System Design

Acknowledge: Atlee and Pfleeger (Software Engineering: Theory and Practice)

Design: HOW to implement a system

- **Goals:**
  - **Satisfy the requirements**
  - **Satisfy the customer**
  - **Reduce development costs**
  - **Provide reliability**
  - **Support maintainability**
  - **Plan for future modifications**

Design Issues

- Architecture
- User Interface
- Data Types
- Operations
- Data Representations
- Algorithms

System Design

- Choose high-level strategy for solving problem and building solution
- Decide how to organize the system into subsystems
- Identify concurrency / tasks
- Allocate subsystems to HW and SW components

Strategic vs. Local Design Decisions

- **Defn**: A high-level or ***strategic*** design decision is one that influences the form of (a large part) of the final code
- Strategic decisions have the most impact on the final system
- So they should be made carefully
- **Question**: Can you think of an example of a strategic decision?

System Design

- Defn: The high-level strategy for solving an [information flow] problem and building a solution
  - Includes decisions about organization of functionality.
  - Allocation of functions to hardware, software and people.
  - Other major conceptual or policy decisions that are prior to technical design.
- Assumes and builds upon thorough requirements and analysis.

Taxonomy of System-Design Decisions

- **<u>Devise a system architecture</u>**
- Choose a data management approach
- Choose an implementation of external control

System Architecture

- A collection of ***subsystems*** and interactions among subsystems.
- Should comprise a small number (<20) of subsystems
- A subsystem is a package of classes, associations, operations, events and constraints that are interrelated and that have a reasonably well-defined interface with other subsystems,
- Example subsystems:
  - Database management systems (RDBMS)
  - Interface (GUI) package

System Topology (also known as SW Architecture)

- Describe information flow
  - Can use DFD to model flow
- Some common topologies
  - Pipes-and-Filter
  - Star topology
  - Client-Server
  - Peer-to-Peer
  - Publish-Subscribe
  - Repositories
  - Layering

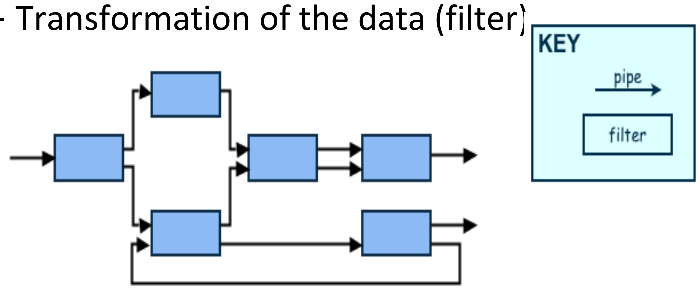
ARCHITECTURAL PATTERNS

Architectural Styles and Strategies

- Pipes-and-Filter
- Client-Server
- Peer-to-Peer
- Publish-Subscribe
- Repositories
- Layering

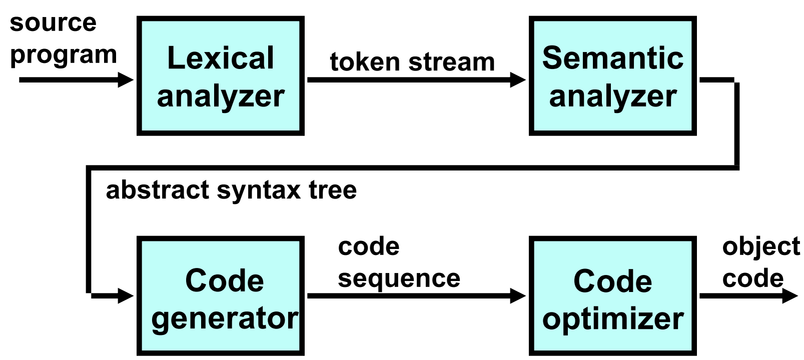
Architectural Styles and Strategies
Pipes-and-Filter

- The system has
  - Streams of data (pipe) for input and output
  - Transformation of the data (filter)



Ex: Pipeline Topology (Architecture)

Compiler:



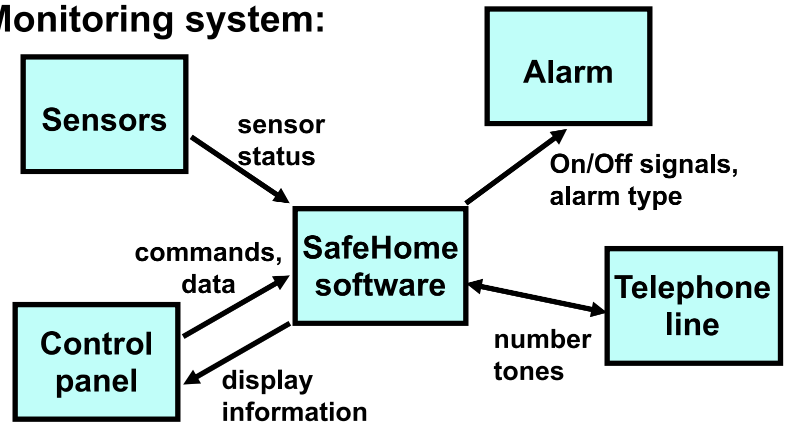
Architectural Styles and Strategies

Pipes-and-Filter (continued)

- Several important properties
  - The designer can understand the entire system's effect on input and output as the composition of the filters
  - The filters can be reused easily on other systems
  - System evolution is simple
  - Allow concurrent execution of filters
- Drawbacks
  - Encourages batch processing
  - Not good for handling interactive application
  - Duplication in filters functions
- Examples:
  - Compilers, scripting applications

Ex: Star Topology (Architecture)

Monitoring system:



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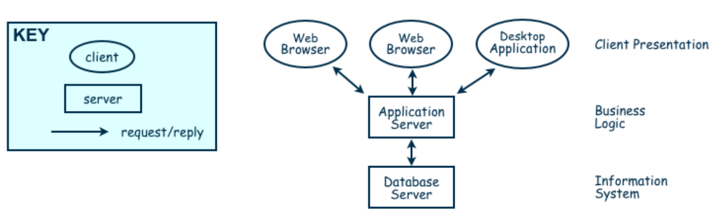
Architectural Styles and Strategies
Client-Server

- Two types of components:
  - Server components offer services
  - Clients access them using a request/reply protocol
- Client may send the server an executable function, called a callback
  - The server subsequently calls under specific circumstances



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Architectural Styles and Strategies
Peer-to-Peer (P2P)

- Each component acts as its own process and acts as both a client and a server to other peer components.
- Any component can initiate a request to any other peer component.
- Characteristics
  - Scales up well
  - Increased system capabilities
  - Highly tolerant of failures
- Examples:
  - Napster, Freenet, BitTorrent, Skype,P2P Marketplaces (e.g., E-bay, Etsy)

18

Architectural Styles and Strategies
Publish-Subscribe

- **Components interact by broadcasting and reacting to events**
  - Component expresses interest in an event by subscribing to it
  - When another component announces (publishes) that event has taken place, subscribing components are notified
  - Implicit invocation is a common form of publish-subscribe architecture
    - Registering: subscribing component associates one of its procedures with each event of interest (called the procedure)
- **Characteristics**
  - Strong support for evolution and customization
  - Easy to reuse components in other event-driven systems
  - Need shared repository for components to share persistent data
  - Difficult to test
- **Examples:** News feeds, social media notifications, etc.

20

Architectural Styles and Strategies

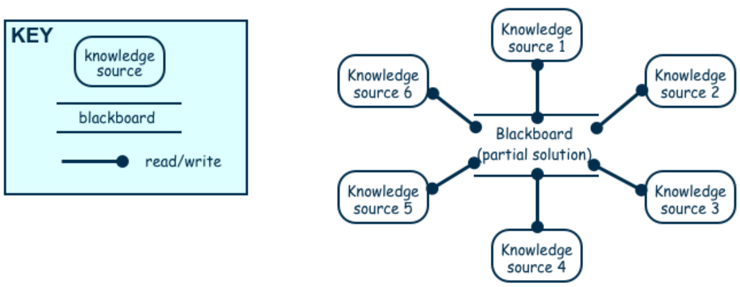
Repositories

- Two components
  - A central data store
  - A collection of components that operate on it to store, retrieve, and update information
- The challenge is deciding how the components will interact
  - A traditional database: transactions trigger process execution
  - A blackboard: the central store controls the triggering process
  - Knowledge sources: information about the current state of the system's execution that triggers the execution of individual data accessors

