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Integration of Reusable Software Components and Frameworks Into a Visual Software Construction Approach*

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Software reuse is an effective means of improving software productivity and software quality. Reusable Software Components (RSCs) are the basic building components for software programs constructed using the software reuse approach. The object-oriented approach is used to design and implement our RSCs. Our laboratory has already implemented more than 300 reusable software components, including design-level frameworks in various application domains and approximately 200,000 lines of code in our library. These components and frameworks have been accumulated in the course of designing and implementing strategy-based game systems, multimedia authoring systems (2-D and 3-D), multimedia playback systems, and other application systems.

Multimedia software plays an important role in the software industry. In contrast to traditional software, multimedia software provides users with visual and audio effects through their interfaces and can more accurately model the real world. A media component may contain various elements, such as text descriptions, voice narration, and animation sequences, which more closely present the subject to be modeled. Such a reusable media component is commonly referred to as a Multimedia Reusable Component (MRC). Using RSCs, frameworks, and MRCs, our laboratory has successfully designed and implemented a commercial product called DIY Magic Cartoon World(for use in making subject-based cartoons.

The RSCs and frameworks can be visualized as icons for a visual programming model. Reuse-in-large practice is, therefore, achieved using visual programming techniques based on these visualized components. In this study, we introduce design principles and implementation techniques for our RSCs, frameworks, and MRCs. RSCs, frameworks, and MRCs are integrated into a visual software construction approach. More specifically, the design concept and implementation of an approach

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for visual software construction are described. In addition to discussing the advantages of the proposed construction approach, this work also presents examples which illustrate how the visual programming environment is used.

Keywords: software component, object-oriented, software reuse, visual programming, framework, multimedia

1. INTRODUCTION

Software productivity, quality, and maintenance, which are of primary concern in the computer software industry, have been studied for decades. With these considerations in mind, various methodologies and techniques have been proposed, including structural approaches, modular approaches, and object-oriented approaches [1, 8, 21]. The Object-Oriented approach is an effective methodology that has been studied and implemented during the recent decade. Fayad presented a transition plan based on real-world experiences and also recommended several effective managerial practices [9]. Designing reusable software components and frameworks using the Object-Oriented approach is an effective means of improving software productivity and software quality.

In 1976, Mcllroy[18] wrote, "Why isn't software more like hardware? Why must every new development start from scratch? There should be catalogs of software modules as there are catalogs of VLSI devices: when we build a new system, we should be ordering components from these catalogs and combining them, rather than reinventing the wheel every time".

His perspective on software reuse led to many subsequent investigations. With the evolution of the Objected-Oriented Paradigm in recent years, the software industry has increasingly focused on software reuse. Notable examples include Cox's Objective-C for Software IC [7], Booch's Ada components [2], Freeman's classification of software reusability[10], Prieto-Diaz's facet scheme for software reusability classification[20], Chen's interface design for reusable software components and C++ reusable components [3,4], Microsoft's component object model (COM)[22], SUN's JavaBeans[23], Eric Gramma's Design Patterns [11], Grady Booch's Application Framework[24], and Talph E. Johnson's Framework[25], from building blocks [16] to design patterns (frameworks) [11]. Pertinent which range articles presenting framework development experiences or design guidelines include the following: Fayad reviewed the current situation, classified strengths/weaknesses, and discussed future trends in frameworks [9, 26]. Demeyer provided design guidelines for developing frameworks [27]. Baumer thoroughly examined domain partitioning, framework layering, and framework construction [28]. Brugali highlighted the relationships between application frameworks, patterns, and pattern languages in the domain of manufacturing systems[29]. Some of the above studies led to practical and commercial software products, such as Software IC from the Stepstone Corporation, Booch's Components (Ada reusable components and C++ components), MacApp, COM/DCOM, and OMG's CORBA. However, these reusable components or frameworks are still difficult for most people to reuse without integrating into an innovative software construction approach. To overcome this problem, reusable software components must be integrated into a visual programming environment to facilitate the use of these reusable components.

Multimedia software has been extensively applied in the application software industry. In contrast to traditional software, it provides users with visual and audio effects through their interfaces and can more effectively model the real world. Therefore, this study has developed reusable media components for use in designing multimedia software application systems. A reusable media component may contain various elements, such as text descriptions, voice narration, and animation sequences, which can more accurately represent the subject to be modeled. They are commonly referred to as reusable software components Multimedia Reusable Components (MRCs). Details regarding this subject can be found in [6].

A visual requirement specification allows a user to view the specification as an animation sequence instead of having to read or study voluminous specification documents. This work also proposes a novel paradigm for software construction, based on the use of RSCs and frameworks. In addition, a prototype of a visual programming environment system is implemented which programmers can use to practice programming at the level of reuse-in-large.

The rest of this paper is organized as follows. Section 2 discusses the Reusable Software Components (RSCs) and frameworks. Section 3 then presents a proposed visual software construction approach. Next, section 4 addresses implementation issues concerning the proposed approach, in particular the interconnection interface requirements for reusable components and their interconnection language requirements. A major portion of this section is devoted to the proposed visual programming model and its supporting programming environment. In addition, illustrative examples demonstrate how the proposed visual programming environment works. Conclusions are finally made in section 5.

