Software Design

Organization of This Lecture

- Introduction to software design
- Goodness of a design
- Functional Independence
- Cohesion and Coupling
- Function-oriented design vs. Object-oriented design
- Summary

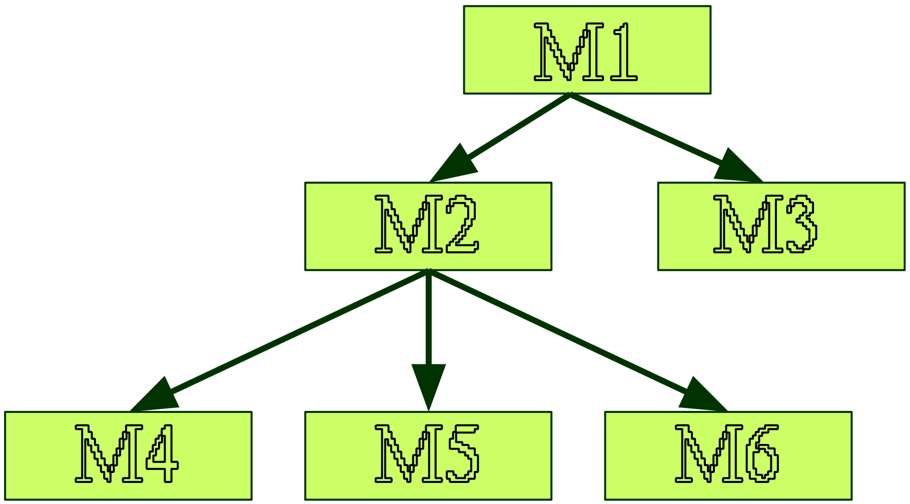
Introduction

- Design phase transforms SRS document:
  - To a form easily implementable in some programming language.

Items Designed During Design Phase

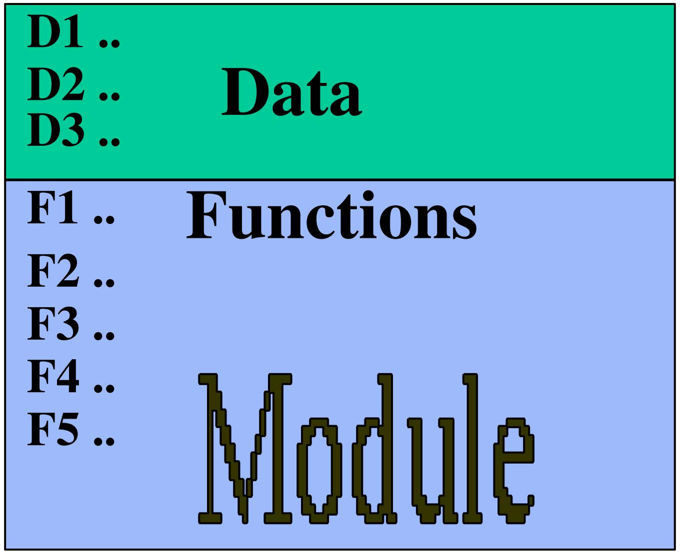
- Module structure,
- Control relationship among the modules
  - call relationship or invocation relationship
- Interface among different modules,
  - Data items exchanged among different modules,
- Data structures of individual modules,
- Algorithms for individual modules.

Module Structure



Introduction

- A module consists of:
  - Several functions
  - Associated data structures.



Introduction

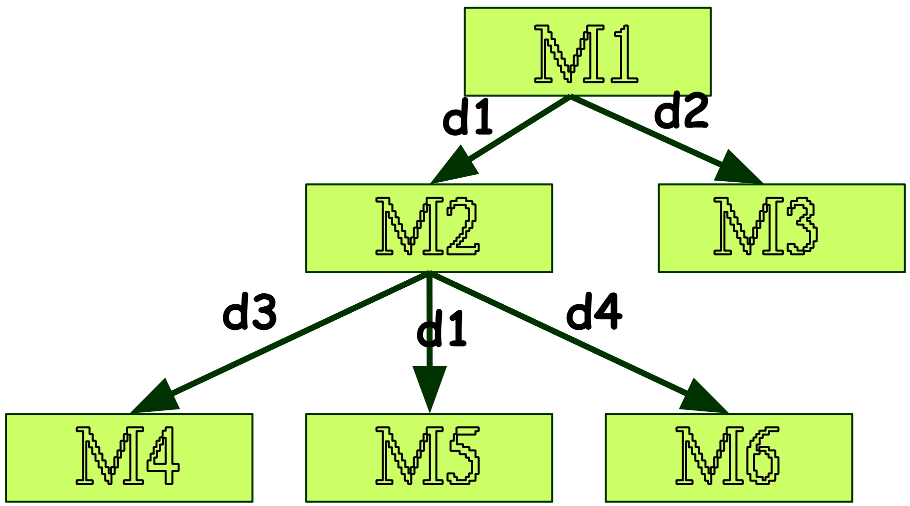
- Good software designs:
  - Seldom arrived through a single step procedure:
  - But through a series of steps and iterations.

