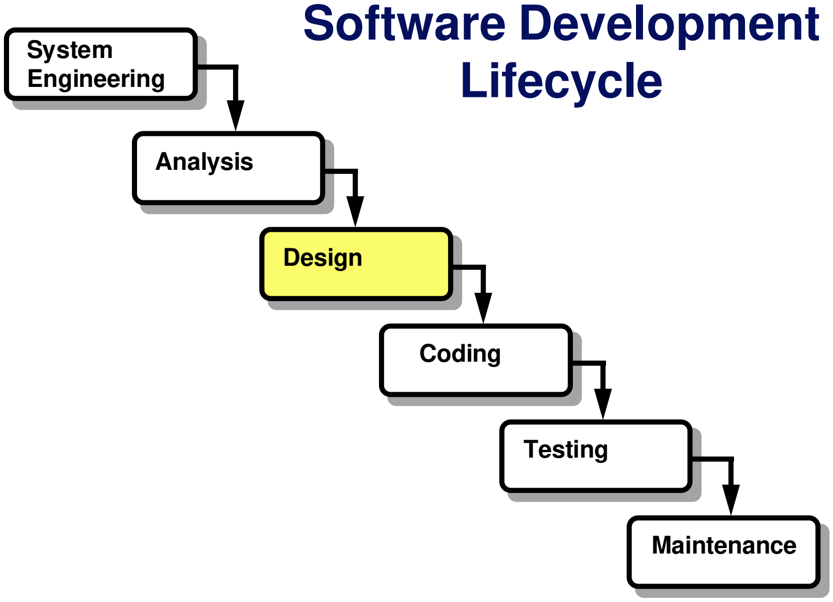
SOFTWARE DESIGN

- **Software Design Fundamentals**
- **Data Flow-Oriented Design**
- **Object-Oriented Design**
- **Data-Oriented Design Methods**
- **User Interface Design**
- **Real-Time Design**

Software Development Lifecycle



Software Design ...

- is the first step in the development phase for any engineered system
- produces a model of the software which is to be coded later

> *"The beginning of wisdom for a computer programmer is to recognize the difference between getting a program to work and getting it right."*
>
> **-- M.A. Jackson, *Principles of Program Design*, 1975**

Design Models

- <u>Architectural Design</u> - Relationship among major structural components of the program.
- <u>Data Design</u> - Transforms the information domain model created during analysis into the data structures required to implement the software.
- <u>Procedural Design</u> - Transforms structural components into a procedural description of the software.

Software design requires all three design models

Software Design Steps

1. **Preliminary Design - The transformation of requirements into a data and procedural architecture.**
2. **Detailed Design - Refining the architectures developed in preliminary design.**

The idea is to transform the structure and details from the problem domain to the implementation domain sufficient for coding.

Quality

Design is the phase where ***quality*** is built into software.

The quality of an evolving design is identified through a series of formal technical reviews.

Guidelines for a Good Design

- A design should exhibit a hierarchical organization.
- A design should be modular, leading to an implementation of strongly cohesive, loosely coupled modules.
- A design should contain a distinct and separate representation of data and procedure.
- A design should be derived using a repeatable method driven by information obtained from the requirements analysis.
- A design should track closely with the requirements - there should be a mapping.

Fundamental Concepts

- ***Stepwise Refinement*** **- the successive definition of levels of detail**
- ***Software Architecture*** **- the hierarchical structure of procedural components and the structure of data**
- ***Program Structure*** **- the flow of control between the procedural components**
- ***Software Procedure*** **- the processing details of each procedural component**
- ***Data Structure*** **- the logical relationship between elements of data**
- ***Levels of Abstraction*** **- the expression of a design in terms of the problem space, usually employing *Stepwise Refinement* in the process**
- ***Information Hiding*** **- the suppression of unnecessary details at a particular level of abstraction**

Diagramming Techniques

Many of the diagramming techniques used during requirements analysis may also be used during design:

- Data Flow diagrams
- State Transition diagrams
- Entity-Relationship diagrams

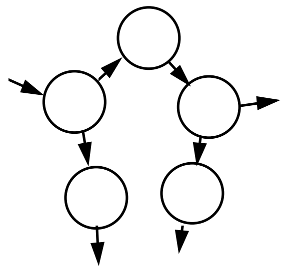
We add several more types of diagrams to specifically support software structure:

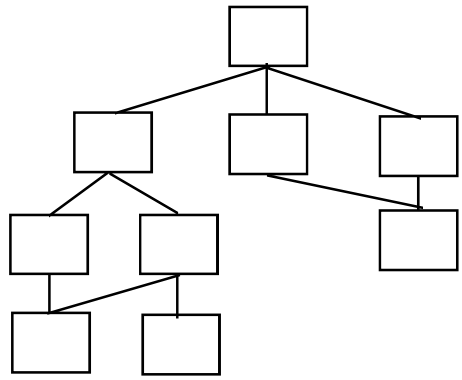
- Structure Charts
- Function diagrams (also called flow-diagrams)

Other diagramming techniques are intended specifically for design and are often language-specific. These techniques are often used when the implementation language supports object oriented programming such as Ada or C++:

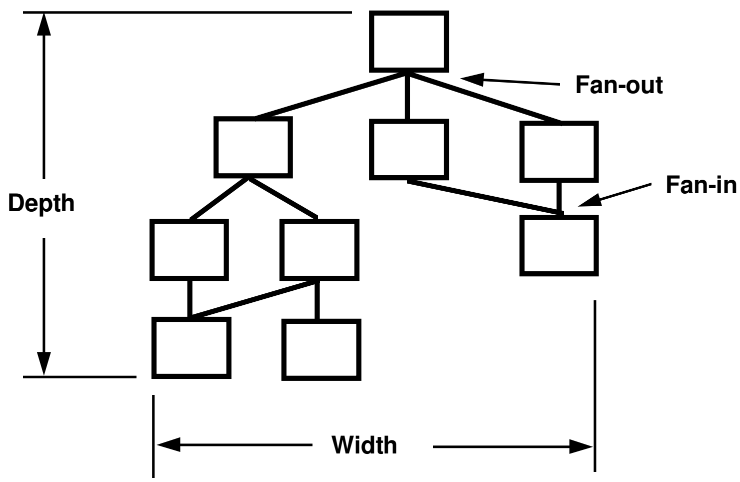
- Object Interaction diagrams
- Booch diagrams

Evolution of Structure

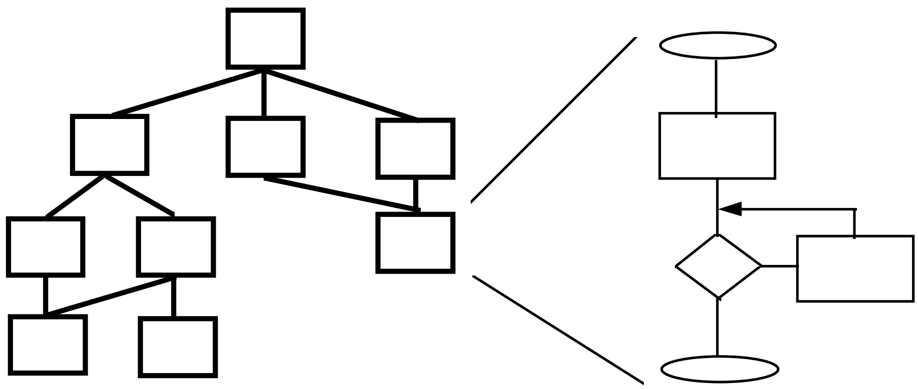




Structure Chart Notation



Modules



Structure Chart

Flow Diagram

Modular Design

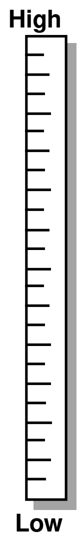
There are three basic types of modules:

- *Sequential* - referenced and executed without apparent interruption
- *Incremental* - can be interrupted by other software prior to completion and restarted at the point of interruption
- *Parallel* - executes concurrently with other modules

As an example, Ada provides features (sometimes independent of the operating system) which directly support the design and coding of these types of modules:

- procedures and functions
- tasks with entry points tied to interrupts
- tasks which may be executed concurrently

Cohesion Spectrum



Functional - module performs one distinct procedural task.