Architectural Styles and Strategies

Repositories (continued)

- Major advantage: openness
  - Data representation is made available to various programmers (vendors) so they can build tools to access the repository
  - But also a disadvantage: the data format must be acceptable to all components



Architectural Design Principles for Layered Systems

- Decompose into subsystems *layers* and *partitions*.
- Separate application logic from user interface
- Simplify the interfaces through which parts of the system will connect to other systems.
- In systems that use large databases:
  - Distinguish between *operational (transactional)* and *inquiry* systems.
  - Exploit features of DBMS

Architectural Styles and Strategies

Layering

- Layers are hierarchical
  - Each layer provides service to the one outside it and acts as a client to the layer inside it
  - Layer bridging: allowing a layer to access the services of layers below its lower neighbor
- The design includes protocols
  - Explain how each pair of layers will interact
- Advantages
  - High levels of abstraction
  - Relatively easy to add and modify a layer
- Disadvantages
  - Not always easy to structure system layers
  - System performance may suffer from the extra coordination among layers

Layered Subsystems

- Set of “virtual” worlds
- Each layer is defined in terms of the layer(s) below it
  - Knowledge is one-way: Layer knows about layer(s) below it
- Objects within layer can be independent
- Lower layer (server) supplies services for objects (clients) in upper layer(s)

Example: Layered architecture

Interactive Graphics Application
Windows Operations
Screen Operations
Pixel Operations
Device I/O Operations

Closed Architectures

- Each layer is built only in terms of the immediate lower layer
- Reduces dependencies between layers
- Facilitates change

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Open Architectures

- Layer can use any lower layer
- Reduces the need to redefine operations at each level
- More efficient /compact code
- System is less robust/harder to change

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Properties of Layered Architectures

- **Top and bottom layers specified by the problem statement**
  - **Top layer is the desired system**
  - **Bottom layer is defined by available resources (e.g. HW, OS, libraries)**
- **Easier to port to other HW/SW platforms**

Partitioned Architectures

- Divide system into weakly-coupled subsystems
- Each provides specific services
- Vertical decomposition of problem

Ex: Partitioned Architecture

Operating System

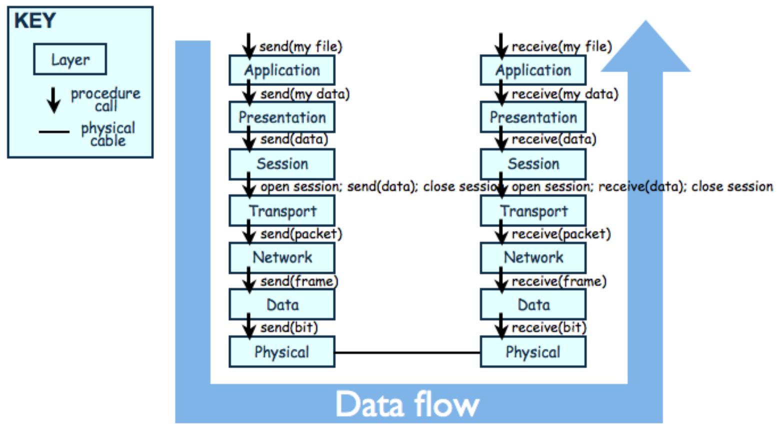
File System	Process Control	Virtual Memory Manage-ment	Device Control

Typical Application Architecture

Application package		
User dialogue control	Window graphics	Simulation package
	Screen graphics	
	Pixel graphics	
Operating system		
Computer hardware		

Architectural Styles and Strategies
Example of Layering System

- The OSI (Open Systems Interconnect) Model
  - Conceptual framework for networking/telecom.

