Defining Software Component Specifications: An Open Approach

Kenneth Klein
Computer Sciences Corporation
A Couple Definitions

• Open
  – Based on widely excepted and supported standards
  – Defines key interfaces using these standards
  – Not proprietary

• Software Component
  – A modular part of a software design that hides its implementation behind a set of external interfaces.
  – Within a system, components satisfying the same interfaces may be substituted freely.

• That’s what the terms mean in the context of these slides….
The Problem

• Given an “as-built” component-based Department of Defense (DoD) software system
  – Code written in Java
  – Interface-based component services

• Needed an approach to documenting each component as a set of well-defined interfaces
  – Required to meet DoD “openness” standards
  – Critical for making components extendible and reusable
**Well-Defined is not Well-Defined**

- A lot of literature available on defining:
  - Information exchange standards, e.g., CORBA, JMS, DDS
  - Specific implementations of these standards
  - Component frameworks, e.g., SOA, EJB
  - Quality of Service requirements
- Not so much out there on defining a service’s functional behavior
The Solution

• Define the component and its services using:
  – Lightweight UML domain modeling
  – Design by Contract (DbC) principles

• Tools used
  – A UML modeling tool that can generate HTML output
  – Doxygen
    • Open source C++/Java documentation generation tool
      – Similar to Javadoc
        » Recognizes Javadoc comment delimiters
      • Reads source code, generates HTML
  • www.doxygen.org
  – A web browser
Navigating the Spec

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Weapon Resource Scheduler Component Specification

Version 2.1

Overview

This document provides the component specification for the specified component. This includes the overall component contract, as well as the contracts for each of the component’s services. A domain model is also included.

How to Use This Document

The overall component contract can be found in the Component Contract page.

The individual service contracts can be found by first navigating to the Component Services page, then clicking down to the classes that contain the functions that provide the services. Each function’s abstract contains its contract. To find a particular function, click Functions to display an alphabetical function list.

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Domain Model: The Context Diagram

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Home • Component Contract • Component Services • Classes • Functions • Domain Model • Glossary

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Context Diagram

• Shows component’s *provided* and *required* interfaces
  – Provided interface declares services that this component offers to external components
  – Required interface declares services that this component requires from external components

• Describes required interfaces in context of this component
  – Each component may describe the same required interface differently based on the component’s needs
  – E.g., given an Illuminator interface, one client may *require it to check Illuminator equipment status*; another client may *require it to Illuminate a target*
Context Diagram Example

WeaponResourceManager: Context Diagram

Provided

WeaponResourceManager

Launcher

ShipState

Illuminator

Required

WeaponResourceControl

WeaponResourceStatus
Context Diagram Example (cont.)

The Illuminator interface is used to request the status of illuminators. It is also notified of illuminator faults.

| Parent Package | ContextDiagram | Abstract | No |
Component Services Example

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Component Services

• What is expected of the client?
• What does the service do?
• State all this with as few implementation details as possible
  – Most implementation choices should not impact the specification
  – More likely specification will remain unclassified
• **Design by Contract provides a solution**
What is Design by Contract (DbC)?

• Defines the *contract* between the *interface* and its *clients*

• **Preconditions**
  – States that must be true when service is invoked

• **Postconditions**
  – If service is invoked when preconditions are true, postconditions describe guaranteed outcome
    • e.g., state changes, messages sent

• **Invariants**
  – Attribute constraints that must always be true:
    • After component instantiation
    • Before/after each service invocation
    • e.g., An Engagement must have exactly one Target

• **Exceptions**
  – Describes what happens when preconditions or invariants are violated or postconditions cannot be met
  – Behavior can be “undefined”
Why DbC?

• Well documented, mature paradigm
  – Term coined by Bertrand Meyer in 1997
  – Since then, large volume of literature written on the topic
  • See resource list

• Decoupled from implementation details
  – Guidelines for “just enough” information
  – Implementation can change without impacting contract

• Encourages discussions that may otherwise never occur
  – Provides common vocabulary for complex concepts
  – Exceptions often discovered when writing contracts
Why DbC? (cont.)