2. REUSABLE SOFTWARE COMPONENTS AND FRAMEWORKS

Traditionally, a software module or routine that can be invoked using a procedure call or function call in an application program is considered to be a reusable software component. Thus, all software functions or procedures can be considered to be reusable software components. However, a reusable component considered in this manner and implemented using conventional programming approaches is not likely to be reused since tailoring such components for different applications is relatively difficult. According to a previous investigation, traditional software routines do not significantly improve software productivity [5]. Thus, what makes a good Reusable Software Component must be re-examined. Our earlier work [3] provided details about what constitutes a good reusable software component based on a tradeoff study of interfaces between reusable software components. In the next section, we will briefly describe the notions underlying the design of these reusable software components.

2.1 Reusable Software Components and Frameworks

Ideally, a Reusable Software Component or Framework must be designed for use in constructing many different applications (maximizing applicability) and for easy reuse or adaptation by software designers and programmers(i.e. ease of tailoring for specific applications). Fig. 1 depicts an ideal RSC or framework in which a 2-dimensional graphic is used.

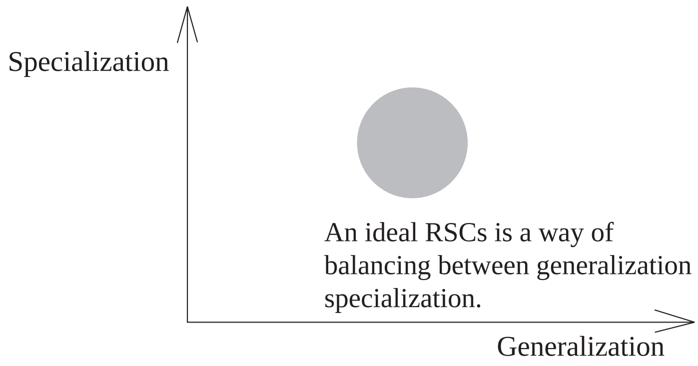


Fig. 1. An ideal Reusable Software Component or Framework.

In this figure, assume that an RSC or framework is designed specifically for a certain application. In doing so, it can be easily adapted for that particular application. However, such an RSC or framework is inappropriate for other applications. On the other hand, if an RSC or framework is designed very generally, theoretically, it can be applied to many applications. However, tailoring for specific applications is relatively difficult. Thus, an RSC or framework must be designed and implemented so that there is a balance between generalization and specialization. Below, the client and server model shown in Fig. 2 are used to depict the role of a reusable software component as a means of describing in detail the basic design and implementation of our RSCs.

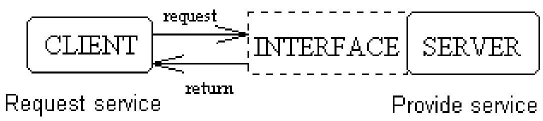


Fig. 2. A client and server model.

A reusable software component can be considered to be a server that provides services for potential clients. A client, an application program, only needs to know the interface specifications of a potential server and does not need to know the details of how the server provides those services. A server can accept various kinds of requests from clients. If the interface constraint is tightly restricted, the server can ascertain that requests for services from clients conform to its interface conditions. However, it may also lose many possible clients whose service requests are statically incompatible. On the other hand, if the interface constraint is relaxed, the server can accept a broader range of service requests from its clients. In doing so, there is a tradeoff between interface compatibility and flexibility[3]. A component can be a client, a server or a client and a server.

We adopted the Object-Oriented approach to construct our RSCs. Generalization is achieved by using multiple polymorphism (dynamic binding) for implementation and specialization, which are performed using refinement (inheritance) for implementation when designing our RSCs. Based on our study conducted over the past seven years on designing and implementing RSCs, we believe that an effective RSC and framework must have the following characteristics:

1. *Easy to generalize*: RSCs and frameworks must be common enough to be used in many applications. Restated, an RSC should be designed to accept various types of data used in different applications.
2. *Ease to refine* (*specialization*): RSCs and frameworks must be adaptable, flexible, and extendable enough for use in specialized applications.
3. *Clear interface specification*: An RSC or framework must provide a set of interfaces for its clients that gives application users a clear picture of how to use the component.
4. *Complete encapsulation*: An RSC or framework must protect all its private information. Application users can only use sets of public interface routines to update internal data, thus ensuring that the component will have no side effects when used in clients' applications.
5. *Complete testing*: RSCs and frameworks must be bug-free. They should be designed and well tested in such a way as to guarantee quality.

Reusable software components designed according to the above principles will be ideal for future reuse. Our laboratory has been attempting to use the Object-Oriented approach according to these principles for the last seven years. In doing so, more than 300 reusable components consisting of approximately 200,000 lines of code have been accumulated. The sizes of the reusable components range from 500 lines of code to 3,000 lines of code, depending on the application.

In addition to good and healthy reusable components, an efficient interconnect language is also required to integrate these reusable components into useful application programs. Later, in section 4, we will discuss an integration tool and its relative interconnection language.

2.2 Standardization and Classification of RSCs and Frameworks

In general, four kinds of software components can be considered for use in reusable software components or frameworks. Starting from high-level and continuing down the low-level, they are as follows:

1. *Requirement specification components*: These can be considered as users' requirement analysis results and analysis-level components (reusable specification analysis components).
2. *Design frameworks* (or *design patterns*): These are design-level components (or reusable design results) that can be reused to design different application domains. This kind of component is referred to herein as a Reusable Software Design Framework (RSDF). They are designed and implemented using the design principles mentioned above and in [4].
3. *Code components*: These are software modules or routines referred to herein as Reusable Software Components(RSCs). They are designed and implemented using the object-oriented approach and the design principles stated above.
4. *Data or media components*: These are numerical data, text data, or data in other media. Multimedia software plays an important role in the software industry. Thus, reuse of media data should not be neglected. These components are referred to herein as Multimedia Reusable Components(MRCs).