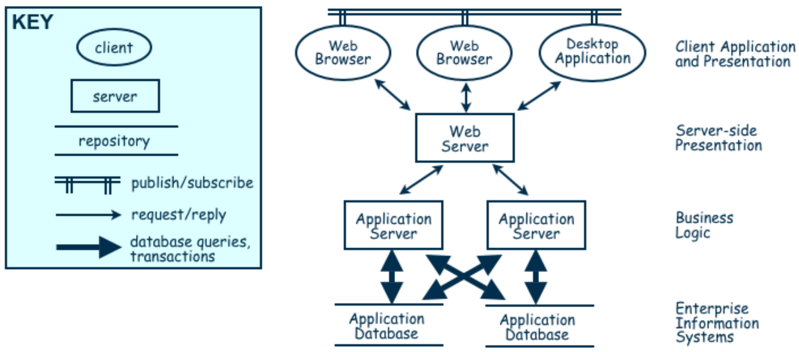


Architectural Styles and Strategies
Combining Architectural Styles

- Actual software architectures rarely based on purely one style
- Architectural styles can be combined in several ways
  - Use different styles at different layers (e.g., overall client-server architecture with server component decomposed into layers)
  - Use mixture of styles to model different components or types of interaction (e.g., client components interact with one another using publish-subscribe communications
- If architecture is expressed as collection of models, documentation must be created to show relation between models

Architectural Styles and Strategies

Combination of Publish-Subscribe, Client-Server, and Repository Architecture Styles



Taxonomy of System-Design Decisions

- Devise a system architecture
- **Choose a data management approach**
- Choose an implementation of external control

Choosing a Data Management Approach

- Databases:
  - Advantages:
    - Efficient management
    - multi-user support.
    - Roll-back support
  - Disadvantages:
    - Performance overhead
    - Awkward (or more complex) programming interface
    - Hard to fix corruption

Choosing a Data Management Approach (continued)

- "Flat" files
  - Advantages:
    - Easy and efficient to construct and use
    - More readily repairable
  - Disadvantages:
    - No rollback
    - No *direct* complex structure support
    - Complex structure requires a ***grammar*** for file format

Flat File Storage and Retrieval

- Useful to define two components (or classes)
  - ***Reader*** reads file and instantiates internal object structure
  - ***Writer*** traverses internal data structure and writes out presentation
- Both can (should) use formal grammar
  - Tools support: Yacc, Lex.

Taxonomy of System-Design Decisions

- Devise a system architecture
- Choose a data management approach
- **Choose an implementation of external control**

Implementation of External Control

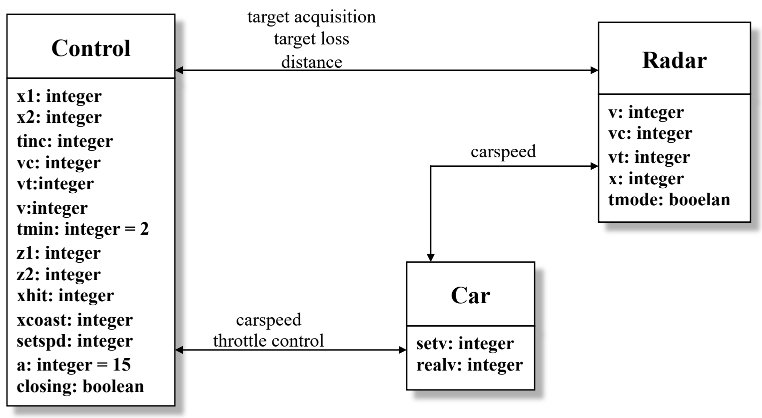
Four general styles for implementing software control

- **Procedure-driven:**
  - Control = location in the source code.
  - Requests block until request returns
- **Event-Driven: Control resides in dispatcher**
  - Uses callback functions registered for events
  - Dispatcher services events by invoking callbacks

Implementation of External Control

- **Concurrent**
  - Control resides in multiple, concurrent objects
  - Objects communicate by passing messages
    - across busses, networks, or memory.
- **Transactional**
  - Control resides in servers and saved state
  - Many server-side E-systems are like this

