Chapter 7, System Design: Addressing Design Goals
Overview

System Design I

- 0. Overview of System Design
- 1. Design Goals
- 2. Subsystem Decomposition
  - Architectural Styles

System Design II

- 3. Concurrency
- 4. Hardware/Software Mapping
- 5. Persistent Data Management
- 6. Global Resource Handling and Access Control
- 7. Software Control
- 8. Boundary Conditions
System Design

1. Design Goals
   Definition
   Trade-offs

2. Subsystem Decomposition
   Layers vs Partitions
   Coherence/Coupling

3. Concurrency
   Identification of Threads

4. Hardware/Software Mapping
   Special Purpose
   Buy vs Build
   Allocation of Resources
   Connectivity

5. Data Management
   Persistent Objects
   File system vs Database

6. Global Resource Handlung
   Access Control List
   vs Capabilities
   Security

7. Software Control
   Monolithic
   Event-Driven
   Conc. Processes

8. Boundary Conditions
   Initialization
   Termination
   Failure

Ø
3. Concurrency
   Identification of Threads
Concurrence

• Nonfunctional Requirements to be addressed: Performance, Response time, latency, availability.

• Two objects are inherently concurrent if they can receive events at the same time without interacting
  • Source for identification: Objects in a sequence diagram that can simultaneously receive events
  • Unrelated events, instances of the same event

• Inherently concurrent objects can be assigned to different threads of control

• Objects with mutual exclusive activity could be folded into a single thread of control
Thread of Control

• A thread of control is a path through a set of state diagrams on which a single object is active at a time
  • A thread remains within a state diagram until an object sends an event to a different object and waits for another event
  • Thread splitting: Object does a non-blocking send of an event to another object.
• Concurrent threads can lead to race conditions.
• A race condition (also race hazard) is a design flaw where the output of a process is depends on the specific sequence of other events.
  • The name originated in digital circuit design: Two signals racing each other to influence the output.
Example: Problem with threads

Assume: Initial balance = 200

**Thread 1**
- c1: Customer
- :WithdrawCtrl
  - withdraw(50)
  - computeNewBalance(200, 50)
  - setBalance(150)

**Thread 2**
- c2: Customer
- :WithdrawCtrl
  - withdraw(50)
  - computeNewBalance(200, 50)
  - setBalance(150)

Final balance = 150 ??!

Should BankAccount be another Thread?
Solution: Synchronization of Threads

Initial balance = 200

Single WithdrawCtrl Instance

Synchronized method

withdraw(50)

getBalance()

computeNewBalance(200, 50)

setBalance(150)

End balance = 100

Bernd Bruegge & Allen H. Dutoit
Concurrency Questions

• To identify threads for concurrency we ask the following questions:
  • Does the system provide access to multiple users?
  • Which entity objects of the object model can be executed independently from each other?
  • What kinds of control objects are identifiable?
  • Can a single request to the system be decomposed into multiple requests? Can these requests and handled in parallel? (Example: a distributed query)
Implementing Concurrency

• Concurrent systems can be implemented on any system that provides
  • Physical concurrency: Threads are provided by hardware or
  • Logical concurrency: Threads are provided by software
• Physical concurrency is provided by multiprocessors and computer networks
• Logical concurrency is provided by threads packages.
Implementing Concurrency (2)

• In both cases, - physical concurrency as well as logical concurrency - we have to solve the scheduling of these threads:
  • Which thread runs when?

• Today’s operating systems provide a variety of scheduling mechanisms:
  • Round robin, time slicing, collaborating processes, interrupt handling

• General question addresses starvation, deadlocks, fairness -> Topic for researchers in operating systems

• Sometimes we have to solve the scheduling problem ourselves
  • Topic addressed by software control (system design topic 7).
System Design

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   - Identification of Threads

4. Hardware/Software Mapping
   - Special Purpose
   - Buy vs Build
   - Allocation of Resources
   - Connectivity

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   - Persistent Objects
   - Filesystem vs Database

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   - Access Control List
   - vs Capabilities
   - Security

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4. Hardware Software Mapping

• This system design activity addresses two questions:
  • How shall we realize the subsystems: With hardware or with software?
  • How do we map the object model onto the chosen hardware and/or software?
    • Mapping the Objects:
      • Processor, Memory, Input/Output
    • Mapping the Associations:
      • Network connections
Mapping Objects onto Hardware

• **Control Objects -> Processor**
  - Is the computation rate too demanding for a single processor?
  - Can we get a speedup by distributing objects across several processors?
  - How many processors are required to maintain a steady state load?

