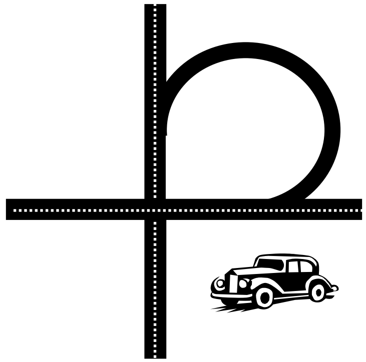
Overview of Patterns

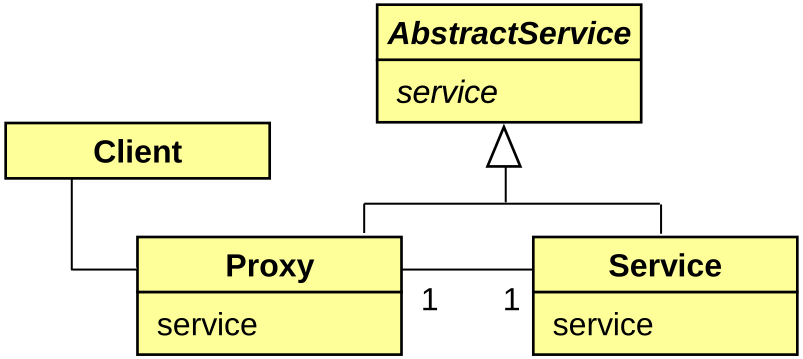
- Present *solutions* to common software *problems* arising within a certain *context*



- Help resolve key software design forces →
  - ***Flexibility***
  - ***Extensibility***
  - ***Dependability***
  - ***Predictability***
  - ***Scalability***
  - ***Efficiency***

- Capture recurring structures & dynamics among software participants to facilitate reuse of successful designs

- Generally codify expert knowledge of design strategies, constraints & "best practices"

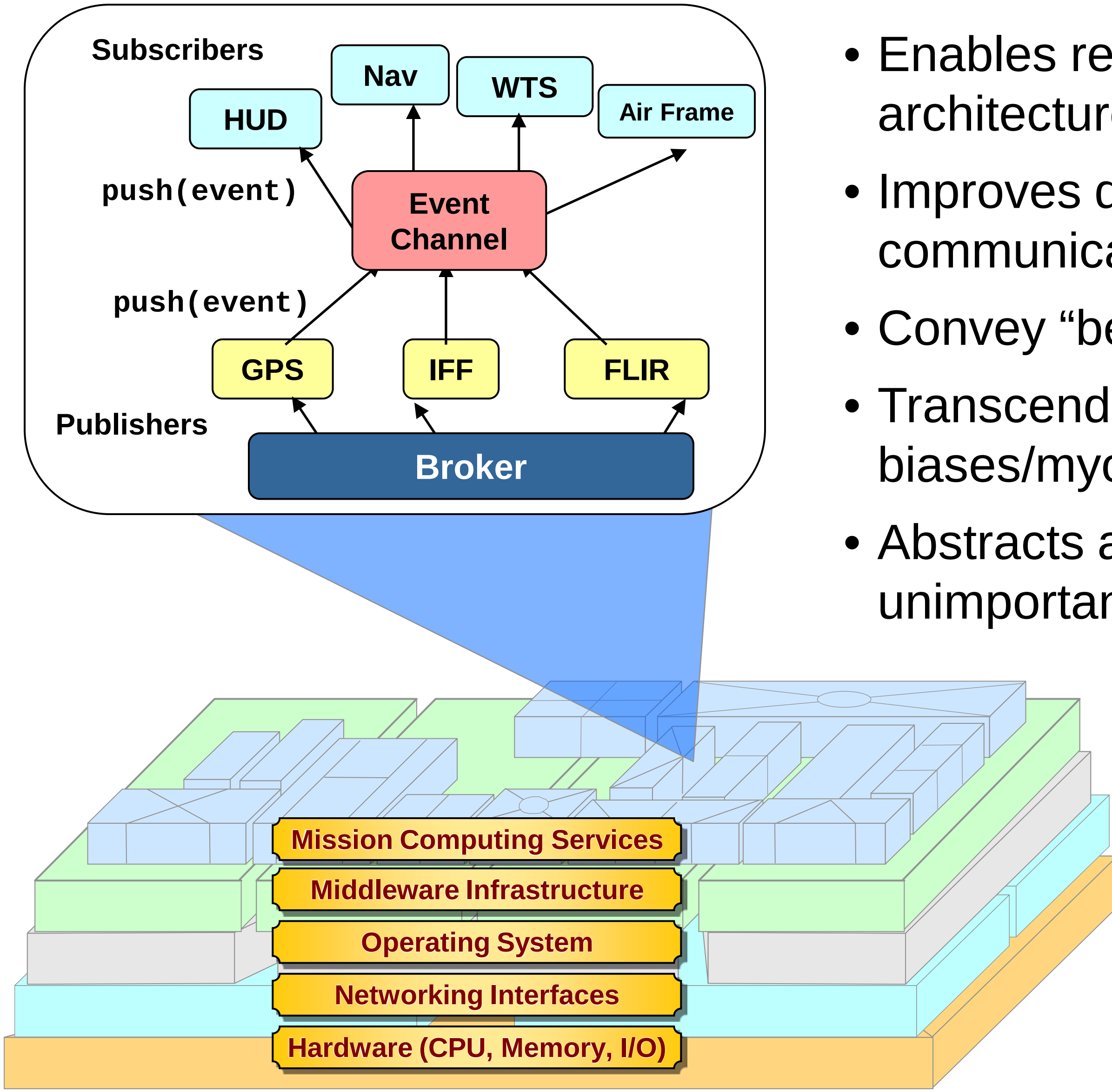


The Proxy Pattern

Taxonomy of Patterns & Idioms

Type	Description	Examples
Idioms	Restricted to a particular language, system, or tool	Scoped locking
Design patterns	Capture the static & dynamic roles & relationships in solutions that occur repeatedly	Active Object, Bridge, Proxy, Wrapper Façade, & Visitor
Architectural patterns	Express a fundamental structural organization for software systems that provide a set of predefined subsystems, specify their relationships, & include the rules and guidelines for organizing the relationships between them	Half-Sync/Half-Async, Layers, Proactor, Publisher-Subscriber, & Reactor
Optimization principle patterns	Document rules for avoiding common design & implementation mistakes that degrade performance	Optimize for common case, pass information between layers

