Architecture/Architectural Design

Software Engineering
Computer Science 520/620
Spring 2014
Prof. Leon Osterweil

Requirements Spec.
Characteristics of System to be built must match required characteristics
Hi level design must show HOW requirements can be met
Test Results must match required behavior

Test Plan
Test plan exercises this code

Design
(high level) Architecture consistent views (low level) specification
Code must implement design

Code
What is the Nature of Design?

- Addresses the question: HOW?
- Goal: Indicate how to develop a solution system that will satisfy requirements
- Complements:
  - Requirements: WHAT
  - System Test Plan: HOW WOULD I KNOW IT IF I SAW IT
- Design is a very broad and encompassing area
  - Hard to separate it from requirements
  - Hard to separate it from code
- Too hard to be done in one large step
  - Especially because of execution platform variation

- Design is essentially a modeling activity
Design

• It is both a noun and a verb
• Design the noun
  – Specification of a plan for something
• Design the verb
  – A process for creating a “design, the noun”
• Both are fundamental and hard
• We will address both
  – But most work has been done on the verb
• We will start with “design, the noun”

Numerous Well-Known Design Notations and Methods

• Jackson System Development (both noun and verb)
• Rational Design Method (verb)
• Shlaer-Mellor (verb)
• Booch Object Oriented Design (both noun and verb, but mostly the noun)
• Using various notations (noun)
  – DFDs
  – FSAs
  – Petri Nets
  – UML
• ...
What Do Designs Model (and Why)?

- Conceptual, architectural, high-level designs model how requirements might be met
  - Vehicles for "what-if" discussions
  - Help clarify requirements—by being related to them
  - Often merge and intersperse with requirements
  - Help suggest implementation issues/concerns
- Coding specifications model the form, content, structure of the eventual code
  - Increasing emphasis on evolvability, rapid modification, and flexible deployment

How are Designs Represented?

- Familiar approaches
  - Use of hierarchy to conquer size/complexity
  - Use of multiple views to capture different aspects
  - Use of pictures and diagrams to appeal to non-technical stakeholders
- Connected to requirements elements they respond to
- Connected to code elements that implement them
**Architecture vs. Specification**

- **Architecture**
  - High level system design
  - Concerned with components and the *interactions* among components
  - Not with the algorithms or data structures
- **Specification (Low Level Design)**
  - Emphasis on data structures and algorithms
  - Focus on implementation issues
    - Stepwise refinement
    - Evolvability
    - Use of abstraction

**Traditional Software “Design”**

- Early 70’s recognized the need for design
  - Emphasis on data structures and algorithms
    - Stepwise refinement
    - Data abstraction
  - More feasible to think of design as one phase
    - Focused on narrow set of issues
    - Still “Preliminary Design” vs “Detailed Design”
  - Corresponds roughly to what we will be calling “specification”
Architecture addresses new issues, requires a new term

- Change in how we do software development
  - Component based, distributed systems
- Previous HL design notations assumed procedure call model
- Need to focus on
  - Nature of components and their loci
  - Component interactions (Connectors)

Typical Architecture Issues

- Component interaction models
  - What are the components’ interfaces?
  - Who can use them? And how?
- How much flexibility is achievable? How modifiable?
  - Is plug and play possible?
- Where is network access used? How?
  - Message passing, broadcasting, etc?
- Late-binding issues
  - Non-determinism
  - Use of proxies
New issues in characterizing system objects

- Interaction protocols
  - Tightly coupled objects
    » Direct or Remote procedure calls
  - Loosely coupled
    » Event based notification, observers

- Degree of separation
  - Locally
  - Internet scale
  - “in the cloud”

- Modes of communicating with each other
  - message passing
  - broadcast
  - multi-cast

Architecture description (specification or design)

- A high level design that defines the components, connectors, constraints and the inter-relationships among these entities
  - Usually compositional
- The form (i.e. the type of graph) is not the point here
  - What it is trying to communicate (i.e. its position in the development process) is what is important
- Suggests the value of elaborate semantics and annotations of the nodes and edges
Example: System Interpreter Architecture

System Model

Step Sequencer

Agent Manager

Artifact Manager

Agenda Item

Agendas

Human Agents

Non-Human Agents

Example: A Simulator Architecture

TimeLine

Agent Behaviors

Agent Behaviors Specification

Simulated Human Agents

Non-Human Agents
Problems with This

• Picture creates an impression
  – But no specifics
• Raises questions
  – Answers few
• A good beginning
• But how to proceed?
• Need a language
  – Capable of specifying details
  – Clear semantics
  – Etc.