• **Entity Objects -> Memory**
  - Is there enough memory to buffer bursts of requests?

• **Boundary Objects -> Input/Output Devices**
  - Do we need an extra piece of hardware to handle the data generation rates?
  - Can the desired response time be realized with the available communication bandwidth between subsystems?
Mapping the Associations: Connectivity

• Describe the physical connectivity
  • (“Physical layer in the OSI reference model”)
    • Describes which associations in the object model are mapped to physical connections

• Describe the logical connectivity (subsystem associations)
  • Associations that do not directly map into physical connections
    • In which layer should these associations be implemented?

• Informal connectivity drawings often contain both types of connectivity
  • Practiced by many developers, sometimes confusing.
Example: Informal Connectivity Drawing

Logical Connectivity

Application Client

Communication Agent for Application Clients

Backbone Network

Ethernet Cat 5

Physical Connectivity

TCP/IP

LAN

Global Data Server

OODBMS

RDBMS

Local Data Server

Global Data Server
Logical vs Physical Connectivity and the relationship to Subsystem Layering

Bidirectional associations for each layer

Processor 1

Processor 2
Hardware-Software Mapping Difficulties

- Much of the difficulty of designing a system comes from addressing externally-imposed hardware and software constraints
  - Certain tasks have to be at specific locations
    - Example: Withdrawing money from an ATM machine
  - Some hardware components have to be used from a specific manufacturer
    - Example: To send DVB-T signals, the system has to use components from a company that provides DVB-T transmitters.
Hardware/Software Mappings in UML

• **A UML component** is a building block of the system. It is represented as a rectangle with a tabbed rectangle symbol inside.

• Components have different lifetimes:
  - Some exist only at design time
    - Classes, associations
  - Others exist until compile time
    - Source code, pointers
  - Some exist at link or only at runtime
    - Linkable libraries, executables, addresses

• The Hardware/Software Mapping addresses dependencies and distribution issues of UML components during system design.
Two New UML Diagram Types

- **Deployment Diagram:**
  - Illustrates the distribution of components at run-time.
  - Deployment diagrams use nodes and connections to depict the physical resources in the system.

- **Component Diagram:**
  - Illustrates dependencies between components at design time, compilation time and runtime
Deployment Diagram

• Deployment diagrams are useful for showing a system design after these system design decisions have been made:
  • Subsystem decomposition
  • Concurrency
  • Hardware/Software Mapping

• A deployment diagram is a graph of nodes and connections (“communication associations”)
  • Nodes are shown as 3-D boxes
  • Connections between nodes are shown as solid lines
  • Nodes may contain components
    • Components can be connected by “lollipops” and “grabbers”
    • Components may contain objects (indicating that the object is part of the component).
**UML Component Diagram**

- Used to model the top-level view of the system design in terms of components and dependencies among the components. Components can be:
  - source code, linkable libraries, executables
- The dependencies (edges in the graph) are shown as dashed lines with arrows from the client component to the supplier component:
  - The lines are often also called connectors
  - The types of dependencies are implementation language specific
- Informally also called “software wiring diagram” because it shows how the software components are wired together in the overall application.
UML Interfaces: Lollipops and Sockets

• A UML interface describes a group of operations used or created by UML components.
  • There are two types of interfaces: provided and required interfaces.
    • A provided interface is modeled using the lollipop notation.
    • A required interface is modeled using the socket notation.
  • A port specifies a distinct interaction point between the component and its environment.
    • Ports are depicted as small squares on the sides of classifiers.
Component Diagram Example

- Scheduler
- Planner
- GUI

Dependency:
- reservations
- update

UML Component

UML Interface
Deployment Diagram Example

- **UML Node**
- **Dependency (between nodes)**
- **Dependency (in a node)**

Diagram:

- :HostMachine
- :Scheduler
- MeetingDB: Database
- :PC
- :Planner

Dependency arrows indicate relationships between nodes.
ARENA Deployment Diagram

:UserMachine

:ArenaClient

:MatchFrontEndPeer

:ServerMachine

:ArenaServer

:Advertisement

:Server

:GamePeer

:ArenaStorage
Another ARENA Deployment Diagram
5. Data Management

• Some objects in the system model need to be **persistent**:  
  • Values for their attributes have a lifetime longer than a single execution

• A persistent object can be realized with one of the following mechanisms:
  • Filesystem:  
    • If the data are used by multiple readers but a single writer
  • Database:  
    • If the data are used by concurrent writers and readers.
Data Management Questions

• How often is the database accessed?
  • What is the expected request (query) rate? The worst case?
  • What is the size of typical and worst case requests?

