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:
  - into a form easily implementable in some programming language.

Items Designed During Design Phase

- Module structure
  - Different modules required are identified
  - Each module is collection of functions and data shared by the functions
  - Each module accomplish some well-defined task
  - Each module should be named according to the task it performs
- control relationship among the modules
  - Due to functions calls across the two modules
  - These relationships existing among the modules should be identified
- interface among different modules
  - data items exchanged among different modules

Items Designed During Design Phase

- data structures of individual modules
  - Suitable data structures for storing and managing the data of a module need to be properly designed

- algorithms for individual modules.
  - Each module performs some processing activity
  - Algorithms required to accomplish the processing activities of various modules need to be carefully designed and documented

Classification of Design activities

- Good software designs:
  - seldom arrived through a single step procedure, rather it requires iterating over a series of steps called *design activities*

Classification of Design activities

- 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

- Traditional function-oriented design approach, it is possible to define the objectives of high-level design:
  - Through high-level design, a problem is decomposed into a set of modules.
  - The control relationship among the modules are identified
  - Interfaces among various modules are identified

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

High-level Design

- Problem should have been decomposed into many small functionally independent modules that are cohesive
- Have low coupling among themselves
- Are arranged in a hierarchy.
- Several notations are available to represent high-level design:
  - Usually a tree-like diagram called structure chart is used.
  - UML diagrams for object oriented-design
  - Other notations:
    - Jackson diagram or Warnier-Orr diagram can also be used.

Detailed design

- For each module, it is examined to design:
  - data structure
  - algorithms

- Outcome of detailed design:
  - module specification.

Good and bad designs

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

What Is Good Software Design?

- Should implement all functionalities of the system correctly.
- Should be easily understandable.
- Should be efficient.
  - Address resource, time and cost optimization issues
- Should be easily amenable to change,
  - i.e. easily maintainable.

What Is Good Software 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.

What Is Good Software 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,

- Design solution should consist of:
  - a cleanly decomposed set of modules (modularity),

- Different modules should be neatly arranged in a hierarchy:
  - in a neat tree-like diagram.

Modularity

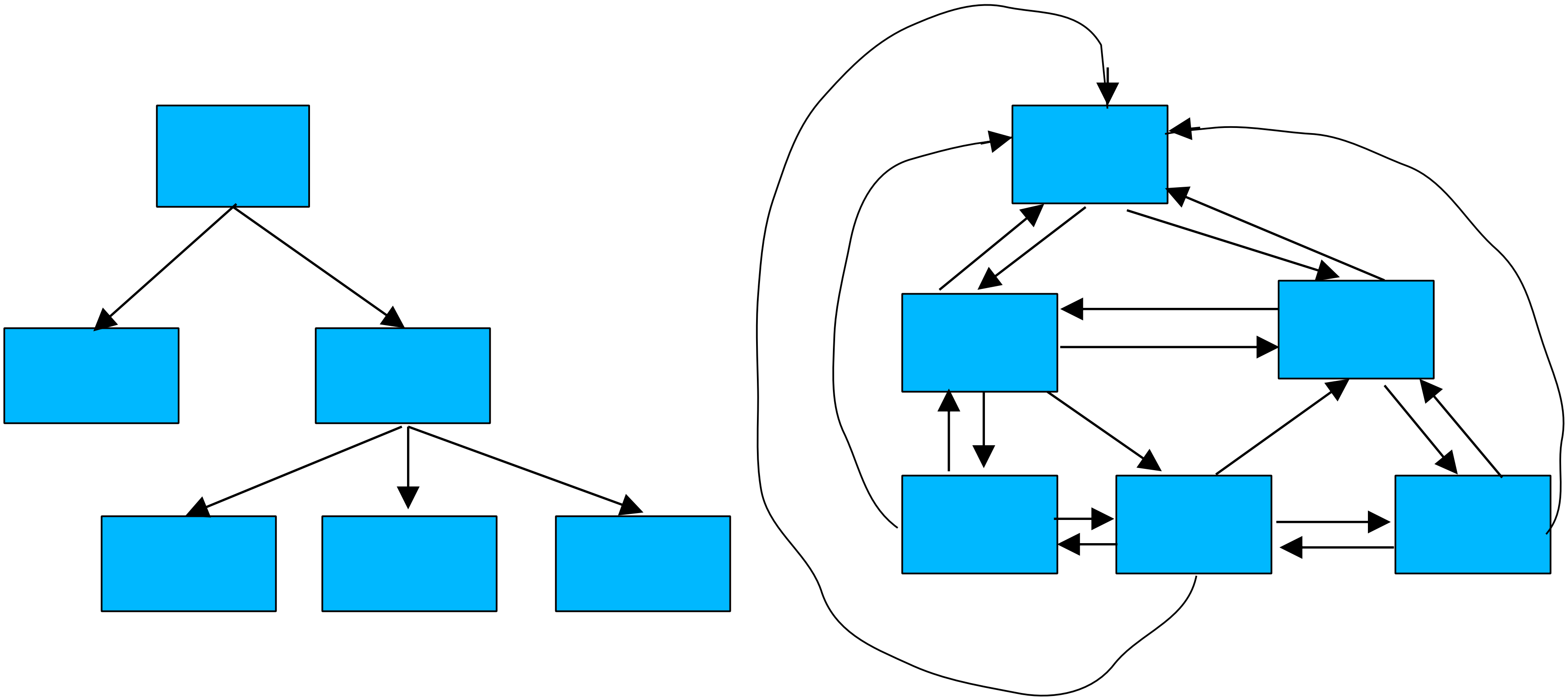
- Modularity is a fundamental attributes of any good design.
  - Decomposition of a problem cleanly into modules
  - Modules are almost independent of each other
  - divide and conquer principle.

