

# Reveal: A Tool to Reverse Engineer Class Diagrams

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## Abstract

Many systems are constructed without the use of modeling and visualization artifacts, due to constraints imposed by deadlines or a shortage of manpower. Nevertheless, such systems might profit from the visualization provided by diagrams to facilitate maintenance of the constructed system. In this paper, we present a tool, Reveal, to reverse engineer a class diagram from the C++ source code representation of the software. In Reveal, we remain faithful to the UML standard definition of a class diagram wherever possible. However, to accommodate the vagaries of the C++ language, we offer some extensions to the standard notation to include representations for namespaces, stand-alone functions and friend functions. We compare our representation to three other tools that reverse-engineer class diagrams, for both compliance to the UML standard and for their ability to faithfully represent the software system under study.

*Keywords* Reverse Engineering, Unified Modeling Language, UML, Class Diagram, Automated Construction, Object-Oriented Programming

## 1 Introduction

The deliverable produced by a quality development process is excellent software that satisfies the evolving needs of its users. One approach to the production of such software requires the construction of models to visualize and control the systems evolving architecture, requirements, structure and behavior. The Unified Modeling Language (UML) has rapidly become the language of choice for developers who wish to visualize and model the system under development. The UML includes *use cases* to facilitate visualization of user requirements, *class diagrams* to visualize the design of the software and *sequence diagrams* to visualize the behavior of the objects in the system.

Unfortunately, many systems are constructed without the use of modeling and visualization artifacts, due to constraints imposed by deadlines, or a shortage of manpower. Nevertheless, such systems might profit from the visualization provided by the UML diagrams to facilitate maintenance of the constructed system. In this paper, we present

a tool, Reveal, to reverse engineer a class diagram from the C++ source code representation of the software. In Reveal, we remain faithful to the UML standard definition of a class diagram wherever possible. However, to accommodate the vagaries of the C++ language, we offer some extensions to the standard notation to include representations for namespaces, stand-alone functions and friend functions. We compare our representation to three other tools that reverse-engineer class diagrams: Superwomble(Jackson & Waingold 2001), Rational Rose<sup>©</sup> and TogetherSoft<sup>TM</sup>(TogetherSoft 2001). We compare the tools for both compliance to the UML standard and for their ability to faithfully represent the software system under study.

We have found Reveal to be useful for reverse engineering class diagrams of legacy code. However, Reveal does not provide *round-trip* engineering; that is, users cannot construct a class diagram, use the diagram as a guide to code development, and then reverse-engineer the resultant code back to a class diagram. Nevertheless, the contributions of our work are threefold. First, our tool is more precise than the three tools that we used in our comparison. We suspect that the other tools do not use a full parse to guide the reverse engineering process, but rather use a *fuzzy parse* that scans the code for keywords(Asveld 1995, Koppler 1997). In Reveal, we use *keystone* to provide a full parse of the code (Power & Malloy 2000, Power & Malloy 2001). A full parse permits reveal to capture class relationships that might be omitted in a fuzzy parse. Second, our extensions to accommodate C++ language constructs provide more complete modeling of the application. Third, our class diagrams are closer to the UML standard, version 1.3, than the other tools.

In the next section, we provide background about class diagrams, graphviz, the tool that we use to draw the class diagrams, and about *keystone* the parser front-end that we use to parse the input program under study. In Section 3, we overview the Reveal system, including a discussion of its usage. In Section 4, we present our API, Clouseau, that permits inspection of the namespaces, classes, functions and variables in a C++ program. In Section 5, we describe construction of Reveal class diagrams and in Section 6, we compare Reveal to three other tools. Finally, we draw conclusions in Section 7.

## 2 Background

In this section, we provide background information about UML class diagrams, the graphviz tool, and the *keystone* parser front-end that we use to parse the

C++ input program (Power & Malloy 2000, Power & Malloy 2001).

## 2.1 UML Class Diagrams

Because of the complexity inherent in large programs, a developer, or group of developers, may not be able to grasp the overall design of the system, even if those involved are familiar with the source code. The Unified Model Language (UML) includes graph structures to represent aspects of the program, providing an overview of the programs structure and behavior (Booch, Rumbaugh & Jacobson 1999). The UML can help even non-programmers get a better grasp of the overall functionality of the system.

A UML class diagram is a static representation of the program consisting of rectangles to represent classes in the system and lines connecting the rectangles to represent the relationships between the classes. In UML, a class is represented as a box with three vertical sections. The top section shows the name of the class. The middle section displays the variables belonging to the class, with symbols representing the visibility (public, protected, or private) and properties (constant or static). The bottom section contains the member functions of the class. Each method has a name, signature, and properties.