• Do the data need to be archived?

• Should the data be distributed?
  • Does the system design try to hide the location of the databases (location transparency)?

• Is there a need for a single interface to access the data?
  • What is the query format?

• Should the data format be extensible?
Mapping Object Models

- UML object models can be mapped to relational databases
- The mapping:
  - Each class is mapped to its own table
  - Each class attribute is mapped to a column in the table
  - An instance of a class represents a row in the table
  - One-to-many associations are implemented with a buried foreign key
  - Many-to-many associations are mapped to their own tables
- Methods are not mapped
- More details in Lecture: *Mapping Models to Relational Schema*
6. Global Resource Handling

- Discusses access control
- Describes access rights for different classes of actors
- Describes how objects guard against unauthorized access.
Defining Access Control

• In multi-user systems different actors usually have different access rights to different functionality and data

• How do we model these accesses?
  • During analysis we model them by associating different use cases with different actors
  • During system design we model them determining which objects are shared among actors.
Access Matrix

- We model access on classes with an access matrix:
  - The rows of the matrix represent the actors of the system
  - The column represent classes whose access we want to control

- **Access Right**: An entry in the access matrix. It lists the operations that can be executed on instances of the class by the actor.
## Access Matrix Example

<table>
<thead>
<tr>
<th>Actors</th>
<th>Arena</th>
<th>League</th>
<th>Tournament</th>
<th>Match</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operator</strong></td>
<td>&lt;&lt;create&gt;&gt; createUser()</td>
<td>&lt;&lt;create&gt;&gt; archive()</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>createUser()</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>view ()</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LeagueOwner</strong></td>
<td>view ()</td>
<td>edit ()</td>
<td>&lt;&lt;create&gt;&gt; archive()</td>
<td>&lt;&lt;create&gt;&gt; end()</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>schedule()</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>view()</td>
<td></td>
</tr>
<tr>
<td><strong>Player</strong></td>
<td>view()</td>
<td>view()</td>
<td>applyFor()</td>
<td>play()</td>
</tr>
<tr>
<td></td>
<td>applyForOwner()</td>
<td>subscribe()</td>
<td>view()</td>
<td>forfeit()</td>
</tr>
<tr>
<td><strong>Spectator</strong></td>
<td>view()</td>
<td>view()</td>
<td>view()</td>
<td>view()</td>
</tr>
<tr>
<td></td>
<td>applyForPlayer()</td>
<td>subscribe()</td>
<td></td>
<td>replay()</td>
</tr>
</tbody>
</table>
Access Matrix Implementations

• **Global access table**: Represents explicitly every cell in the matrix as a triple (actor, class, operation)

  - `LeagueOwner, Arena, view()`
  - `LeagueOwner, League, edit()`
  - `LeagueOwner, Tournament, <<create>>`
  - `LeagueOwner, Tournament, view()`
  - `LeagueOwner, Tournament, schedule()`
  - `LeagueOwner, Tournament, archive()`
  - `LeagueOwner, Match, <<create>>`
  - `LeagueOwner, Match, end()`
Better Access Matrix Implementations

- **Access control list**
  - Associates a list of (actor,operation) pairs with each class to be accessed.
  - Every time an instance of this class is accessed, the access list is checked for the corresponding actor and operation.

- **Capability**
  - Associates a (class,operation) pair with an actor.
  - A capability provides an actor to gain control access to an object of the class described in the capability.
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Player

Match

play()
forfeit()
Access Control List Realization

I am joe, I want to play in match m1

Gatekeeper checks identification against list and allows access.

joe:Player

m1:Match

Access Control List for m1

joe may play
alice may play
Here’s my ticket, I’d like to play in match m1

Gatekeeper checks if ticket is valid and allows access.

