Supporting Behavioral Contracts for COM Components

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Abstract: Specifying behavioral specifications for components apart from the conventional syntactic interface specifications can be very useful in component based system development. Preconditions and postconditions describe one form of behavioral aspects of components. We discuss a tool and an implementation mechanism to incorporate behavioral contracts expressed in terms of preconditions and postconditions for COM components. A method invocation on a component is executed only if the precondition is satisfied. Similarly, the results are successfully returned upon successful execution of the postcondition. A design criterion was to facilitate contract specifications for existing components with least amount of changes at client and server side code. The tool requires that the component should implement an additional interface called *IAccess* if the behavioral contract needs component state. No modification is required to existing clients of the component.

1 Introduction

Though contracts play an important role in component based system development, the conventional syntactic contracts specifying name, constituents and type signatures of component's interfaces are not sufficient for many software engineering tasks. For example, the conventional interface specifications do not specify the behavioral aspects such as constraints on interface parameters and the semantics of interfaces. The behavioral aspects are important for many tasks such as selecting the right component for reuse and achieving correct composition of components. Hence the notion of behavioral contracts [Ba99], [CR99] is gaining importance. Behavioral contracts in *Design by contract* method [JM97] include Boolean invariants, preconditions and postconditions. A JAVA implementation of the design by contract method through Biscotti, a language extension, can be found in [CR99]. Components can be associated with various kinds of information. A framework for handling different kinds of metadata about components can be found in Orso et al. [OHR00].

In this paper, we describe a method and a tool for integrating behavioral contracts in the form of preconditions and postconditions to existing COM components. It is possible to design similar tools for other component systems. One goal has been to allow contract specifications to existing components with as little modifications to existing code as possible. The behavioral contract itself is specified in a *contract component*. A method invocation on a component is invoked only if the precondition is satisfied in its contract

component. Similarly the contract component ensures that the postcondition is satisfied after the execution of the method. Upon failure, an exception is returned to the client. The client remains unaware of the existence of the intermediate contract component. This approach is similar to filter objects [Jr00], in which, the intermediate filter object traps every method invocation transparently and carries out computations before and after the method invocation without the knowledge of the client.

By specifying behavioral contracts in the form of intermediate contract components, not only preconditions and postconditions can be verified, but other intermediate tasks also can be performed. A contract component may require access to implementation of the associated server component. In this case, the component needs to implement an interface called *IAccess* through which the contract component can gain access to the component's implementation. Access to the component through *IAccess* is restricted and only the contract component is allowed to invoke the methods through this interface.

A tool has been built to support the development of the contract components. The tool generates the necessary abstractions and partial implementations for contract specification for a given component. We will describe the design and implementation aspects of this method in subsequent sections.

2 Design

The tool requires an IDL specification of the server component and the desired name of the contract component. The IDL specification of the server component is typically specified in a file with *.idl* extension, containing the description of the interfaces that are implemented by the server component. The tool parses the *.idl* file to generate required abstractions and partial implementations. Let us consider an input *.idl* containing the interface declaration as shown in Figure 1.

```
// Interface ISampleInterface
[       object, uuid (…),
        helpstring ("ISampleInterface Interface"),
        pointer_default (unique)
]
interface ISampleInterface : IUnknown  {
        HRESULT function ([in] int a,[in] int b, [out] int* c);
};

// Interface IAccess
[       object, uuid (…),
        helpstring ("IAccess Interface"),
        pointer_default (unique)
]
interface IAccess: IUnknown {
        HRESULT getPrivateMember ([in] CLSID clsid, [out] int* av);
};
```

Figure 1: The Component IDL

As required by the contract component, the server component implements the *IAccess* interface. The *IAccess* interface contains methods for accessing the implementation members of the server component, which may be required for evaluating the precondition and the postcondition code. Access to interface *IAccess* is provided only to the contract component. This is ensured through one of the input parameters to all methods of *IAccess* interface, which is the CLSID of the contract component. By comparing the CLSIDs, implementation of *IAccess* may reject an invocation. Figure 2 depicts the class diagram of the system of components after it is made contract aware.