Components, Connectors, Constraints: Central Software Architecture Entities

• Components--computational units
  – Subsystems
  – Classes
  – Objects
• Connectors--interaction model
  – Which components are connected to which?
  – How are they connected?
  – Are connectors just components with restricted semantics?
• Constraints
  – Guides and limits to the ways components and connectors can be configured
Architectural Styles

• Sets of constraints that are widely used because they offer understood capabilities and features
• Examples:
  – Pipe and Filter
  – Client/Server
    » REST
  – Publish/Subscribe
  – Model/View/Controller

Pipeline Architecture:
Each component has one input connector, one output connector
Pipe and Filter:
Pipeline architecture where some connectors have a “filter”

Filters:
Components that have particular properties
(they “filter” the data moving thru the connectors)

Client/Server

Request

Reply
Client/Server

Larger App

Request

Reply

Client

Server

Lots of Other Data

Multiple Clients

Larger App

Request

Reply

Client

Server

Lots of Other Data

Lots of Other Data
Need To Specify Details

- What will a request look like?
- What will a reply look like?
- How will multiple simultaneous requests be served?
- Any constraints on requests, replies?
  - E.g. speed

Different Substyles

- How to specify different ways for client/server to perform
- REST Architecture
  - Server is “stateless”
  - No memory of details of client
  - A key property that www infrastructure is built upon
Service-Oriented Architecture

• Applications composed from components
• Components are accessed via the Web
  – Specified generically (as a “service”)
  – Located by web searches (using proxies)
  – Accessed via the web
• How to compose such services?
  – What composition constructs
• How to be sure they provide correct services?
• How to maintain privacy and security?

SOA Variants

• SaaS (Software as a service)
• HaaS (Hardware as a service)
• SyaaS (Systems as services)
• Staas (Storage as a service)
• DaaS (Databases as a service)
• TaaS (Tools as a service)
• Each emphasizes just what kinds of components are to be searched for and integrated
Cloud Architecture

• SOA approach, but
  – Don’t know/don’t care where or how services are provided via the Web
• Service may be different each time the system runs
• Similar problems, but now more worrisome
  – Correctness
  – Security
  – Privacy

Architecture description language (ADL)

• A language for defining an architecture
  – Components, connectors, constraints, configurations
• Supports specifying styles and details
• Often has associated capabilities
  – For editing
  – For visualization
  – For analysis
  – For system generation
  – For testing
Some Notable ADLs

• Different ADLs emphasize specification of different architectural issues and features
• Some examples
  – Darwin
  – Rapide
  – MetaH
  – ACME
  – Menage

References

• Overview:
Future Issue to be Addressed: Consistency Verification

- Internal consistency of specification
- Internal consistency of architecture
- Consistency between specification and architecture
- Consistency between architecture and requirements
- Consistency between specification and implementation (in code)
- All of the above are done better when all these artifacts are defined more rigorously

Jackson System Development: An Ancient Example

- JSD produces models of the real world and the way in which the system to be built must interact with it
- Primary focus of this is actions (or events)
- Actions can have descriptive attributes
- The set of actions are organized into sets of processes
- Processes describe which actions must be grouped together and what the "legal" sequences of actions are
- Processes can overlap in various ways
- Data are described in the context of actions
  (NOTE: In JSD data considerations are subordinate to actions)
- Processes are aggregated into an overall system model
  --Done with connectors
An Early Precursor to ADLs: Focus on Some Basic Essentials

- JSD: Jackson Structured Design
  - Named after Michael Jackson
  - British software design pioneer
- Focus on high-level design: architecture
  - Lower levels addressed by JSP: Jackson Structured Programming
- Together they span from requirements to coding
- Now largely overtaken by use of various UML notations

Starts with “Process Models”—The Components

- Primary building blocks of a JSD design
- Contain all actions characterizing a key real-world process
- Actions are structured into a tree
- Only the leaf nodes of the tree are real-world actions
- Interior nodes are conceptual
- Interior nodes can be annotated to show choice or iteration
- Traversals of this tree constitute the only "legal" sequences of actions for this process
- Model a process as a tree: defines a regular expression
- Set of traversals is a regular set
- Process models are usually multiply instantiated
An Example:
A Library Information System