There are four types of relationships in a class diagram: association, dependency, generalization and realization. Each relationship is represented in the diagram by a different type of arrow.

An *association* is a structural relationship that describes a set of links, where a link is a connection among objects. An association can be a one-way or two-way relationship. Class A has an association with class B if class A has a data member of type B. If class B also has a data member of type A, then the relationship is bi-directional. A directed arrow to the associated class specifies a one-way relationship. A line (no arrowhead) signifies a bi-directional relationship. Associations are often adorned with numbers or symbols representing the *multiplicity* of the relationship, or how many objects of one class the other is using.

*Dependency* is a semantic relationship between two classes in which a change to one class (the independent class) may affect the semantics of the other class (the dependent class). A method is said to use an object of a class if the object is passed in as a parameter, created in the method, or returned from a method. In UML, dependencies are designated by a dashed arrow from the dependent class to the class on which it depends. If both classes depend on the other, a double-headed dashed arrow is used.

Dependency may also be used to show a special type of relationship between classes: friendship. If class A is a friend of class B, class A can access class B's private information. Friend classes are denoted by a dependency arrow with the stereotype <<friend>> on the arrow.

*Generalization*, or inheritance, is a specialization/generalization relationship where objects of the specialized element (the child) are substitutable for objects of the generalized element (the parent). *Realization* is a semantic relationship between classifiers, wherein one classifier specifies a contract that another classifier guarantees to carry out. In C++, an abstract base class, parent, has one or more purely virtual methods that every immediate child must overwrite. The contract between the parent and the child is that the child will overwrite these methods. Abstract classes are written in italics. Children of abstract classes are connected to the class by a dashed arrow with a hollow arrowhead.

## 2.2 The Graphviz Tool

*Graphviz* is a set of open-source drawing tools for creating directed or undirected graphs. Graphviz has two main purposes: creating graphs with good quality automated layout, and providing web drawing services that are easy to use. The layout of graphviz graphs is, in some cases, better than graphs drawn manually.

Among the Graphviz tools, dot is best suited to drawing UML diagrams. dot constructs directed graphs laid out in a hierarchical fashion. In addition to its layout ability, dot also allows a great deal of variation, including different node shapes, various arrow types for connecting the nodes, and graphs inside graphs. dot's layout algorithm places nodes in such a way that connecting lines seldom intersect and nodes appear organized. Part of dot's algorithm for placement of nodes involves determining a node's rank, or importance. When nodes are placed on a graph (with no arrows), dot will place them side-by-side, since these nodes all have the same rank. If an arrow is drawn between two nodes, the target will be moved down below the source of the arrow. The target now has a lower rank. In this manner, dot places each node. It is possible to specify that certain items must have equal rank.

Dot provides for three possible output formats for the graphs it creates: graphics interchange format (GIF), portable network graphics format (PNG), or Postscript format. Reveal generates the UML diagram using dot and automatically displays the outputted Postscript.

## 2.3 Keystone

*Keystone* is a parser front-end for the ISO C++ programming language. Keystone uses a bottom-up, backtracking parse algorithm, together with techniques such as *token decoration* to facilitate recognition of ambiguous language constructs.

Figure 1 summarizes the design of keystone, our system to construct a parser front-end for ISO C++. The figure presents two subsystems, illustrated as tabbed folders and designated by the <<subsystem>> stereotype. The ProgramProcessor subsystem is shown on the left and the Symbol Table subsystem is shown on the right of Figure 1.

The ProgramProcessor subsystem includes a Scanner and Parser and is responsible for initiating and directing symbol table construction and name lookup. This responsibility includes two phases: (1) assembling the necessary information for creation of a NameOccurrence object, and (2) directing the search for a corresponding NameDeclaration object in the Symbol Table subsystem.

The NameOccurrence object encapsulates local information relevant to name lookup, including the String representation of the name, a boolean to indicate name qualification (by class or namespace), and an enumeration, OccurSpecifier, that captures lexical information about the context in which the name occurred.

## 3 Overview of the Reveal Tool

In this section, we overview the Reveal Tool. In Section 3.1, we describe the important subsystems used to build Reveal, including the Clouseau API that is an interface into the keystone parser front-end (Power & Malloy 2000, Power & Malloy 2001). In Section 3.2, we describe use of the Reveal tool, including our graphical user interface that permits users to set options to adjust the view of the class diagram.

