Software Design Principles and Guidelines

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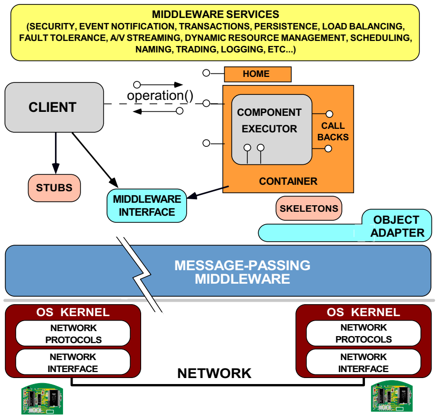
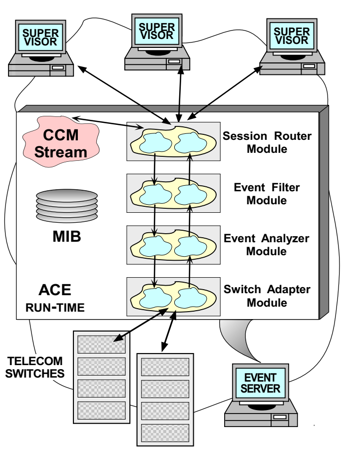
May 25, 2003

Design Principles and Guidelines Overview



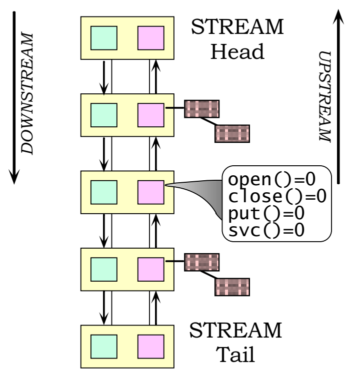
- Design Principles
  - Important design concepts
  - Useful design principles
- Development Methodologies
  - Traditional approaches
  - Agile programming
- Design Guidelines
  - Motivation
  - Common Design Mistakes
  - Design Rules

Motivation: Goals of the Design Phase (1/2)



- Decompose system into components
  - *i.e.*, identify the software architecture
- Determine relationships between components
  - *e.g.*, identify component dependencies
- Determine intercomponent communication mechanisms
  - *e.g.*, globals, function calls, shared memory, IPC/RPC

Motivation: Goals of the Design Phase (2/2)



- Specify component interfaces
  - Interfaces should be well-defined
    - ∗ Facilitates component testing and team communication
- Describe component functionality
  - *e.g.*, informally or formally
- Identify opportunities for systematic reuse
  - Both top-down and bottom-up

Macro Steps in the Design Process

- In the design process the orientation moves from
  - Customer to developer
  - *What* to *how*
- Macro steps include:

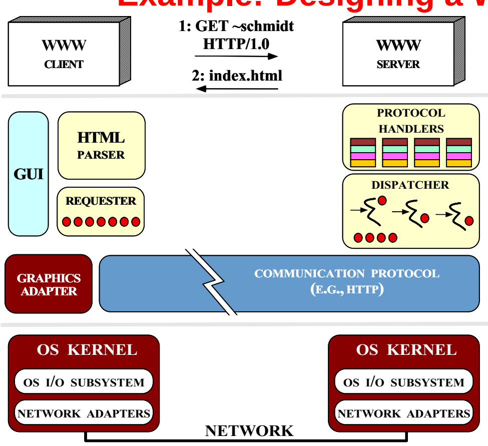
1. *Preliminary Design*
   - External design describes the real-world model
   - Architectural design decomposes the requirement specification into software subsystems
2. *Detailed Design*
   - Specify each subsystem
   - Further decomposed subsystems, if necessary

Micro Steps in the Design Process

- Given a requirements spec, *design* is an iterative decision process with the following general steps:

1. List the hard decisions and decisions likely to change
2. Design a component specification to hide each such decision
   - Make decisions that apply to whole program family first
   - Modularize *most likely* changes first
   - Then modularize remaining difficult decisions and decisions likely to change
   - Design the *uses* hierarchy as you do this (include reuse decisions)
3. Treat each higher-level component as a specification and apply above process to each
4. Continue refining until all design decisions are:
   - hidden in a component
   - contain easily comprehensible components
   - provide individual, independent, low-level implementation assignments

Example: Designing a Web Server



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- **Web server design decisions**
  - Portability issues
  - I/O demuxing and concurrency
  - HTTP protocol processing
  - File access
- **Web server components**
  - Event dispatcher
  - Protocol handler
  - Cached virtual filesystem

Key Design Concepts and Principles

Key design concepts and design principles include:

1. *Decomposition*
2. *Abstraction and information hiding*
3. *Component modularity*
4. *Extensibility*
5. *Virtual machine architectures*
6. *Hierarchical relationships*
7. *Program families and subsets*

Main goal of these concepts and principles is to:

- Manage software system complexity
- Improve software quality factors
- Facilitate systematic reuse
- Resolve common design challenges