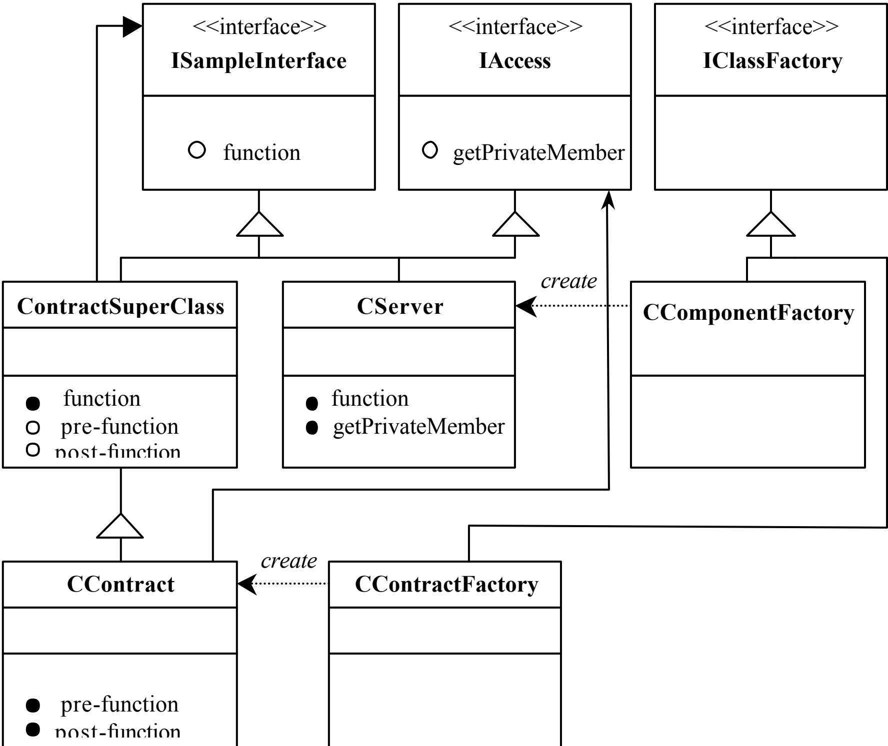

Figure 2: The Class Diagram

As shown in Figure 2, CServer implements interfaces *IAccess* and *ISampleInterface*. The tool generates the classes *ContractSuperClass*, CContract and *CContractFactory*. Class *CContract* is the contract component class and class *CContractFactory* creates the contract component. Class *ContractSuperClass* implements the interfaces implemented by *CServer* making the classes conceptually compatible. This allows the component class to be transparently filtered through the same abstractions provided by

the contract component. The contract programmer only needs to implement the abstract methods in this class through inheritance. This class implements the server component's interface in such a way that preconditions and postconditions are invoked before and after the intended function invocation on the component. Preconditions and postconditions are modeled as abstract methods (hooks) in this class.

As the client invokes a method on the *CServer,* it should actually invoke the corresponding *ContractSuperClass* method, which ensures that the necessary precondition and postcondition is satisfied. This is achieved through COM's support to change implementations keeping the same abstraction through the *treat as* directive.

```
HRESULT __stdcall ContractSuperClass::function (int a, int b, int* c) {
        if (pre_function (a, b)) {
                int contract_c;
                pISampleInterface->function (a, b, &contract_c);
                if (post_function (&contract_c)) {
                        *c = contract_c;
                        return S_OK;
                } else return CContract_E_POSTCONDITION;
        } else return CContract_E_PRECONDITION;
}
```

Figure 3: Contract Implementation of Component's Interface

An example contract class implementation of a method in the component interface is given in Figure 3. It can be seen that if the precondition is not satisfied, an error code *CContract_E_PRECONDITION* is returned to the client without passing on the invocation to the server component. An existing client will be able to handle this error code in a generic fashion.