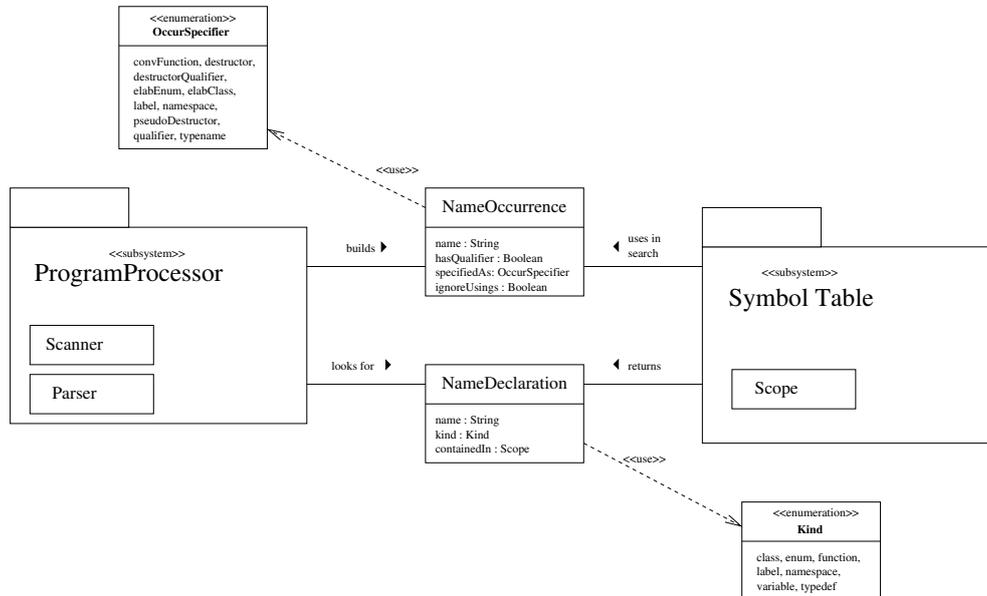


Figure 1: *Keystone*. This figure summarizes the design of *keystone*, a parser front-end for ISO C++. The *ProgramProcessor* subsystem is responsible for initiating and directing symbol table construction and name lookup by marshaling information about the name in a *NameOccurrence* object and directing the search for a corresponding *NameDeclaration* in the *Symbol Table* subsystem.

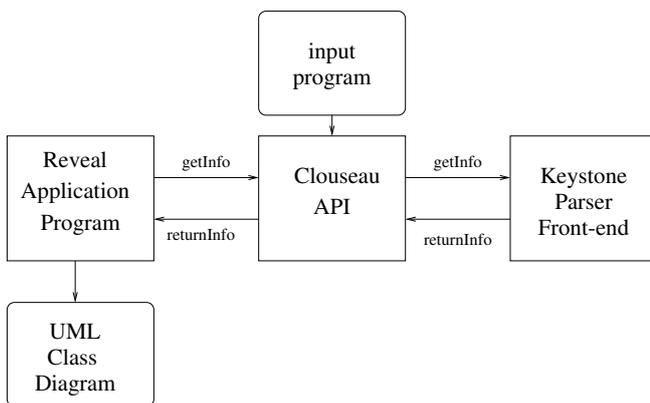


Figure 2: **Reveal System Overview.**

### 3.1 Overview of the Reveal System

Figure 2 illustrates the important subsystems in the Reveal tool. The box on the left of the figure is the *Reveal* program that contains the algorithm and data structures to construct a class diagram. The box on the right of the figure is the *keystone* parser front-end that we use to parse the input program, providing information such as type, scope and accessibility for variables, classes, and namespaces in the program. The box that is interposed between the *Reveal* program and *keystone* is an API, *Clouseau*, that allows the *Reveal* program to access *keystone* without having to understand *keystone*. Thus, the *Reveal* program never actually “sees” code, but rather retrieves any required information about the input program using *Clouseau*.

The rounded box at the top of Figure 2, illustrates the C++ input code, *input program*, for which the *Reveal* system will construct a class diagram; the constructed class diagram is represented by the rounded box on the lower left of the figure, *UML Class Diagram*.

### 3.2 Using the Reveal Tool

Figure 3 illustrates a sample usage of the *Reveal* tool. The large rectangle on the left is the graphical user interface, GUI, that facilitates use of the tool, and the large rectangle on the right is an abbreviated version of a class diagram for the example program in Figure 4. *Reveal* permits users to choose many options including either a full class diagram that lists all data attributes and member functions for each class, or an abbreviated class diagram where the data attributes and member functions are elided from the diagram. *Reveal* writes the class diagram in postscript format and uses *ghostview* as the viewer.

The GUI on the left of Figure 3 is developed using the V GUI Toolkit (Wampler 2001), has two drop down menus, *File* and *Options*, and four buttons, *New*, *Refresh*, *Redraw* and *Exit*. The *File* menu permits the user to select a file and load the C++ program into the workspace. Once loaded, *Reveal* preprocesses the input file to generate a file containing all of the C++ files used by the input program, displays the code on the read-only canvas, and displays the UML class diagram. The preprocessing, loading and displaying are all performed by the single *load* command. Also, by displaying all of the source files in one window, the user can easily compare the code with the corresponding class diagram that is being displayed.