• Facilitates Liskov Substitutability Principle (LSP)
  – Service implementations/extensions must not add preconditions or remove postconditions

• Supports:
  – Maintainability/Extendibility/Reusability
DbC Note: Preconditions and Callbacks

• Callback services should not change the state that triggered the callback
  – Remaining observers will receive incorrect notifications
    • Subject component has a list of color observers
    • Subject reports “I just turned red”
    • One of the observers changes subject to blue
    • The remaining observers will incorrectly be notified that subject is red

• Mitigation
  – Subject component keeps track of whether a callback is in progress
  – Any offered service that could change an observed state has a precondition that notifications are not in progress
    • Above observer’s attempt to make subject blue would be rejected
DbC Note: Maintaining the Invariants

• Exceptional service termination must restore component invariants
  – Otherwise, component is not stable, so its services’ behavior is undefined
  – May be criteria for invoking recovery path
• Concurrency should only be allowed for services that can guarantee that preemption can only occur while the component invariants are in place
  – Mitigated by many concurrency oriented architecture and design patterns
  • See Pattern-Oriented Software Architecture Vol. 2: Patterns for Concurrent and Networked Objects
Component Service Contracts

• Method signature
  – Captured as-is from source code

• Preconditions/Postconditions/Exceptions

• Query or Command
  – Does the service change the parameters’ or the component’s state?

• Parameters
  – Constraints
    • E.g., valid ranges, precision, units
  – Is ownership transferred?
    • If “no,” client must be notified of any state changes

• Type Definitions
  • Imported as-is from source code
  • Linked via hypertext
Component Service Contracts (cont.)

- Quality of Service
  - Performance, throughput, blocking, availability
- Is concurrency allowed?
Service Contracts as Comments in the Code

  - We typically attempt to maintain a machine-readable form of a program and an independent set of human-readable documentation, consistent of prose and flow charts.
  - The results in fact confirm our teachings about the folly of separate files. Program documentation is notoriously poor, and its maintenance is worse.
  - The solution, I think, is to merge the files, to incorporate the documentation in the source program.

- This is what Doxygen does…
/**
 * DESCRIPTION:
 * <p>
 * This method will distribute the request to the WeaponResourceManager.
 * <p>
 * @param[in] request The request being sent to the WeaponResourceManager.
 * -# Valid ranges
 * -# Not null
 * @par Query or Command:
 * Command
 * @pre
 * -# None.
 * @post
 * -# If the request is an Alpha Request, it was added to the
 * Illuminator Schedule.
 * ...
 */

public void setRequest( RequestIF request );
Component Services Example: Doxygen Output

```c++
void WeaponResourceManager::setRequest ( RequestIF request )
```

**DESCRIPTION:**
This method will distribute the request to the `WeaponResourceManager`.

**Parameters:**
- `[in] request` The request being sent to the `WeaponResourceManager`.

1. Valid ranges
   - Not null
2. Ownership transferred (Y/N)? Y

**Query or Command:**
Command

**Precondition:**
1. None.

**Postcondition:**
1. If the request is an Alpha Request, it was added to the Illuminator Schedule. This processing includes the use of the Illuminator interface to acquire equipment status.
2. If the request is a Beta Request, it was added to the Launcher Schedule. This processing includes the use of the Launcher interface to acquire equipment status.

**Exceptions:**
- `nullRequest` The request is null. Behavior undefined.

**Blocking (Y/N):**
N
Component Contract Example

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Component Contracts

• Preconditions/Postconditions
  – Before and after component startup, respectively

• Invariants
  – Applicable to component as a whole
    • Each is a pre & post condition for every service

• Exceptions
  – If pre/post conditions or invariants violated

• “Full load” memory requirements

• Proven hardware platform and OS support

• Communication standards and implementations
  – E.g., JMS/Websphere, DDS/NDDS 4.0, CORBA/ACE TAO

• Other Protocols/Standards
  – POSIX, SNMP, .NET, etc.
Component Contracts (cont.)

• Programming Languages
• Configuration file dependencies
• Availability requirements, e.g., MTBF
Component Contract Example

WeaponResourceManager Component Contract

Precondition:
The AlphaProperties configuration file must exist.
The initial state must be provided.

Postcondition:
The WeaponResourceManager was started and the initial state was set using the provided parameter.
The WeaponResourceManager applied the states found in the AlphaProperties file.
Communications were established with the Illuminator, Ship and Launcher components.

Invariant:
Communication must be maintained with the Illuminator, Ship and Launcher components.

Exceptions:
- MissingPropertiesFile: The AlphaProperties file does not exist. Error is logged and program exits.
- InvalidProperties: Properties in the AlphaProperties file were missing or invalid. The properties are set to their default values.
- RequiredComponentsUnavailable: Unable to communicate with the Illuminator, Ship or Launcher. Behavior undefined.

Standard Used for Invoking Services
JMS/Tibco 4.0.0

Language Dependencies
Java 5.0

More below…
Contract Ambiguity Problem

• From *M3* pp. 63-64
  – Human language is not naturally a precision instrument for [specification] definitions.
  – Formal definitions are precise. What they lack is comprehensibility.
  – I think we will see future specifications to consist of both a formal definition and a prose definition.