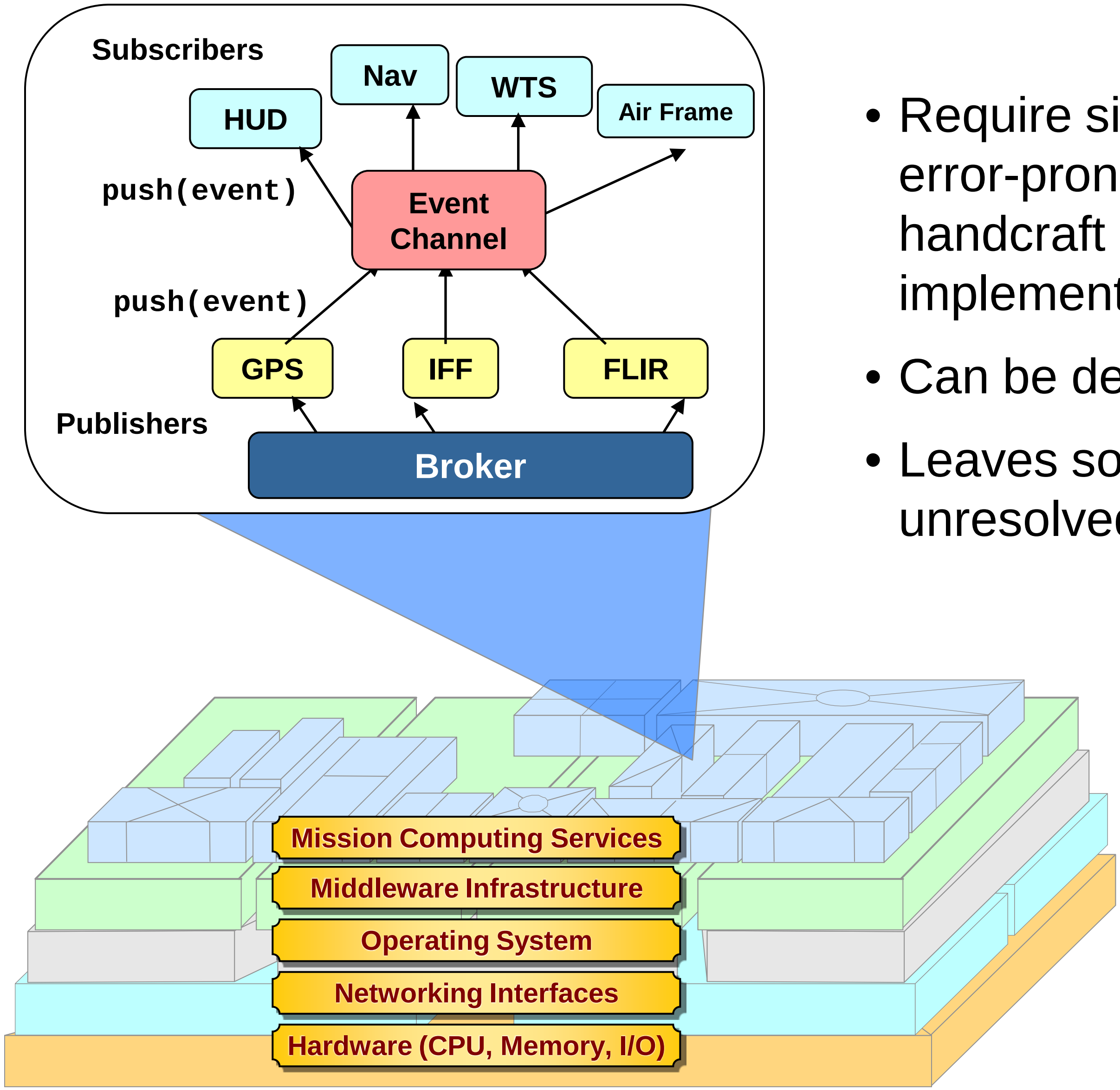
Benefits of Patterns



- Enables reuse of software architectures & designs
- Improves development team communication
- Convey “best practices” intuitively
- Transcends language-centric biases/myopia
- Abstracts away from many unimportant details

www.cs.wustl.edu/~schmidt/patterns.html

Limitations of Patterns



- Require significant tedious & error-prone human effort to handcraft pattern implementations
- Can be deceptively simple
- Leaves some important details unresolved

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Legacy Avionics Architectures

Key System Characteristics

- Hard & soft real-time deadlines
  - ~20-40 Hz
- Low latency & jitter between boards
  - ~100 *u*secs
- Periodic & aperiodic processing
- Complex dependencies
- Continuous platform upgrades

Avionics Mission Computing Functions

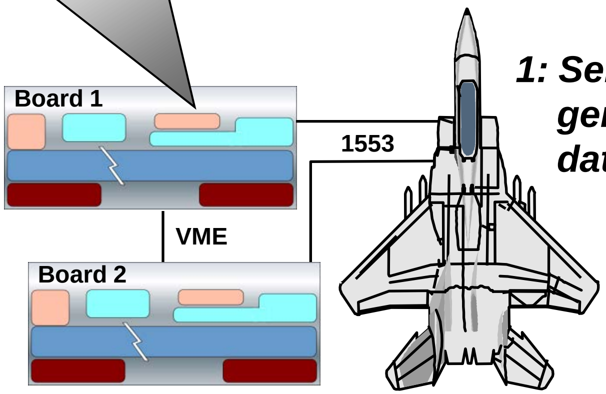
- Weapons targeting systems (WTS)
- Airframe & navigation (Nav)
- Sensor control (GPS, IFF, FLIR)
- Heads-up display (HUD)
- Auto-pilot (AP)