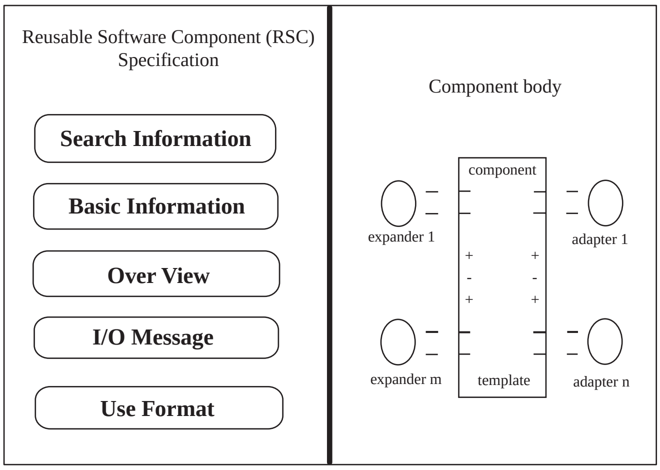


Fig. 3. Format of a Reusable Software Component.

Below, we will consider standardization for our RSCs. Our reusable software components include two major types: 1) Reusable Software Component Specifications and 2) Reusable Software Component Bodies. Fig. 3 shows details of these parts, which are described below. A standardized format for framework implementation based on the same considerations was reported in [4].

1. *Search information*: This includes the component name, author, taxonomy code, application domain, creation date, and modification history of the component. These items can be used as keywords for retrieving components.
2. *Basic information*: This includes the component size, version and file name in a system.
3. *Overview*: This describes the basic functions and characteristics of the component, and the public interfaces supported by the component.
4. *Input/Output message*: This describes the meaning and format of parameters passed from/ to the application program through public interfaces.
5. *Use format*: This contains examples and guidelines for using the component in applications. Thus, programmers do not need to study or read the actual component codes.

In our implementations, we use four different files to store all the information about each RSC:

1. File *.doc is used to store the component's specification information.
2. File *.h is used to store the component header file that will be included in application programs in which the component is to be used.
3. File *.cpp is used to store the component body. This is the source code and is compiled so as to produce an object code that is included in a library file with the extension lib. Eventually, it will be linked to the main application program that uses this component to produce an execution code.
4. File *.c is used to store the test program, which can be used to test the component when it is used in an application program.

Previous investigations have placed too much emphasis on innovative and clever search as well as query approaches to finding components(conventional routines and functions). Those investigations commonly assume that hundreds of thousands of components are available. However, many investigation have neglected the fact that designing good reusable components significantly reduces the number of related components. For example, our laboratory designed and implemented thousands of sorting routines to perform sorting functions for thousands of different data-type applications. These routines can be reduced to one design by adopting the object-oriented approach to implement a sorting routine. The RSC space which needs to be searched is, thus, greatly reduced.

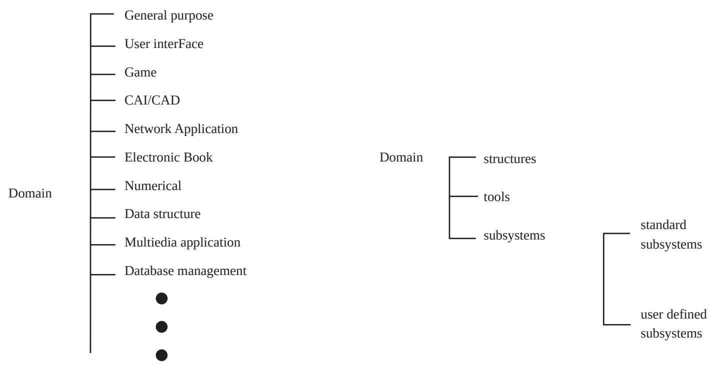


Fig. 4. RSC classification.

In the following, our approach to classifying RSCs is described. Basically, a software program can be modeled as a composition of data structures and algorithms, along with various tools and subsystems in a computer system (for example, operating systems, compilers and other useful software). Logically, the hierarchy shown in Fig. 4 is adopted for RSC classification. The first level catalogs the domain type, and the second the component types, i.e., structures, tools, and subsystems.

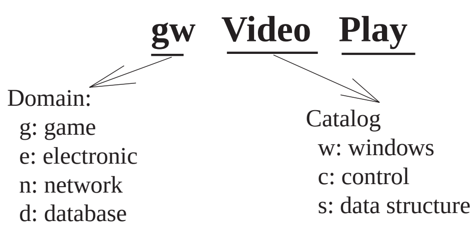


Fig. 5. A naming system example.

A naming system for RSCs is also needed. Component naming attempts to inform users about where to look for components by examining general information about it. A relatively easy means of doing so is to separate component names into three parts, as shown in Fig. 5. The first letter in the component name is used to represent the application domain, the second letter is used to represent the component type, and the final part is used to represent the component function. Fig. 5 shows a Windows game component that can used for playing a video.

The above information provides a basis for users to retrieve and use existing components in their applications. Later, in section 4, we will present a Component Retrieval System, using the proposed classification structure and naming system, and then implement and integrate it into a visual programming environment.