Introduction

- Design activities are usually classified into two stages:
  - Preliminary (or high-level) design.
  - Detailed design.
- Meaning and scope of the two stages:
  - Vary considerably from one methodology to another.

High-Level Design

- Identify:
  - Modules
  - Control relationships among modules
  - Interfaces among modules.



High-Level Design

- The outcome of high-level design:
  - Program structure (or software architecture).

High-Level Design

- Several notations are available to represent high-level design:
  - Usually a tree-like diagram called structure chart is used.
  - Other notations:
    - Jackson diagram or Warnier-Orr diagram can also be used.

Detailed Design

- For each module, design:
  - Data structure
  - Algorithms
- Outcome of detailed design:
  - Module specification.

A Classification of Design Methodologies

- Procedural (aka Function-oriented)
- Object-oriented
- More recent:
  - Aspect-oriented
  - Component-based (Client-Server)

Does a Design Technique Lead to a Unique Solution?

- **No:**
  - **Several subjective decisions need to be made to trade off among different parameters.**
  - **Even the same designer can come up with several alternate design solutions.**

Analysis versus Design

- An analysis technique helps elaborate the customer requirements through careful thinking:
  - And at the same time consciously avoids making any decisions regarding implementation.
- The design model is obtained from the analysis model through transformations over a series of steps:
  - Decisions regarding implementation are consciously made.

A Fundamental Question

- How to distinguish between the superior of two alternate design solutions?
  - Unless we know what a good software design is:
    - We can not possibly design one.

Good and Bad Designs

- There is no unique way to design a system.
- Even using the same design methodology:
  - Different designers can arrive at very different design solutions.
- We need to distinguish between good and bad designs.

Which of Two is a Better Design?

- Should implement all functionalities of the system correctly.
- Should be easily understandable.
- Should be efficient.
- Should be easily amenable to change,
  - i.e. easily maintainable.

Which of Two is a Better Design?

- Understandability of a design is a major issue:
  - Determines goodness of design:
  - A design that is easy to understand:
    - Also easy to maintain and change.

Which of Two is a Better Design?

- Unless a design is easy to understand,
  - Tremendous effort needed to maintain it
  - We already know that about 60% effort is spent in maintenance.
- If the software is not easy to understand:
  - Maintenance effort would increase many times.

Understandability

- Use consistent and meaningful names:
  - For various design components.
- Should make use of abstraction and decomposition principles in ample measure.

How are Abstraction and Decomposition Principles Used in Design?