4: Mission functions perform avionics operations

3: Sensor proxies process data & pass to missions functions

2: I/O via interrupts

1: Sensors generate data



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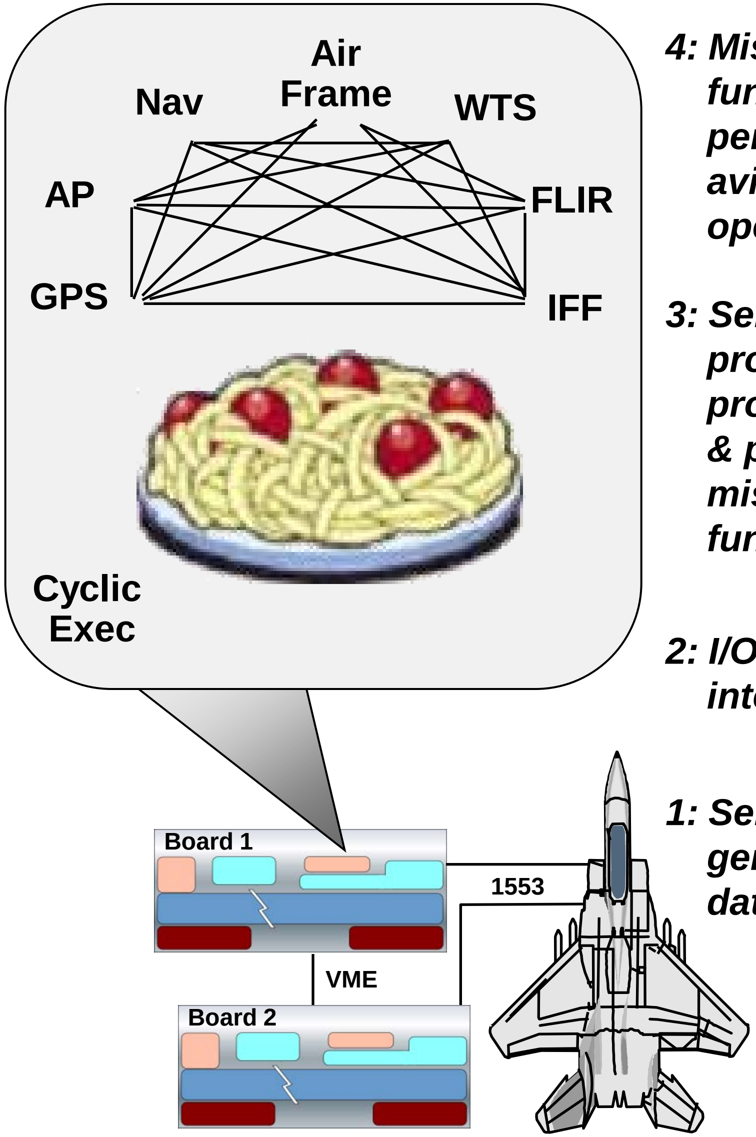
- Complex dependencies
- Continuous platform upgrades

Limitations with Legacy Avionics Architectures

- Stovepiped
- Proprietary
- Expensive
- Vulnerable
- ***Tightly coupled***
- ***Hard to schedule***
- ***Brittle & non-adaptive***



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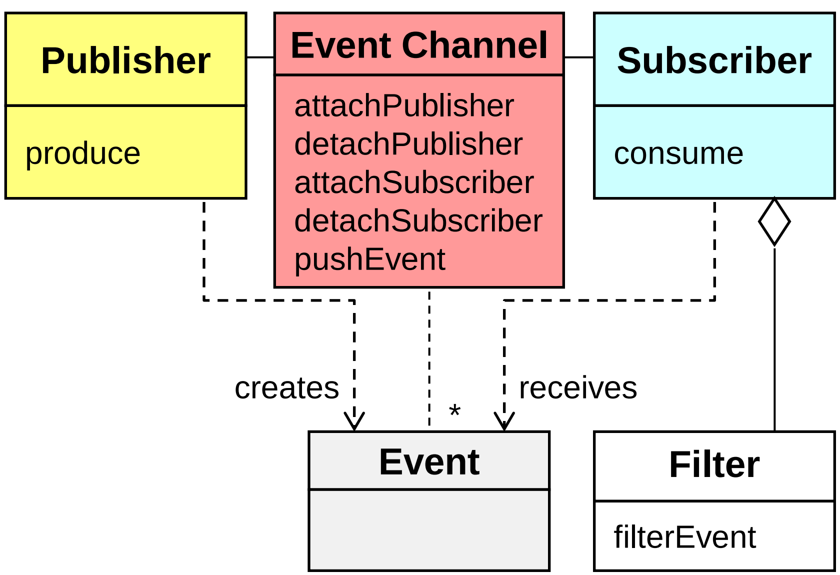
1: Sensors generate data

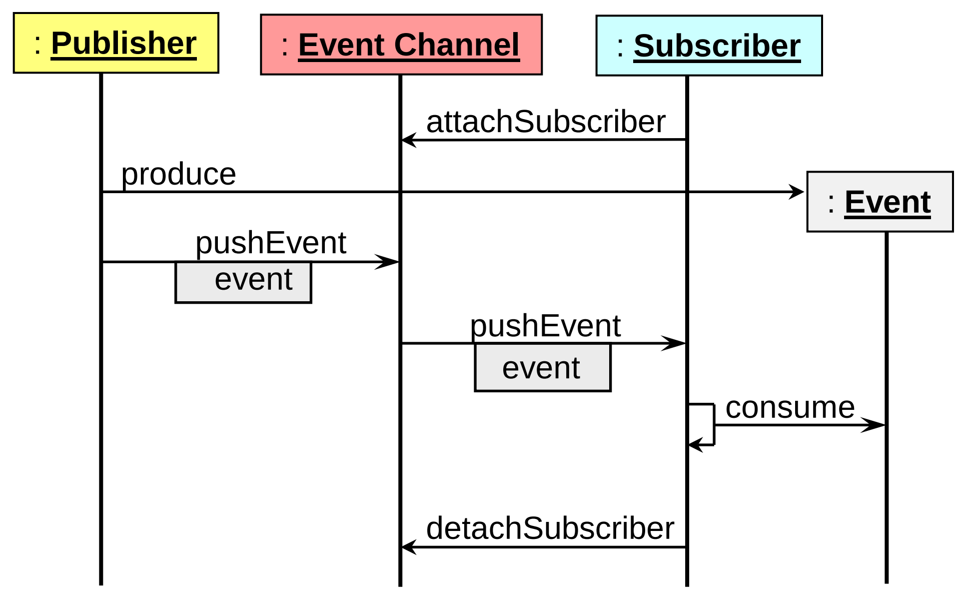
Decoupling Avionics Components

Context	Problems	Solution
• I/O driven DRE application • Complex dependencies • Real-time constraints	• Tightly coupled components • Hard to schedule • Expensive to evolve	• Apply the ***Publisher-Subscriber*** architectural pattern to distribute periodic, I/O-driven data from a single point of source to a collection of consumers