• Functional requirements:
  – The way books are dealt with
    » Buy, lend, track, dispose
  – The way members are dealt with
    » Enrol, service requests (borrow, reserve, return)
  – Support bookkeeping requirements
    » Check status, answer queries

• Non Functional requirements
  – Inquiries should be processed as soon as they are received
  – Reports have to be generated at the end of each day
  – Maintain privacy of transactions
  – Used primarily by librarians

Main Architectural Features

• Some Key Components
  – Book
  – Book repository
  – Member
  – Librarian

• Some Key Connectors (i.e. links between them)
  – Librarian interactions with Book Repository
  – Member interactions with Book
  – Etc.
Some Key Architecture Decisions

- What are the characteristics of each component?
  - What capabilities does it have
  - What properties does it have?
  - Where is it located?
  - Etc.
- How will the components interact with each other?
  - By what media and protocols?
  - Subject to what restrictions?
  - Etc.

Starts with Process Models

- Primary building blocks of a JSD design
- Contain all actions characterizing a key real-world process
- Actions are structured into a tree
- Only the leaf nodes of the tree are real-world actions
- Interior nodes are conceptual
- Interior nodes can be annotated to show choice or iteration
- Traversals of this tree constitute the only "legal" sequences of actions for this process
- Model a process as a tree: defines a regular expression
- Set of traversals is a regular set
- Process models are usually multiply instantiated
A JSD Component: The Book Process

Fig. 2.
Component Defined as Actions and Entities

- Actions have the following characteristics:
  - An action takes place at a point in time
  - An action must take place in the real world outside of the system.
  - An action is atomic, cannot be divided into subactions.

- Entities have the following characteristics:
  - An entity performs or suffers actions in time.
  - An entity must exist in the real world, and not be a construct of a system that models the real world.
  - An entity must be capable of being regarded as an individual; and, if there are many entities of the same type, of being uniquely named.

Two More Processes

Fig. 8.
Processes and Data

- Details of actions on data hang off of process model leaf nodes
- Input and Output actions too
  -- These are important during the network phase
- Global data is necessary too
  -- For functions that must combine data from >1 model process
  -- To assure consistency between processes
  -- To coordinate between different instances of the same process

Actions/Attributes

- Acquire
  - attributes: in the library, on loan
- Classify
  - attributes: in the library, requested, time out on loan
- Lend
  - attributes: in the library, on loan, time out on loan, loan date
- Renew
  - attributes: time out on loan, loan date
- Return
  - attributes: in the library, time out on loan, loan date
- Sell
  - attributes: in the library, out of loan
The Book Process
With Actions
and Attributes

JSD Hierarchy

Fig. 4.

Fig. 12
Message Passing

- Data stream carries a message from one process activity to an activity in another process (a DFG edge)
  --Must correlate with output leaf of sending model process
  --Must correlate with input leaf of receiving model process

- Data transfer assumed to be asynchronous
  --less restrictive assumption

- No timing constraints are assumed

- Messages are queued in infinitely long queues

- Messages interleaved nondeterministically when multiple streams arrive at same activity

JSD Connectors

Fig. 12.
State Vector Inspection

- Modeling mechanism used when one process needs considerable information about another

- State vector includes
  -- values of all internal variables
  -- execution text pointer

- Process often needs to control when its state vector can be viewed

- Process may need exclusive access to its vector

- Could be modeled as message passing, but --important to underscore characteristic differences

JSD Connectors

Fig. 12.
Fig. 14.

Fig. 15.

1. read next REQUEST
2. read next BOOK SV (overdue books only, sorted by borrower)
3. write LIST-HDR
4. write LIST-TAIL
5. write BORROWER-HDR
6. write BOOK-LINE
IF I WERE YOU...
I'd assume that the following members have left...

IF I WERE YOU...
I'd cancel the following reservations...
About those Graphs

• There are formal semantics of these graphs
  – Defined by Jackson and colleagues
• Components are defined precisely using
  – Hierarchy
  – Abstract interfaces
• Connectors are defined precisely too
• And their relations to each other

Comments/Evaluation

• This is an architectural design.
  – Should not assume the system will be built this way
• Based upon model of real world
• Careful (and experienced) analysis of the model generally suggests implementation tactics, though
• Treatment of data is very much subordinated/secondary
• Does a good job of suggesting possible parallelism
• Contrasts strongly with Objected Oriented notions (eg. Booch, UML), that we will see next
How Does One Go About Doing (Architectural) Design – the Verb?