Challenge 1: Determining the Web Server Architecture

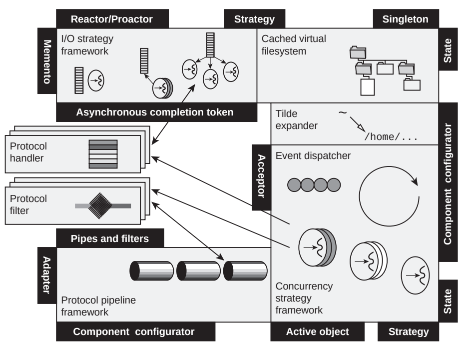
- Context: A large and complex production web server
- Problems:
  - Designing the web server as a large monolithic entity is tedious and error-prone
  - Web server developers must work concurrently to improve productivity
  - Portability and resuability are important quality factors

Solution: Decomposition

- Decomposition handles complexity by splitting large problems into smaller problems
- This “divide and conquer” concept is common to all life-cycle processes and design techniques
- Basic methodology:

1. Select a piece of the problem (initially, the whole problem)
2. Determine the components in this piece using a design paradigm, *e.g.*, functional, structured, object-oriented, generic, etc.
3. Describe the components interactions
4. Repeat steps 1 through 3 until some termination criteria is met
   - *e.g.*, customer is satisfied, run out of time/money, etc. ;-)

Decomposition Example: Web Server Framework



- **Features**
  - High-performance
  - Flexible concurrency, demuxing, and caching mechanisms
  - Uses frameworks based on ACE

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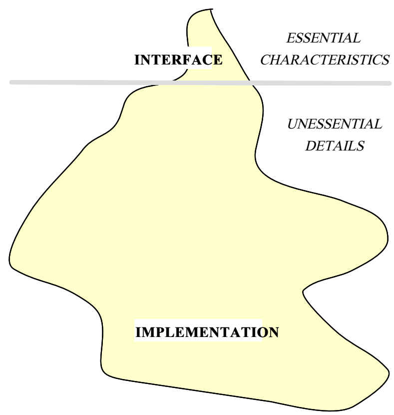
Object-Oriented Decomposition Principles

1. Don’t design components to correspond to execution steps
   - Since design decisions usually transcend execution time
2. Decompose so as to limit the effect of any one design decision on the rest of the system
   - Anything that permeates the system will be expensive to change
3. Components should be specified by all information needed to use the component
   - and *nothing more*!

Challenge 2: Implementing a Flexible Web Server

- Context: The requirements that a production web server must meet will change over time, *e.g.*:
  - New platforms
  - New compilers
  - New functionality
  - New performance goals
- Problems:
  - If the web server is "hard coded" using low-level system calls it will be hard to port
  - If web server developers write software that's tightly coupled with internal implementation details the software will be hard to evolve

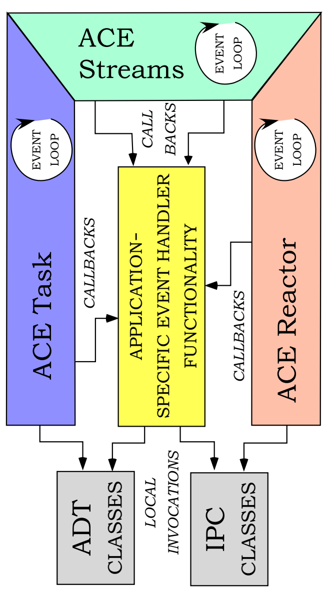
Solution: Abstraction



- Abstraction manages complexity by emphasizing *essential characteristics* and suppressing *implementation details*
- Allows postponement of certain design decisions that occur at various levels of analysis, *e.g.*,
  - Representational and algorithmic considerations
  - Architectural and structural considerations
  - External environment and platform considerations

Common Types of Abstraction

1. Procedural abstraction
   - *e.g.*, closed subroutines
2. Data abstraction
   - *e.g.*, ADT classes and component models
3. Control abstraction
   - *e.g.*, loops, iterators, frameworks, and multitasking



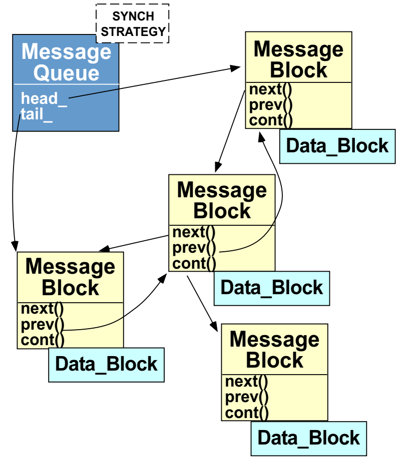
Information Hiding

- Information hiding is an important means of achieving abstraction
  - *i.e.*, design decisions that are subject to change should be hidden behind abstract interfaces
- Application software should communicate only through well-defined interfaces
- Each interface should be specified by as little information as possible
- If internal details change, clients should be minimally affected
  - May not even require recompilation and relinking...