Sequential - module performs sequence of procedural tasks.

Communicational - module performs all tasks on a single area of a data structure.

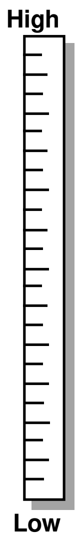
Procedural - procedural tasks are related and performed in some order.

Temporal - All procedural tasks must be performed within a given span of time.

Logical - All procedures have some logical relationship.

Coincidental - No relationship exists between the tasks in the module.

Coupling Spectrum



Content - modules make use of data or control info from each other or has branches into middle of module.

Common - modules commonly reference a global data area.

External - modules regularly reference an external environment like I/O or comm protocol.

Control - modules regularly pass control info between each other, but data access outside of modules is infrequent.

Stamp - All, or part, of data structures passed between modules rather than single-value arguments.

Data - Simple, single-vallues arguments passed between modules.

No direct coupling - modules do not communicate with each other.

Desirable Attributes of Modules

- ***Functional Independence*** **- the isolation of particular functions to particular modules**
- ***Cohesion*** **- the binding of a single task to a single module without interaction with or side effects from other modules;** ***Strong Cohesion*** **is desirable**
- ***Coupling*** **- a measure of the interconnection between modules;** ***Loose Coupling*****, usually implemented by exclusive use of interfaces through subprograms, is desirable**

Design Documentation

The documentation of a design should include the following information:

- A description of the design
  - A description of the data, including the data flow and data structure
  - A description of the program structure
  - A description of interfaces within the program structure
  - A description of interfaces between the program and other elements in its environment
- A description of each module
- A description of the structure and details of the global data and files
- Test provisions
- A cross-reference between the design and the requirements which drove the design

DI-MCCR-80012A

DoD-STD-2167A Software Design Document

- Preliminary Design
  - CSCI Overview, including architecture, system states, and memory and processing time constraints
  - CSCI Design Description, including descriptions of the component CSCs
- Detailed Design
  - CSC Design and Constraints, including I/O data elements, local data elements, interrupts and signals, algorithms, error handling, data conversion, use of external elements, logical flow, data structures, local data files or database
  - Global CSCI data and data files
- Requirements Traceability

Evaluation Criteria for Designs

- Internal consistency
- Understandability
- Traceability to requirements documents
- Appropriate analysis, design, or coding techniques used
- Appropriate allocation of sizing and timing resources
- Adequacy of requirements allocation for the CSCIs and CSCs
- Consistency between data definition and data use
- Accuracy and required precision of constants and variables

CASE Tools often support the developing of designs by providing automated checking of these and other criteria.

Design Methodologies
Data Flow-Oriented Design

- **Data Flow-Oriented Design**
- **Data Structure-Oriented Design**
- **Object-Oriented Design**
- **Real-Time Design**

Note

The first three classes are heavily driven by the *Information Domain.*

Data Flow-Oriented Design

- Uses information flow characteristics to derive the program structure
- There are two design analysis techniques:
  - *Transform Analysis and Design* - the information flow exhibits distinct boundaries between incoming and outgoing data (i.e., input, processing, and output are the three key elements of the data flow)
  - *Transaction Analysis and Design* - an information item causes the flow to branch along a choice of paths
- Data Flow Diagrams (DFD's) are the common graphical means to represent the flow of data

Transform Analysis and Design

Design Steps:

- **Review the fundamental system model**
- **Review and refine the DFD's for the software**
- **Determine the transform and transaction characteristics of the DFD's**
- **Isolate the transform center by specifying incoming and outgoing flows**
- **Perform "first-level factoring" - derive the mapping from the major parts of the DFD to a program structure**
- **Perform "second-level factoring" - map individual bubbles in the DFD into modules in the program structure**
- **Refine the above "first-cut" program structure - maximize cohesion, minimize coupling, and build a structure hierarchy**

Transaction Analysis and Design

Design Steps:

- **Review the fundamental system model**
- **Review and refine the DFD's for the software**
- **Determine the transform and transaction characteristics of the DFD's**
- **Isolate the transaction center and the flow characteristics of each action path**
- **Map the DFD into a software structure amenable to transaction processing**
- **Factor and refine the transaction structure and the structure of each action path**
- **Refine the above "first-cut" program structure - maximize cohesion, minimize coupling, and build a structure hierarchy**

Design Heuristics

- Minimize coupling and maximize cohesion
- Minimize fan-out and strive for fan-in as the depth increases
- Minimize side-effects; keep the scope of the effect of a module within the scope of control of that module
- Evaluate module interfaces to reduce complexity and redundancy; improve consistency of the module
- Define modules whose function is predictable and testable
- Strive for single-entry, single-exit modules
- Package softwawre based on design constraints and portability requirements

Design Methodologies
Data Structure-Oriented Design

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Data Structure-Oriented Design

- Three key methods:
  - *Jackson System Development* - concentrates on process modeling and control
  - *Logical Construction of Programs (Warnier)* - rigorous view of data structure and focus on detailed procedural design
  - *Data Structured System Development (Orr)* - incorporates data flow analysis with the Logical Construction of Programs and Jackson System Development (JSD to a lesser extent)
- This is 1970's technology and is not covered in detail

Design Methodologies
Object-Oriented Design

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Object-Oriented Design (OOD)

- Concerns itself with creating a model of the real world
- Objects represent the information domain, and the operations associated with that information are grouped with the objects
- Messages (interfaces) provide a means by which operations are invoked
- Packaging of objects with their associated operations takes place - data and procedural abstractions are combined in a single program component called an *object* or a *package*
- OOD representations are more prone than others to programming language dependency

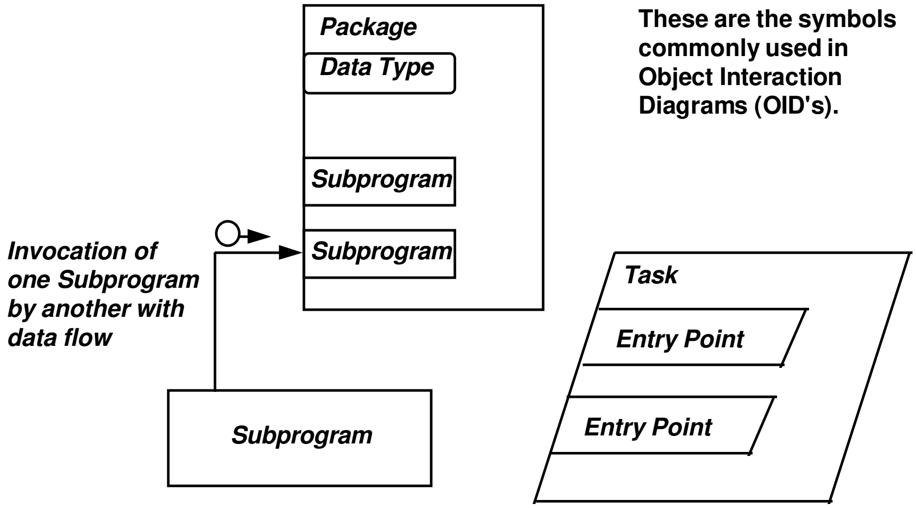
Terminology Overview

- ***Object*** **- a component of the real world that is mapped into the software domain or an information item**
- ***Operations*** **or** ***Methods*** **- processes which act on objects to transform their internal data structure or provide information on their internal data structures**
- ***Message*** **- a request to an object to perform one of its operations**
- ***Class*** **- a set of objects which share common characteristics**
- ***Instance*** **- an individual object of a class**