The *Options* menu permits the user to set options to display library classes, namespace partitions, data members and member signatures for classes. These options permit the user to display only the information required to understand the code under study. The rectangle on the right side of the GUI, labeled *Diagram Options*, is the dialog box that permits the user to set these options. There are five options listed in the dialog box and none of these are checked, which produces the abbreviated class diagram on the right side of the figure.

The buttons in the GUI permit the user to clear the workspace, *New*, refresh the canvas in case the user has changed the code that is currently depicted, *Refresh*, redraw the current class diagram, *Redraw*, or to quickly exit the program: *Exit*. The code listed

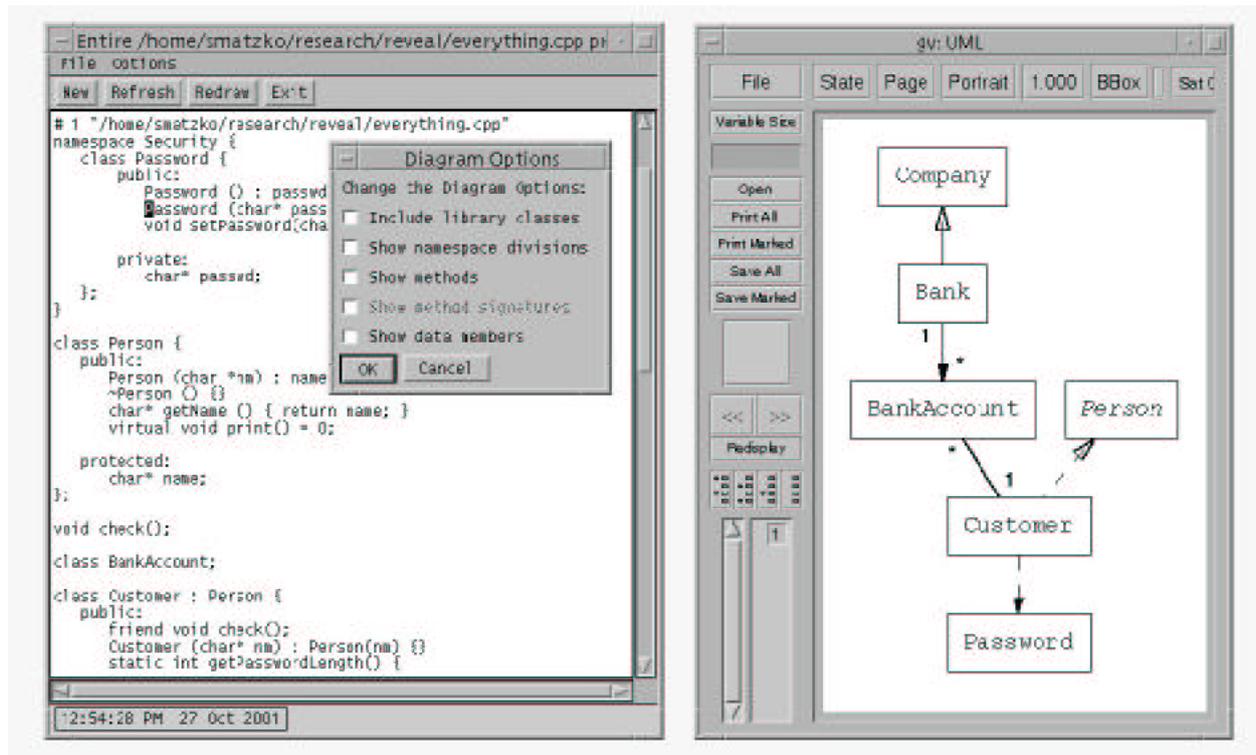


Figure 3: **GUI and abbreviated class diagram.** This figure illustrates the GUI that provides an interface for Reveal. The canvas of the GUI contains a C++ program; the corresponding class diagram is shown on the right of the figure. The user has chosen an abbreviated class diagram, but Reveal permits the user to choose options to view the full class diagram.

on the canvas of the GUI is the C++ program that corresponds to the class diagram on the right side of the figure. This canvas permits the user to scroll through the code listing, but does not permit the user to modify the code. The full code listing for the example program is listed in Figure 4; this example threads our paper and we later use this example to compare and contrast Reveal with three other tools that reverse-engineer class diagrams. In Section 5, we present more explanation of the example program in Figure 4, together with a full class diagram drawn by Reveal.