Typical Information to be Hidden

- Data representations
  - *i.e.*, using abstract data types
- Algorithms
  - *e.g.*, sorting or searching techniques
- Input and Output Formats
  - Machine dependencies, *e.g.*, byte-ordering, character codes
- Lower-level interfaces
  - *e.g.*, ordering of low-level operations, *i.e.*, process sequence
- Separating policy and mechanism
  - Multiple policies can be implemented by same mechanisms
    - *e.g.*, OS scheduling and virtual memory paging
  - Same policy can be implemented by multiple mechanisms
    - *e.g.*, reliable communication service can be provided by multiple protocols

Information Hiding Example: Message Queueing



- A `Message_Queue` is a list of `ACE_Message_Blocks`
  - Efficiently handles arbitrarily-large message payloads
- Design encapsulates and parameterizes various aspects
  - *e.g.*, synchronization, memory allocators, and reference counting can be added transparently

The ACE_Message_Block Class

```
ACE_Message_Block
# rd_ptr_ : size_t
# wr_ptr_ : size_t
# cont_ : ACE_Message_Block *
# next_ : ACE_Message_Block *
# prev_ : ACE_Message_Block *
# data_block_ : ACE_Data_Block *
+ init (size : size_t) : int
+ msg_type (type : ACE_Message_Type)
+ msg_type () : ACE_Message_Type
+ msg_priority (prio : u_long)
+ msg_priority () : u_long
+ clone () : ACE_Message_Block *
+ duplicate () : ACE_Message_Block *
+ release () : ACE_Message_Block *
+ set_flags (flags : u_long) : u_long
+ clr_flags (flags : u_long) : u_long
+ copy (buf : const char *,n : size_t) : int
+ rd_ptr (n : size_t)
+ rd_ptr () : char *
+ wr_ptr (n : size_t)
+ wr_ptr () : char *
+ length () : size_t
+ total_length () : size_t
+ size () : size_t

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ACE_Data_Block
# base_ : char *
# refcnt_ : int
```
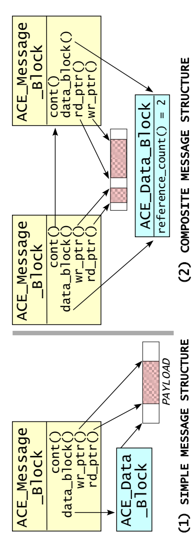

Class characteristics

- Hide messaging implementations from clients



The ACE_Message_Queue Class

```
SYNCH_STRATEGY
ACE_Message_Queue
# head_ : ACE_Message_Block *
# tail_ : ACE_Message_Block *
# high_water_mark_ : size_t
# low_water_mark_ : size_t
+ ACE_Message_Queue (high_water_mark : size_t = DEFAULT_HWM,
                     low_water_mark : size_t = DEFAULT_LWM,
                     notify : ACE_Notification_Strategy * = 0)
+ open (high_water_mark : size_t = DEFAULT_HWM,
        low_water_mark : size_t = DEFAULT_LWM,
        notify : ACE_Notification_Strategy * = 0) : int
+ flush () : int
+ notification_strategy (s : ACE_Notification_Strategy *) : void
+ is_empty () : int
+ is_full () : int
+ enqueue_tail (item : ACE_Message_Block *,
                timeout : ACE_Time_Value * = 0) : int
+ enqueue_head (item : ACE_Message_Block *,
                timeout : ACE_Time_Value * = 0) : int
+ enqueue_prio (item : ACE_Message_Block *,
                timeout : ACE_Time_Value * = 0) : int
+ dequeue_head (item : ACE_Message_Block *&,
                timeout : ACE_Time_Value * = 0) : int
+ dequeue_tail (item : ACE_Message_Block *&,
                timeout : ACE_Time_Value * = 0) : int
+ high_water_mark (new_hwm : size_t) : void
+ high_water_mark (void) : size_t
+ low_water_mark (new_lwm : size_t) : void
+ low_water_mark (void) : size_t
+ close () : int
+ deactivate () : int
+ activate () : int
+ pulse () : int
+ state () : int
```

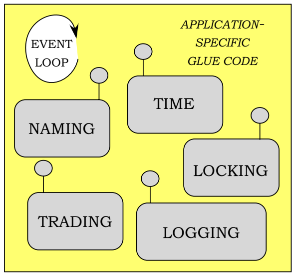
Class characteristics

- Note how the synchronization aspect can be strategized!

Challenge 3: Determining the Units of Web Server Decomposition

- Context: A production web server that uses abstraction and information hiding
- Problems:
  - Need to determine the appropriate units of decomposition, which should
    - Possess well-specified *abstract interfaces* and
    - Have high *cohesion* and low *coupling*

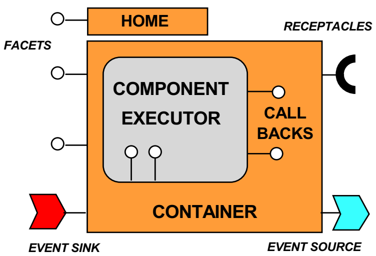
Solution: Component Modularity



- A *modular system* is one that's structured into identifiable abstractions called *components*
  - A software entity that represents an abstraction
  - A "work" assignment for developers
  - A unit of code that
    - has one or more names
    - has identifiable boundaries
    - can be (re-)used by other components
    - encapsulates data
    - hides unnecessary details
    - can be separately compiled