Object-Oriented Design Steps

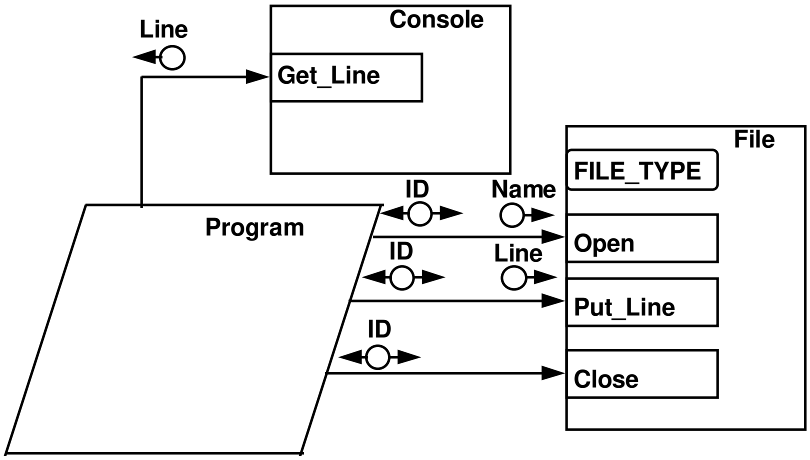
- Identify the objects
- Identfy the attributes of the objects
- Identify the operations that may be applied to the objects
- Establish the interfaces of the objects to the outside world (Ada package specifications may be used if Ada is the implementation language)
- Implement the objects (Ada package bodies may be used if Ada is the implementation language)
- Graphical representation may be employed; Booch Diagrams and Object Interaction Diagrams are the recommended diagramming techniques

Object Interaction Diagrams (OIDs)

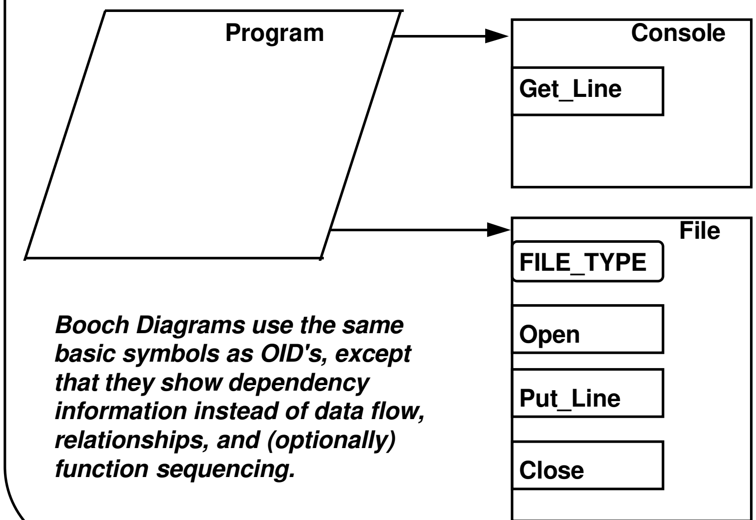


These are the symbols commonly used in Object Interaction Diagrams (OID's).

OIDs - Example



Booch Diagrams - Example



Booch Diagrams use the same basic symbols as OID's, except that they show dependency information instead of data flow, relationships, and (optionally) function sequencing.

Design Methodologies
Real-Time Design

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- Data Structure-Oriented Design
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Real-Time Design

- Encompasses all aspects of conventional software design while simultaneously introducing timing and sizing constraints; these constraints must be satisfied by the code
- All classes of design (architectural, procedural, and data) become more complex due to the response time required by the real-world constraints
- Mathematical modeling and simulation are common tools used for real-time design

Real-Time System Concerns

- Interrupt handling and context switching
- Response time
- Data transfer rate
- CPU and system throughput
- Resource allocation and priority handling
- Task synchronization and intertask communication