#### 4 The Clouseau API

The Clouseau<sup>1</sup> application programmers interface (API), was designed to facilitate symbol table inspection of programs written in the C++ language. Clouseau provides information about the accessibility, visibility, and type of namespaces, classes, functions, and variables for the program under consideration. With Clouseau, the application programmer is completely separated from the complexity of parsing. Figure 2 illustrates the relationship between Clouseau and the other parts of the Reveal system, where the **input program** is actually read by the Clouseau API, rather

<sup>1</sup>The Clouseau API is named after *Inspector Clouseau*, a character in the *Pink Panther* movies, because the API permits users to “inspect” symbol table information.

than the **Reveal Program**. Moreover, the Clouseau API forms a facade for the **keystone** parser, so that users can access its functionality without the burden of dealing with its complexity (Gamma, Helm, Johnson & Vlissides 1995). Clouseau users are relieved of the burden of parsing the program, since the API exploits the **keystone** parser to provide this functionality. Clouseau is implemented as a Unix<sup>TM</sup> shared object.

A goal of the Clouseau API is to provide a complete and minimal interface to provide parsing and symbol table information for various and sundry applications. Clouseau is currently being used by two different applications: **Reveal**, and **Taxonomy**, an application that describes a taxonomy for implementation-based testing of object-oriented classes (Clarke & Malloy 2001). The parsing and symbol table information required by **Taxonomy** is mostly boolean, such as information to determine if a variable is a pointer. However, the information required by **Reveal** is more comprehensive, such as information about the list of classes that might be contained in a namespace. Clouseau provides both types of information, while presenting a minimum interface for easy use.

The important classes in the Clouseau interface are illustrated in Figure 5, including member functions for two of the classes, **ScopeInfo** and **ClassInfo**. **ScopeInfo** is a base class for the other classes in the API; **ClassInfo** contains functionality to provide information about classes to users of the

```

1 namespace Security {
2   class Password {
3     public:
4       Password () : passwd("password") {}
5       Password (char* password)
6         : passwd(password) {}
7       void setPassword(char* newPasswd) {}

8     private:
9       char* passwd;
10  };
11 }

12 class Person {
13 public:
14   Person (char *nm) : name (nm) {}
15   Person () {}
16   char* getName () { return name; }
17   virtual void print() = 0;

18 protected:
19   char* name;
20 };

21 void check(); // stand-alone friend function

22 class BankAccount;

23 class Customer : Person {
24 public:
25   friend void check();
26   Customer (char* nm) : Person(nm) {}
27   static int getPasswordLength() {
28     return LENGTH;
29   }
30   void print () { }
31   void checkPassword() {
32     Security::Password p;
33   }

34 private:
35   static const int LENGTH;
36   BankAccount *b1;
37 };

38 const int Customer::LENGTH = 7;

39 class Company{
40 public:
41   Company (float pr) : profits (pr) {}
42   ~ Company() {}
43   float getProfits () {
44     return profits;
45   }

46 protected:
47   float profits;
48 };

49 class BankAccount {
50 public:
51   BankAccount (Customer c)
52     : holder(c) { }
53   void deposit (float amt) {}
54   float getTotal () {
55     return total;
56   }

57 private:
58   float total;
59   Customer holder;
60 };

61 class Bank : Company {
62 public:
63   Bank (float profits)
64     : Company (profits) { }
65   void addAccount (
66     const BankAccount& b) { }

67 private:
68   BankAccount* acctList;
69 };

70 int main () {
71   Customer myCustomer("sarah");
72   Bank b(1000);
73   b.addAccount(
74     BankAccount(myCustomer));
75   return 0;
76 }

```

Figure 4: *C++ Code Example*. This figure shows a complete C++ program including six classes, a namespace and function main.

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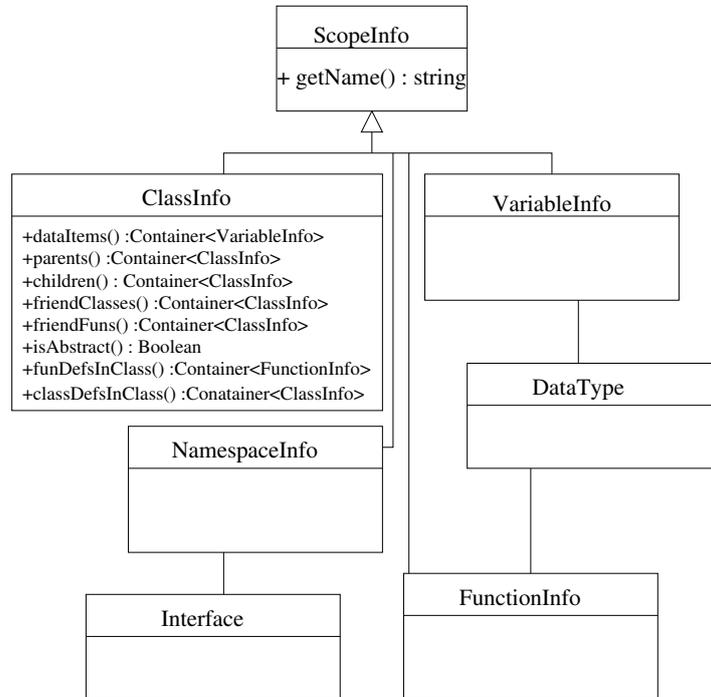