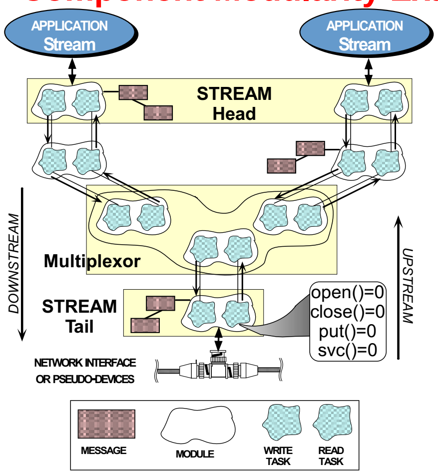
Designing Component Interfaces

- A component interface consists of several types of ports:
  - Exports
    - Services provided to other components, *e.g.*, facets and event sources
  - Imports
    - Services requested from other components, *e.g.*, receptacles and event sinks
  - Access Control
    - Not all clients are equal, *e.g.*, protected/private/public



- Define components that provide multiple interfaces and implementations
- Anticipate change

Component Modularity Example: Stream Processing



- A Stream allows flexible configuration of layered processing modules
- A `Stream` component contains a stack of `Module` components
- Each `Module` contains two `Task` components
  - *i.e.*, *read* and *write* `Tasks`
- Each `Task` contains a `Message_Queue` component and a `Thread_Manager` component

Benefits of Component Modularity

Modularity facilitates software quality factors, *e.g.*,:

- Extensibility → well-defined, abstract interfaces
- Reusability → low-coupling, high-cohesion
- Compatibility → design "bridging" interfaces
- Portability → hide machine dependencies

Modularity is important for good designs since it:

- Enhances for *separation of concerns*
- Enables developers to reduce overall system complexity via *decentralized* software architectures
- Increases *scalability* by supporting independent and concurrent development by multiple personnel

Criteria for Evaluating Modular Designs

Component decomposability

- Are larger components decomposed into smaller components?

Component composability

- Are larger components composed from existing smaller components?

Component understandability

- Are components separately understandable?

Component continuity

- Do small changes to the specification affect a localized and limited number of components?

Component protection

- Are the effects of run-time abnormalities confined to a small number of related components?

Principles for Ensuring Modular Designs

Language support for components

- Components should correspond to syntactic units in the language

Few interfaces

- Every component should communicate with as few others as possible

Small interfaces (weak coupling)

- If any two components communicate at all, they should exchange as little information as possible

Explicit Interfaces

- Whenever two components A and B communicate, this must be obvious from the text of A or B or both

Information Hiding

- All information about a component should be private unless it's specifically declared public

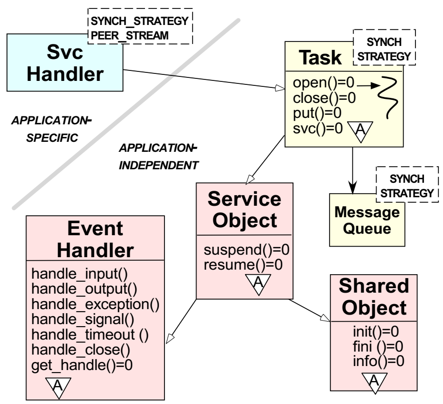
Challenge 4: "Future Proofing" the Web Server

- Context: A production web server whose requirements will change over time
- Problems:
  - Certain design aspects seem constant until they are examined in the overall structure of an application
  - Developers must be able to easily refactor the web server to account for new sources of variation

Solution: Extensibility

- Extensible software is important to support successions of quick updates and additions to address new requirements and take advantage of emerging opportunities/markets
- Extensible components must be *both* open and closed, *i.e.*, the "open/closed" principle:
  - Open component → still available for extension
    - This is necessary since the requirements and specifications are rarely completely understood from the system's inception
  - Closed component → available for use by other components
    - This is necessary since code sharing becomes unmanageable when reopening a component triggers many changes

Extensibility Example: Active Object Tasks



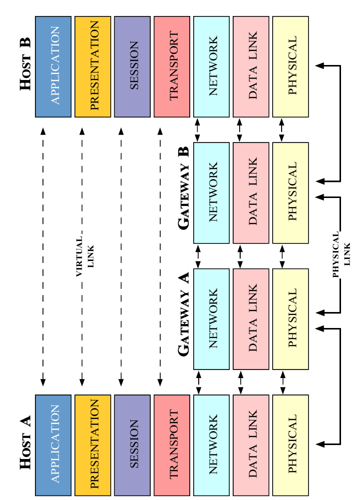
- **Features**
  - `Tasks` can register with a `Reactor`
  - They can be dynamically linked
  - They can queue data
  - They can run as "active objects"
- JAWS uses inheritance and dynamic binding to produce task components that are *both* open and closed