- **Two principal ways:**
  - **Modular Design**
  - **Layered Design**

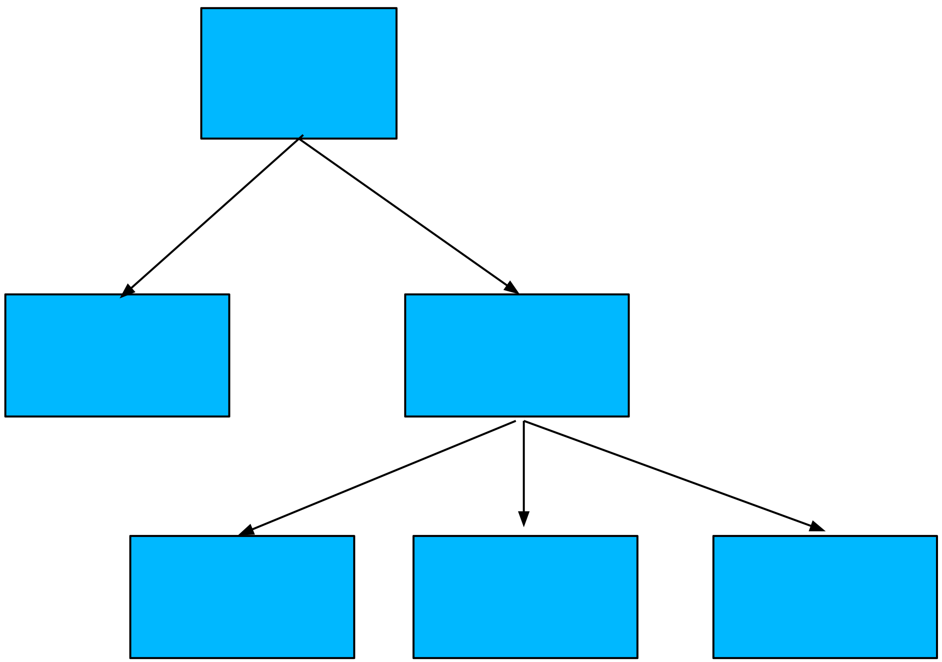
Modularity

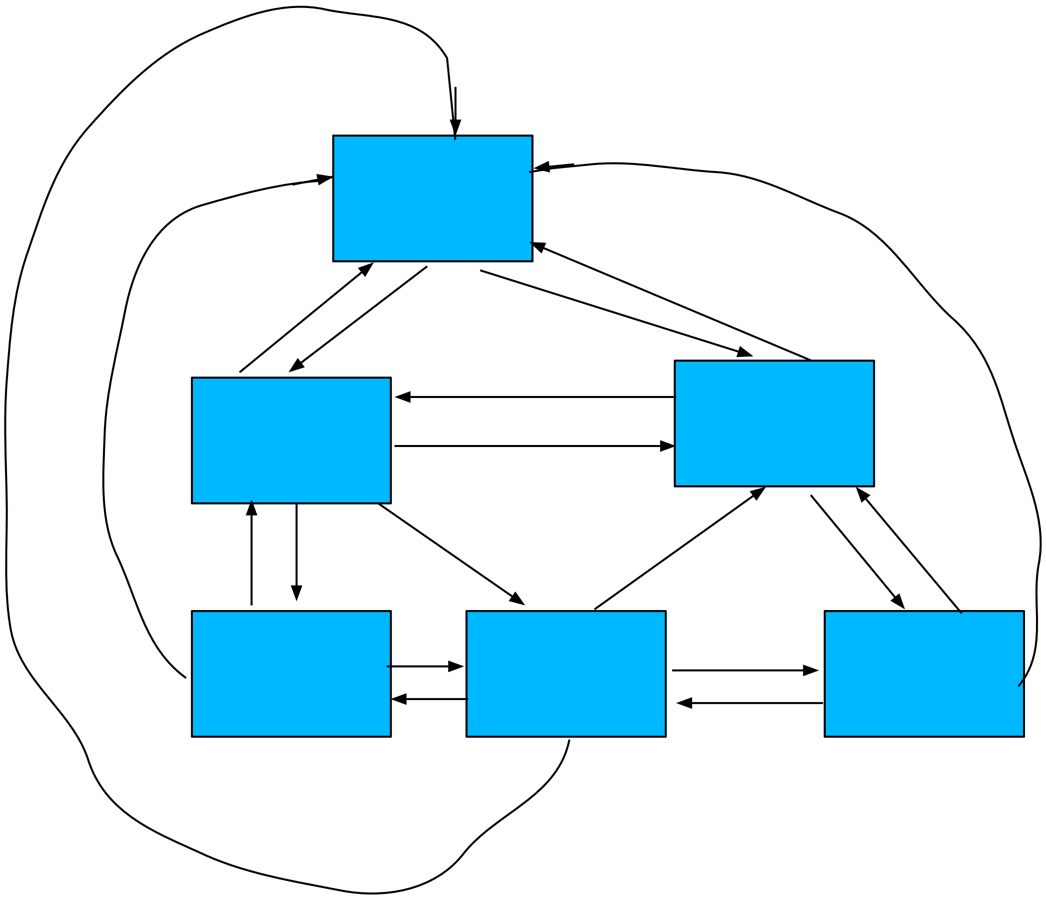
- Modularity is a fundamental attributes of any good design.
  - Decomposition of a problem cleanly into modules:
  - Modules are almost independent of each other
  - Divide and conquer principle.

Modularity

- If modules are independent:
  - Modules can be understood separately,
    - Reduces the complexity greatly.
  - To understand why this is so,
    - Remember that it is very difficult to break a bunch of sticks but very easy to break the sticks individually.

Layered Design





Layered Design

- Neat arrangement of modules in a hierarchy means:
  - Low fan-out
  - Control abstraction

Modularity

- In technical terms, modules should display:
  - High cohesion
  - Low coupling.
- We shall next discuss:
  - cohesion and coupling.

Cohesion and Coupling

- Cohesion is a measure of:
  - functional strength of a module.
  - A cohesive module performs a single task or function.
- Coupling between two modules:
  - A measure of the degree of the interdependence or interaction between the two modules.

Cohesion and Coupling

- A module having high cohesion and low coupling:
  - functionally independent of other modules:
    - A functionally independent module has minimal interaction with other modules.

Advantages of Functional Independence

- Better understandability and good design:
- Complexity of design is reduced,
- Different modules easily understood in isolation:
  - Modules are independent

Advantages of Functional Independence

- Functional independence reduces error propagation.
  - Degree of interaction between modules is low.
  - An error existing in one module does not directly affect other modules.
- Reuse of modules is possible.

Advantages of Functional Independence

- *A* functionally independent module:
  - Can be easily taken out and reused in a different program.
    - Each module does some well-defined and precise function
    - The interfaces of a module with other modules is simple and minimal.