3. A VISUAL SOFTWARE CONSTRUCTION PARADIGM FOR REUSABLE COMPONENTS AND FRAMEWORKS

MRCs are developed in order to represent requirement scenarios[6]. Using visual representations of requirement specifications allows one to view such requirements as animation sequences so that one does not have to read or study voluminous requirement documents. Such an innovative software approach provides users with visual aids which can help them better understand the software requirements. This approach also provides designers with a natural means of communicating with users and, thus, to receive more accurate feedback from users regarding the requirements under consideration. In section 2, we presented the design principles and implementation approach for our RSCs and Frameworks in RSCs, Frameworks, MRCs, and the visual programming environment. A novel paradigm for software construction is presented in the following.

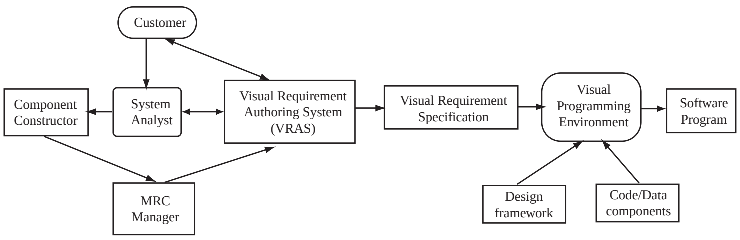


Fig. 6. A Visual Software Construction (VSC) model.

3.1 A Visual Software Construction Model

Semantic pictures, commonly referred to as icons, can be used to represent RSCs, frameworks, and MRCs in a visual programming environment [17]. Restated, an icon is created for each RSC, MRC, and Framework. Consequently, a bank of icons are cataloged and named as described in section 2.2. To effectively use these icons, a software construction paradigm must be developed. Consider the Visual Software Construction (VSC) Model depicted in Fig. 6.

The software construction process can be divided into two major phases, requirement construction and program construction. MRCs are the bases for requirement construction while RSCs and Frameworks are the bases for program construction.

During the requirement construction phase, a Visual Requirement Authoring System (VRAS) is employed to produce a visual requirement specification using MRCs. Such a visual requirement specification is achieved by system analysts and passed onto users (customers) for evaluation. Modifications are made when analysts and users disagree. During modification, analysts again invoke the VRAS to instruct the MRC Manager System to retrieve an appropriate MRC for modification. If the MRC Manager System does not locate such an MRC, then such an MRC is fabricated by invoking the MRC Component Constructor. The constructed MRC is then stored in the MRCs Manager System by the analyst using the Visual Requirement Authoring System. During fabrication of an MRC, tools for aggregating video, motion pictures, static image picture, voice, and text together to produce a visual presentation are supported for most common multimedia computer systems. The VRAS also provides a rich set of functions to help MRC designers fabricate desired MRCs. This innovative requirement representation paradigm provides analysts and designers with a natural means of communicating with users (customers) and receiving more accurate responses from users concerning the requirement under consideration.

During the program construction phase, the Visual Programming Environment (VPE) is employed to produce programs according to the requirements obtained during the requirement construction phase. Ideally, the requirement representation film from the MRC is automatically verifed to produce a list of design patterns (frameworks) that are closely applicable to the requirement under consideration. Also, a list of RSCs applicable to the design pattern (framework) is produced automatically. However, at the present time, the kinds of design patterns (or frameworks) and RSCs that are needed must be manually identified to construct programs for the requirements under consideration. Once a list of these frameworks and RSCs has been identified, the VPE provides tools which designers can use to produce the corresponding programs. Thus, the Visual Programming Environment must provide the following: 1) a visual paradigm for producing visual programs, based on the use of icons to represent various frameworks and RSCs, and a code generator for translating the visual program into target code (high-level programs), and 2) a hyper-text editor that allows programmers to edit programs when they reuse the design frameworks and RSCs. An interconnection language is defined for connecting icons so as to produce an iconic program. A Code Generator takes these iconic programs and translates them into programming language source code.

3.2 Advantages of the Proposed Construction Model

Many investigations have cited traditional software construction models as causing problems in requirement specification, design, coding, testing, and maintenance. A detailed list of problems can be found in [19]. Some of these problems can be alleviated using the proposed construction model. The benefits of the proposed construction approach are as follows.

1. A Visual Requirement Authoring System, instead of the traditional (NOTE: “conventional” instead ?) requirement-gathering process, provide users with visual images that allow them to better understand the software requirements. It also provides analysts and designers with a natural means of communicating with users and receiving more accurate feedback from users concerning the requirements under consideration.
2. The proposed approach provides a prototyping capability, as evidenced by its reuse of design frameworks and RSCs during the construction of application software. A prototype satisfying the software requirements under consideration can be built using the icons representing frameworks and RSCs. Thus, users (and customers) can observe whether or not the functionality satisfies their requirement at an early stage before the final system is implemented.

3. The proposed approach encourages good software programming practices. Encouraging designers and programmers to reuse the design frameworks and components leads to accumulation of their own design frameworks and RSCs. Accumulation of reusable components and frameworks is essential for improving software productivity and quality.
4. Frameworks and RSCs are thoroughly implemented and tested before reuse. Doing so encourages the design and implementation of healthy (bug-free and side-effect-free) components. Consequently, the application software based on these healthy components or frameworks needs less time for debugging. Thus, the testing cost can be reduced.
5. In a visual programming paradigm, a top-level iconic program represents the system structure while a lower-level one represents the software program. When a modification or change in the iconic program is required, designers or programmers can easily locate the icon requiring replacement or modification. By substituting the icon or reconnecting icons, the code generator can immediately generate a new version of the software program.
6. The proposed construction model encourages reuse-in-large practice, thereby improving software productivity and quality.

