System Design

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

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

System Architecture

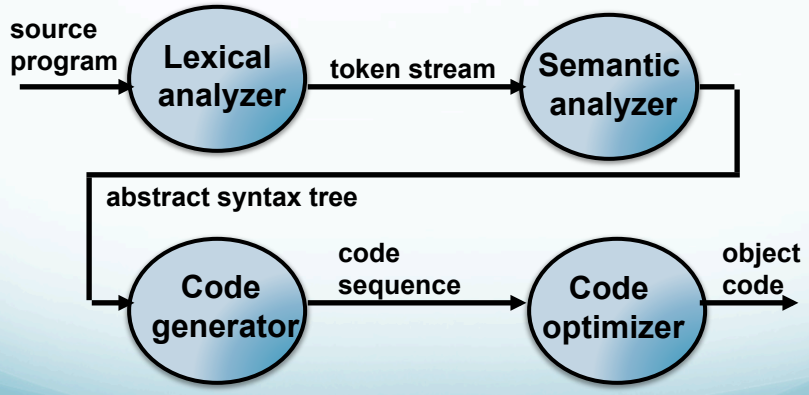
- A collection of *subsystems* and interactions among subsystems.
- Should comprise a small number (<20) of subsystems
- A subsystem is a package of classes, associations, operations, events and constraints that are interrelated and that have a reasonably well-defined interface with other subsystems,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

System Topology (also known as SW Architecture)

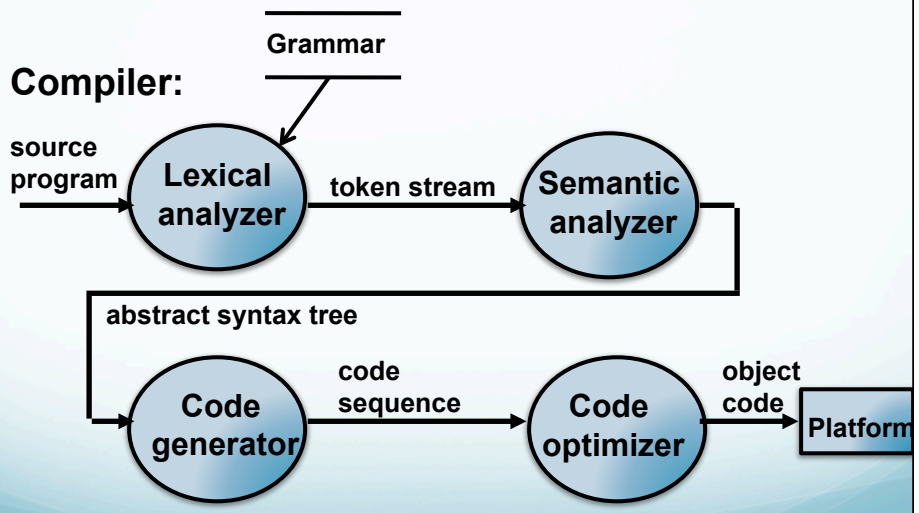
- Describe information flow
  - Can use DFD to model flow
- Some common topologies
  - Pipeline (batch)
  - Star topology
  - Client-server; P2P
  - Layered

Ex: Pipeline Topology (Architecture)

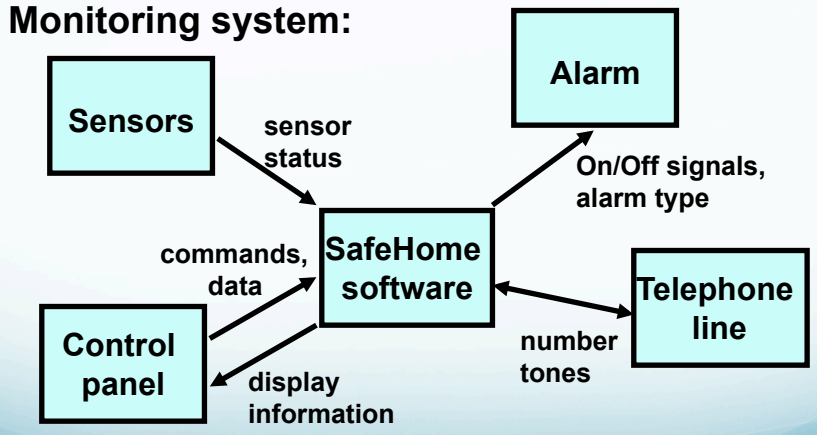
Compiler:



Ex: Pipeline Topology (DFD notation example)

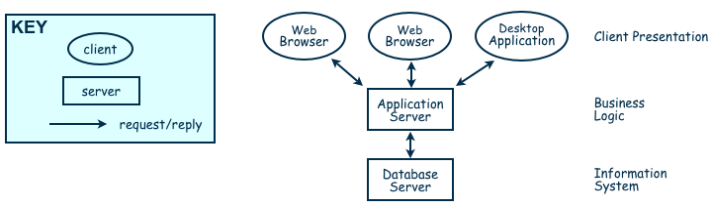


Ex: Star Topology (Architecture: Components/Connectors)



Client-Server Architecture

- 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



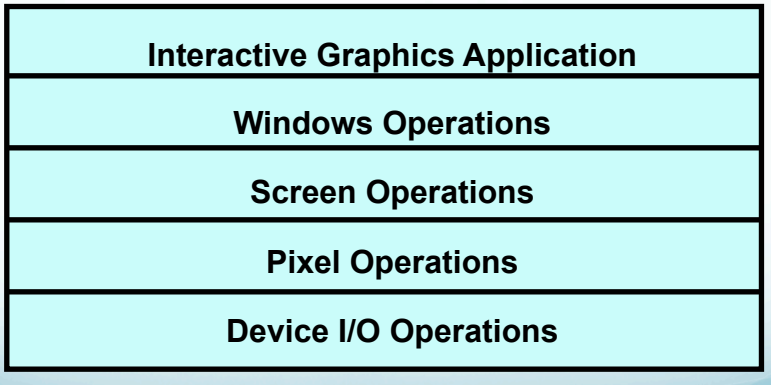
Layered Subsystems

- 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)

Architectural Design Principles

- 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

Example: Layered architecture



Closed Architectures

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

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

Properties of Layered Architectures

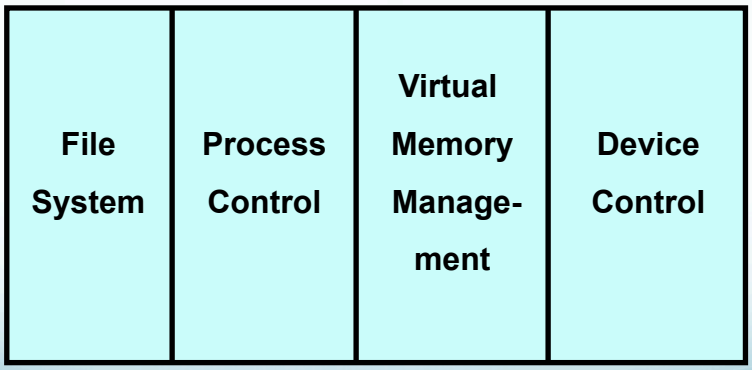
- **Top and bottom layers specified by the problem statement**
  - **Top layer is the desired system**
  - **Bottom layer is defined by available resources (e.g. HW, OS, libraries)**
- **Easier to port to other HW/SW platforms**