Figure 5: **Class Diagram for the Clouseau API.** The Clouseau API permits users to acquire information about the type, accessibility and visibility of namespaces, classes, functions and variables in the  $C++$  program under consideration. This figure illustrates the important classes in the API, including the member functions for two of the classes, `ScopeInfo` and `ClassInfo`.

API. Other classes in the interface are `NamespaceInfo`, `VariableInfo`, and `FunctionInfo`, providing information about namespaces, variables and functions. The class `DataType` encapsulates type information about variables and functions and the line connecting `DataType` with `VariableInfo` and `FunctionInfo` represents this relationship.

Whenever possible, we have designed Clouseau using a  $C++$  idiom, rather than a Java idiom. Thus, Clouseau containers use templates, rather than inheritance and polymorphism, to allow variation in type. Moreover, the `Container` class in the API is derived from the `vector` class in the  $C++$  standard library so that the full complement of STL functionality is exploited by the API (Institute 1998, Josuttis 1999). Furthermore, Clouseau includes iterators to permit users of the API to iterate through the lists of classes, namespaces, functions and variables. For example, the user may wish to search the list of functions contained in a class by iterating through the container returned by the `funDefsInClass()` function in `ClassInfo`, shown in Figure 5.

## 5 Class Diagram Construction

We reviewed the UML in Section 2 and described class diagrams, which consist of rectangles representing classes, and lines connecting the rectangles representing the relationships between the classes. We also described the four types of relationships that classes can have and their representation in the UML class diagram. We now show how the class diagram is constructed by the Reveal tool and how these relationships appear in the diagram.

In Reveal, we remain faithful to the UML standard definition of a class diagram wherever possible; however, we offer extensions to the standard notation to accommodate  $C++$  namespaces, stand-alone functions and friend functions. We also present these extensions in this section.

The first step in constructing a class diagram in Reveal is to identify the  $C++$  program's namespaces. Namespaces act as a modularization construct in  $C++$ , allowing the programmer to partition the names used in a program to prevent them from interfering with each other. Namespaces may be nested, in which case name occurrences inside the inner namespace may refer to those already declared at the outer level, with this process continuing recursively, eventually reaching the global namespace where all namespaces are ultimately nested (Institute 1998). Figure 6 illustrates a class diagram for the example program shown in Figure 4. Figure 6 includes two namespaces, `_GlobalNamespace` and `Security`. The entire diagram is enclosed in a rectangle that represents the global namespace; the name of the global namespace is shown in the upper left corner of the square. A second namespace, `Security`, is shown in the lower right corner of Figure 6.

Several benefits derive from including namespaces in the class diagram. First, the viewer can visually differentiate the code segments that have been placed in different namespaces in the input program. Second, if a name is used in two different namespaces, the user will be able to distinguish the names in the diagram by the enclosing namespace rectangle.

A *stand-alone function* is a function that is not contained in a class. Some object-oriented languages do not have stand-alone functions;  $C++$ , derived from  $C$ , does include stand-alone functions. Reveal uses a class rectangle for stand-alone functions and global variables, except that the rectangle is dotted rather than solid. Stand-alone functions are placed in the member function partition of the box and global variables are placed in the data attribute partition of the box.

A friend function is a special kind of stand-alone function. Although a friend function is not a member of a class, it can access the private attributes of the friend class. Reveal handles friend functions as any