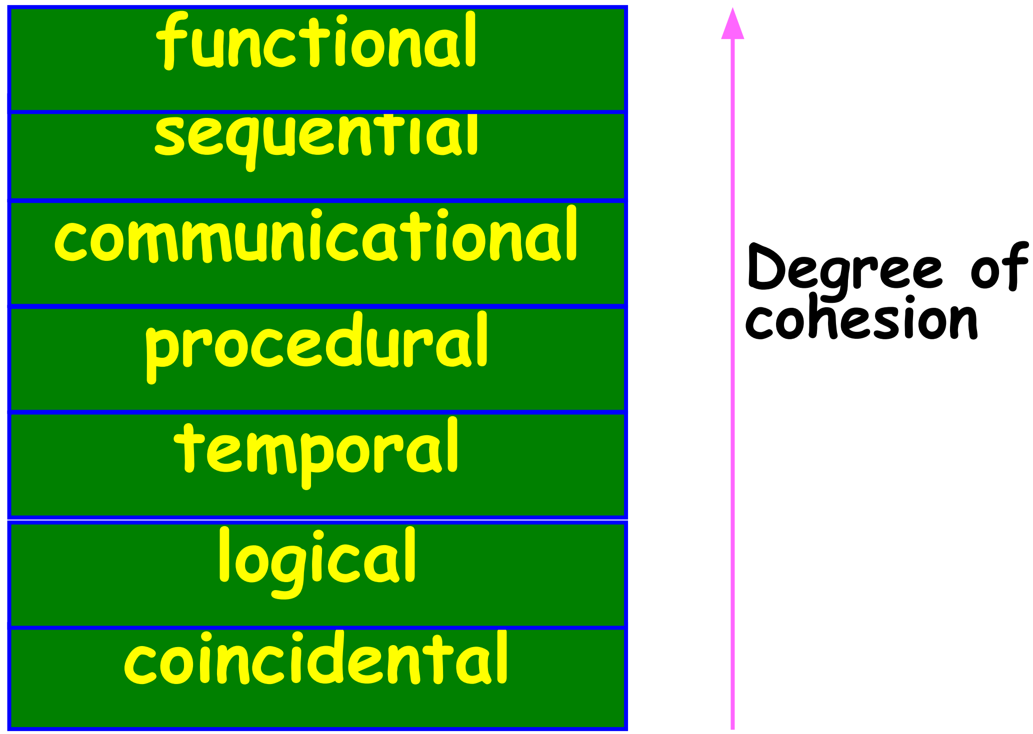
Functional Independence

- Unfortunately, there are no ways:
  - To quantitatively measure the degree of cohesion and coupling.
  - Classification of different kinds of cohesion and coupling:
    - Can give us some idea regarding the degree of cohesiveness of a module.

Classification of Cohesiveness

- Classification is often subjective:
  - Yet gives us some idea about cohesiveness of a module.
- By examining the type of cohesion exhibited by a module:
  - We can roughly tell whether it displays high cohesion or low cohesion.

Classification of Cohesiveness



Coincidental Cohesion

- The module performs a set of tasks:
  - Which relate to each other very loosely, if at all.
    - The module contains a random collection of functions.
    - Functions have been put in the module out of pure coincidence without any thought or design.

Logical Cohesion

- All elements of the module perform similar operations:
  - e.g. error handling, data input, data output, etc.
- An example of logical cohesion:
  - A set of print functions to generate an output report arranged into a single module.

Temporal Cohesion

- The module contains tasks that are related by the fact:
  - All the tasks must be executed in the same time span.
- Example:
  - The set of functions responsible for
    - initialization,
    - start-up, shut-down of some process, etc.

Procedural Cohesion

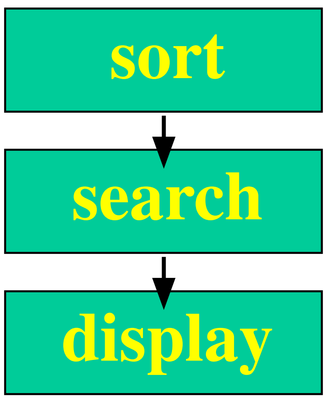
- The set of functions of the module:
  - All part of a procedure (algorithm)
  - Certain sequence of steps have to be carried out in a certain order for achieving an objective,
    - e.g. the algorithm for decoding a message.

Communicational Cohesion

- All functions of the module:
  - Reference or update the same data structure,
- Example:
  - The set of functions defined on an array or a stack.

Sequential Cohesion

- Elements of a module form different parts of a sequence,
  - Output from one element of the sequence is input to the next.
  - Example:



Functional Cohesion

- Different elements of a module cooperate:
  - To achieve a single function,
  - e.g. managing an employee's pay-roll.
- When a module displays functional cohesion,
  - We can describe the function using a single sentence.