Partitioned Architectures

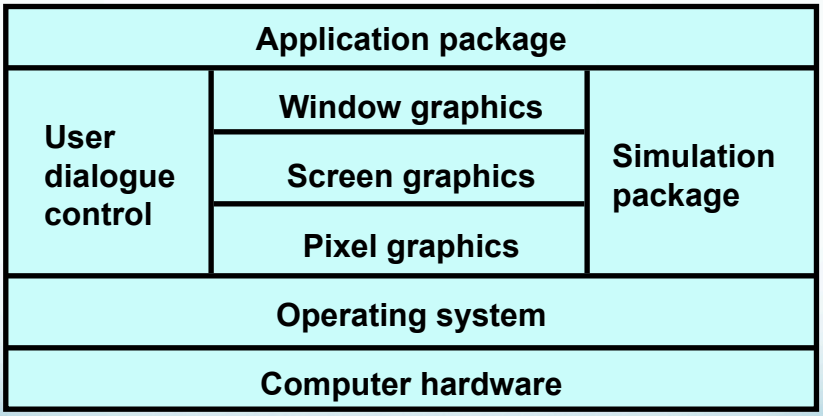
- Divide system into weakly-coupled subsystems
- Each provides specific services
- Vertical decomposition of problem

Ex: Partitioned Architecture

Operating System



Typical Application Architecture



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

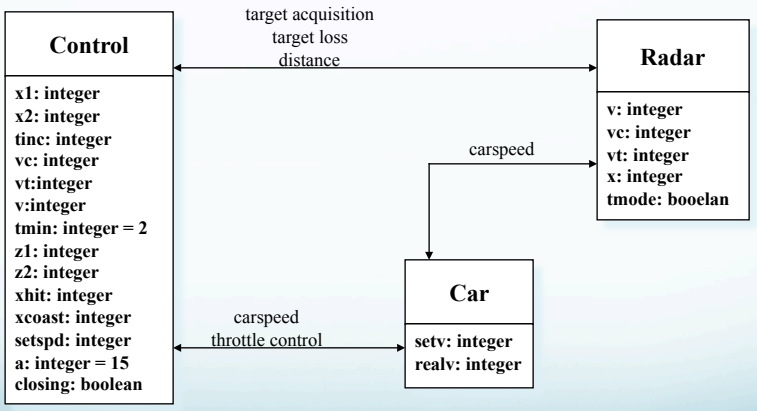
Four general styles for implementing software control

- **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

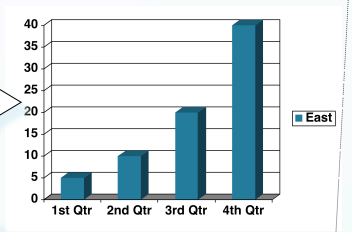
Sample Concurrent System

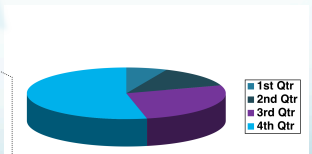


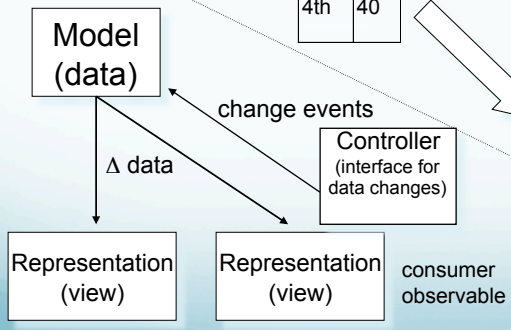
MVC (Model/View/Controller)

