Overview - Design

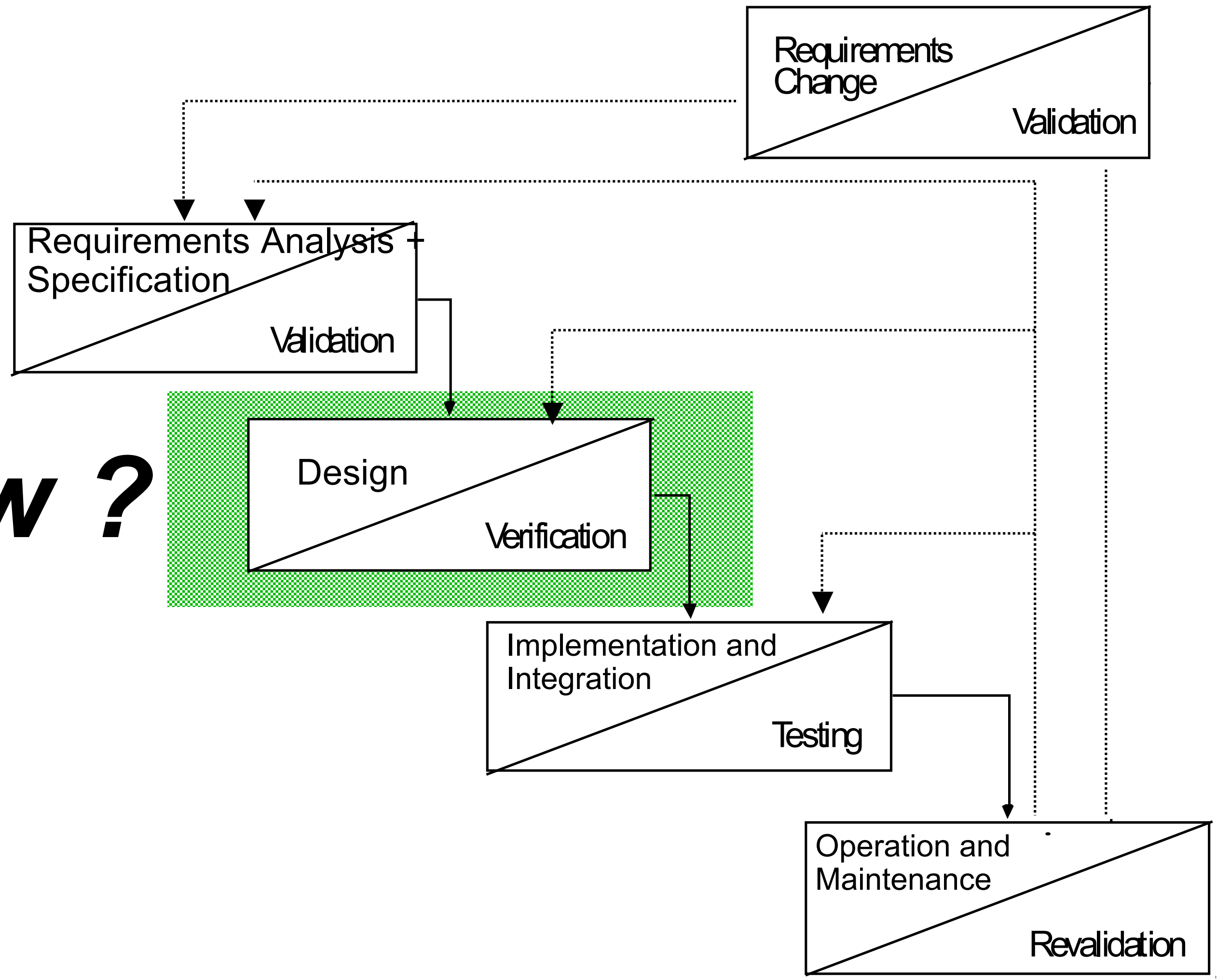
- Introduction to Design
- Architectural Design
- Modules
- Structured Design
- Objects
- Object-Oriented Design
- Detailed Design
- Integration Testing

Goals and Objectives

- Develop a coherent representation of a software system that will satisfy the requirements
- Identify inadequacies in the requirements
- Can develop review plan that demonstrates coverage of the requirements
  – yields confidence in design
- Can develop test plan that covers design
  – yields confidence in both design and implementation

Introduction to Design

How ?