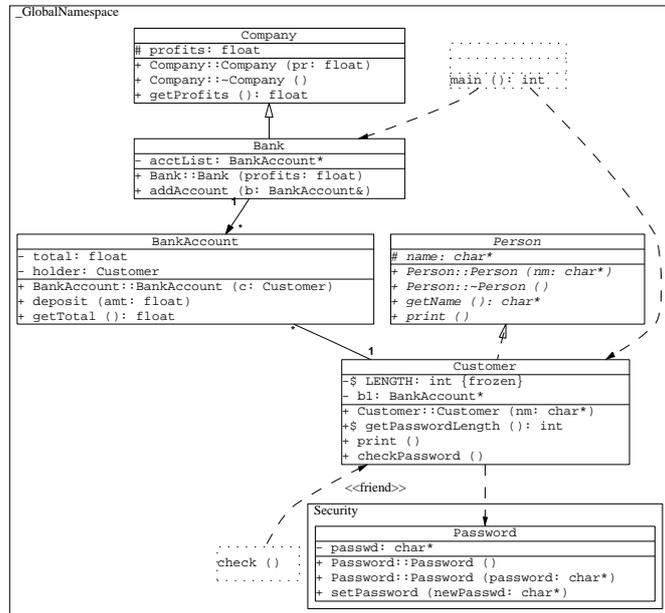


Figure 6: **Full Class Diagram.** This figure contains a class diagram, showing the data attributes and member functions for each class, the relationships between the classes, and accessibility information of the class member attributes. The figure also illustrates our extensions to the UML class diagram to accommodate C++ namespaces, stand-alone functions and friend functions.

stand-alone function, placing them in a separate dotted box, indicating the dependency with a directed line connecting the friend function to its associated class. This directed line is adorned in Reveal with the `<<friend>>` stereotype.

Figure 6 depicts a stand-alone function, `main`, in the upper right corner of the diagram, and a friend function, `check`, at the bottom of the diagram. The dependencies between `main` and classes `Bank` and `Customer` are illustrated in the diagram by dashed, directed lines. The dependency between `check` and `Customer` is illustrated in the diagram with the dashed, directed line, adorned with the `<<friend>>` stereotype.

Generalization, or inheritance, is a specialization/generalization relationship in which objects of the specialized element are substitutable for objects of the generalized element. Figure 6 illustrates inheritance at the top of the figure where `Company` is shown as the base class and `Bank` is shown as the derived class. The line with the hollowed arrowhead indicates the inheritance relationship between two classes.

Realization is a semantic relationship between classifiers, wherein one classifier specifies a contract that another classifier guarantees to carry out. In C++, an abstract base class has one or more purely virtual methods that every immediate child must overwrite. The contract between the parent and the child is that the child will overwrite these methods.

In Reveal, children of abstract classes are connected to the parent class by a dashed arrow with a hollow arrowhead. In Figure 6, this relationship is illustrated between `Customer`, the derived class, and `Person`, the abstract base class.

## 6 Comparison with Other Tools

In this section we compare our tool, Reveal, to three other tools that reverse-engineer code, including Superwomble, Rational Rose<sup>TM</sup> C++ Demo 4.0.3 and Together ControlCenter<sup>TM</sup>. We first give a brief overview of Superwomble, Rational Rose and Together. We then use the C++ example illustrated in Figure 4, Section 3, to compare the generated class diagrams for Reveal, and the other three tools.

### 6.1 Overview of the Tools

Superwomble generates object models from Java byte code. The object model is used to describe the abstract features not explicitly expressed in code. An object model is a subset of UML consisting of nodes and objects. A node in the model is used to represent an object. Nodes are connected using either a relation edge or a subset edge. The relation edge may be annotated to reflect multiplicity and/or mutability.

Superwomble performs inferences on associations that allow it to filter out associations not relevant to

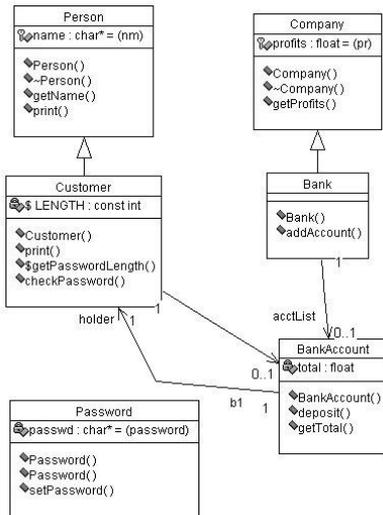


Figure 7: **Rational Rose Diagram for C++**. This figure shows the class diagram produced by the Rational Rose tool using the C++ example of Figure 4.

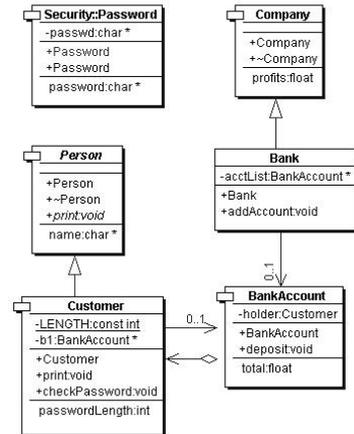


Figure 8: **Together Diagram for C++**. This figure shows the class diagram produced by the Together tool using the C++ example of Figure 4.

the application. This inference mechanism allows the user to ignore standard Java library classes when creating the model. This tool also infers multiplicity and mutability depending on how the fields of an object are used.