Separates data model, data view, and behavior into separate components

1ST	5
2nd	10
3rd	20
4th	40

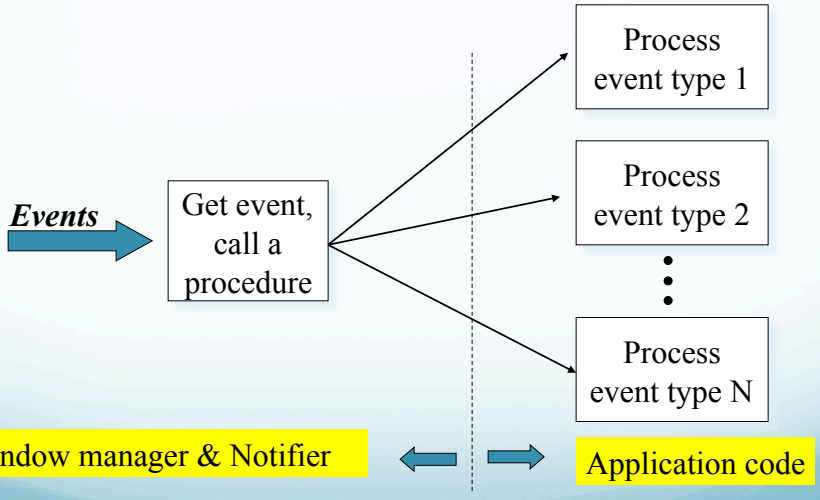




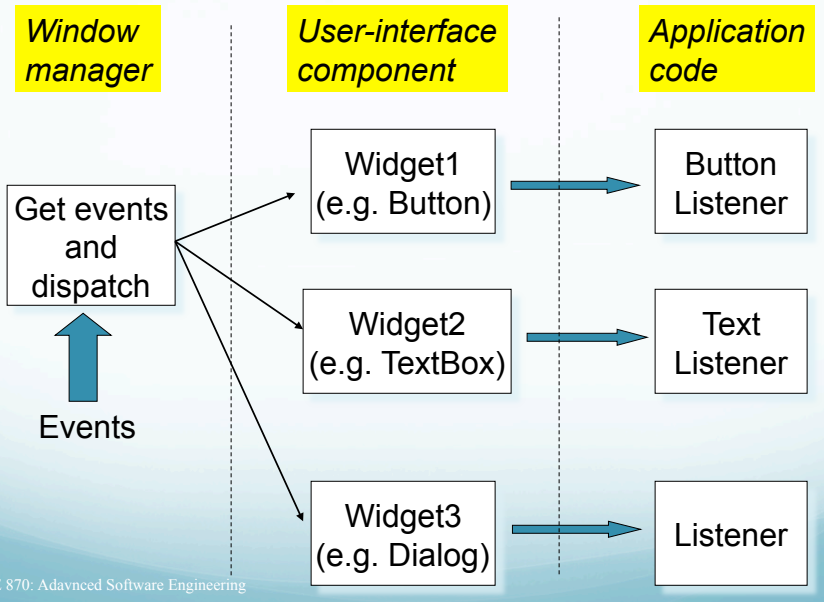


Dispatcher Model

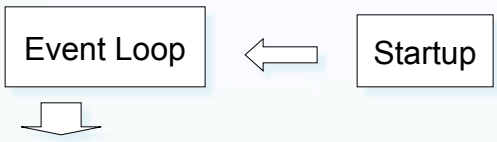
(event driven)



Event-driven architecture in UI toolkits

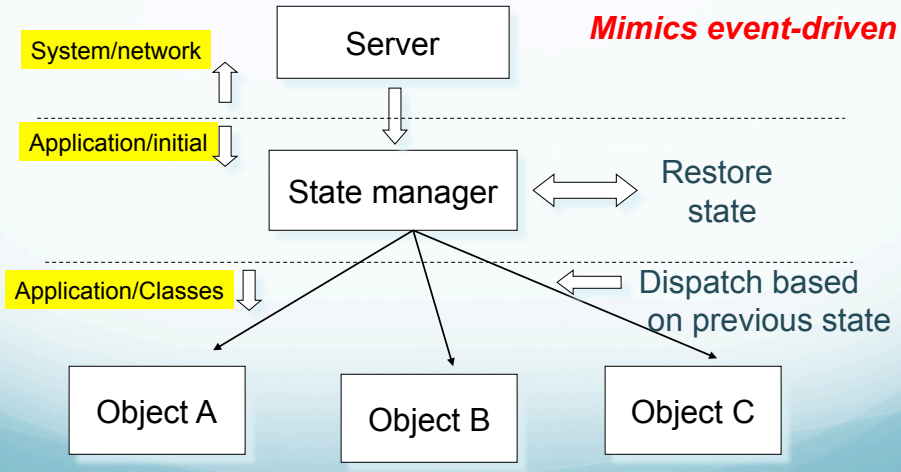


Typical Dispatcher Code




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

Transactional Model



General Design Concerns

- Modularity
- Abstraction
- Cohesion
- Coupling
- Information Hiding
- Abstract Data Types
- Identifying Concurrency