Other merits of using a visual programming technique, such as 2-D graphic programming, are as follows: it is able to easily learn and understand; graphic programs can easily present higher-level abstractions; graphic programs are easily modified with few errors; icon replacement is easier than text modification. Further details can be found in [12, 13, 15].

4. IMPLEMENTATION ISSUES CONCERNING THE PROPOSED CONSTRUCTION APPROACH

In section 3, we briefly described the visualized software construction model. In the following, we will present implementation issues concerning the proposed construction approach. These issues can generally be divided into two main groups: 1) requirement-construction phase issues and 2) program-construction phase issues.

4.1 Implementation Issues in the Requirement-Construction Phase

The requirement-construction phase focuses mainly on implementing a Visual Requirement Authoring System that allows users to select the various MRCs stored in the MRCs Manager System and turn them into films (visual presentations) that can be played for users (customers). Fig. 7 depicts the model.

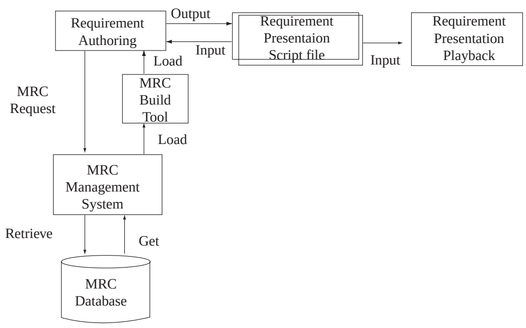


Fig. 7. A Visual Requirement Authoring System.

The MRCs must be designed in a standardized format, and MRC designers usually seek the assistance of artists in drawing meaningful and simple motion pictures to describe the basic meanings of events(requirements scenarios). The authoring system must provide various functions that allow analysts to change MRC attributes, to make animation sequences for events in MRCs, and to assemble several MRCs to satisfy scenario-based requirements. These scenario-based requirements are then combined into feature presentations(films) and played for user evaluation. We have discussed this subject in detail in [6]. Below, we will highlight some functions supported by our commercial product, DIY Magic Cartoon World [14], which is similar to the Visual Requirement Authoring System discussed herein.

In the authoring system, visual requirement specification is analogous to a cartoon film. Cartoon films contain sets of scenes, which are similar to sets of MRCs. The scenes are the base of a cartoon film. Correspondingly, MRCs is the base of a visual requirement. A scene can have several actors whose characteristics can be defined using a set of functions provided by the authoring tool, depending on the user's needs. For example, an actor's scenario can be described using the authoring tool. Several acting scenarios can be defined so as to make a scene. Similarly, an MRC may contain several requirement scenarios based on the user's needs. Thus, an MRC can be created and edited by an analyst based on the functions provided by the authoring system. Functions supported in the current authoring system include the following:

1. selecting and moving actors (representing requirement scenarios) from an actor bank (representing requirement scenario databases) to a designated place in a scene (representing MRCs);
2. recording voice narrative sessions for actors (requirement scenarios) and scenes (MRCs);
3. enlarging and scaling-down selected actors (representing particular requirement scenarios);
4. allowing left and right sequence changes between two actors (representing requirement scenarios);
5. allowing up and down sequence changes between two actors (representing requirement scenarios);
6. making animations of scenarios at different presentation speeds;
7. allowing foreground and background changes among actors (representing requirement scenarios);
8. making sequential presentations of several selected actors (representing requirement scenarios);
9. making several selected actors perform in parallel;
10. defining beginnings, progressions, and endings for scenes;
11. providing other features such as setting special effects and background music for scenes, previewing scenes just completed, discarding unwanted actors, and so on.

Notably, the above features are all presented in visual form. Thus, users are performing visual programming when they are using these functions to make cartoon films (or visual requirement representations). The details of how to use MRCs to produce a visual requirement can be found in [6].

4.2 Implementation Issues in the Program-Construction Phase

Program construction concentrates mainly on implementing a Visual Programming Environment. The Visual Programming Environment takes visual requirements and transforms them into target software programs. Fig. 8 presents an outline of the system structure.

According to Fig. 8, several non-trivial tasks must be performed to implement a visual programming environment.

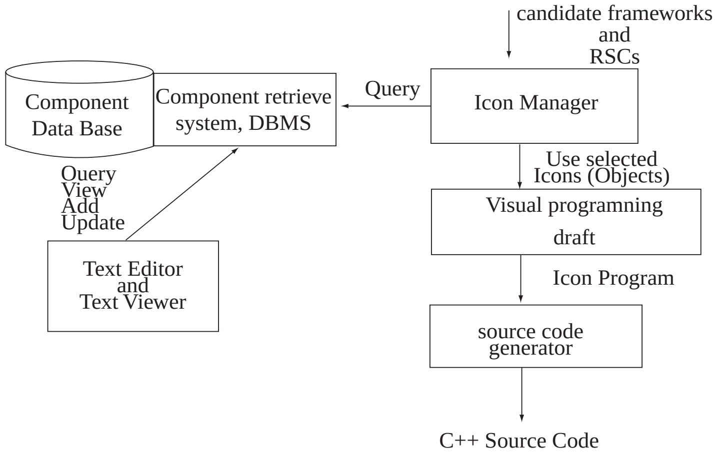


Fig. 8. Visual programming system structure.