Structure



Dynamics



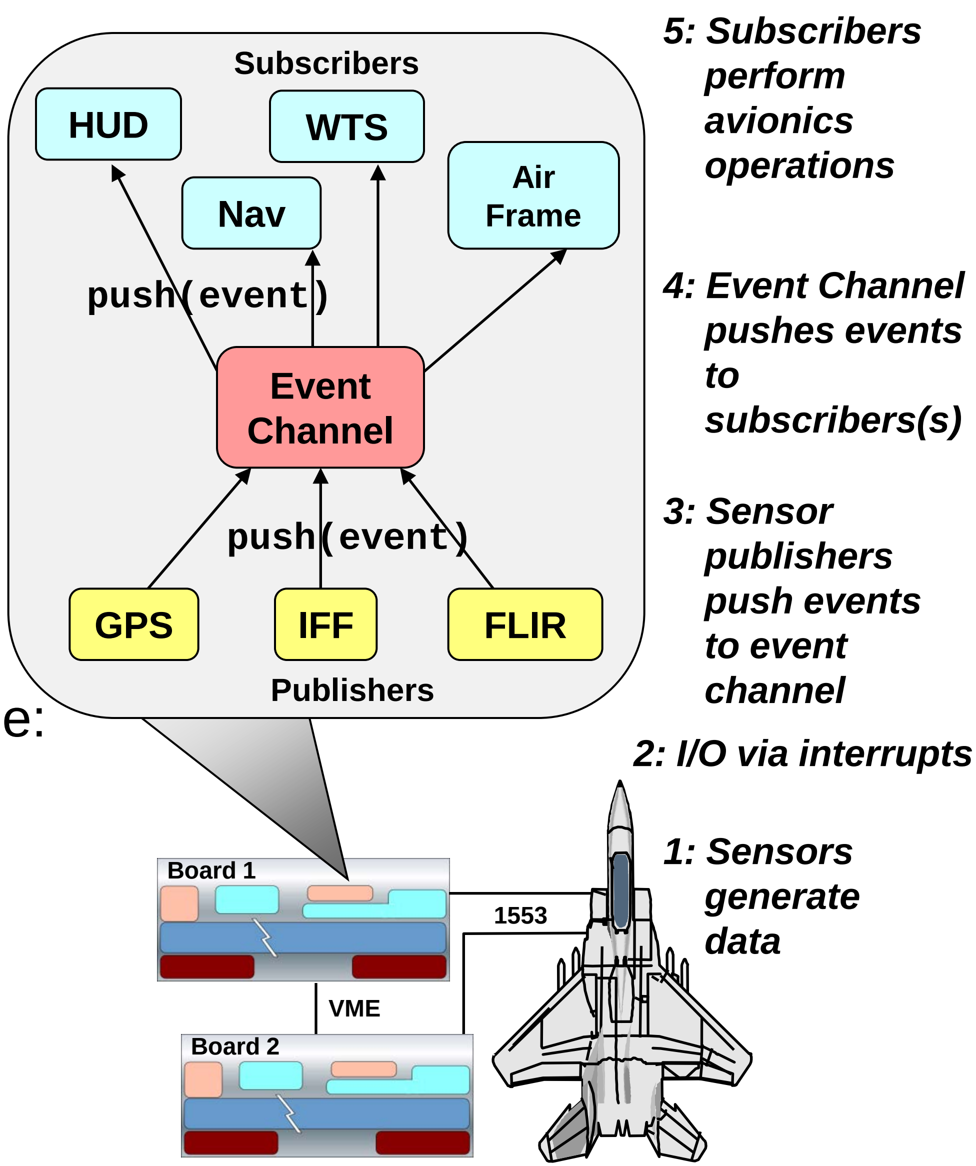
Applying the Publisher-Subscriber Pattern to Bold Stroke

Bold Stroke uses the ***Publisher-Subscriber*** pattern to decouple sensor processing from mission computing operations

- Anonymous publisher & subscriber relationships
- Group communication
- Asynchrony

Considerations for implementing the ***Publisher-Subscriber*** pattern for mission computing applications include:

- ***Event notification model***
  - Push control vs. pull data interactions
- ***Scheduling & synchronization strategies***
  - e.g., priority-based dispatching & preemption
- ***Event dependency management***
  - e.g.,filtering & correlation mechanisms



Pros & Cons of Pub/Sub Pattern

This pattern provides the following **benefits**:

- ***Separation of concerns***
  - This pattern decouples application-independent dissemination from application-specific functionality
- ***Flexibility on data dissemination***
  - The Pub/Sub pattern supports aggregating, filtering, and prioritizing of data
- ***Scalability***
  - Since senders and receivers are decoupled, applications can scale in the number of receivers and senders

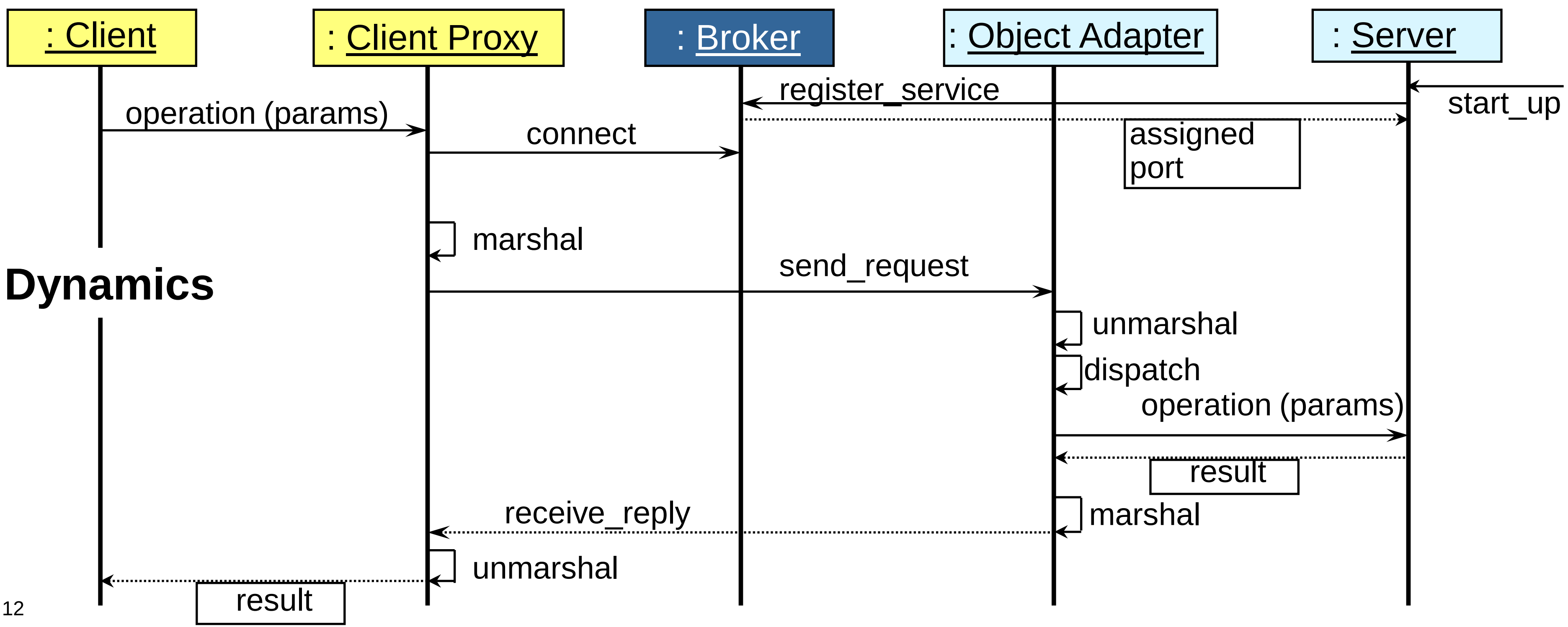
This pattern also incur **liabilities**:

- ***Complexity of debugging & testing***
  - Applications written with this pattern can be hard to debug due its transparency
- ***Added overhead***
  - A pub/sub architecture can increase overhead of system management and data delivery