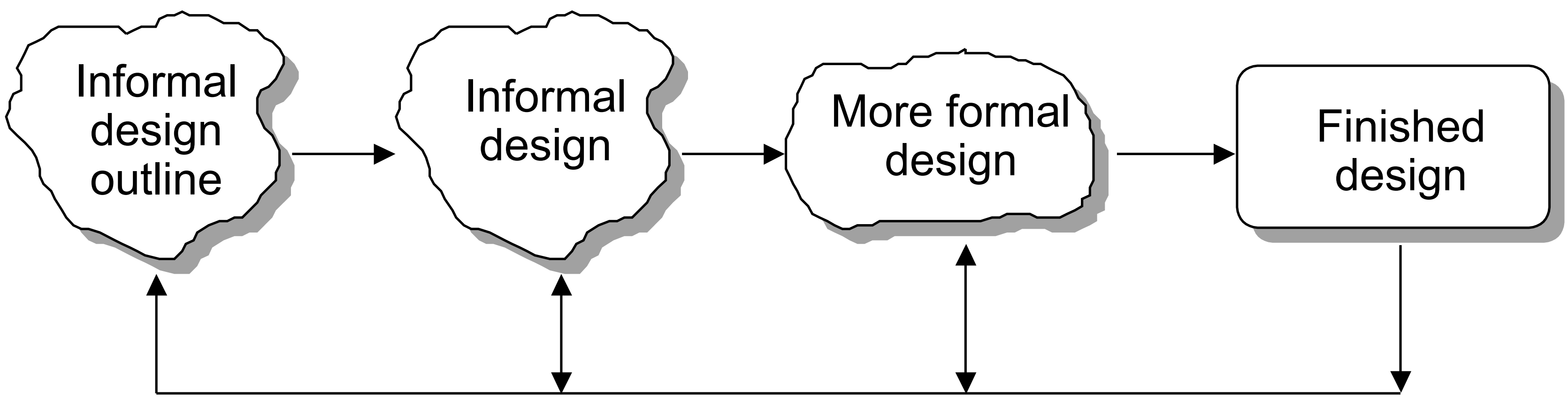


Relationship to other lifecycle phases

- Requirements
  - Specifies the “app domain” not the “machine”
  - Provides conceptual boundaries
    - € keeps design focused
- Implementation
  - When design specifications are sufficient for coding assignments (now it can be “executable” on a <u>machine</u>
    - € each assignment, theoretically, can be given to a programmer unaware of the overall system architecture
      - and the code will satisfy the associated requirements