The precondition method receives the input parameters as arguments. It also has an access to the *IAccess* interface on the server component. A pointer to this interface is made available through a tool-generated implementation. The *IAccess* interface can be used by the precondition and postcondition implementation if required by their semantics. Similarly, the postcondition method receives the output parameters. If the postcondition is not satisfied, an error code *CContract_E_POSTCONDITION* is returned to the caller. If an error code is returned by the server component itself, it is passed on to client. This special case has been omitted from Figure 3 for the sake of readability.
The concrete contract component specifies the implementations of postcondition and precondition. As shown in the class diagram, class *CContract* implements the contract. The user through an interface provided by the tool chooses the name of the contract component. The tool generates the skeleton of the contract class and the contract developer only needs to complete the implementations of the hook methods in the base

class. The tool also generates a factory class for the contract component, in this example, class *CContractFactory* as shown in the class diagram.

A *CoCreateInstance* for the server component invokes a *CoCreateInstance* on the contract component, which in turn directs the component's server process to create an instance of the server component. In this way, from the user's viewpoint, the relationship can be described through COM's containment model as shown in Figure 4. However, from the system's viewpoint, it is an example of *using* relationship since it is possible to remove or change a contract component at any point of time. The implementation mechanism is discussed in the next section.

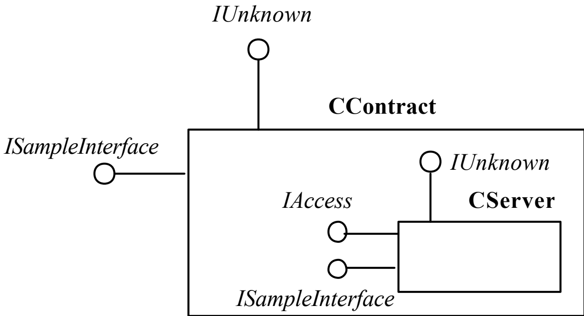

Figure 4: Containment of Server Component by Contract Component

3 Implementation Mechanism

The sequence of events leading to an installation of a contract component is shown in the interaction diagram in Figure 5. The mechanism uses out-of-process servers. When the server process is brought up, it creates and registers an instance of the component's class factory. Whereas, when the contract server process is started, it calls the *CoTreatAsClass (CLSID_S, CLSID_C)* API to switch the implementation of the server component. *CLSID_S* represents the CLSID of the server component and *CLSID_C* represents the CLSID of the contract component. This API call assigns the *TreatAs* key of the server component to *CLSID_C*. This causes the contract component class to emulate the server component class. Subsequently, calls to *CoGetClassObject* with *CLSID_S* as the parameter transparently use *CLSID_C*.

As shown in Figure 5, creating an object of *CLSID_S* results in *CreateInstance* being invoked on *CContractFactory*. The contract factory now needs to perform two tasks: the server component be created and returned to the user as desired, and a contract component be created and assigned in relationship with the server component.