• This is what the Domain Model does…
Contract Ambiguity Solution: The Domain Model

• Provides formality of UML
  – Each domain class is clearly defined in the model
• Contracts reference domain classes in plain English
• What is a domain class?
  – Real-situation *notional* class in a domain, e.g., Launcher Schedule, Target, etc.
  – They are not actual software implementation classes
• Why not implementation classes?
  – *M3* says (pg. 175): “If one uses only a *highest-level structure graph*, it might safely be kept as a separate document, for *it is not subject to frequent change*."
  – Notional domain classes are stable, because they are decoupled from implementation details
Domain Model Example

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Domain Model Example

WeaponResourceManager: Schedules and Scheduled Events

Multiplicity is an invariant

IlluminatorSchedule

0..*

IlluminatorScheduleEvent

LauncherSchedule

0..*

LauncherScheduleEvent
How Domain Model Relates to Contracts

**Postcondition:**
1. If the request is an Alpha Request, it was added to the Illuminator Schedule.
2. If the request is a Beta Request, it was added to the Launcher Schedule. This to acquire equipment status.

**Class IlluminatorSchedule**

**Documentation**
The IlluminatorSchedule contains all of the current illuminator reservations.
Glossary

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Glossary Excerpt

**Component Contracts**

Component contracts apply to the component as a whole. They should not be confused with **Component Service Contracts** which apply to particular services.

**Precondition:**
- System and/or environment states required in order to successfully instantiate the component, e.g., config files must exist.

**Postcondition:**
- Component states that exist upon completion of component instantiation and initialization. For OA, this includes completion of the component’s start method. Examples of component level postconditions include:
  - Indicating if the component was placed in active or standby state
  - Listing which config files were read
  - Stating that communications with other specific components were initialized
  - Listing which subscriptions and publications were defined

**Invariant:**
- Component states that must be true after component instantiation/initialization and at the start and completion of any offered service. Multiplicity invariants are specified in the Domain Model (e.g., an Engagement may have between 0 and X weapons), so they should not be specified here. Note that when a service terminates due to exceptional behavior, part of the component’s exception handling should insure that the invariant states are still true. If they are not true, the component should restore the invariant states. If this is not done, the component will be in an unstable state.

**Exceptions:**
- **NameOfException**
  - What happens if component initialized when preconditions are not met.
  - What happens if preconditions are met, but postconditions cannot be met.
  - What happens if an invariant fails to be maintained.
  - Notes
    - An exception is only handled if explicitly stated, otherwise component behavior is undefined.
    - "Exception" means behavior in the event of contract violation. It is not meant to imply that a C++
Summary: Comp Spec Artifacts

- Modeling Tool
- Domain Model
- Code w/ Service Contracts
- Comp Contract
- Glossary
- Doxygen
- Contract Glossary
- Comp Contract
- Service Contract
- Domain Model

Text
HTML

Has Doxygen tags

Doxygen
How This Technique Addresses Openness

• Provides *well-defined* interfaces using open paradigms
  – DbC and UML Domain Modeling
• Generated using open tools
• Output is readable in any HTML browser
What the Component Spec Provides

• Software Architect
  – Defines a component’s role in overall architecture
  – Facilitates component reuse

• Software Developer
  – Defines implementation constraints
  – Describes exceptional behavior

• System Engineer
  – Facilitates understanding of the component’s role in fulfilling requirements

• Component Test Engineers
  – Provides basis for writing component level tests

Lets the stakeholders know the rules
Level of Effort for Sample Component

• Task requires domain knowledge
  – *Does not need to be expert*, but does need access to an expert
• Documented 40 services
  – 28 trivial, e.g., getters/setters
  – 12 non-trivial
• 3.5 staff weeks

Writing specs takes time
For More Information

Kenneth Klein
kklein1@csc.com
856-252-2359

Joanis Ploumitsakos
jploumit@csc.com
856-252-2091
Backup
DbC Resources

- [http://ootips.org/lsp.html](http://ootips.org/lsp.html)
Comp Spec Development Process

Start

Install Doxygen on classified PC

Create a directory structure for component API output

Use a modeling tool to create an empty domain model.

Create text file with HTML link to Domain Model's HTML index file.

Set up Doxygen to parse needed source files and the HTML Link to the domain model.

Write component contract using the Glossary guidelines (from Support Files) as a template.

Select a client interface to document. Using the Glossary guidelines as a template, add service contract to each client interface function's source code abstract.

If necessary, insert Doxygen tags into source code to exclude classified information.

Run Doxygen. Verify that output is acceptable and unclassified.

Domain Expert and Methodology Expert Review

Comments resolved

Are All interfaces documented for the component?

Yes

Place comp spec and domain model HTML files into controlled zip files.

Done

NO