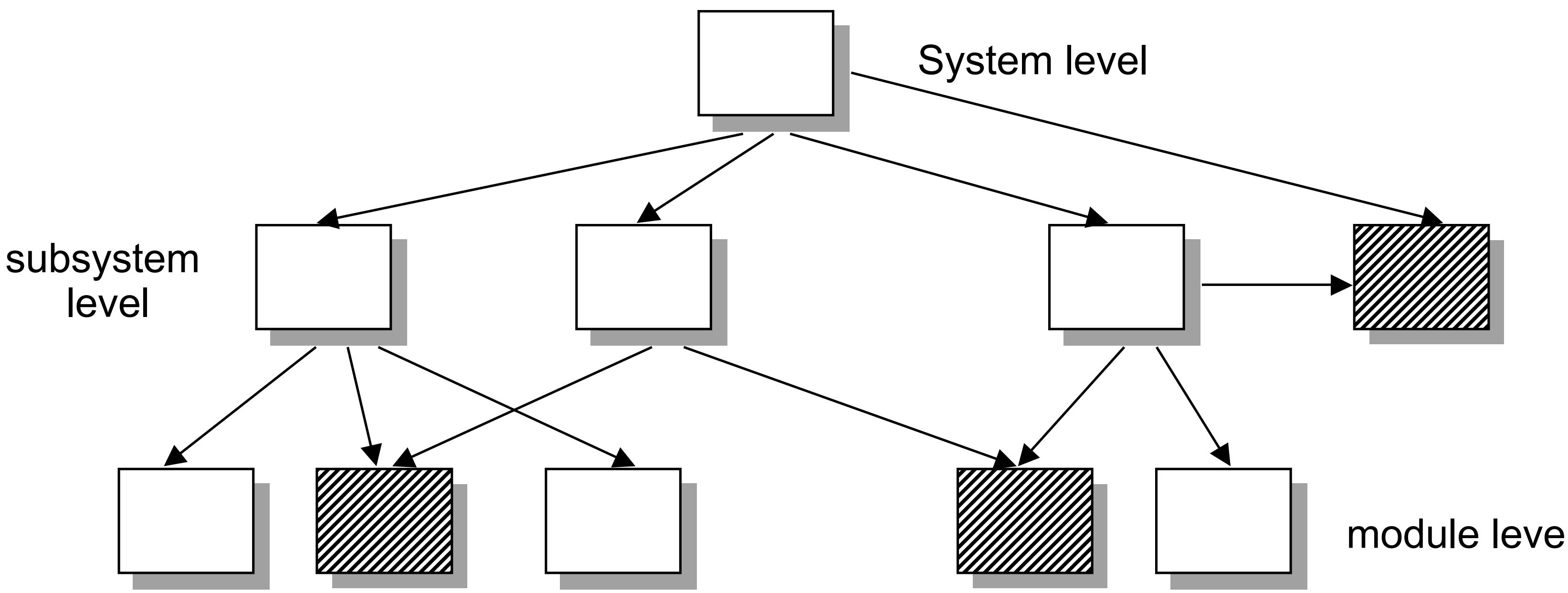
Basic Design Process

- The design process develops several models of the software system at different levels of abstraction
  - Trial and Error in many ways
  - Starting point is an informal “boxes and arrows” design
  - Add information to make it more consistent and complete
  - Provide feedback to earlier designs for improvement



Top-Down Design

- Recursively partition a problem into sub-problems until tractable (solvable) problems are identified



Design Activities

- Architectural design
  - Subsystem identification
    - € services and constraints are specified
  - Module design
    - € modular decomposition is performed; relationships specified
- Detailed design
  - Interface design
    - € module interfaces are negotiated, designed and documented
  - Data structure and algorithm design
    - € module details (data structures and algorithms) to provide system services are specified

Design Products

- Refined requirements specification
- Description of systems to be constructed
  - software architecture (diagrams and rationale)
  - modular decomposition (hierarchy)
  - abstract module interface specifications
  - detailed module designs
- Documentation of decisions and rationale
- Data dictionary of all defined objects
- Validation review plan
- Integration test plan

Desirable Characteristics/ Common Problems

- Uniform
- Complete
- Rigorous
- Confirmable, verifiable, testable
- Supportable by tools
- Desensitized to change
- Accommodates independent coding

- Depth-first design: only partial satisfaction of requirements
- Failure to consider potential changes
- Too detailed: overly constrains implementation
- Ambiguous: misinterpreted during implementation
- Undocumented: designers become essential
- Inconsistent: system cannot be integrated

Architectural Design

- Architectural Design
  - decomposition of large systems that provide some related set of services + establishing a framework for control and communication
- Architectural styles establish guidelines
  - a relatively new area of research
- No generally accepted architectural design process (Well, maybe UML, Rational Unified Process…)
  - some important sub-processes
    - € System structuring: structuring of the system into a number of subsystems, where a subsystem is an independent software unit
    - € Control modeling: establishing a general model of control relationships between the parts of the system
    - € Modular decomposition: decomposing each identified subsystem into modules

Architecture, Subsystems and Modules

- Architecture consists of interacting subsystems
  - € describes the subsystem decomposition in terms of subsystem responsibilities, dependencies among subsystems, subsystem mapping to hardware, and major policy decisions such as control flow, access control and data storage. (Bruegge)
- Subsystems
  - a component whose operation does not depend on the services provided by other subsystems
  - communicates with other subsystems via defined interfaces
  - is further decomposed further into modules during design

Basic concerns

- Define design goals
  - identify and prioritize qualities of the system to be optimized
    - € find these in nonfunctional requirements
- Decompose system into smaller subsystems
  - to support the design goals

Software Architecture

- Components (subsystems)
  - The elements out of which the system is built
  - Examples: filters, databases, objects, ADTs
- Connectors
  - The interaction or communication mechanisms
  - The glue that combines the components
  - Examples: procedure calls, pipes, event broadcast, messages, secure protocols
- Constraints
  - Limitations on the composition of components and connectors

