20. };
21. /*
22. Update the waiting time value for myActivity.
23. */
24. const Component * SequentialActivityList::owner() const
25. {
26. return myActivity->owner();
27. // SequentialActivityList delegates Activity's owner() operation.
28. }

29. class Activity : public Phase //Activity inherits Phase
30. {
31. public:
32. //...
33. virtual const Component * owner() const; //virtual operation
34. private:
35. //...
36. };
37. const Component *
38. Activity::owner() const
39. {
40. return myTask;
41. }
```

Comments:

All comments are put together here for give a view of the static information needed for extraction of the Adapter design pattern.
// class Activity
// owner() is virtual operation in class Activity
//SequentialActivityList inherits ActivityList
//owner() in SequentialActivityList is virtual operation
//Activity's instance as data member of SequentialActivityList

```
// SequentialActivityList delegates Activity's owner() operation
//owner() in Activity class is virtual operation
The above information is exactly what we use to extract the Adapter design
pattern.
```

2. Storing program information in “cccc.db” after parsing the code

- *Data format for Classes:*

CCCC_Module@ModuleName@ModuleType

CCCC_ModExt@ModuleName@ModuleType@

FileName@Line@Definition/Declaration@Properties@Metrics

CCCC_Module@Activity@class@

CCCC_ModExt@Activity@class@activity.h@186@definition@T??T0@LOC:16 COM:16

MVG:0@0@d@

CCCC_ModExt@Activity@class@activity.h@280@declaration@T??T2@LOC:1 COM:0

MVG:0@2@d@

CCCC_ModExt@Activity@class@phase.h@126@declaration@????2@LOC:1 COM:0

MVG:0@2@d@

CCCC_ModExt@Activity@class@task.h@114@declaration@????2@LOC:1 COM:0

MVG:0@2@d@

CCCC_ModExt@Activity@class@entry.h@120@declaration@????2@LOC:1 COM:0

MVG:0@2@d@

CCCC_Module@ActivityList@class@

CCCC_ModExt@ActivityList@class@activity.h@166@declaration@????2@LOC:1 COM:0

MVG:0@2@d@

CCCC_ModExt@ActivityList@class@activity.h@278@definition@T??T2@LOC:11 COM:6

MVG:0@2@d@

CCCC_ModExt@ActivityList@class@phase.h@125@declaration@????2@LOC:1 COM:0

MVG:0@2@d@

CCCC_ModExt@ActivityList@class@task.h@116@declaration@????2@LOC:1 COM:0

MVG:0@2@d@

CCCC_Module@SequentialActivityList@class@

CCCC_ModExt@SequentialActivityList@class@activity.h@323@definition@T??T0@LOC:7 COM:1 MVG:0@0@d@

- *Data format for Operations:*

CCCC_Member@ModuleName@OperationName@ReturnType@Parameter@

CCCC_MemExt@ModuleName@OperationName@ReturnType@Parameter@

FileName@Line@Declaration/Definition@OperationType@Metrics

CCCC_Member@Activity@owner@@()@

CCCC_MemExt@Activity@owner@@()@activity.h@223

@declaration@T??T0@LOC:1 COM:0 MVG:0@0@d@

CCCC_MemExt@Activity@owner@@()@activity.C@421

@definition@TT??@LOC:4 COM:0 MVG:1@?@

CCCC_Member@ActivityList@owner@@()@

CCCC_MemExt@ActivityList@owner@@()@activity.h@296@declaration@T??T0@LOC:1 COM:0 MVG:0@0@d@

CCCC_MemExt@ActivityList@owner@@()@activity.C@962@definition@TT??@LOC:5 COM:0 MVG:1@?@

CCCC_Member@SequentialActivityList@owner@@()@

CCCC_MemExt@SequentialActivityList@owner@@()@activity.h@328@declaration@T??T0@LOC:1 COM:0 MVG:0@0@d@

CCCC_MemExt@SequentialActivityList@owner@@()@activity.C@1046@definition@TT??@LOC:4 COM:0 MVG:1@?@

- *Data format for basic relationships among classes (pass by reference, has by value, inheritance) and class attribute: data member in class.*

```
CCCC_UseRel@ModuleName1@ModuleName2@(Pointer/Reference)@
CCCC_UseExt@ModuleName1@ModuleName2@(Pointer/Reference)
```