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.

Example of Cleanly and Non-cleanly Decomposed Modules



Modularity

- In technical terms, modules should display:
  - high cohesion
  - low coupling.

- We will shortly discuss:
  - cohesion and coupling.

Modularity

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

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 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

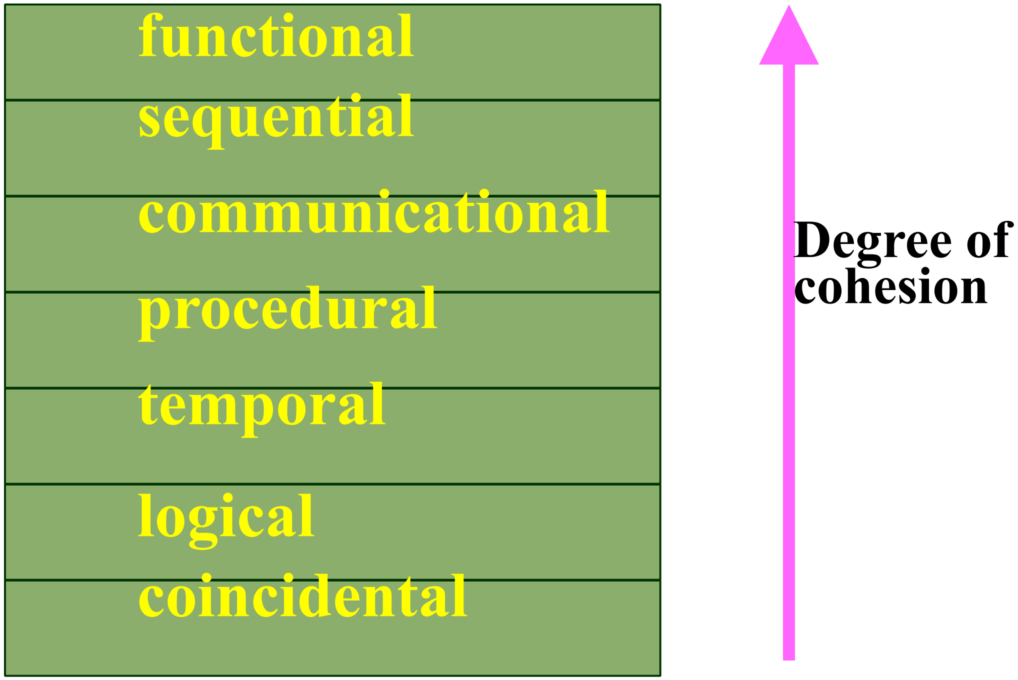
- Unfortunately, there are no ways:
  - to quantitatively measure the degree of cohesion and coupling:
  - classification of different kinds of cohesion and coupling:
    - will give us some idea regarding the degree of cohesiveness of a module.

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

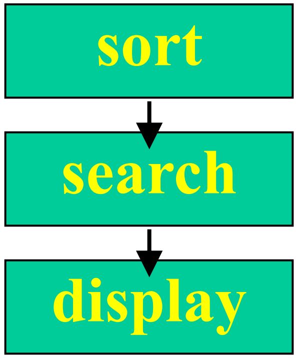
- The set of functions of the module:
  - all part of a procedure (algorithm)
  - certain sequence of steps have to be carried out in a certain order for achieving an objective,
    - e.g. the algorithm for decoding a message.

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, setup, shutdown
    - it probably has temporal cohesion.

Coupling

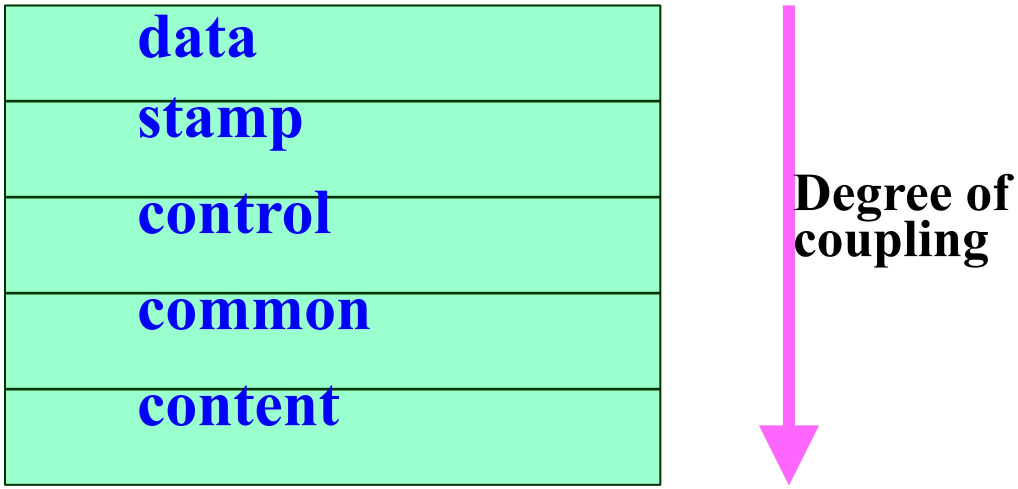
- Coupling indicates:
  - how closely two modules interact or how interdependent they are.
  - The degree of coupling between two modules depends on their interface complexity.

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 stamp coupled,
  - 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 common coupled,
  - 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.

Neat Arrangement of modules

- Essentially means:
  - low fan-out
  - abstraction

Characteristics of Module Structure

- 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.

Goodness of 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.

Abstraction

- 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 layered design.

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

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.
- 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:
  - names of the employees,
  - their code numbers,
  - basic salaries, etc.

- Whereas, in object oriented systems:
  - 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.
- 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.
- 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.
- 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.