Architectural Style

- Example architectural styles
  - Batch sequential
  - Pipe and filter
  - Main program and subroutines
  - Blackboard
  - Interpreter
  - Client-server
  - Communicating processes
  - Event systems
  - Object-oriented
  - Layered Systems

Families of systems defined by patterns of composition

Architectural Design: System Structuring

- Model of the system structure and decomposition
  - € how subsystems share data
  - € how they are distributed
  - € how they interface with each other
- Three standard models
  - ***Repository model:*** how subsystems exchange and share information
    - E.g., all shared data is held in a central database or each sub-system maintains its own database
  - ***Distribution model*:** how data and processing is distributed across a range of processors
    - E.g., Client-server or peer-to-peer processes
  - ***Abstract machine model:*** the interfacing of subsystems as abstract machines each of which provides a set of services to others
    - E.g., each subsystem defines an abstract machine

Architectural Design: Control Modeling

- Control of subsystems so that services are delivered to the right place at the right time
- Two general approaches
  - *Centralized control*
    - € One subsystem has overall responsibility for control and starts/stops other subsystems
      - call-return model (sequential)
      - manager model (concurrent)
  - *Event-based control*
    - € each subsystem responds to externally generated events (from other subsystems or the environment)
      - broadcast model
      - interrupt-driven model

Simple Overview (very basic Architecture)

- Design major subsystems
  - use UML, class diagrams, event trace or sequence diagrams
    - € don't forget the error handling subsystem
  - keep #subsystems small (5 to 9 rule of thumb)
  - keep communication between subsystems to a minimum
  - explain what each subsystem does
- Traceability matrices
  - show allocation of requirements to subsystems
  - show subsystems and the requirements they handle
    - € assign a requirement to to as few subsystems as possible
      - why? (coupling and cohesion, covered later in modules…)

Simple Overview

- Subsystem Interfaces
  - traceability matrices can help
    - € subsystems that appear together may need to communicate
  - one required function - one interface
    - € minimize #ways to invoke or call a subsystem
  - know who will be calling the subsystem and why
    - € record this rationale
  - keep complex data structures out of the interfaces
- Environment Interface
  - don’t worry about O.S., that really is background
  - UI is important
  - other environmental interfaces?

Architecture should address:

- external interfaces, user interface
- db if needed, other data storage issues
- key algorithms
- memory management, key string storage (such as error messages)
- concurrency
- security
- localization
- networking
- portability
- programming language
- error handling

Architecture Documentation

- System Overview
- Architectural Goals and Constraints
- Subsystems and Organization
  - diagrams and rationale
- Can find templates on line if you wish

Design: Modular decomposition

- After decomposition of the system into subsystems, subsystems must be decomposed into modules
  - *No rigid distinction between system and modular decomposition*
- Two important approaches for decomposing subsystems into modules:
  - *Data-flow (structured design)*
    - system is decomposed into functional modules which accept input data and transform it to output data
    - process-based decomposition
    - achieves mostly procedural abstractions
  - *Object-oriented (object-oriented analysis and design)*
    - system is decomposed into a set of communicating objects
    - object-based decomposition
    - achieves both procedural + data abstractions

Design: Hierarchy

- Hierarchies support modular decomposition
  - *Uses relation: a uses b* only if the correct functioning of *a* depends on the existence of a correct implementation of *b*
    - € modular decomposition can be specified by *uses*, where
      - Level 0 is the set of all programs that use no other program
      - Level *i* (*i* > 0) is the set of all programs that use at least one program on level *i* -1 and no program at level ≥ *i.*
      - Note: the *uses* relation does not always provide a hierarchy
  - *Is-composed-of relation: a is-composed-of b* if *b* is a component of *a* and encapsulated within *a*
    - € modular decomposition can be specified by *is-composed-of*, where
      - non-terminals are virtual code
      - terminals are the only units represented by code
      - Then, the *uses* relation is specified over the set of terminals only
      - Note: the *is-composed-of* relation is acyclic

Modules

- Definition: a software entity encapsulating the representation of an abstraction and providing an abstract interface to it
- Module interaction
  - Module hides implementation details so that the rest of the system is insulated and protected from the details AND vice versa
  - Modules communicate only through well-defined interfaces
- Negotiating module interfaces
  - design interface to component to be insensitive to change
  - determine likely usage patterns and purposes
  - disseminate minimal information as useful generalities
    - € abstract Interfaces: one specification, many possible implementations
  - suppress unnecessary detail of a design decision