Ensuring Platform-neutral & Network-transparent Communication

Context	Problems	Solution

• Mission computing requires remote IPC
• Stringent DRE requirements
	• Applications need capabilities to:
	  • Support remote communication
	  • Provide location transparency
	  • Handle faults
	  • Manage end-to-end QoS
	  • Encapsulate low-level system details
		• Apply the ***Broker*** architectural pattern to provide platform-neutral communication between mission computing boards



Dynamics

Pros & Cons of Broker Pattern

This pattern provides the following **benefits**:

- ***Separation of concerns***
  - This pattern decouples application-independent object location & dispatching mechanisms from application-specific functionality
- ***Application programming simplicity***
  - The Broker pattern simplifies the programming of business logic for the application
- ***Reuse***
  - Since it's application independent the implementation can be reused in various application domains or subsystems of the same application

This pattern also incur **liabilities**:

- ***Complexity of debugging & testing***
  - Applications written with this pattern can be hard to debug due its indirection and transparency
- ***Added level of indirection***
  - A brokered architecture can be less efficient than a monolithic architecture

Separating Concerns Between Tiers

Context

- Distributed systems are now common due to the advent of
  - The global Internet
  - Ubiquitous mobile & embedded devices

Problem

- It's hard to build distributed systems due to the complexity associated with many capabilities at many levels of abstraction

Solution

- Apply the *Layers* pattern (P1) to create a multi-tier architecture that separates concerns between groups of tasks occurring at distinct layers in the distributed system

Presentation Tier

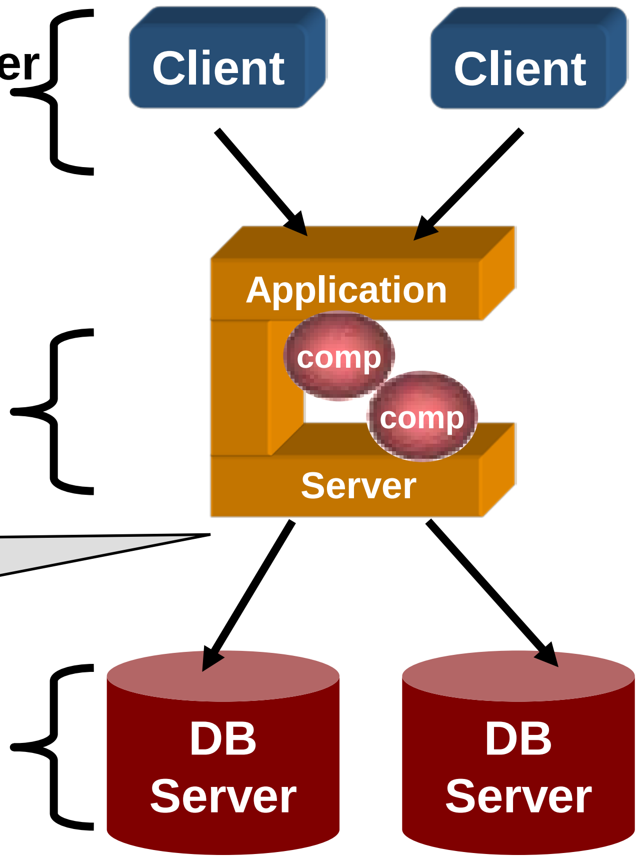
- *e.g.*, thin client displays

Middle Tier

- *e.g.*, common business logic

Database Tier

- *e.g.*, persistent data



Services in the *middle tier* participate in various types of tasks, *e.g.*,

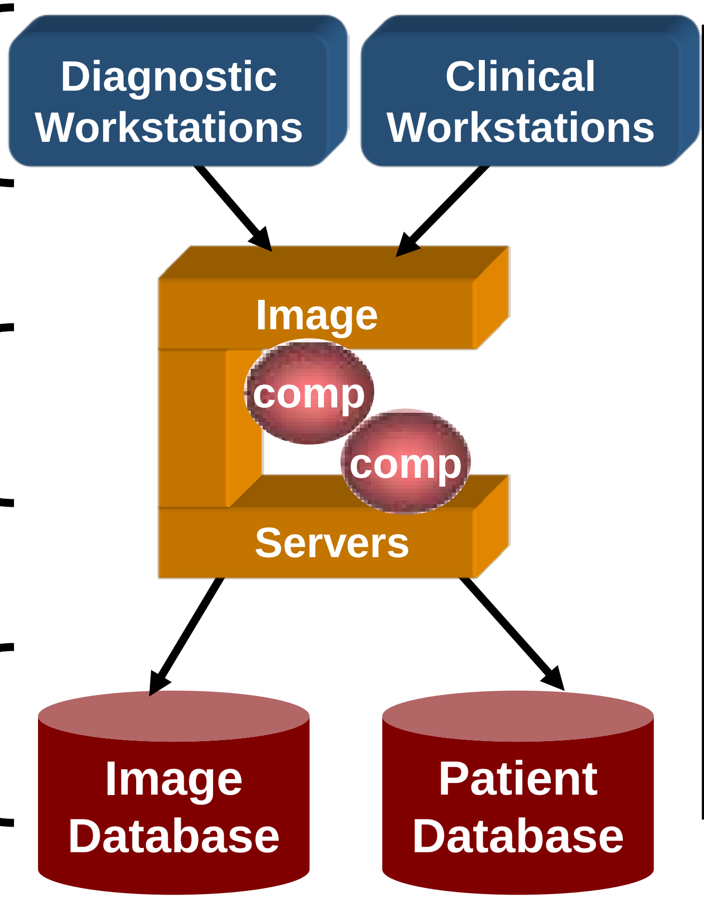
- Workflow of integrated "business" processes
- Connect to databases & other backend systems for data storage & access

Applying the Layers Pattern to Image Acquisition

Presentation Tier
- *e.g.*, radiology clients

Middle Tier
- *e.g.*, image routing, security, & image transfer logic

Database Tier
- *e.g.*, persistent image data



Diagnostic & clinical workstations are presentation tier entities that:
- Typically represent sophisticated GUI elements
- Share the same address space with their clients
  - Their clients are containers that provide all the resources
- Exchange messages with the middle tier components

Image servers are middle tier entities that:
- Provide server-side functionality
  - *e.g.*, they are responsible for scalable concurrency & networking
- Can run in their own address space
- Are integrated into containers that hide low-level OS platform details

Pros & Cons of the Layers Pattern

This pattern has four **benefits**:

- ***Reuse of layers***
  - If an individual layer embodies a well-defined abstraction & has a well-defined & documented interface, the layer can be reused in multiple contexts
- ***Support for standardization***
  - Clearly-defined & commonly-accepted levels of abstraction enable the development of standardized tasks & interfaces
- ***Dependencies are localized***
  - Standardized interfaces between layers usually confine the effect of code changes to the layer that is changed
- ***Exchangeability***
  - Individual layer implementations can be replaced by semantically-equivalent implementations without undue effort