Determining Cohesiveness

- Write down a sentence to describe the function of the module
  - If the sentence is compound,
    - It has a sequential or communicational cohesion.
  - If it has words like "first", "next", "after", "then", etc.
    - It has sequential or temporal cohesion.
  - If it has words like initialize,
    - It probably has temporal cohesion.

Coupling

- Coupling indicates:
  - How closely two modules interact or how interdependent they are.
  - The degree of coupling between two modules depends on their interface complexity.

Coupling

- There are no ways to precisely determine coupling between two modules:
  - Classification of different types of coupling will help us to approximately estimate the degree of coupling between two modules.
- Five types of coupling can exist between any two modules.

Classes of coupling

Data coupling

- Two modules are data coupled,
  - If they communicate via a parameter:
    - an elementary data item,
    - e.g an integer, a float, a character, etc.
  - The data item should be problem related:
    - Not used for control purpose.

Stamp Coupling

- Two modules are <u>stamp coupled</u>,
  - If they communicate via a composite data item
    - such as a record in PASCAL
    - or a structure in C.

Control Coupling

- Data from one module is used to direct:
  - Order of instruction execution in another.
- Example of control coupling:
  - A flag set in one module and tested in another module.

Common Coupling

- Two modules are <u>common coupled</u>,
  - If they share some global data.

Content Coupling

- Content coupling exists between two modules:
  - If they share code,
  - e.g, branching from one module into another module.
- The degree of coupling increases
  - from data coupling to content coupling.

Neat Hierarchy

- Control hierarchy represents:
  - Organization of modules.
  - Control hierarchy is also called program structure.
- Most common notation:
  - A tree-like diagram called structure chart.

Layered Design

- Essentially means:
  - Low fan-out
  - Control abstraction

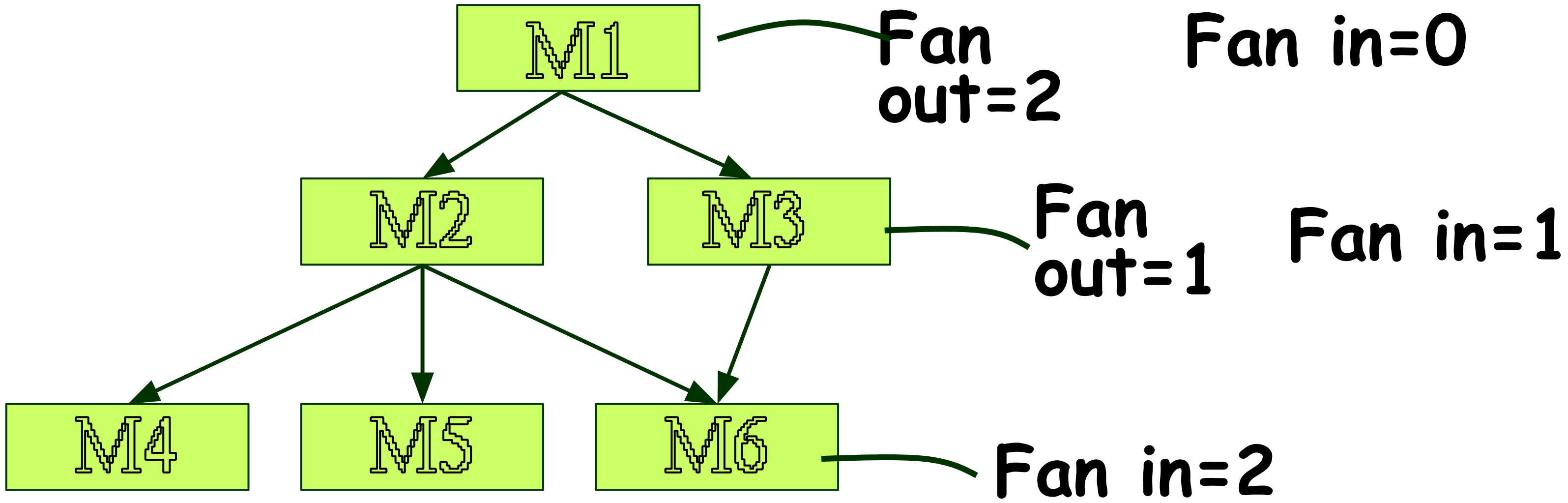
Characteristics of Module Hierarchy

- **Depth:**
  - Number of levels of control
- **Width:**
  - Overall span of control.
- **Fan-out:**
  - A measure of the number of modules directly controlled by given module.

Characteristics of Module Structure

- Fan-in:
  - Indicates how many modules directly invoke a given module.
  - High fan-in represents code reuse and is in general encouraged.

Module Structure



Layered Design

- A design having modules:
  - With high fan-out numbers is not a good design:
  - A module having high fan-out lacks cohesion.

Goodness of Design

- A module that invokes a large number of other modules:
  - Likely to implement several different functions:
  - Not likely to perform a single cohesive function.