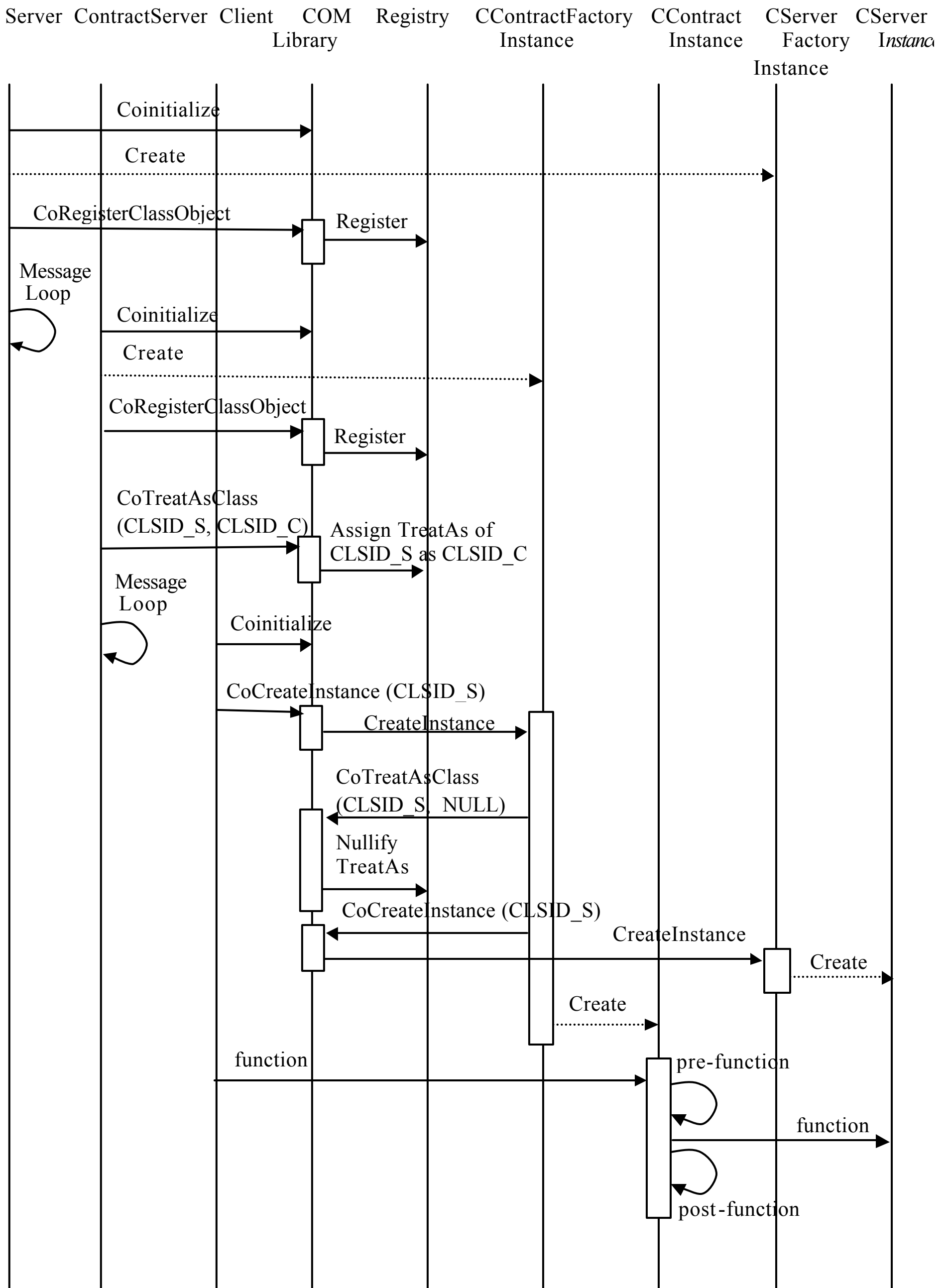

Figure 5: Interaction diagram

At this stage, the contract component cannot directly instantiate the server component, as create calls on the component are redirected to itself. Hence, it momentarily disables redirection by calling *CoTreatAsClass(CLSID_S ,CLSID_NULL)*. *CContractFactory* instance then calls *CoCreateInstance* on server component factory. After remembering the pointer to the server component, it switches back to redirection and returns server component's interface to client. Subsequently, the contract component filters message invocations sent to the server component.

Although we can view the relationship between the contract component and the server component as *COM containment*, it is not desirable to implement this as a simple *COM containment* since the clients will need to instantiate the contract component, thus requiring a change in the client code. This would not satisfy the requirement of keeping the client code unchanged.

This design can be extended to include an elaborate contract plug-unplug protocol to remove or change contract components dynamically. This method does not require the client code to be modified. An existing server needs to provide an additional interface namely *IAccess,* if the contract component requires access to component's implementation.

4 Conclusion

A method of specifying behavioral contracts for existing COM components was discussed. The method considers contract specification in terms of preconditions and postconditions for existing COM components. A tool support for the development of contract components has been provided. The implementation is built around COM's *treat as* directives. The contract component remains transparent to the clients of the server component.

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