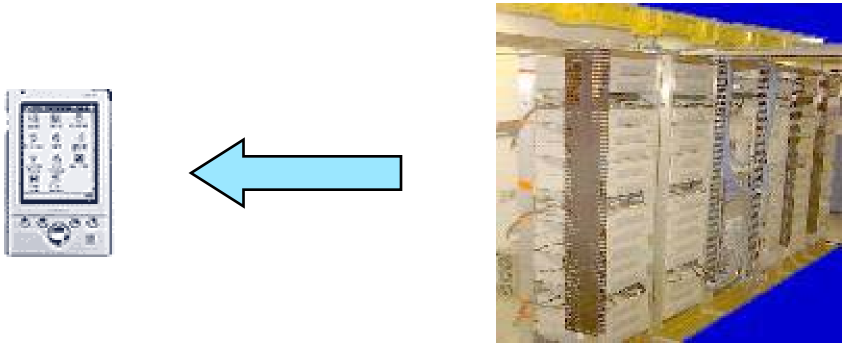
This pattern also has **liabilities**:

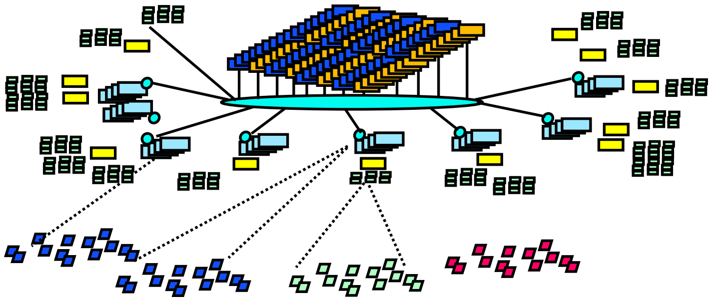
- ***Cascades of changing behavior***
  - If layer interfaces & semantics aren't abstracted properly then changes can ripple when behavior of a layer is modified
- ***Higher overhead***
  - A layered architecture can be less efficient than a monolithic architecture
- ***Unnecessary work***
  - If some services performed by lower layers perform excessive or duplicate work not actually required by the higher layer, performance can suffer
- ***Difficulty of establishing the correct granularity of layers***
  - It's important to avoid too many & too few layers

Scaling Up Performance via Threading

Context

- HTTP runs over TCP, which uses flow control to ensure that senders do not produce data more rapidly than slow receivers or congested networks can buffer & process
- Since achieving efficient end-to-end *quality of service* (QoS) is important to handle heavy Web traffic loads, a Web server must scale up efficiently as its number of clients increases





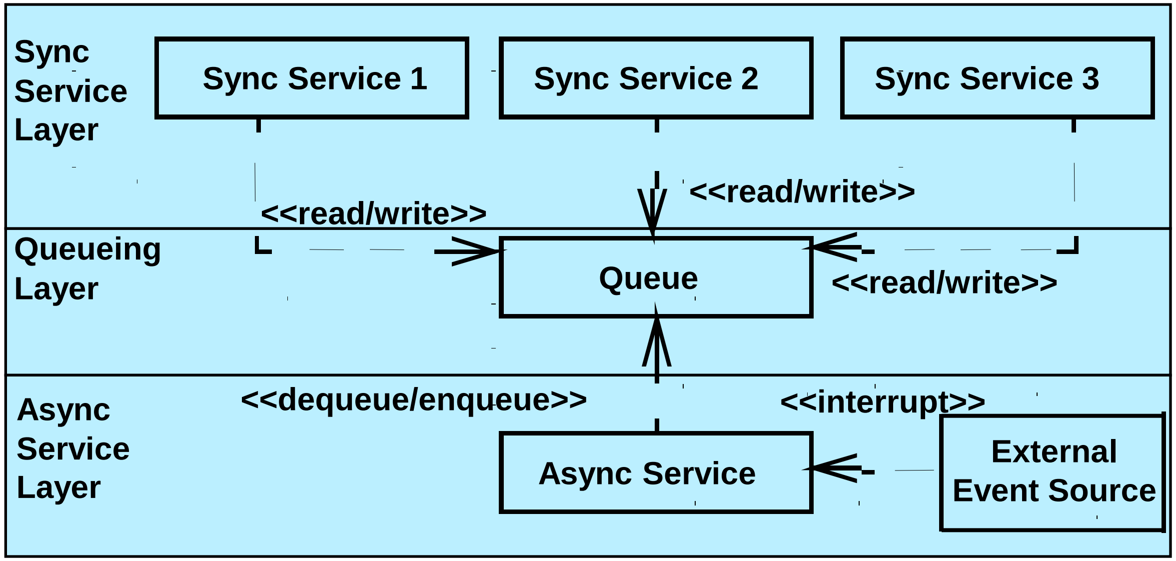
Problem

- Similarly, to improve QoS for all its connected clients, an entire Web server process must not block while waiting for connection flow control to abate so it can finish sending a file to a client
- Processing all HTTP GET requests reactively within a single-threaded process does not scale up, because each server CPU time-slice spends much of its time blocked waiting for I/O operations to complete

The Half-Sync/Half-Async Pattern

Solution

- Apply the *Half-Sync/Half-Async* architectural pattern (P2) to scale up server performance by processing different HTTP requests concurrently in multiple threads