Sample Concurrent System



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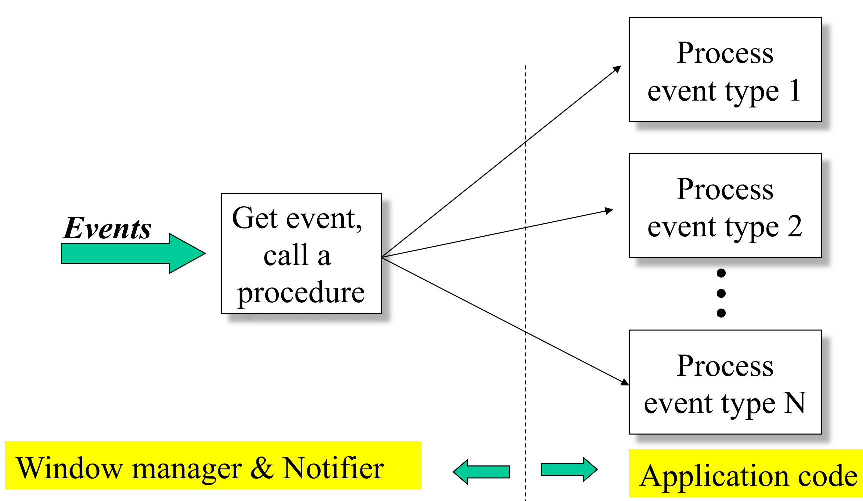
Dispatcher Model
(event driven)



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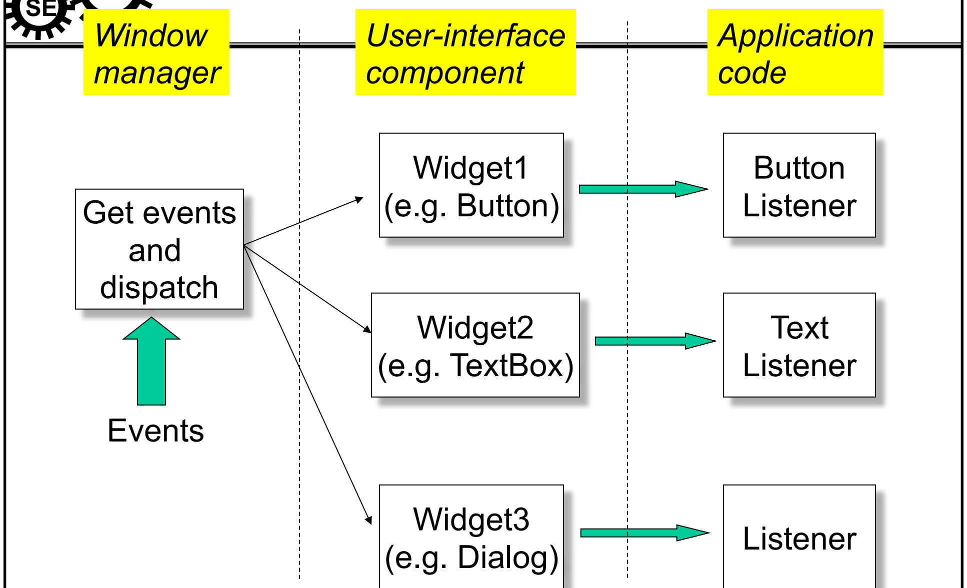
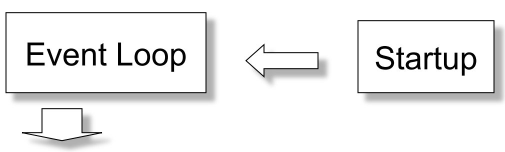
Event-driven architecture in UI toolkits