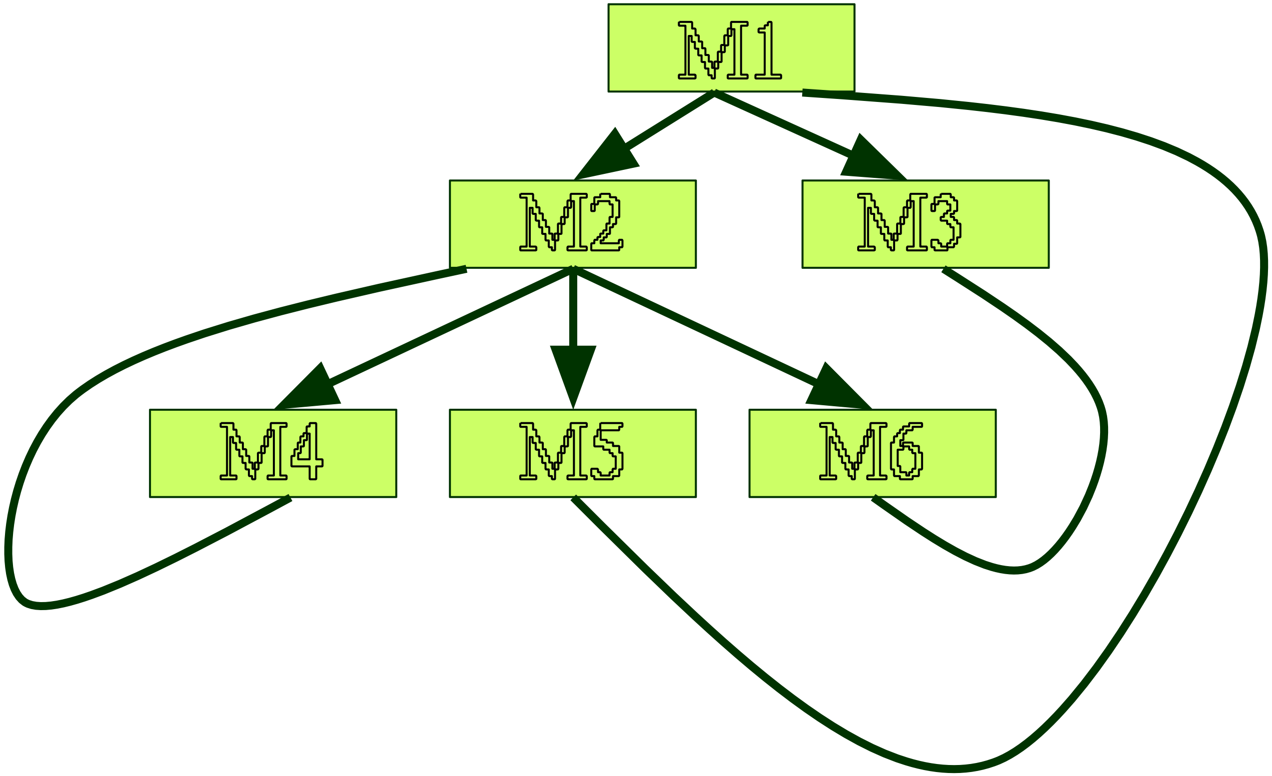
Control Relationships

- A module that controls another module:
  - Said to be superordinate to it.
- Conversely, a module controlled by another module:
  - Said to be subordinate to it.

Visibility and Layering

- *A* module *A* is said to be visible by another module B,
  - If *A* directly or indirectly calls B.
- The layering principle requires
  - Modules at a layer can call only the modules immediately below it.

Bad Design



Abstraction

- A module is unaware (how to invoke etc.) of the higher level modules.
- Lower-level modules:
  - Do input/output and other low-level functions.
- Upper-level modules:
  - Do more managerial functions.