Challenge 5: Separating Concerns for Layered Systems

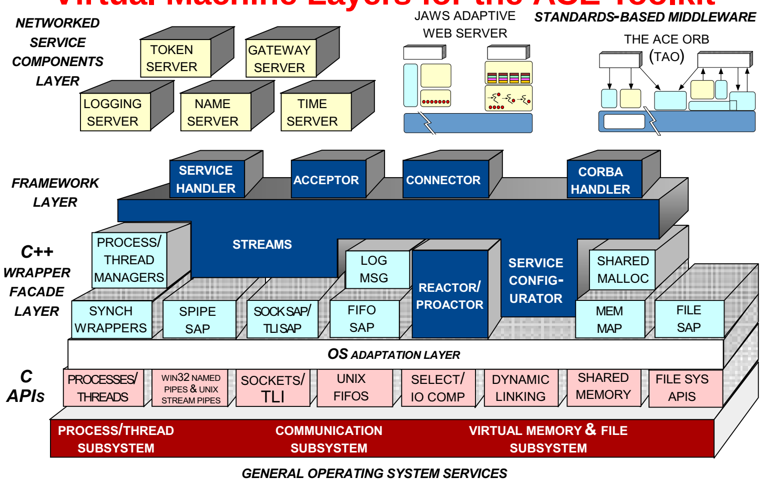
- Context: A production web server whose requirements will change over time
- Problems:
  - To enhance reuse and flexibility, it is often necessary to decompose a web server into smaller, more manageable units that are *layered* in order to
    - Enhance reuse, *e.g.*, multiple higher-layer services can share lower-layer services
    - Transparently and incrementally enhancement functionality
    - Improve performance by allowing the selective omission of unnecessary service functionality
    - Improve implementations, testing, and maintenance

Solution: Virtual Machine Architectures

- A virtual machine provides an extended "software instruction set"
  - Extensions provide additional data types and associated "software instructions"
  - Modeled after hardware instruction set primitives that work on a limited set of data types
- A virtual machine layer provides a set of operations that are useful in developing a *family* of similar systems



Virtual Machine Layers for the ACE Toolkit



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Other Examples of Virtual Machines

Computer architectures

- *e.g.*, compiler → assembler → obj code → microcode → gates, transistors, signals, etc.

Operating systems

- *e.g.*, Linux

Hardware Machine	**Software Virtual Machine**
instruction set	set of system calls
restartable instructions	restartable system calls
interrupts/traps	signals
interrupt/trap handlers	signal handlers
blocking interrupts	masking signals
interrupt stack	signal stack

Java Virtual Machine (JVM)

- Abstracts away from details of the underlying OS

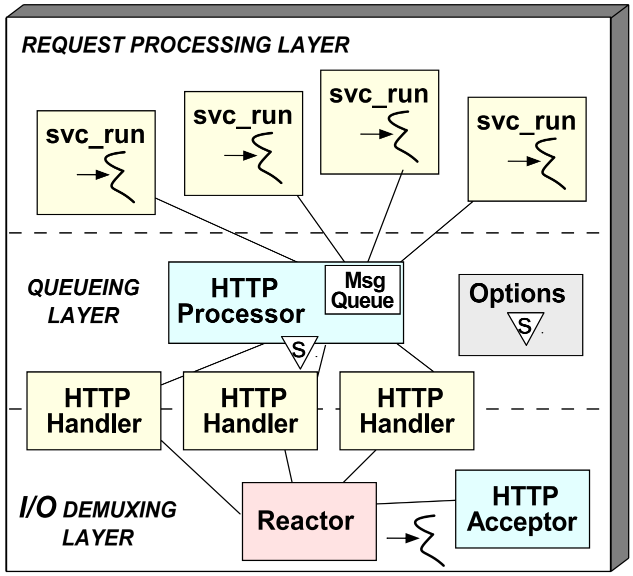
Challenge 6: Separating Concerns for Hierarchical Systems

- Context: A production web server whose requirements will change over time
- Problems:
  - Developers need to program components at different levels of abstraction independently
  - Changes to one set of components should be isolated as much as possible from other components
  - Need to be able to “visualize” the structure of the web server design

Solution: Hierarchical Relationships

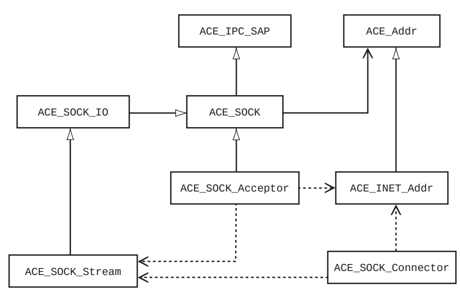
- Hierarchies reduce component interactions by restricting the topology of relationships
- A relation defines a hierarchy if it partitions units into levels (note connection to *virtual machine architectures*)
  - Level 0 is the set of all units that use no other units
  - Level i is the set of all units that use at least one unit at level $< i$ and no unit at level $\geq i$.
- Hierarchies form the basis of *architectures* and *designs*
  - Facilitates independent development
  - Isolates ramifications of change
  - Allows rapid prototyping