```
CCCC_UseRel@Activity@SequentialActivityList@myActivity@
CCCC_UseExt@Activity@SequentialActivityList@myActivity@activity.h@334@has by
reference@T??T1@LOC:0 COM:0 MVG:0@1@h@
CCCC_UseRel@ActivityList@SequentialActivityList@@
CCCC_UseExt@ActivityList@SequentialActivityList@@activity.h@323@
inheritance@T??T0@*@0@I@
```

- *Data Format for Delegation Instances:*

```
CCCC_Delegation@Reference/Pointer@CalledOperation@CallingModule@
CallingOperation@
CCCC_Delegation@myActivity@owner@SequentialActivityList@owner@
```

3.Extracting static information (classes and their interrelationships) from program information in the file “cccc.db” and storing it into “writepro.pl” in Prolog representation.

- *The facts generated by running “detect cccc.db”*

```
class(concrclass,activity).
class(concrclass,activityList).
class(concrclass,sequentialActivityList).
operation(_,_,activityList,owner,_,_,_).
operation(_,_,activity,owner,_,_,_).
operation(_,_,sequentialActivityList,owner,_,_,_).
inheritance(activityList,sequentialActivityList).
delegation(sequentialActivityList,activity).
```

- *The rules for identifying “Adapter” design pattern*

```
adapter(Target,Adapter,Adaptee,N):-
    adapter_stcrelations(Target,Adapter,Adaptee),
    adapter_classes(Target,Adapter,Adaptee),
    adapter_ops(Adapter,Adaptee,Target,Request,SpecRequest),
    increment(N).
adapter_classes(Target,Adapter,Adaptee):-
    class(_,Target),
    class(concrclass,Adapter),
    class(concrclass,Adaptee),
    !.
adapter_ops(Adapter,Adaptee,Target,Request,SpecRequest):-
    operation(_,_,Adaptee,SpecRequest,_,_,_),
    operation(_,_,Target,Request,_,_,_),
    operation(_,_,Adapter,Request,_,_,_),
    !.
adapter_stcrelations(Target,Adapter,Adaptee):-
    inheritance(Target,Adapter),
    delegation(Adapter,Adaptee).
```

The above diagram is UML representation of “Adapter” design pattern existing among these three classes.

4. By running SWI-Prolog inference engine to identify design patterns:

Target = activityList
 Adapter= sequentialActivityList
 Adaptee= activity

Appendix B The Data Format for Source Code Information

The data formats used in the extraction process is shown below.

- *Data format for Classes:*

CCCC_Module@ModuleName@ModuleType

CCCC_ModExt@ModuleName@ModuleType@

FileName@Line@Definition/Declaration@Properties@Metrics

- *ModuleType: Class and Struct*
- *Meaning: At the Line of the FileName file, there is a Definition/Declaration of ModuleName module of ModuleType (class/struct) type with Properties and Metrics.*

- *Data format for Operations:*

CCCC_Member@ModuleName@OperationName@ReturnType@Parameter@

CCCC_MemExt@ModuleName@OperationName@ReturnType@Parameter@

FileName@Line@Declaration/Definition@OperationType@Metrics

- *Meaning: At the Line of the FileName file, there is a Definition/Declaration of OperationName of OperationType in ModuleName with ReturnType, Parameter and Metrics.*

- *Data format for basic relationships among classes (pass by reference, has by value, inheritance) and class attribute: data member in class.*

CCCC_UseRel@ModuleName1@ModuleName2@(Pointer/Reference)@

CCCC_UseExt@ModuleName1@ModuleName2@(Pointer/Reference)

@FileName@Line@BasicRelationships@Properties@Metrics

<ul style="list-style-type: none"> ▪ Meaning: At the Line of the FileName file, there is a basic Relationship between ModuleName1 and ModuleName2 with Properties and Metrics.
<ul style="list-style-type: none"> • <i>Data Format for Delegation Instances:</i> CCCC_Delegation@Reference/Pointer@CalledOperation@CallingModule@ CallingOperation@ ▪ Meaning: CallingOperation of CallingModule invokes a CalledOperation of Object Reference/Pointer.
<ul style="list-style-type: none"> • <i>Data Format for Creation Information:</i> CCCC_Composition@InstanceClass@InstanceObject@ScopeClass@ ScopeOperation@ • Meaning: There is an InstanceObject of type of InstanceClass created in ScopeOperation of ScopeClass.
<ul style="list-style-type: none"> • <i>Data Format for ReturnType of operation:</i> CCCC_Return@RealClassType@ReturnPointer@ReturnClassType@ ReturnOperation@ • Meaning: The ReturnOperation of ReturnClassType Returns a ReturnPointer or an object of RealClassType.

Appendix C The Results Of Profiling The Sample Code of *Chain of Responsibility* Design Patterns

The graph below is the complete call graph obtained by profiling the sample code of Chain of Responsibility design patterns in Section 5.3.2.

It consists of two parts. One is call graph profile and the other is flat profile.