- Global Resources

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

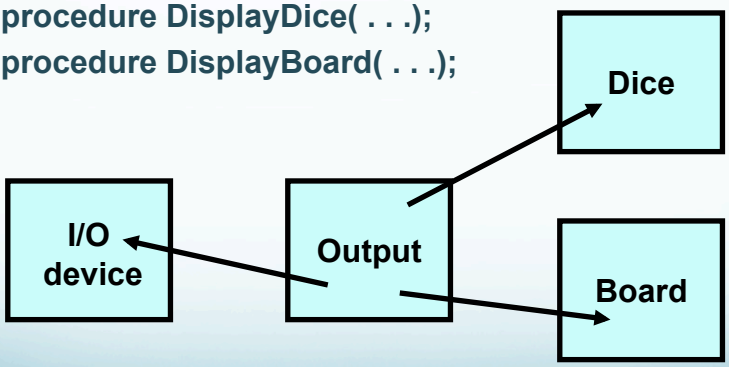
- Coincidentally cohesive
  - contiguous lines of code not exceeding a maximum size
- Logically cohesive
  - all output routines
- Temporally cohesive
  - all initialization routines

(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

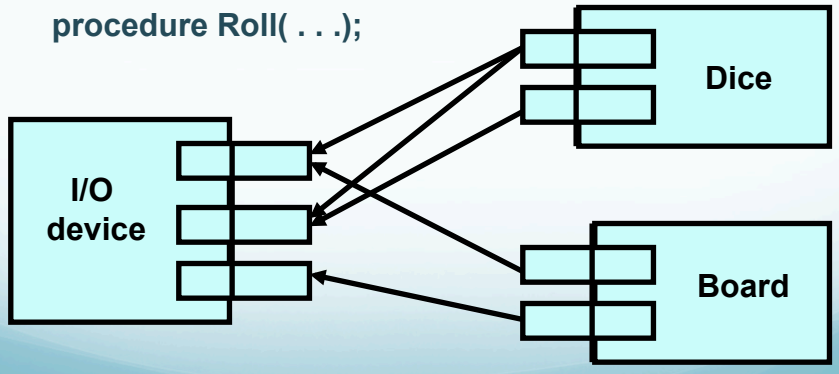
Example: Poor Cohesion

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



Example: Good Cohesion

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



Coupling

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

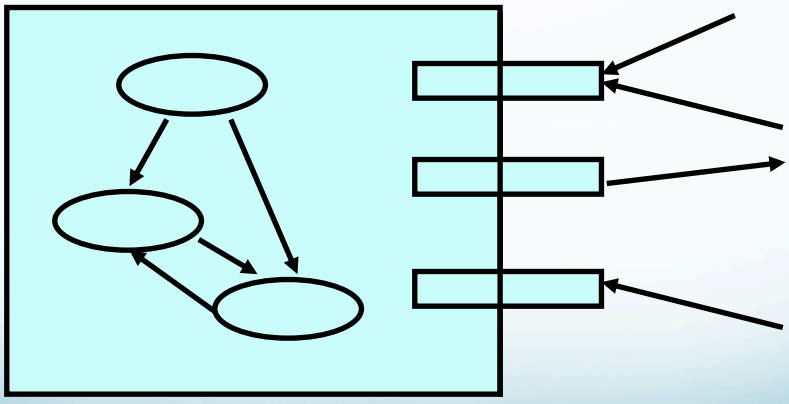
Coupling (cont.)

- *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



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

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

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

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)

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

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, . . .