Hierarchy Example: JAWS Architecture

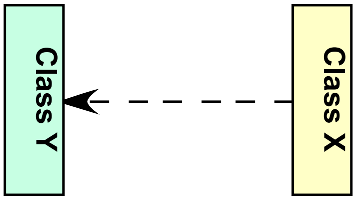


Defining Hierarchies

- Relations that define hierarchies include:
  - *Uses*
  - *Is-Composed-Of*
  - *Is-A*
  - *Has-A*
- The first two are general to all design methods, the latter two are more particular to OO design and programming



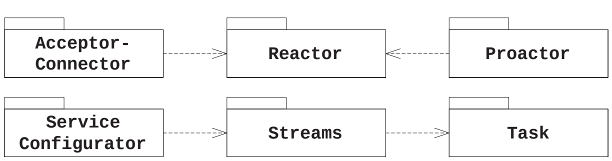
The Uses Relation (1/3)



- *X Uses Y* if the correct functioning of *X* depends on the availability of a correct implementation of *Y*
- Note, *uses* is not necessarily the same as *invokes*:
  - Some invocations are not uses
    - *e.g.*, error logging
  - Some uses don't involve invocations
    - *e.g.*, message passing, interrupts, shared memory access
- A *uses* relation does not necessarily yield a hierarchy (avoid cycles...)

The Uses Relation (2/3)

- Allow *X* to use *Y* when:
  - *X* is simpler because it uses *Y*
    - *e.g.*, Standard C++ library classes
  - *Y* is not substantially more complex because it is not allowed to use *X*
  - There is a useful subset containing *Y* and not *X*
    - *i.e.*, allows sharing and reuse of *Y*
  - There is no conceivably useful subset containing *X* but not *Y*
    - *i.e.*, *Y* is necessary for *X* to function correctly
- Uses relationships can exist between classes, frameworks, subsystems, etc.

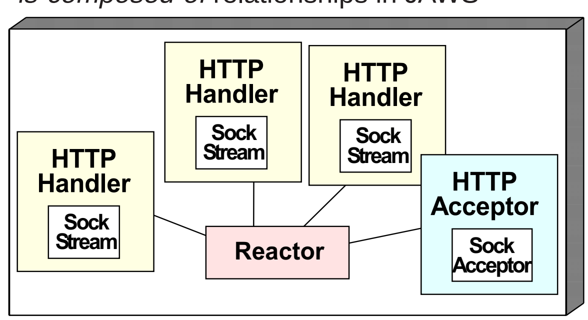


The Uses Relation (3/3)

- A hierarchy in the *uses* relation is essential for designing reusable software systems
- However, certain software systems require controlled violation of a uses *hierarchy*
  - *e.g.*, asynchronous communication protocols, OO callbacks in frameworks, signal handling, etc.
  - *Upcalls* are one way to control these non-hierarchical dependencies
- *Rule of thumb:*
  - Start with an invocation hierarchy and eliminate those invocations (*i.e.*, "calls") that are not uses relationships

The Is-Composed-Of Relation

- The *is-composed-of* relationship shows how the system is broken down in components
- X *is-composed-of* $\{x_i\}$ if X is a group of components x_i that share some common purpose
- The following diagram illustrates some of the *is-composed-of* relationships in JAWS

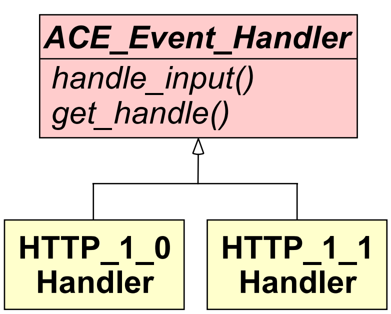


The Is-Composed-Of Relation

- Many programming languages support the *is-composed-of* relation via some higher-level component or record structuring technique
- However, the following are not equivalent:
  - level (virtual machine)
  - component (an entity that hides one or more "secrets")
  - a subprogram (a code unit)
- Components and levels need not be identical, as a component may appear in several levels of a uses hierarchy

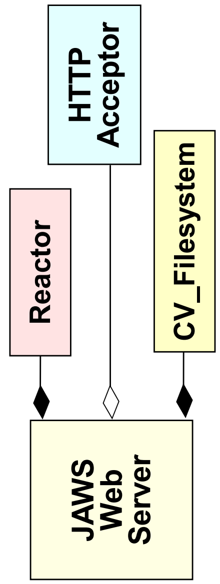
The Is-A Relation

- This "ancestor/descendant" relationship is associated with object-oriented design and programming languages that possess inheritance and dynamic binding
- class X possesses *Is-A* relationship with class Y if instances of class X are specialization of class Y.
  - *e.g.*, an `HTTP_1_0_Handler` *Is-A* `ACE_Event_Handler` that is specialized for processing HTTP 1.0 requests



The Has-A Relation

- This "client" relationship is associated with object-oriented design and programming languages that possess classes and objects
- class X possesses a *Has-A* relationship with class Y if instances of class X contain an instance(s) of class Y.
  - *e.g.*, the JAWS web server *Has-A* `Reactor`, `HTTP_Acceptor`, and `CV_Filesystem`