```
/*
 * Copyright (c) 1993 by Sun Microsystems, Inc.
 */

#pragma ident      "@(#)gprof.callg.blurb  1.8   93/06/07 SMI"
```

call graph profile:

The sum of self and descendents is the major sort for this listing.

function entries:

index	the index of the function in the call graph listing, as an aid to locating it (see below).
%time	the percentage of the total time of the program accounted for by this function and its descendents.
self	the number of seconds spent in this function itself.
descendents	the number of seconds spent in the descendents of this function on behalf of this function.
called	the number of times this function is called (other than recursive calls).
self	the number of times this function calls itself recursively.
name	the name of the function, with an indication of its membership in a cycle, if any.
index	the index of the function in the call graph listing, as an aid to locating it.

parent listings:

self* the number of seconds of this function's self time
 which is due to calls from this parent.

descendents* the number of seconds of this function's
 descendent time which is due to calls from this
 parent.

called** the number of times this function is called by
 this parent. This is the numerator of the
 fraction which divides up the function's time to
 its parents.

total* the number of times this function was called by
 all of its parents. This is the denominator of
 the propagation fraction.

parents the name of this parent, with an indication of the
 parent's membership in a cycle, if any.

index the index of this parent in the call graph
 listing, as an aid in locating it.

children listings:

self* the number of seconds of this child's self time
 which is due to being called by this function.

descendent* the number of seconds of this child's descendent's
 time which is due to being called by this
 function.

called** the number of times this child is called by this
 function. This is the numerator of the
 propagation fraction for this child.

total* the number of times this child is called by all
 functions. This is the denominator of the
 propagation fraction.

children the name of this child, and an indication of its
 membership in a cycle, if any.

index the index of this child in the call graph listing,
 as an aid to locating it.

* these fields are omitted for parents (or
children) in the same cycle as the function. If
the function (or child) is a member of a cycle,
the propagated times and propagation denominator

represent the self time and descendent time of the cycle as a whole.

** static-only parents and children are indicated by a call count of 0.

cycle listings:
the cycle as a whole is listed with the same fields as a function entry. Below it are listed the members of the cycle, and their contributions to the time and call counts of the cycle.

granularity: each sample hit covers 4 byte(s) for 100.00% of 0.01 seconds

index	%time	self	descendents	called/total called+self called/total	parents name index children
[1]	100.0	0.00	0.01	3+4	<cycle 1 as a whole> [1]
		0.00	0.01	4	_malloc_unlocked
	<cycle 1>	[3]			
		0.00	0.00	3	_smalloc <cycle 1>
[307]					

[2]	100.0	0.00	0.01		<spontaneous>
		0.00	0.01	3/3	malloc [2]
	<cycle 1>	[3]			_malloc_unlocked
		0.00	0.00	3/18	_mutex_lock [302]
		0.00	0.00	3/18	_mutex_unlock [303]