• Process by which design is built is understandably complex
• Various authors have differing ideas about this
• A key essence of human creativity
  – Little understood
• Most efforts aim at supporting humans
• Much work on analyzing and verifying designs

JSD is done in Phases

• The modeling phase
  – Entity/action step
  – Entity structure step
• The network phase
  – Connect model processes and functions in a single system specification diagram (SSD)
• The implementation phase
  – Examine the timing constraints of the system
  – Consider possible hardware and software for implementing the system
  – Design a system implementation diagram (SID)

Jackson is far less articulate about the verb than about the noun
The Modeling Phase: JSD Models

- JSD produces models of the real world and the way in which the system to be built interacts with it.
- Primary focus of this is actions (or events).
- Actions can have descriptive attributes.
- The set of actions must be organized into a set of processes.
- Processes describe which actions must be grouped together and what the "legal" sequences of actions are.
- Processes can overlap in various ways.
- Data are described in the context of actions. (NOTE: In JSD data considerations are subordinate to actions.)
- Processes are aggregated into an overall system model.
- Done with the aid of two canonical models of interprocess communication.

The Network Phase: Communication Between Processes

- Weave Processes together incrementally to form the total system specification.
- Also add new processes during this phase: eg. input, output, user interface, data collection.
- Goal is to indicate how processes communicate with each other, use each other, are connected to user and outside world.
- Linkage through two types of communication:
  --Message passing
  --State vector inspection
- Indicates which data moves between which processes and more about synchronization.
Implementation Phase

- JSD outputs suggest how to proceed with JSP
- Network Phase suggests ideal traversal paths through model processes and their local data
  - suggests internal implementation of model processes
  - studying use of model processes suggests internal structure of their data
- Communication by data streams and state vector inspection often suggest real implementations
  - But often not

“New” Development Approaches
Exploiting Architecture Perspectives

- Model-based Development
- Component Based Development
- Service-Oriented Architecture
- Cloud Computing
Model-Based Development

- Start development by creating a model of the system to be built
  - Often specified using an architecture definition language
- Use the model to guide development of the system
- Hmmm. Sounds like “design before coding”
  - Think first (?)

Component-Based Development

- Think of development as the composition of pieces (components)
- So, start with a plan for how the pieces will fit together
  - A model?
  - A design?
- Start with some kind of catalog of what pieces are available
  - And what their interfaces are
- Fit the components into their places
Various Approaches to Doing This

• Build systems out of “components”
  – Parts that have already been built
• Components are large bodies of code
• But also accompanying
  – Test results
    » Explicit or Implicit
  – Design elements
  – Requirements
  – Etc.

Component-Based Development Example:
A Japanese Software Factory

What is a "software factory"?

• Japanese hardware manufacturers built them in 70's, 80's
• Actual building designed to support software development
  --Ergonomic offices and amenities
• Strong computing support
• Library of existing, reusable components
• Clear and rigorously defined development processes
  – Emphasizing reuse of the existing components
• Heavy use of metrics measure degree of reuse
Reuse in the Software Factory

- Developers assigned tasks (generally coding)
- Task specification includes target reuse level
- Task specification includes suggestions about which components in reuse library are expected to be reusable
  --In some cases reuse probabilities are assigned
- Reusable components are more than code
  --Include related artifacts (e.g., design, testcases)
- Developer is measured in part by how closely the reuse target has been met
- Adapted versions of reused components are contributed to the reuse library
  --Accompanied by related artifacts
  --With explanations of why adaptation was necessary
- Explanations of why components that were expected to be reused were not reused

Some software factory projects have achieved factor-of-ten improvements in "quality" and "productivity"

Why Did This Work?

- Strong incentives to reuse (based on social pressure and productivity measurement)
- Investment in reuse
  --Costs extra to build components for reuse
  --Cost to maintain reuse database
  --Cost to resubmit adaptations to reuse database
- A software reuse process that works
- Focus on narrow software product line
  --One software factory builds only device drivers
  --Another may build operating system components
  --Another may build compilers for similar languages