1. Each Framework or RSC stored in the Components Database must be visualized at the time it is selected as a candidate for program construction and then placed into an icon pool by the Icon Manager.
2. A visual programming model must be defined in order to make an iconic program.
3. An icon interconnection language and its corresponding code generator must be implemented.

4.2.1 Visualizing the frameworks and RSCs

In contrast to hardware ICs, which have fixed semantic meanings (true, false, or don't care) for their pins when they are connected to other ICs, software programs depend on message names, and on parameter types and numbers during message-binding with other software programs. Visualization of software components (frameworks and RSCs) by defining graphic bitmaps (icons) of their input and output layouts is used in our system. Fig. 9 presents a component layout.

Fig. 9. Component layout.

Creating a visualized component involves re-packaging a component from its original text description. Re-packaging a component consists of the following three steps:

Step 1: Find or draw a meaningful picture or icon to represent the component.
Step 2: Modify the original component by adding a virtual member function, called a *connect ()*, to the component. The *connect()* member function is implemented by means of dynamic binding that links with other components. Thus, a component can be dynamically bound to another components needing service from this component.
Step 3: Define component input pins and output pins according to the member functions defined in the component.

For example, the nth output pin of component A is connected to the input pin of component B, as shown in Fig. 10. According to this figure, execution of component B invokes function n in component A. Using C++ notation, it will be implemented as B. connect(&A, n). If the component is a design framework, we add an execution() function to it to initiate the execution sequence. An invocation of this function initiates the execution of all the connected components.

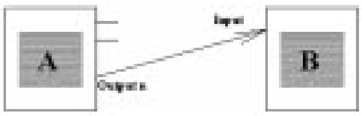


Fig. 10. Component interconnection.

4.2.2 A visual programming model

Many visual programming models have been proposed [12, 13, 15]. A visual programming model can be as complex as a general-purpose programming language, with support for complicated programming structures. This visual programming model provides users a convenient way to produce powerful and complicated visual programs (or iconic programs) for modeling low-level applications. Meanwhile, another type of visual programming model provides only a limited set of programming structures, thus enabling users to produce simple but reasonable visual programs (or iconic programs) for special domains. The visual programming model proposed herein is of the latter type. Our choice was made on the basis of programming-in-large and reuse-in-large practices. Writing a simple subroutine, such as sorting or finding a square root, using visual or icon programming would be unnecessary except for very special purposes. Instead, these simple routines should be implemented using a high-level language and encapsulated as icons for use in higher-level applications. In this manner, the power of a visual program can be enhanced. In the following, we introduce a relatively simple visual programming model for program construction based on the use of our RSCs and frameworks.

We use a computer processing model which contains three parts: an input unit, processing unit, and output unit, as shown in Fig. 11, to present the visual programming model.

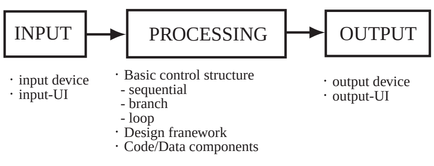
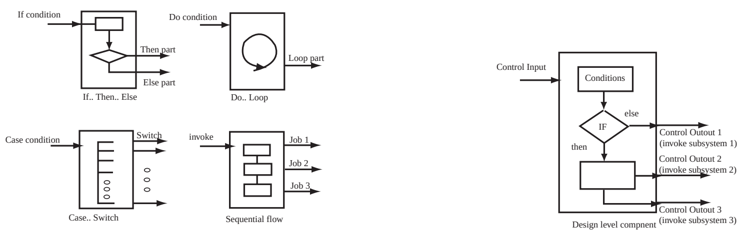


Fig. 11. The visual programming model.

The input unit handles all input devices and input-end user interfacing while the output unit takes care of all output devices and output-end user interfacing. The processing unit performs all operational flows according to application requirements. In the proposed model, each device (user interface) in the input, output, and processing units is treated as a component or as a combination of components. Simple control structures, including sequential, branching, and looping, structures, are provided in the processing unit to describe the control flow. Icon types, such as frameworks and RSCs, are also introduced for programming-in-large (or reuse-in-large) through interconnections among icons.

4.2.3 Control structure

The programming control structures are also represented as visualized icons. Two levels of control structure are defined, the basic control structure and the system-level control structure. Fig. 12 (a) shows that the basic control structure includes an if-then-else structure, a do-loop structure, a case-switch structure and sequential flows in the component layout. The system-level control structure is the design framework component shown in Fig. 12(b).



(a) (b)

Fig. 12. Control structure.

4.2.4 Data types

Primitive data types, such as integers, characters, and floating points, provided in conventional procedural programming languages are not recommended for programming-in-large or reuse-in-large practices. As mentioned earlier, these data types introduce a great deal of interconnection complexity and should only be used as icons for constructing reusable components or frameworks. Thus, our system uses extension data types and user-defined data types as well as primitive data types. Extension data types contain not only data, but also operations on the data. The RSCs discussed earlier are of this data type. User-defined data contains more information than do RSCs, and interconnection information (control flow) for several RSCs is provided; frameworks are examples of this kind of data.

Type conversion can be done implicitly or explicitly. Primitive data types are handled by the compiler. All extension data type conversions are handled by the component object itself. User-defined type objects may also need to perform type conversions. In the proposed system, all conversion functions are defined and implemented using polymorphism mechanisms. During parsing of component interconnections, the conversion functions are invoked automatically.

4.2.5 A visual program example

An icon program consists of icons, links, and labels.