				1	_smalloc <cycle 1>
[307]		0.00	0.01	3/3	malloc [2]
[3]	100.0	0.00	0.01	4	_malloc_unlocked <cycle 1>
[3]		0.01	0.00	1/1	_morecore [4]
		0.00	0.00	4/4	cleanfree [5]
		0.00	0.00	1/1	realloc [18]
				3	_smalloc <cycle 1>
[307]					

		0.01	0.00	1/1	_malloc_unlocked
	<cycle 1>	[3]			
[4]	100.0	0.01	0.00	1	_morecore [4]
		0.00	0.00	2/2	_sbrk [312]

		0.00	0.00	4/4	_malloc_unlocked
	<cycle 1>	[3]			
[5]	0.0	0.00	0.00	4	cleanfree [5]

		0.00	0.00	1/3	internal_mcount [125]
		0.00	0.00	2/3	_start [798]
[6]	0.0	0.00	0.00	3	atexit [6]
		0.00	0.00	3/3	get_mem [7]
		0.00	0.00	3/18	_mutex_lock [302]
		0.00	0.00	3/18	_mutex_unlock [303]

		0.00	0.00	3/3	atexit [6]
[7]	0.0	0.00	0.00	3	get_mem [7]
		0.00	0.00	3/18	_mutex_lock [302]
		0.00	0.00	3/18	_mutex_unlock [303]
		0.00	0.00	1/1	mem_init [17]

		0.00	0.00	2/2	_fwrite_unlocked [310]
[8]	0.0	0.00	0.00	2	.udiv [8]

		0.00	0.00	2/2	_cleanup [320]
[9]	0.0	0.00	0.00	2	fflush [9]
		0.00	0.00	2/2	_fflush_u_iops [309]
		0.00	0.00	1/5	_fflush_u [304]

		0.00	0.00	2/2	_exithandle [321]
[10]	0.0	0.00	0.00	2	free_mem [10]
		0.00	0.00	2/18	_mutex_lock [302]
		0.00	0.00	2/18	_mutex_unlock [303]

		0.00	0.00	1/1	main [16]
[11]	0.0	0.00	0.00	1	HandleHelp__Button [11]
[12]		0.00	0.00	1/1	HasHelp__HelpHandler

		0.00	0.00	1/1	HandleHelp__Button [11]
[12]	0.0	0.00	0.00	1	HasHelp__HelpHandler [12]

		0.00	0.00	1/1	___Dialog:HelpHandleri
[316]					

[13]	0.0	0.00	0.00	1	SetHandler__HelpHandler:HelpHandler [13]

		0.00	0.00	1/1	_init [610]
[14]	0.0	0.00	0.00	1	check_nlspath_env [14]
		0.00	0.00	1/18	_mutex_lock [302]
		0.00	0.00	1/1	_geteuid [324]
		0.00	0.00	1/1	_getuid [326]
		0.00	0.00	1/1	_getegid [323]
		0.00	0.00	1/1	_getgid [325]
		0.00	0.00	1/18	_mutex_unlock [303]

		0.00	0.00	1/1	_start [798]
[15]	0.0	0.00	0.00	1	exit [15]
		0.00	0.00	1/1	_exithandle [321]

		0.00	0.00	1/1	_start [798]
[16]	0.0	0.00	0.00	1	main [16]
		0.00	0.00	1/1	__Application [314]
		0.00	0.00	1/1	__Dialog:HelpHandler
[316]		0.00	0.00	1/1	__Button:Widget [315]
		0.00	0.00	1/1	HandleHelp__Button [11]

		0.00	0.00	1/1	get_mem [7]
[17]	0.0	0.00	0.00	1	mem_init [17]

		0.00	0.00	1/1	_malloc_unlocked
[18]	<cycle 1> 0.0	[3] 0.00	0.00	1	realloc [18]

[718]		0.00	0.00	4/46	_pthread_mutex_lock
[193]		0.00	0.00	4/46	pthread_mutex_unlock
		0.00	0.00	19/46	_mutex_lock [302]
		0.00	0.00	19/46	_mutex_unlock [303]
[301]	0.0	0.00	0.00	46	_return_zero [301]

		0.00	0.00	1/18	check_nlspath_env [14]
		0.00	0.00	2/18	free_mem [10]
		0.00	0.00	2/18	_sbrk [312]
		0.00	0.00	3/18	atexit [6]

		0.00	0.00	3/18	get_mem [7]
		0.00	0.00	3/18	malloc [2]
		0.00	0.00	4/18	_exithandle [321]
[302]	0.0	0.00	0.00	18	_mutex_lock [302]
		0.00	0.00	19/46	_return_zero [301]

		0.00	0.00	1/18	check_nlspace_env [14]
		0.00	0.00	2/18	free_mem [10]
		0.00	0.00	2/18	_sbrk [312]
		0.00	0.00	3/18	atexit [6]
		0.00	0.00	3/18	get_mem [7]
		0.00	0.00	3/18	malloc [2]
		0.00	0.00	4/18	_exithandle [321]
[303]	0.0	0.00	0.00	18	_mutex_unlock [303]
		0.00	0.00	19/46	_return_zero [301]

		0.00	0.00	1/5	fflush [9]
		0.00	0.00	4/5	_fflush_u_iops [309]
[304]	0.0	0.00	0.00	5	_fflush_u [304]
		0.00	0.00	2/2	_lseek64 [311]

		0.00	0.00	1/4	__flsbuf [318]
		0.00	0.00	1/4	_xflsbuf [336]
		0.00	0.00	2/4	_fwrite_unlocked [310]
[305]	0.0	0.00	0.00	4	_realbufend [305]

		0.00	0.00	1/3	__Application [314]
		0.00	0.00	2/3	__Widget:Widget [308]