Modular Decomposition: Abstraction

- Abstraction is a tool that supports focus on important, inherent properties and suppression of unnecessary detail
  - permits separation of conceptual aspects of a system from the implementation details
  - allows postponement of design decisions
- Three basic abstraction mechanism
  - procedural abstraction
    - € specification describes input/output
    - € implementation describes algorithm
  - data abstraction
    - € specification describes attributes, values, properties, operations
    - € implementation describes representation and implementation
  - control abstraction
    - € specification describes desired effect
    - € implementation describes mechanism

Modular Decomposition: Information Hiding

- Information hiding is a decomposition principle that requires that each module hides its internal details and is specified by as little information as possible
  - forces design units to communicate only through well-defined interfaces
  - enables clients to be protected if internal details change
- Sample entities to encapsulate
  - abstract data types
  - algorithms
  - input and output formats
  - processing sequence
  - machine dependencies
  - policies (e.g. security issues, garbage collection, etc.)

Modular Decomposition: Cohesion and Coupling

- Cohesion
  - the degree to which the internals of a module are related
- Coupling
  - the degree to which the modules of a design are related
- The ideal system has highly cohesive modules that are loosely coupled
  - high cohesion -> well-designed reusable module
  - low coupling -> coherent design, resistant to change

Types of Cohesion

- coincidental
  - multiple, completely unrelated actions
- logical
  - series of related actions, often selected by parameters
- temporal
  - series of actions related in time
- procedural
  - series of actions sharing sequence of steps
- communicational
  - procedural cohesion but on the same data
- informational
  - series of independent actions on the same data
- functional: exactly one action

(Bad)

(Good)

Types of Coupling

(Bad)

- content
  - one module directly references content of another
- common
  - both modules have access to same global data
- control
  - one module passes an element of control to another
- stamp
  - one module passes a data structure to another; which only uses part of the passed information
- data
  - one module passes only homogeneous data items

(Good)

Some examples of cohesion

- Logical cohesion
  - Input/Output libraries
  - Math libraries
- Temporal cohesion
  - Program initialization
- Communicational cohesion
  - “calculate data and write it to disk”
  - Closely related: sequential cohesion
    - € the output of one element is the input to another

Some examples of coupling

- Control coupling
  - One module passes control flags (parameters or global variables) that control the sequence of processing steps in another module
- Stamp coupling (alternative definition)
  - Similar to common coupling (modules that share global data) except that globals are shared selectively among routines that require the data
  - Ada packages support stamp coupling since variables defined in a package specification are shared between all modules which use the package.

Structured Design

- System is completely specified by the functions that is to perform
  - Top-down, iterative refinement of functionality
    - € break the [system] function into subfunctions
    - € determine hierarchy and data interaction
  - Function refinement guides data refinement
  - Hierarchical organization is a tree with one module per subfunction
- Pros and Cons
  - modules are highly functional
  - best suited when state information is not pervasive
  - data decisions must be made earlier
  - changes in data ripple through entire structure
  - little chance for reusability