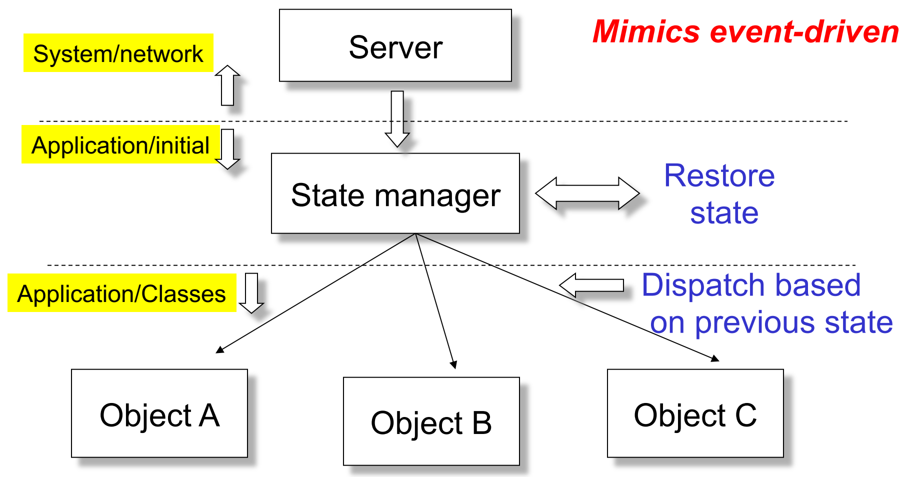


Typical Dispatcher Code




```
while (!quit) {
   WaitEvent(timeout, id);
    switch (id) {
       case ID1:  Procedure1(); break;
       case ID2:  Procedure2(); break;
       ….
    }
}
```

Transactional Model



Terminology

- **Idioms:**
  - paradigm/language-specific programming techniques.
- **Design Patterns:**
  - reusable (problem, design strategy) pair with context for application, consequences for use.
- **Architectural Patterns/Styles:**
  - High-level strategies for system design
  - Involves large-scale components and their relationships

General Design Concerns

- Modularity
- Abstraction
- Cohesion
- Coupling
- Information Hiding
- Abstract Data Types
- Identifying Concurrency
- Global Resources
- Boundary Conditions
- Tradeoffs

Modularity

- Organize modules according to resources/objects/data types
- Provide cleanly defined interfaces
  - operations, methods, procedures, ...
- Hide implementation details
- Simplify program understanding
- Simplify program maintenance

Abstraction

- Control abstraction
  - structured control statements
  - exception handling
  - concurrency constructs
- Procedural abstraction
  - procedures and functions
- Data abstraction
  - user defined types

Abstraction (cont.)

- Abstract data types
  - encapsulation of data
- Abstract objects
  - subtyping
  - generalization/inheritance

Cohesion

- Contents of a module should be *cohesive*
  - Somehow related
- Improves maintainability
  - Easier to understand
  - Reduces complexity of design
  - Supports reuse

(Weak) Types of cohesiveness

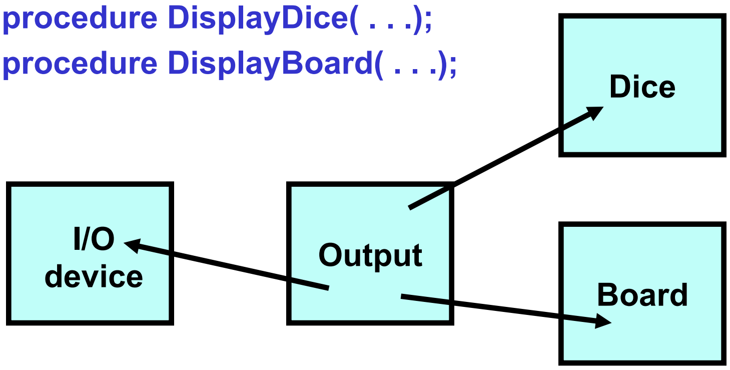
- Coincidentally cohesive
  - contiguous lines of code not exceeding a maximum size
- Logically cohesive
  - all output routines
- Temporally cohesive
  - all initialization routines

(Better) Types of cohesiveness

- Procedurally cohesive
  - routines called in sequence
- Communicationally cohesive
  - work on same chunk of data
- Functionally cohesive
  - work on same data abstraction at a consistent level of abstraction