[306]	0.0	0.00	0.00	3	__HelpHandler:HelpHandler
[306]					

				3	_malloc_unlocked
	<cycle 1> [3]				
[307]	0.0	0.00	0.00	3	_smalloc <cycle 1> [307]
				1	_malloc_unlocked
	<cycle 1> [3]				

		0.00	0.00	1/2	__Button:Widget [315]
		0.00	0.00	1/2	__Dialog:HelpHandleri
[316]					
[308]	0.0	0.00	0.00	2	__Widget:Widget [308]
		0.00	0.00	2/3	

__HelpHandler:HelpHandler [306]					

		0.00	0.00	2/2	fflush [9]
[309]	0.0	0.00	0.00	2	_fflush_u_iops [309]
		0.00	0.00	4/5	_fflush_u [304]

		0.00	0.00	2/2	fwrite [96]
[310]	0.0	0.00	0.00	2	_fwrite_unlocked [310]
		0.00	0.00	2/4	_realbufend [305]
		0.00	0.00	2/2	.udiv [8]
		0.00	0.00	1/1	_wrtchk [335]
		0.00	0.00	1/1	__flsbuf [318]

		0.00	0.00	2/2	_fflush_u [304]
[311]	0.0	0.00	0.00	2	_lseek64 [311]

		0.00	0.00	2/2	_morecore [4]
[312]	0.0	0.00	0.00	2	_sbrk [312]
		0.00	0.00	2/18	_mutex_lock [302]
		0.00	0.00	2/2	_sbrk_unlocked [313]
		0.00	0.00	2/18	_mutex_unlock [303]

		0.00	0.00	2/2	_sbrk [312]
[313]	0.0	0.00	0.00	2	_sbrk_unlocked [313]

		0.00	0.00	1/1	main [16]
[314]	0.0	0.00	0.00	1	__Application [314]
		0.00	0.00	1/3	
__ExceptionHandler:ExceptionHandler [306]					

		0.00	0.00	1/1	main [16]
[315]	0.0	0.00	0.00	1	__Button:Widget [315]
		0.00	0.00	1/2	__Widget:Widget [308]

		0.00	0.00	1/1	main [16]
[316]	0.0	0.00	0.00	1	__Dialog:ExceptionHandler [316]
		0.00	0.00	1/2	__Widget:Widget [308]
		0.00	0.00	1/1	
SetHandler__ExceptionHandler:ExceptionHandler [13]					

		0.00	0.00	1/1	_isatty [328]
[317]	0.0	0.00	0.00	1	__errno [317]

		0.00	0.00	1/1	_thr_main [333]

[318]	0.0	0.00	0.00	1/1	_fwrite_unlocked [310]
		0.00	0.00	1	__flsbuf [318]
		0.00	0.00	1/4	_realbufend [305]
		0.00	0.00	1/1	_xflsbuf [336]

[319]	0.0	0.00	0.00	1/1	_init [610]
		0.00	0.00	1	_atexit_init [319]

[320]	0.0	0.00	0.00	1/1	_fini [578]
		0.00	0.00	1	_cleanup [320]
		0.00	0.00	2/2	fflush [9]

[321]	0.0	0.00	0.00	1/1	exit [15]
		0.00	0.00	1	_exithandle [321]
		0.00	0.00	4/18	_mutex_lock [302]
		0.00	0.00	4/18	_mutex_unlock [303]
		0.00	0.00	2/2	free_mem [10]

[322]	0.0	0.00	0.00	1/1	_wrtchk [335]
		0.00	0.00	1	_findbuf [322]
		0.00	0.00	1/1	_isatty [328]
		0.00	0.00	1/1	_setbufend [331]

[323]	0.0	0.00	0.00	1/1	check_nlspath_env [14]
		0.00	0.00	1	_getegid [323]

[324]	0.0	0.00	0.00	1/1	check_nlspath_env [14]
		0.00	0.00	1	_geteuid [324]

[325]	0.0	0.00	0.00	1/1	check_nlspath_env [14]
		0.00	0.00	1	_getgid [325]

[326]	0.0	0.00	0.00	1/1	check_nlspath_env [14]
		0.00	0.00	1	_getuid [326]

[327]	0.0	0.00	0.00	1/1	_isatty [328]
		0.00	0.00	1	_ioctl [327]

[328]	0.0	0.00	0.00	1/1	_findbuf [322]
		0.00	0.00	1	_isatty [328]
		0.00	0.00	1/1	__errno [317]
		0.00	0.00	1/1	_ioctl [327]

[329]	0.0	0.00	0.00	1/1	moncontrol [145]
		0.00	0.00	1	_profil [329]

[330]	0.0	0.00	0.00	1/1	_thr_main [333]
		0.00	0.00	1	_return_negone [330]

[331]	0.0	0.00	0.00	1/1	_findbuf [322]
		0.00	0.00	1	__setbufend [331]

[332]	0.0	0.00	0.00	1/1	fwrite [96]
		0.00	0.00	1	_setorientation [332]

[333]	0.0	0.00	0.00	1/1	__errno [317]
		0.00	0.00	1	__thr_main [333]
		0.00	0.00	1/1	_return_negone [330]

[334]	0.0	0.00	0.00	1/1	_xflsbuf [336]
		0.00	0.00	1	_write [334]

[335]	0.0	0.00	0.00	1/1	_fwrite_unlocked [310]
		0.00	0.00	1	_wrtchk [335]
		0.00	0.00	1/1	_findbuf [322]

[336]	0.0	0.00	0.00	1/1	__flsbuf [318]
		0.00	0.00	1	_xflsbuf [336]
		0.00	0.00	1/4	_realbufend [305]
		0.00	0.00	1/1	_write [334]