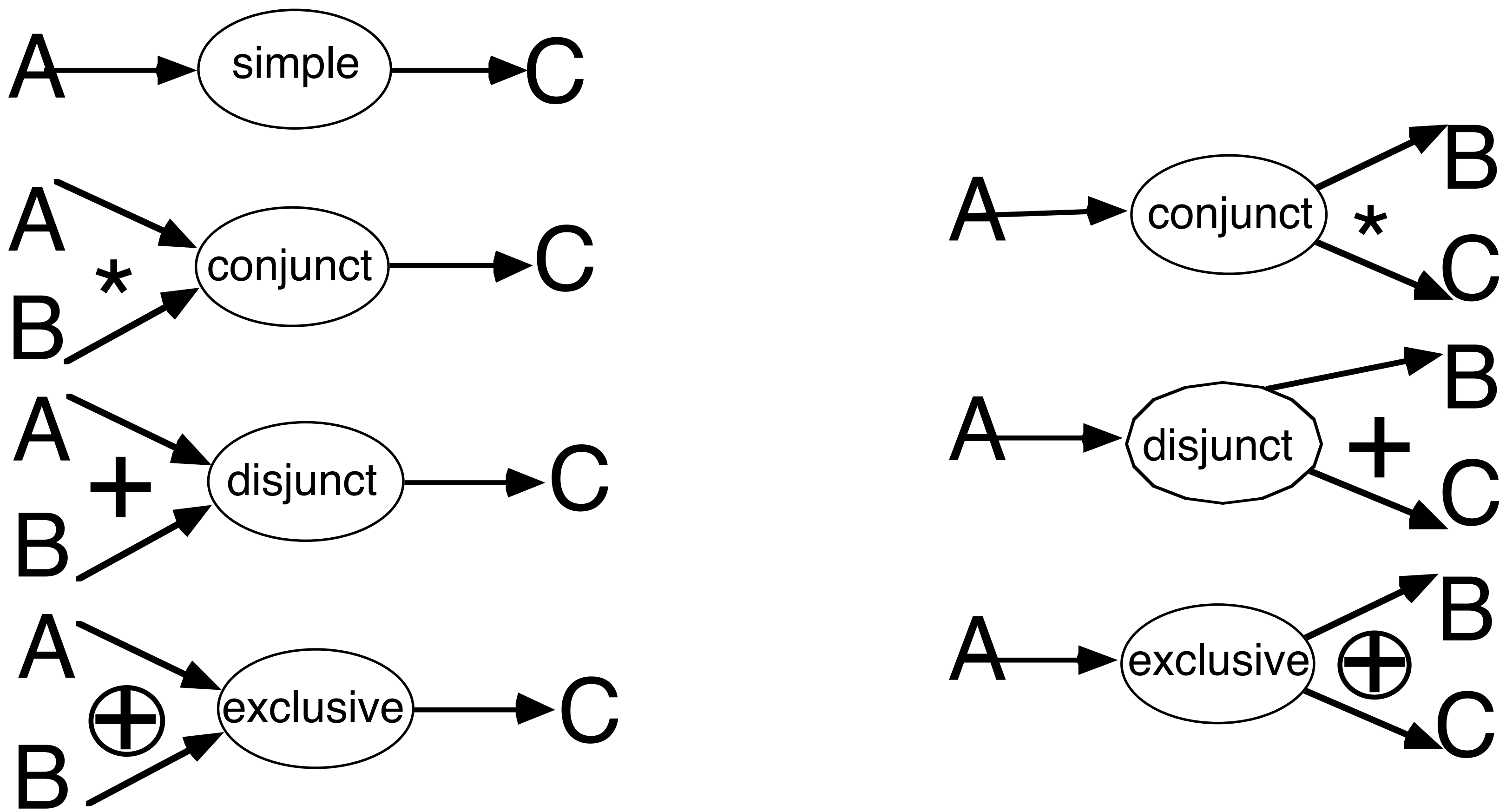
Structured Design Process

- Identify flow of data and incorporate detail and structure iteratively
  - given specification loop
    - € identify data flow and transformations
      - nouns as data, verbs as transformations
    - € derive data flow diagrams
    - € identify "natural aggregates"
      - identify highest level input and output units
      - remaining units are central transforms
      - form level of structure chart
      - control module (coordinate)
        - input module (afferent)
        - central module(s) (transform)
        - output module (efferent)
      - form structure chart
  - until implementation is immediate

Data Flow Diagrams

- Software system as flow of data from logical processing unit A (transformation) to B
  - do not include control information
  - data flow diagram elements
    - € round-cornered rectangle = transformation
    - € vector = data flow
    - € vector operation = data flow link
      - * (and)
      - + (or)
      - + (exclusive or)
    - € arc with data flow link = bracketing to override precedence
      - and over or over exclusive or
    - € rectangle = data store
    - € circle = user interaction (input/output)

Data Flow Templates



Structure Charts

- Depict software structure as a hierarchy of modules and data communication
  - may have control info defining selection and loops
  - structure chart elements
    - € rectangle = module
    - € four types of module based on data flow
      - control (coordinate)
      - input (afferent)
      - central (transform)
      - output (efferent)

Structure Charts (cont'd)

- € vector = control relationship
- € arrow with circular tail = directed data relationship
  - data couple (open), control couple (closed)
- € round-cornered rectangle = data store
- € circle = user interaction (input/output)

Structure Chart Templates