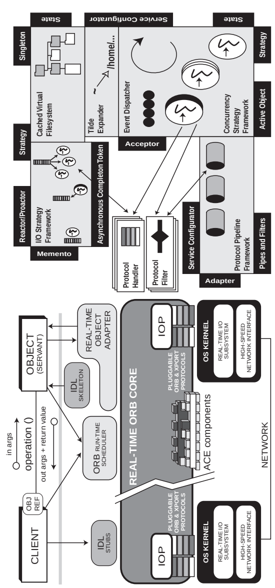
Challenge 7: Enabling Expansion and Contraction of Software

- Context: A production web server whose requirements will change over time
- Problems:
  - It may be necessary to reduce the overall functionality of the server to run in resource-constrained environments
  - To meet externally imposed schedules, it may be necessary to release the server without all the features enabled

Solution: Program Families and Subsets

- This principle should be applied to facilitate *extension* and *contraction* of large-scale software systems, particularly reusable middleware infrastructure
  - *e.g.*, JAWS, ACE, etc.
- Program families are natural way to detect and implement *subsets*
  - Minimize footprints for embedded systems
  - Promotes system reusability
  - Anticipates potential changes
- Heuristics for identifying subsets:
  - Analyze requirements to identify minimally useful subsets
  - Also identify minimal increments to subsets

Example of Program Families: JAWS and TAO



(1) THE ACE ORB (TAO)

(2) The JAWS Web Server Framework

- TAO is a high-performance, real-time implementation of the CORBA specification
- JAWS is a high-performance, adaptive Web server that implements the HTTP specification
- JAWS and TAO were developed using the wrapper facades and frameworks provided by the ACE toolkit

Other Examples of Program Families and Subsets

- Different services for different markets
  - *e.g.*, different alphabets, different vertical applications, different I/O formats
- Different hardware or software platforms
  - *e.g.*, compilers or OSs
- Different resource trade-offs
  - *e.g.*, speed vs space
- Different internal resources
  - *e.g.*, shared data structures and library routines
- Different external events
  - *e.g.*, UNIX I/O device interface
- Backward compatibility
  - *e.g.*, sometimes it is important to retain bugs!

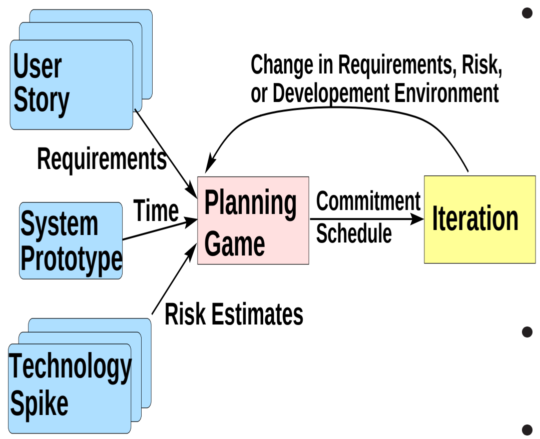
Conventional Development Processes

- Waterfall Model
  - Specify, analyze, implement, test **(in sequence)**
  - Assumes that requirements can be specified up front
- Spiral Model
  - Supports iterative development
  - Attempts to assess risks of changes
- Rapid Application Development
  - Build a prototype
  - Ship it :-)

Agile Processes

- Stresses customer satisfaction, and therefore, involvement
  - Provide what the customer wants, as quickly as possible
  - Provide *only* what the customer wants
- Encourages changes in requirements
- Relies on testing
- For example, eXtreme Programming practices
  - Planning, designing, coding, testing

eXtreme Programming: Planning



based on http://www.extremeprogramming.org/rules/planninggame.html

- Start with *user stories*
  - Written by customers, to specify system requirements
  - Minimal detail, typically just a few sentences on a card
  - Expected development time: 1 to 3 weeks each, roughly
- Planning game creates commitment schedule for entire project
- Each iteration should take 2-3 weeks

eXtreme Programming: Designing

- Defer design decisions as long as possible
- Advantages:
  - Simplifies current task (just build what is needed)
  - You don't need to maintain what you haven't built
  - Time is on your side: you're likely to learn something useful by the time you need to decide
  - Tomorrow may never come: if a feature isn't needed now, it might never be needed
- Disadvantages:
  - Future design decisions may require rework of existing implementation
  - Ramp-up time will probably be longer later
    - Therefore, always try to keep designs as simple as possible

eXtreme Programming: Coding

- *Pair programming*
  - *Always* code with a partner
  - *Always* test as you code
- Pair programming pays off by supporting good implementation, reducing mistakes, and exposing more than one programmer to the design/implementation
- If any deficiencies in existing implementation are noticed, either fix them or note that they need to be fixed

eXtreme Programming: Testing

- Unit tests are written *before* code
- Code **must** pass both its unit test **and** all regression tests before committing
- In effect, the test suite defines the system requirements
  - Significant difference from other development approaches
  - If a bug is found, a test for it **must** be added
  - If a feature isn't tested, it can be removed