Icons are the bases of visual programs. The top-level icons represent the system structure, relationships among subsystems. An icon can be any kind of RSC. The details of a subsystem can be viewed by clicking on the icon representing the subsystems. In addition, the body of an RSC can be viewed by clicking on the icon representing that component. Connections between icons alone can define the semantic meanings of visual programs.

Links are used to interconnect components so that they to form visual programs. Links represent message-passing and control transfers between components. Message resolution is achieved by individual components. When designing RSC interfaces, all possible message-passing must be considered. Links can only be used to connect input and output pins. The code generator detects illegal connection patterns, such as attempts to connect two inputs.

Labels are used only for documentation purposes and can appear anywhere in icon programs. The code generator skips all labels during source code-generation.

Fig. 13 shows a simple example of an icon program. This example program accepts inputs from a keyboard, converts input characters from upper-case to lower-case, encodes the input characters and finally outputs them to the screen.

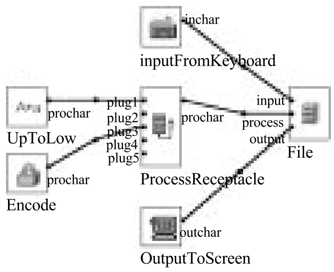
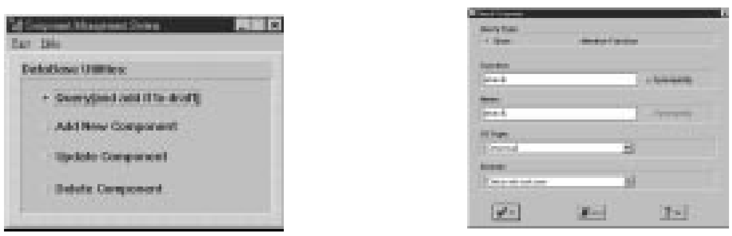


Fig. 13. An example of an iconic program.

4.3 A Visual Programming Environment (VPE)

In this section, we will present the environment used to produce the visual program shown in Fig. 13.

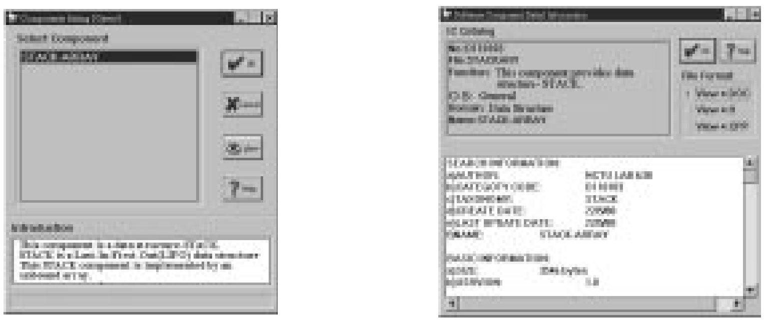
The environment starts with a Component Retrieval System that allows users to locate potential RSCs and frameworks for use in their applications. Similar to most database systems, it provides functions like querying, inserting, updating, and deleting for RSC management. Fig. 14 shows the user interface.



(a) Functions of the retrieval system (b) RSC querying, insertion, updating, and deleting

Fig. 14. Component retrieval system user interface.

Fig. 14(a) shows the functions provided by the component retrieval system while Fig. 14(b) demonstrates how the system can be asked to locate a general-purpose RSC *stack*. When the keyword for a desired component is input, the system responds with a list of potential candidates. Fig. 15(a) shows matched the RSC STACK-ARRAY with its general information given in the introduction field. Users can also more closely examine the matched RSC by clicking on the view button on the right-hand side of the window. This opens a new window that displays relevant information about the RSC, as shown in Fig. 15(b). This RSC information, as described in Fig. 3, is stored in a ***.doc*** file and is now seen in this window. Furthermore, by clicking on the ***view *.H*** button, one can view the component header. The test program can be viewed by clicking on ***view *.CPP***.



(a) A matched RSC (b) Detailed information about an RSC

Fig. 15. A matched RSC with its relevant information.

Once the matched component has been examined and evaluated for application suitability, the OK button is clicked to determine whether the match is appropriate; in addition, an icon representing this matched RSC is created and added to the Icon Manager. If a matched RSC requires modification, then the Text Editor is invoked to perform this task.

Eventually, a set of icons representing the matched RSCs for visual program construction will be present in the Icon Manager. These icons are displayed in the Visual Icon Manger area shown in Fig. 16. The Visual Programming Draft is a hyper-text editor for creating visual programs (or iconic programs). Programmers can drag icons from the Icon Manager to the draft area and drag *links* to connect icons according to their interface connections. Icons dragged into the draft area represent instances of matched RSCs, and labels can be used to make these icons more understandable.

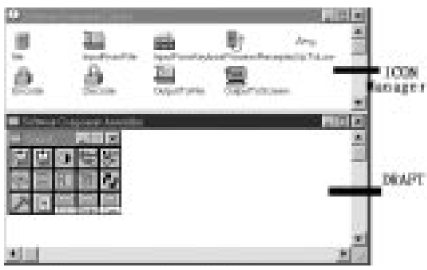
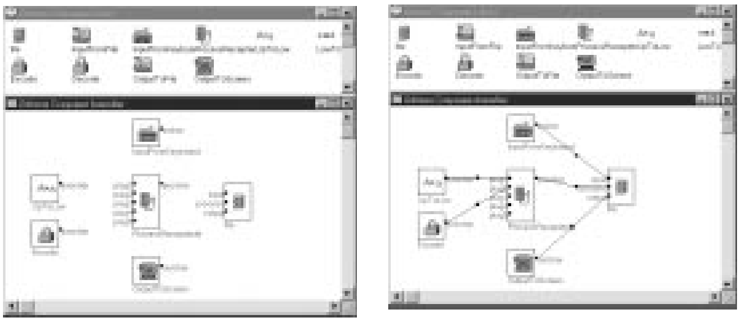


Fig. 16. The Icon Manager and the visual programming draft area.