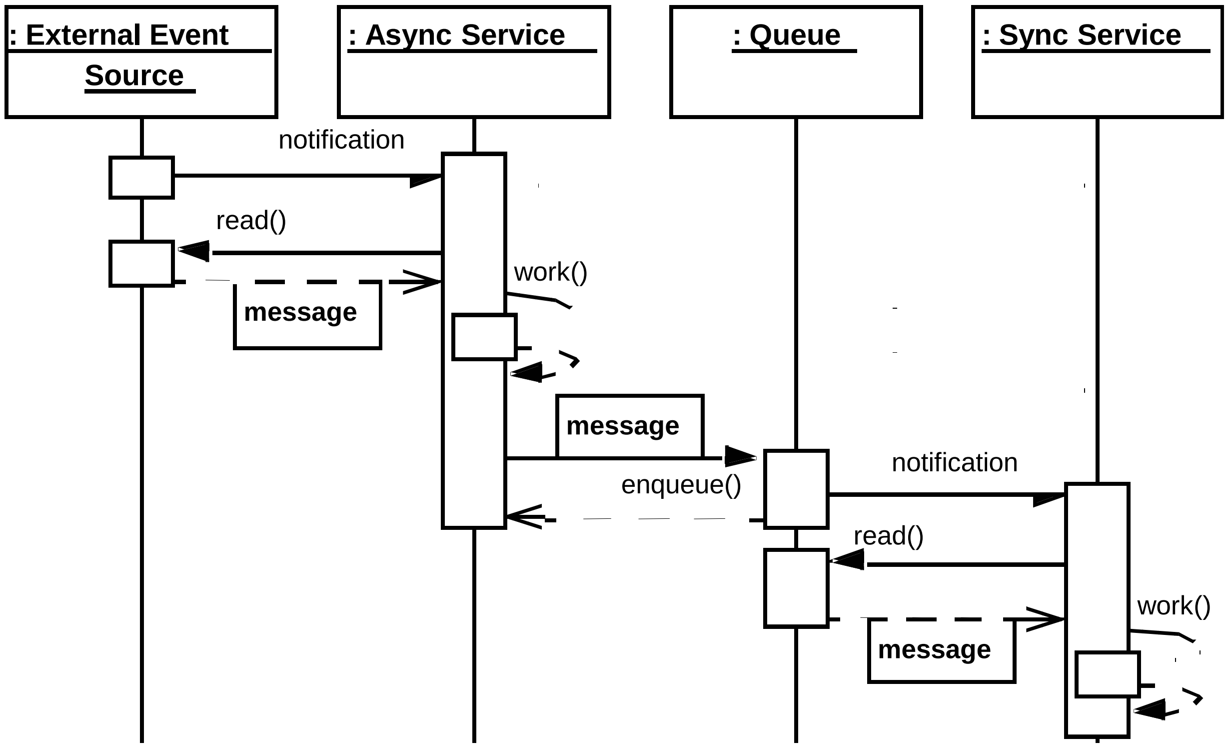


The *Half-Sync/Half-Async* architectural pattern decouples async & sync service processing in concurrent systems, to simplify programming without unduly reducing performance

This solution yields two benefits:

1. Threads can be mapped to separate CPUs to scale up server performance via multi-processing
2. Each thread blocks independently, which prevents a flow-controlled connection from degrading the QoS that other clients receive

Half-Sync/Half-Async Pattern Dynamics



- This pattern defines two service processing layers—one async & one sync—along with a queueing layer that allows services to exchange messages between the two layers
- The pattern allows sync services, such as HTTP protocol processing, to run concurrently, relative both to each other & to async services, such as event demultiplexing

Pros & Cons of Half-Sync/Half-Async Pattern

This pattern has three **benefits**:

- ***Simplification & performance***
  - The programming of higher-level synchronous processing services are simplified without degrading the performance of lower-level system services
- ***Separation of concerns***
  - Synchronization policies in each layer are decoupled so that each layer need not use the same concurrency control strategies
- ***Centralization of inter-layer communication***
  - Inter-layer communication is centralized at a single access point, because all interaction is mediated by the queueing layer

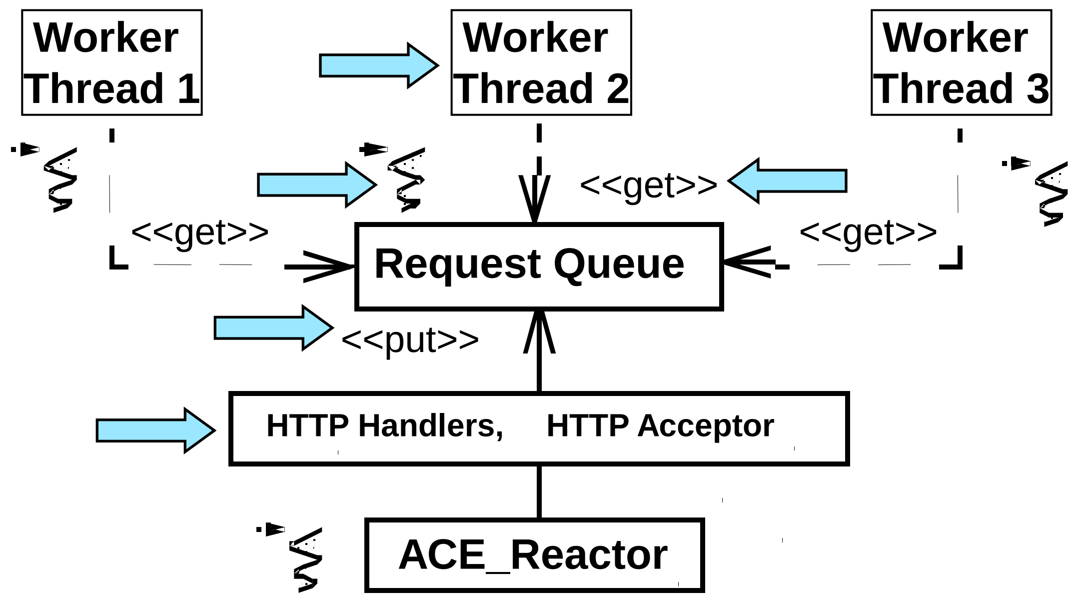
This pattern also incurs **liabilities**:

- ***A boundary-crossing penalty may be incurred***
  - This overhead arises from context switching, synchronization, & data copying overhead when data is transferred between the sync & async service layers via the queueing layer
- ***Higher-level application services may not benefit from the efficiency of async I/O***
  - Depending on the design of operating system or application framework interfaces, it may not be possible for higher-level services to use low-level async I/O devices effectively
- ***Complexity of debugging & testing***
  - Applications written with this pattern can be hard to debug due its concurrent execution

Drawbacks with Half-Sync/Half-Async

Problem

- Although Half-Sync/Half-Async threading model is more scalable than the purely reactive model, it is not necessarily the most efficient design
  - *e.g.*, passing a request between the Reactor thread & a worker thread incurs:
    - *Dynamic memory (de)allocation*,
    - *Synchronization operations*,
    - *A context switch*, &
    - *CPU cache updates*
- This overhead makes JAWS' latency unnecessarily high, particularly on operating systems that support the concurrent **`accept()`** optimization