Ticket for match “m1”

m1: Match
Global Resource Questions

• Does the system need authentication?
• If yes, what is the authentication scheme?
  • User name and password? Access control list
  • Tickets? Capability-based
• What is the user interface for authentication?
• Does the system need a network-wide name server?
• How is a service known to the rest of the system?
  • At runtime? At compile time?
  • By Port?
  • By Name?
7. Decide on Software Control

Two major design choices:
1. Choose implicit control
2. Choose explicit control
   • Centralized or decentralized

• **Centralized control:**
  • Procedure-driven: Control resides within program code.
  • Event-driven: Control resides within a dispatcher calling functions via callbacks.

• **Decentralized control**
  • Control resides in several independent objects.
    • Examples: Message based system, RMI
  • Possible speedup by mapping the objects on different processors, increased communication overhead.
Software Control

Explicit Control

Implicit Control

Rule-based Control

Logic Programming

Decentralized Control

Centralized Control

Event-based Control

Procedural Control
Centralized vs. Decentralized Designs

• **Centralized Design**
  • One control object or subsystem ("spider") controls everything
    • Pro: Change in the control structure is very easy
    • Con: The single control object is a possible performance bottleneck

• **Decentralized Design**
  • Not a single object is in control, control is distributed; That means, there is more than one control object
    • Con: The responsibility is spread out
    • Pro: Fits nicely into object-oriented development
Centralized vs. Decentralized Designs (2)

- Should you use a centralized or decentralized design?
- Take the sequence diagrams and control objects from the analysis model
- Check the participation of the control objects in the sequence diagrams
  - If the sequence diagram looks like a fork => Centralized design
  - If the sequence diagram looks like a stair => Decentralized design.
8. Boundary Conditions

- **Initialization**
  - The system is brought from a non-initialized state to steady-state

- **Termination**
  - Resources are cleaned up and other systems are notified upon termination

- **Failure**
  - Possible failures: Bugs, errors, external problems

- Good system design foresees fatal failures and provides mechanisms to deal with them.
Boundary Condition Questions

• Initialization
  • What data need to be accessed at startup time?
  • What services have to be registered?
  • What does the user interface do at start up time?

• Termination
  • Are single subsystems allowed to terminate?
  • Are subsystems notified if a single subsystem terminates?
  • How are updates communicated to the database?

• Failure
  • How does the system behave when a node or communication link fails?
  • How does the system recover from failure?
Modeling Boundary Conditions

- Boundary conditions are best modeled as use cases with actors and objects
- We call them boundary use cases or administrative use cases
- Actor: often the system administrator
- Interesting use cases:
  - Start up of a subsystem
  - Start up of the full system
  - Termination of a subsystem
  - Error in a subsystem or component, failure of a subsystem or component.
Example: Boundary Use Case for ARENA

- Let us assume, we identified the subsystem AdvertisementServer during system design.
- This server takes a big load during the holiday season.
- During hardware software mapping we decide to dedicate a special node for this server.
- For this node we define a new boundary use case ManageServer.
- ManageServer includes all the functions necessary to start up and shutdown the AdvertisementServer.
ManageServer Boundary Use Case

- Server Administrator
  - ManageServer
    - <<include>>
      - StartServer
    - <<include>>
      - ShutdownServer
  - <<include>>
    - ConfigureServer
Summary

• System design activities:
  • Concurrency identification
  • Hardware/Software mapping
  • Persistent data management
  • Global resource handling
  • Software control selection
  • Boundary conditions

• Each of these activities may affect the subsystem decomposition

• Two new UML Notations
  • UML Component Diagram: Showing compile time and runtime dependencies between subsystems
  • UML Deployment Diagram: Drawing the runtime configuration of the system.
Additional Slides
Component Diagram (UML 1.0 Notation)

- Scheduler
  - reservations
- Planner
  - update
- GUI
  - UML Interface

UML Interface

Dependency.
Deployment Diagram (UML 1.0 Notation)

- **UML Node**: Represents the components of the system.
- **Dependency**: Indicates relationships between components.
- **UML Interface**: Specifies the contract between components.
- **Dependency (between nodes)**: Shows the flow of data or control between nodes.
ARENA Deployment Diagram
(UML 1.0 Notation)