The icon program shown in Fig. 13 was constructed using the VPE shown in Fig. 17.

The internal form (script file) representing the icon program is then read and parsed by the Code Generator to produce the corresponding source code. Table 1 lists the source code for the icon program shown in Figs. 13 and 17.

If a programmer wants to change the input device from a keyboard to a file for the program shown in Fig. 17 and the output device from a screen to a file, all he or she has to do is replace the input and output icons with other input and output icons. Fig. 18 shows such a replacement.



(a) (b)

Fig. 17. An icon program example.

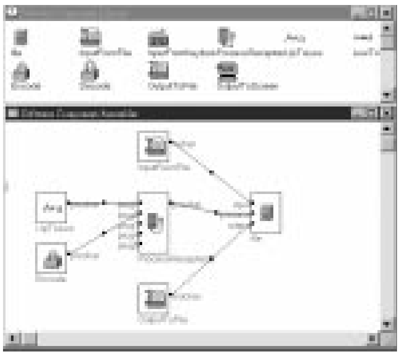


Fig. 18. An example of icon replacement.

Reuse of the rest of the program structure can be accomplished through this kind of simple replacement in a VPE system. Thus, an entire visual program can be treated as a framework.

4.4 Visual Programs and Frameworks

Application frameworks are very important for the software industry and academia since software systems are becoming increasingly complex. Designing frameworks is already a challenging task. Lack of an appropriate method for accumulating frameworks and reusing them discourages software constructors from using them in their programming

Table 1. Sample source code.

```
#include "C:\SOFTIC\ICDATA\file.h"
#include "C:\SOFTIC\ICDATA\infromke.h"
#include "C:\SOFTIC\ICDATA\outtoscr.h"
#include "C:\SOFTIC\ICDATA\ProRecep.h"
#include "C:\SOFTIC\ICDATA\uptolow.h"
#include "C:\SOFTIC\ICDATA\encode.h"
#include <windows.h>
#pragma argsused
int PASCAL WinMain(HANDLE hInstance,
                   HHANDLE hPrevInstance,
                   LPSTR IpszCmdLine,
                   int cmdShow)
{
_InitEasyWin();
file file_0;
InputFromKeyboard InputFromKeyboard_1;
OutputToScreen OutputToScreen_2;
Process Receptacle ProcessReceptacle_3;
UpToLow UpToLow_4;
Encode Encode_5;
file_0.connect (& InputFromKeyboard_1,0);
file_0.connect(&Process Receptacle_3,1);
Process Receptace_3.connect(&Up ToLow_4,0);
Process Receptacle_3.connect (&Encode_5,1);
file_0.connect(& Output To Screen_2,2);
return file_0.execution();
}
```

work. The visual programming approach provides a natural method for framework accumulation and reuse. The visual program depicted in Fig. 13 can be viewed as a framework because it also gives the designer a relatively easy means of replacing or modifying icons to produce another application program. The visual program depicted in Fig. 17 also provides another example, indicating the frameworks' ease of modification. Accumulating visual programs simply involves creating other meaningful icons to represent the visual programs and storing them in the Component Retrieval System for future reuse. Thus, a visual programming approach makes reuse and accumulation of frameworks easy.

5. CONCLUSIONS

Software reuse is an effective means of increasing software productivity and quality. Many reusable components have already been designed and used in various applications. Framework design is also promising as a major programming paradigm for the next century. However, reusable components and frameworks are still difficult to reuse unless they are integrated into an innovative software construction approach.

This study has presented a novel approach to developing a visual software construction system for reusing software components and frameworks. The proposed approach addresses three important issues:

1. Reusable components and frameworks must be integrated into a software construction process. Integration using visual programming is a natural choice since the visual programming model offers the optimum means of describing programming-in-large and reuse-in-large practice. Reusable components and frameworks can be encapsulated and visualized as icons for higher-level programming using visual programming, thus making the reuse of existing reusable components and frameworks in future application. Thus, reuse-in-large can be achieved.
2. Reusable components and frameworks must be accumulated in a standardized format. In addition, an appropriate classification structure and a naming system must be employed to manage them. More specifically, a component-management system for these reusable components and frameworks must be integrated into a visual programming model to provide a visual programming environment for software constructors. When this environment is used, a visual program can be treated as a new framework and can be accumulated into the environment for future reuse.
3. Requirement specification can be visualized. Multimedia Reusable Components make visual requirement presentation possible. The use of visual requirement specification allows one to view requirements as animation sequences so that it is not necessary to read or study voluminous requirement documents. This innovative software requirement representation paradigm provides designers with a natural means of communicating with users and, thus, receiving more accurate feedback from them concerning the requirements under consideration.

The visual software construction paradigm provides a new direction for academic researchers and for software developers who wish to obtain better solutions for software construction.

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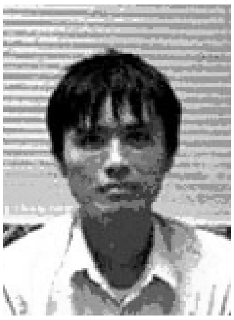

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