```

/*
 * Copyright (c) 1998 by Sun Microsystems, Inc.
 * All rights reserved.
 */

#pragma ident      "@(#)gprof.flat.blurb    1.9    98/04/09 SMI"

```

flat profile:

```

%           the percentage of the total running time of the
time        program used by this function.

cumulative  a running sum of the number of seconds accounted
seconds     for by this function and those listed above it.

self        the number of seconds accounted for by this
seconds     function alone. This is the major sort for this
            listing.

calls       the number of times this function was invoked, if
            this function is profiled, else blank.

self        the average number of milliseconds spent in this
ms/call     function per call, if this function is profiled,
            else blank.

total       the average number of milliseconds spent in this
ms/call     function and its descendents per call, if this
            function is profiled, else blank.

name        the name of the function. This is the minor sort
            for this listing. The index shows the location of
            the function in the gprof listing. If the index is
            in parenthesis it shows where it would appear in
            the gprof listing if it were to be printed.

```

Index by function names and Object modules listing:

The index entries are mapped to the function names. If the same function name appears in multiple object modules, each of these names is prefixed with a module identifier followed by a colon. The shared object modules listing that follows maps these identifiers to appropriate objects.

granularity: each sample hit covers 4 byte(s) for 100.00% of 0.01 seconds

% time	cumulative seconds	self seconds	calls	self ms/call	total ms/call	name
100.0	0.01	0.01	1	10.00	10.00	_morecore [4]
0.0	0.01	0.00	46	0.00	0.00	_return_zero [301]

0.0	0.01	0.00	18	0.00	0.00	_mutex_lock [302]
0.0	0.01	0.00	18	0.00	0.00	_mutex_unlock [303]
0.0	0.01	0.00	5	0.00	0.00	_fflush_u [304]
0.0	0.01	0.00	4	0.00	2.50	_malloc_unlocked
<cycle 1> [3]						
0.0	0.01	0.00	4	0.00	0.00	_realbufend [305]
0.0	0.01	0.00	4	0.00	0.00	cleanfree [5]
0.0	0.01	0.00	3	0.00	0.00	
__Handler:Handler [306]						
0.0	0.01	0.00	3	0.00	0.00	_sbrk <cycle 1>
[307]						
0.0	0.01	0.00	3	0.00	0.00	atexit [6]
0.0	0.01	0.00	3	0.00	0.00	get_mem [7]
0.0	0.01	0.00	2	0.00	0.00	.udiv [8]
0.0	0.01	0.00	2	0.00	0.00	__Widget:Widget [308]
0.0	0.01	0.00	2	0.00	0.00	_fflush_u_iops [309]
0.0	0.01	0.00	2	0.00	0.00	_fwrite_unlocked [310]
0.0	0.01	0.00	2	0.00	0.00	_lseek64 [311]
0.0	0.01	0.00	2	0.00	0.00	_sbrk [312]
0.0	0.01	0.00	2	0.00	0.00	_sbrk_unlocked [313]