Agile Processes: Information Sources

- Kent Beck, *Extreme Programming Explained: Embrace Change*, Addison-Wesley, ISBN 0201616416, 1999
- Kent Beck, “Extreme Programming”, *C++ Report* 11:5, May 1999, pp. 26–29+
- John Vlissides, “XP”, interview with Kent Beck in the Pattern Hatching Column, *C++ Report* 11:6, June 1999, pp. 44-52+
- Kent Beck, “Embracing Change with Extreme Programming”, *IEEE Computer* 32:10, October 1999, pp. 70-77
- `http://www.extremeprogramming.org/`
- `http://www.xprogramming.com/`
- `http://c2.com/cgi/wiki?ExtremeProgrammingRoadmap`

Design Guidelines: Motivation

- Design is the process of organizing structured solutions to tasks from a problem domain
- This process is carried out in many disciplines, in many ways
  - There are many similarities and commonalities among design processes
  - There are also many common design mistakes . . .
- The following pages provide a number of "design rules."
  - Remember, these rules are simply suggestions on how to better organize your design process, *not* a recipe for success!

Common Design Mistakes (1/2)

- Depth-first design
  - only partially satisfy the requirements
  - experience is best cure for this problem . . .
- Directly refining requirements specification
  - leads to overly constrained, inefficient designs
- Failure to consider potential changes
  - always design for extension and contraction
- Making the design too detailed
  - this overconstrains the implementation

Common Design Mistakes (2/2)

- Ambiguously stated design
  - misinterpreted at implementation
- Undocumented design decisions
  - designers become essential to implementation
- Inconsistent design
  - results in a non-integratable system, because separately developed modules don't fit together

Rules of Design (1/8)

- *Make sure that the problem is well-defined*
  - All design criteria, requirements, and constraints, should be enumerated before a design is started
  - This may require a "spiral model" approach
- *What comes before how*
  - *i.e.*, define the service to be performed at every level of abstraction before deciding which structures should be used to realize the services
- *Separate orthogonal concerns*
  - Do not connect what is independent
  - Important at many levels and phases . . .

Rules of Design (2/8)

- *Design external functionality before internal functionality.*
  - First consider the solution as a black-box and decide how it should interact with its environment
  - Then decide how the black-box can be internally organized. Likely it consists of smaller black-boxes that can be refined in a similar fashion
- *Keep it simple.*
  - Fancy designs are buggier than simple ones; they are harder to implement, harder to verify, and often less efficient
  - Problems that appear complex are often just simple problems huddled together
  - Our job as designers is to identify the simpler problems, separate them, and then solve them individually

Rules of Design (3/8)

- *Work at multiple levels of abstraction*
  - Good designers must be able to move between various levels of abstraction quickly and easily
- *Design for extensibility*
  - A good design is "open-ended," *i.e.*, easily extendible
  - A good design solves a class of problems rather than a single instance
  - Do not introduce what is immaterial
  - Do not restrict what is irrelevant
- *Use rapid prototyping when applicable*
  - Before implementing a design, build a high-level prototype and verify that the design criteria are met

Rules of Design (4/8)

- Details should depend upon abstractions
  - Abstractions should not depend upon details
  - Principle of Dependency Inversion
- The granule of reuse is the same as the granule of release
  - Only components that are released through a tracking system can be effectively reused
- Classes within a released component should share common closure
  - That is, if one needs to be changed, they all are likely to need to be changed
  - *i.e.*, what affects one, affects all

Rules of Design (5/8)

- Classes within a released component should be reused together
  - That is, it is impossible to separate the components from each other in order to reuse less than the total
- The dependency structure for released components must be a DAG
  - There can be no cycles
- Dependencies between released components must run in the direction of stability
  - The dependee must be more stable than the depender
- The more stable a released component is, the more it must consist of abstract classes
  - A completely stable component should consist of nothing but abstract classes

Rules of Design (6/8)

- Where possible, use proven patterns to solve design problems
- When crossing between two different paradigms, build an interface layer that separates the two
  - Don't pollute one side with the paradigm of the other

Rules of Design (7/8)

- Software entities (classes, modules, etc) should be open for extension, but closed for modification
  - The Open/Closed principle – Bertrand Meyer
- Derived classes must usable through the base class interface without the need for the user to know the difference
  - The Liskov Substitution Principle

Rules of Design (8/8)

- *Make it work correctly, then make it work fast*
  - Implement the design, measure its performance, and if necessary, optimize it
- *Maintain consistency between representations*
  - *e.g.*, check that the final optimized implementation is equivalent to the high-level design that was verified
  - Also important for documentation . . .
- Don't skip the preceding rules!
  - Clearly, this is the most frequently violated rule!!! ;-)

Concluding Remarks

- Good designs can generally be distilled into a few key principles:
  - Separate interface from implementation
  - Determine what is *common* and what is *variable* with an interface and an implementation
  - Allow substitution of *variable* implementations via a *common* interface
    * *i.e.*, the "open/closed" principle
  - Dividing *commonality* from *variability* should be goal-oriented rather than exhaustive
- Design is not simply the act of drawing a picture using a CASE tool or using graphical UML notation!!!
  - Design is a fundamentally *creative* activity