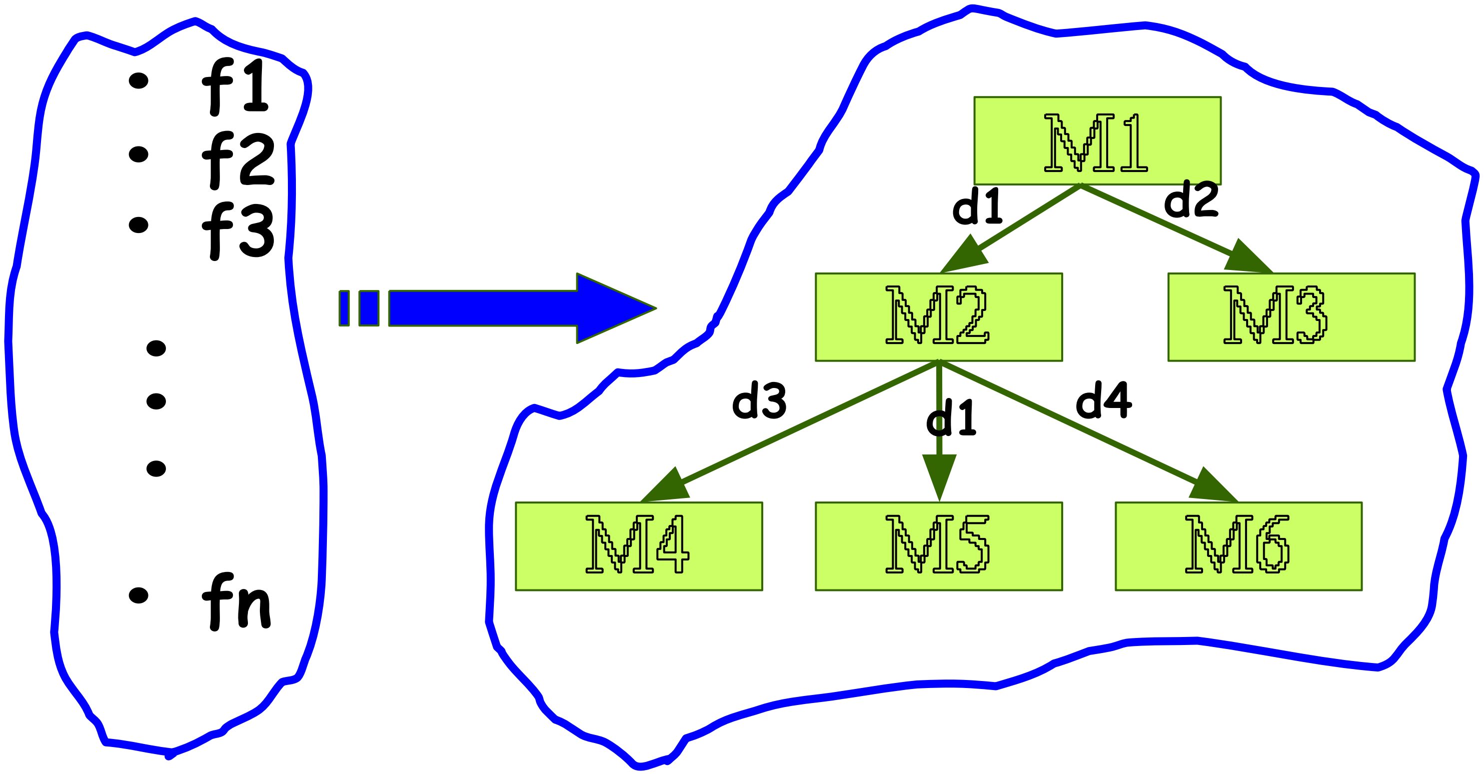
Abstraction

- The principle of abstraction requires:
  - Lower-level modules do not invoke functions of higher level modules.
  - Also known as <u>layered design</u>.

High-level Design

- High-level design maps functions into modules {fi} {mj} such that:
  - Each module has high cohesion
  - Coupling among modules is as low as possible
  - Modules are organized in a neat hierarchy

High-level Design



Design Approaches

- Two fundamentally different software design approaches:
  - Function-oriented design
  - Object-oriented design

Design Approaches

- These two design approaches are radically different.
  - However, are complementary
    - Rather than competing techniques.
  - Each technique is applicable at
    - Different stages of the design process.

Function-Oriented Design

- A system is looked upon as something
  - That performs a set of functions.
- Starting at this high-level view of the system:
  - Each function is successively refined into more detailed functions.
  - Functions are mapped to a module structure.

Example

- The function create-new-library-member:
  - Creates the record for a new member,
  - Assigns a unique membership number
  - Prints a bill towards the membership

Example

- Create-library-member function consists of the following sub-functions:
  - Assign-membership-number
  - Create-member-record
  - Print-bill

Function-Oriented Design

- Each subfunction:
  - Split into more detailed subfunctions and so on.

Function-Oriented Design

- The system state is centralized:
  - Accessible to different functions,
  - Member-records:
    - Available for reference and updation to several functions:
      - Create-new-member
      - Delete-member
      - Update-member-record

Function-Oriented Design

- Several function-oriented design approaches have been developed:
  - Structured design (Constantine and Yourdon, 1979)
  - Jackson's structured design (Jackson, 1975)
  - Warnier-Orr methodology
  - Wirth's step-wise refinement
  - Hatley and Pirbhai's Methodology

Object-Oriented Design

- System is viewed as a collection of objects (i.e. entities).
- System state is decentralized among the objects:
  - Each object manages its own state information.

Object-Oriented Design Example

- Library Automation Software:
  - Each library member is a separate object
    - With its own data and functions.
  - Functions defined for one object:
    - Cannot directly refer to or change data of other objects.

Object-Oriented Design

- Objects have their own internal data:
  - Defines their state.
- Similar objects constitute a class.
  - Each object is a member of some class.
- Classes may inherit features
  - From a super class.
- Conceptually, objects communicate by message passing.