Rational Rose C++ Demo 4.0.3 is a model driven software development tool. The models used in this tool are based on UML. The Rose C++ analyzer requires the user to set up the appropriate environment identifying all the directories containing the files required for analysis. Before the design is exported, the user chooses the level of detail required in the model. The model exported to Rose contains a logical view and a component view. The logical view consists of class diagrams for each package, as well as detailed specifications for each class. The component view shows the dependencies between the packages and classifies packages as either an interface or an implementation.

Together is a comprehensive end-to-end Model-Build-Deploy development platform for building enterprise solutions. Together provides the following services: creation and editing of several types of diagrams including UML diagrams, synchronization between design and implementation code (round-trip engineering), offers a workbench for writing code and integrates with different version control systems.

## 6.2 Comparison of the Tools

Since SuperWomble will only accept Java byte code, we translated the C++ example of Figure 4 into Java. The Java version of the example does not contain any stand-alone functions or friend functions, and namespace Security was replaced by the Java package Security. Thus, for our comparison, we use a Java version of the example for SuperWomble, and

the C++ version for Rational Rose, Together and Reveal.

Figure 6 shows the class diagram produced by Reveal, Figure 7 shows the class diagram produced by Rational Rose, Figure 8 shows the class diagram produced by Together, and Figure 9 shows the class diagram produced by SuperWomble.

All four of the tools show the inheritance relationship between classes Bank and Company in a similar manner. The Reveal, Rational Rose and Together representation of this inheritance relationship is consistent with the UML standard. Although the SuperWomble tool does not show a hollow arrow, this is likely an artifact of the graphviz drawing tool. The inheritance relationship between classes Customer and Person are also shown similarly. However, the Reveal representation of this inheritance shows a dashed line between Customer and Person; the dashed arrow in the Reveal diagram indicates that the relationship between Customer and Person as a realization (Rumbaugh, Jacobson & Booch 1999). Similarly, in the Together diagram, the Person class is underlined and the class name italicized, indicating that Person is an abstract base class.

The Reveal, Rational Rose and Together tools also model the association between the classes Customer and BankAccount. Rational Rose and Together model this bi-directional relationship using two arrows, one for each of the dependencies. However, Reveal uses a more succinct notation, combining the bidirectional relationship into a single, undirected line between classes Customer and BankAccount. Reveal, Rational Rose and Together model the multiplicity of this relationship differently, yet each captures the fact that there is a single instance of Customer in BankAccount: Reveal adorns the undirected line with the number 1, Rational Rose adorns the directed line from BankAccount to Customer with the number 1.

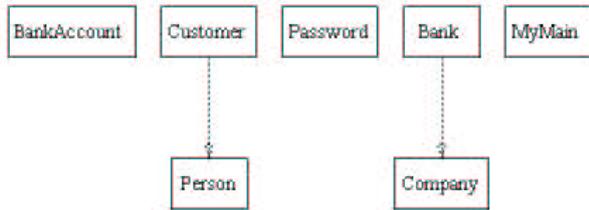


Figure 9: **SuperWomble Diagram for Java.** This figure shows the class diagram produced by the SuperWomble tool using a Java version of the example of Figure 4.

Together uses aggregation to show this multiplicity, indicating that the `Customer`, `BankAccount` relationship is a part-whole relationship.

The Reveal, Rational Rose and Together tools also model class data attributes and member functions, including an indication of accessibility. We note that Reveal and Together are more resonant with the UML standard, using `+` and `-` to indicate public and protected; Reveal uses the `#` notation for protected. Rational Rose uses icons to model accessibility, which is inconsistent with the UML standard.

SuperWomble provides an abbreviated version of the class diagram, which might be more useful for large programs with many classes; however, we note that SuperWomble does not include provision for the full class diagram.

The Reveal diagram for class `Customer` indicates that the `LENGTH` data attribute is *frozen* (constant); this indication that `LENGTH` is constant is consistent with the UML standard; both Together and Rational Rose indicate this constness by attaching *const* as a prefix to the type of `LENGTH`, `int`.

Finally, Reveal offers extensions to the UML class diagram to model namespaces, stand-alone functions and friend functions. However, the user may choose to turn this facility off, by de-selecting these extensions in the options menu of the GUI.

## 7 Concluding Remarks

We have presented our design and implementation of a tool, Reveal, to reverse engineer a UML class diagram for a `C++` program. We have also presented extensions to the UML class diagram to accommodate namespaces, stand-alone functions and friend functions in the `C++` language. We have compared Reveal to three other tools, Rational Rose, Together and SuperWomble, indicating compliance of the generated diagrams with the UML standard.

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