0.0	0.01	0.00	2	0.00	0.00	fflush [9]
0.0	0.01	0.00	2	0.00	0.00	free_mem [10]
0.0	0.01	0.00	1	0.00	0.00	HandleHelp__Button [11]
0.0	0.01	0.00	1	0.00	0.00	HasHelp__Handler
[12]						
0.0	0.01	0.00	1	0.00	0.00	
SetHandler__Handler:Handler [13]						
0.0	0.01	0.00	1	0.00	0.00	__Applicationi [314]
0.0	0.01	0.00	1	0.00	0.00	__Button:Widget [315]
0.0	0.01	0.00	1	0.00	0.00	__Dialog:Handleri
[316]						
0.0	0.01	0.00	1	0.00	0.00	__errno [317]
0.0	0.01	0.00	1	0.00	0.00	__flsbuf [318]
0.0	0.01	0.00	1	0.00	0.00	_atexit_init [319]
0.0	0.01	0.00	1	0.00	0.00	_cleanup [320]
0.0	0.01	0.00	1	0.00	0.00	_exithandle [321]
0.0	0.01	0.00	1	0.00	0.00	_findbuf [322]
0.0	0.01	0.00	1	0.00	0.00	_getegid [323]
0.0	0.01	0.00	1	0.00	0.00	_geteuid [324]
0.0	0.01	0.00	1	0.00	0.00	_getgid [325]
0.0	0.01	0.00	1	0.00	0.00	_getuid [326]
0.0	0.01	0.00	1	0.00	0.00	_ioctl1 [327]
0.0	0.01	0.00	1	0.00	0.00	_isatty [328]
0.0	0.01	0.00	1	0.00	0.00	_profil [329]
0.0	0.01	0.00	1	0.00	0.00	_return_negone [330]
0.0	0.01	0.00	1	0.00	0.00	_setbufend [331]
0.0	0.01	0.00	1	0.00	0.00	_setorientation [332]
0.0	0.01	0.00	1	0.00	0.00	_thr_main [333]
0.0	0.01	0.00	1	0.00	0.00	_write [334]
0.0	0.01	0.00	1	0.00	0.00	_wrtchk [335]
0.0	0.01	0.00	1	0.00	0.00	_xflsbuf [336]
0.0	0.01	0.00	1	0.00	0.00	check_nlspace_env [14]
0.0	0.01	0.00	1	0.00	0.00	exit [15]
0.0	0.01	0.00	1	0.00	0.00	main [16]
0.0	0.01	0.00	1	0.00	0.00	mem_init [17]
0.0	0.01	0.00	1	0.00	0.00	realloc [18]

Index by function name

[8] .udiv	[323] _getegid	[332] _setorientation
[11] HandleHelp__Button	[324] _geteuid	[307] _smalloc
[12] HasHelp__HelpHand	[325] _getgid	[333] _thr_main
[13] SetHandler__HelpH	[326] _getuid	[334] _write
[314] __Application	[327] _ioctl	[335] _wrtchk
[306] __HelpHandler:H	[328] _isatty	[336] _xflsbuf
[315] __Button:Widget	[311] _lseek64	[6] atexit
[316] __Dialog:HelpHan	[3] _malloc_unlocked	[14] check_nlspath_env
[308] __Widget:Widget	[4] _morecore	[5] cleanfree
[317] __errno	[302] _mutex_lock	[15] exit
[318] __flsbuf	[303] _mutex_unlock	[9] fflush
[319] _atexit_init	[329] _profil	[10] free_mem
[320] _cleanup	[305] _realbufend	[7] get_mem
[321] _exithandle	[330] _return_negone	[16] main
[304] _fflush_u	[301] _return_zero	[17] mem_init
[309] _fflush_u_iops	[312] _sbrk	[18] realloc
[322] _findbuf	[313] _sbrk_unlocked	[1] <cycle 1>
[310] _fwrite_unlocked	[331] _setbufend	

Object modules

1: chain

The complete call graph for the sample code of Chain of Responsibility in Section 5.2.3

Appendix D Class Diagrams in LQNS

D.1 Class hierarchy of Server class in LQNS

D.2 Part of Class Diagram of LQNS

This class diagram is based on the database file “writepro.pl” generated by DPET.