Object-Oriented versus Function-Oriented Design

- Unlike function-oriented design,
  - In OOD the basic abstraction is not functions such as "sort", "display", "track", etc.,
  - But real-world entities such as "employee", "picture", "machine", "radar system", etc.

Object-Oriented versus Function-Oriented Design

- In OOD:
  - Software is not developed by designing functions such as:
    - update-employee-record,
    - get-employee-address, etc.
  - But by designing objects such as:
    - employees,
    - departments, etc.

Object-Oriented versus Function-Oriented Design

- Grady Booch sums up this fundamental difference saying:
  - "Identify verbs if you are after procedural design and nouns if you are after object-oriented design."

Object-Oriented versus Function-Oriented Design

- In OOD:
  - State information is not shared in a centralized data.
  - But is distributed among the objects of the system.

Example:

- In an employee pay-roll system, the following can be global data:
  - employee names,
  - code numbers,
  - basic salaries, etc.
- Whereas, in object oriented design:
  - Data is distributed among different employee objects of the system.

Object-Oriented versus Function-Oriented Design

- Objects communicate by message passing.
  - One object may discover the state information of another object by interrogating it.

Object-Oriented versus Function-Oriented Design

- Of course, somewhere or other the functions must be implemented:
  - The functions are usually associated with specific real-world entities (objects)
  - Directly access only part of the system state information.

Object-Oriented versus Function-Oriented Design

- Function-oriented techniques group functions together if:
  - As a group, they constitute a higher level function.
- On the other hand, object-oriented techniques group functions together:
  - On the basis of the data they operate on.

Object-Oriented versus Function-Oriented Design

- To illustrate the differences between object-oriented and function-oriented design approaches,
  - let us consider an example ---
  - An automated fire-alarm system for a large building.

Fire-Alarm System

- We need to develop a computerized fire alarm system for a large multi-storied building:
  - There are 80 floors and 1000 rooms in the building.

Fire-Alarm System

- Different rooms of the building:
  - Fitted with smoke detectors and fire alarms.
- The fire alarm system would monitor:
  - Status of the smoke detectors.

Fire-Alarm System

- Whenever a fire condition is reported by any smoke detector:
  - the fire alarm system should:
    - Determine the location from which the fire condition was reported
    - Sound the alarms in the neighboring locations.

Fire-Alarm System

- The fire alarm system should:
  - Flash an alarm message on the computer console:
    - Fire fighting personnel man the console round the clock.

Fire-Alarm System

- After a fire condition has been successfully handled,
  - The fire alarm system should let fire fighting personnel reset the alarms.

Function-Oriented Approach:

- ```
  /* Global data (system state) accessible by various functions */
  BOOL  detector_status[1000];
  int   detector_locs[1000];
  BOOL  alarm-status[1000]; /* alarm activated when status set */
  int   alarm_locs[1000]; /* room number where alarm is located */
  int   neighbor-alarms[1000][10];/*each detector has at most*/
                        /* 10 neighboring alarm locations */
  ```
  The functions which operate on the system state:
  ```
   interrogate_detectors();
   get_detector_location();
   determine_neighbor();
   ring_alarm();
   reset_alarm();
   report_fire_location();
  ```
  ```

Object-Oriented Approach:

- class detector
- attributes: status, location, neighbors
- operations: create, sense-status, get-location,
- find-neighbors
- class alarm
- attributes: location, status
- operations: create, ring-alarm, get_location,
- reset-alarm
- In the object oriented program,
  - appropriate number of instances of the class detector and alarm should be created.

Object-Oriented versus Function-Oriented Design

- In the function-oriented program :
  - The system state is centralized
  - Several functions accessing these data are defined.
- In the object oriented program,
  - The state information is distributed among various sensor and alarm objects.

Object-Oriented versus Function-Oriented Design

- Use OOD to design the classes:
  - Then applies top-down function oriented techniques
    - To design the internal methods of classes.

Object-Oriented versus Function-Oriented Design

- Though outwardly a system may appear to have been developed in an object oriented fashion,
  - But inside each class there is a small hierarchy of functions designed in a top-down manner.

Summary

- We started with an overview of:
  - Activities undertaken during the software design phase.
- We identified:
  - The information need to be produced at the end of the design phase:
    - So that the design can be easily implemented using a programming language.

Summary

- We characterized the features of a good software design by introducing the concepts of:
  - fan-in, fan-out,
  - cohesion, coupling,
  - abstraction, etc.

Summary

- We classified different types of cohesion and coupling:
  - Enables us to approximately determine the cohesion and coupling existing in a design.

Summary

- Two fundamentally different approaches to software design:
  - Function-oriented approach
  - Object-oriented approach

Summary

- We looked at the essential philosophy behind these two approaches
  - These two approaches are not competing but complementary approaches.