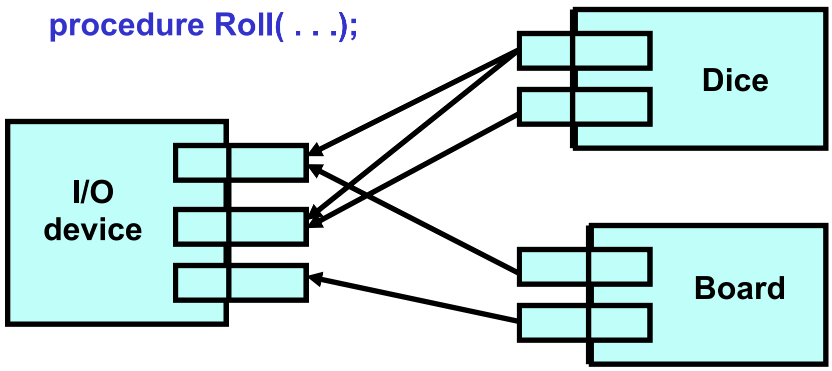
Example: Poor Cohesion

package Output is
procedure DisplayDice(. . .);
procedure DisplayBoard(. . .);



Example: Good Cohesion

package Dice is
  procedure Display (. . .);
  procedure Roll(. . .);



60

Coupling

- *Connections* between modules
- Bad coupling
  – Global variables
  – Flag parameters
  – Direct manipulation of data structures by multiple classes

61

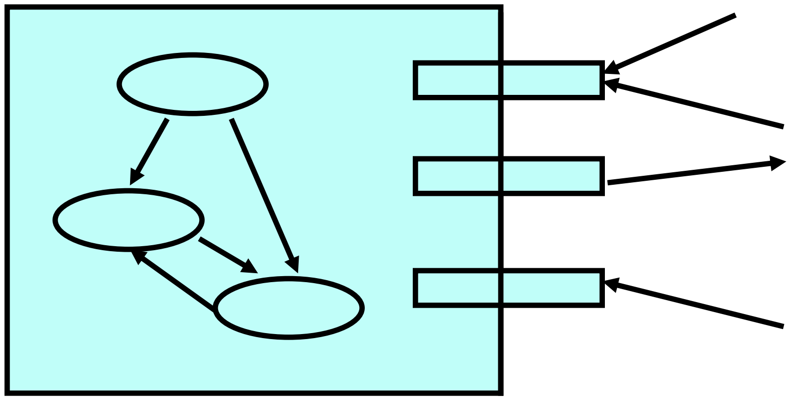
Coupling (cont.)

- ***Good coupling***
  - Procedure calls
  - Short argument lists
  - Objects as parameters
- Good coupling improves maintainability
  - Easier to localize errors, modify implementations of an objects, ...

Information Hiding

- Hide decisions likely to change
  - Data representations, algorithmic details, system dependencies
- Black box
  - Input is known
  - Output is predictable
  - Mechanism is unknown
- Improves maintainability

Information Hiding



64

Abstract data types

- Modules (Classes, packages)
  - Encapsulate data structures and their operations
  - Good cohesion
    - implement a single abstraction
  - Good coupling
    - pass abstract objects as parameters
  - Black boxes
    - hide data representations and algorithms

65

Identifying Concurrency

- Inherent concurrency
  - May involve synchronization
  - Multiple objects receive events at the same time with out interacting
  - Example:
    - User may issue commands through control panel at same time that the sensor is sending status information to the SafeHome system

66

Determining Concurrent Tasks

- ***Thread of control***
  - Path through state diagram with only one active object at any time
- Threads of control are implemented as *tasks*
  - Interdependent objects
  - Examine state diagram to identify objects that can be implemented in a task

67

Global Resources

- Identify global resources and determine access patterns
- Examples
  - physical units (processors, tape drives)
  - available space (disk, screen, buttons)
  - logical names (object IDs, filenames)
  - access to shared data (database, file)

68

Boundary Conditions

- Initialization
  - Constants, parameters, global variables, tasks, guardians, class hierarchy
- Termination
  - Release external resources, notify other tasks
- Failure
  - Clean up and log failure info

69

Identify Trade-off Priorities

- Establish priorities for choosing between incompatible goals
- Implement minimal functionality initially and embellish as appropriate
- Isolate decision points for later evaluation
- Trade efficiency for simplicity, reliability, . . .