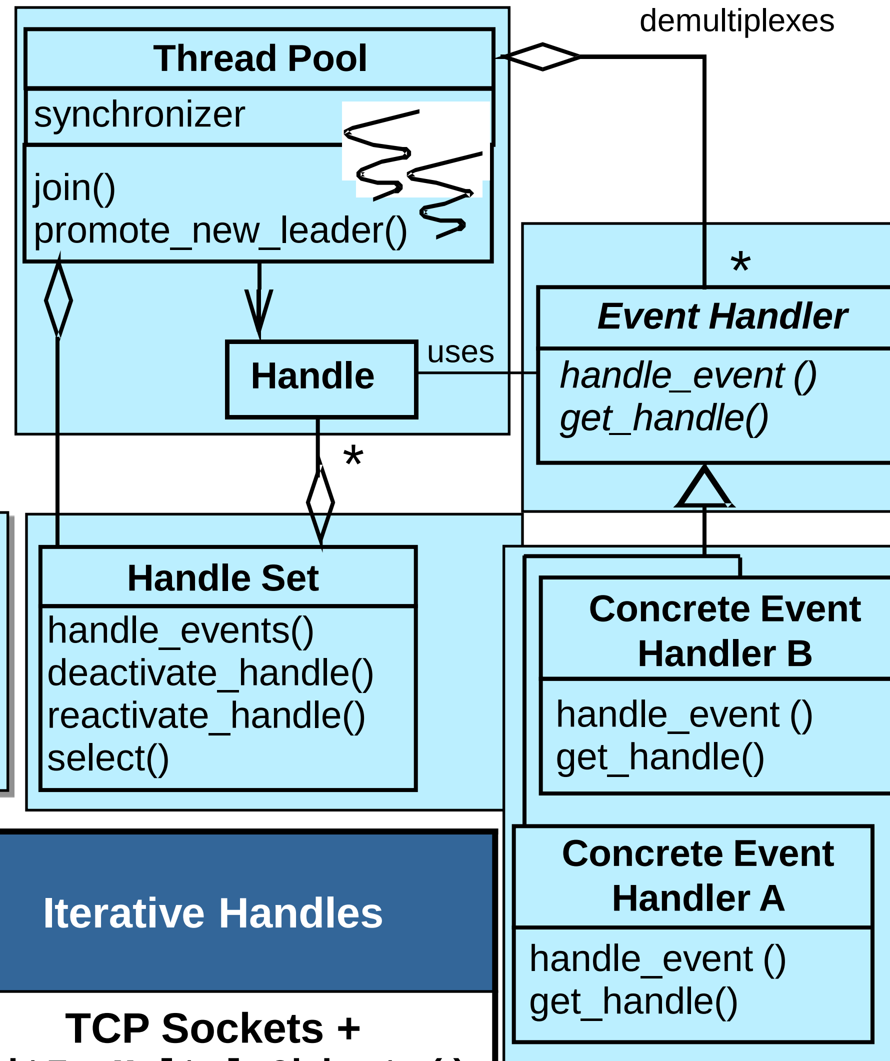


Solution

- Apply the *Leader/Followers* architectural pattern (P2) to minimize server threading overhead

The Leader/Followers Pattern

The Leader/Followers architectural pattern (P2) provides an efficient concurrency model where multiple threads take turns sharing event sources to detect, demux, dispatch, & process service requests that occur on the event sources

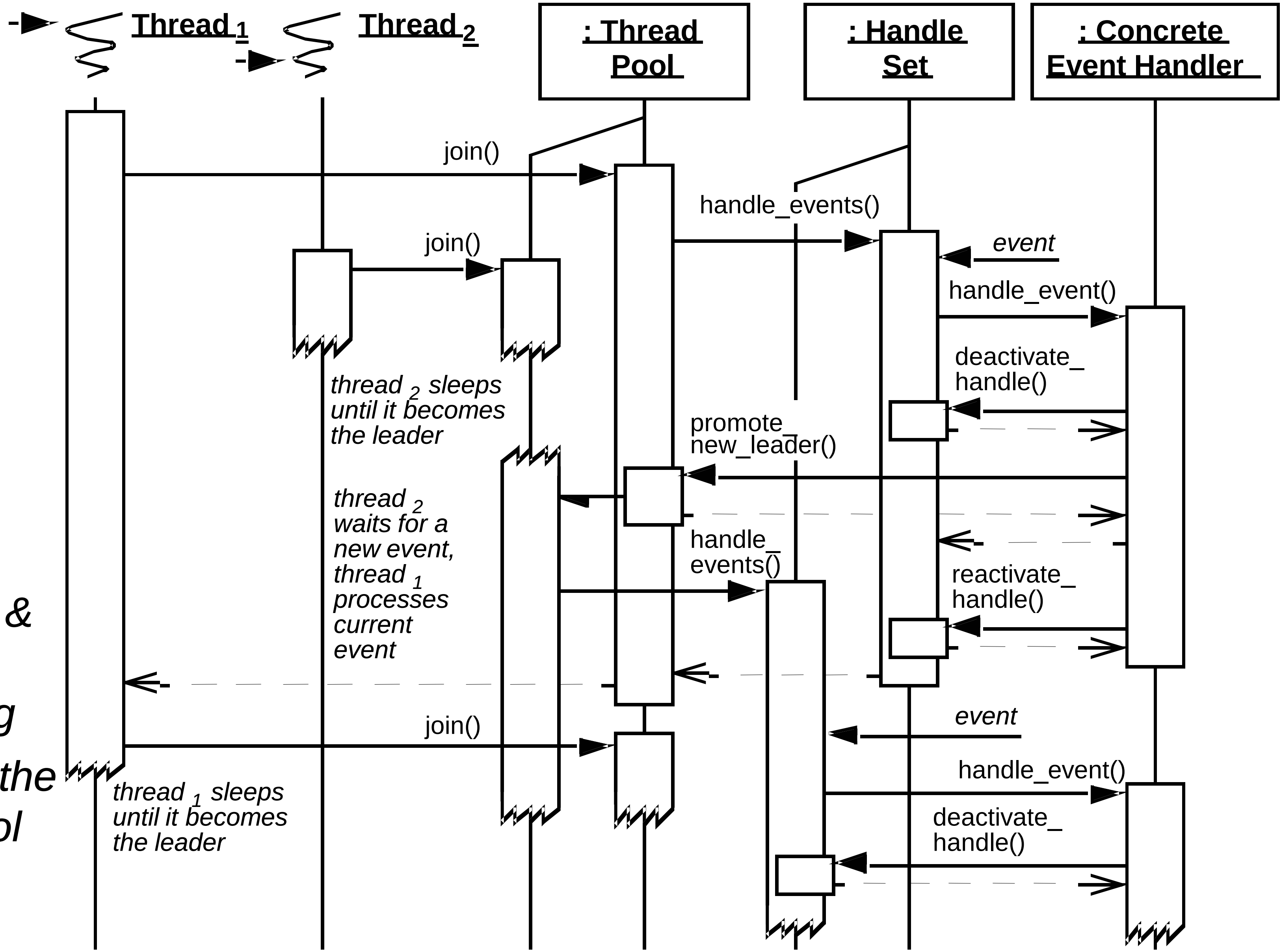


This pattern eliminates the need for—& the overhead of—a separate Reactor thread & synchronized request queue used in the Half-Sync/Half-Async pattern

Handles / Handle Sets	Concurrent Handles	Iterative Handles
Concurrent Handle Sets	**UDP Sockets + `WaitForMultipleObjects()`**	**TCP Sockets + `WaitForMultpleObjects()`**
Iterative Handle Sets	**UDP Sockets + `select()/poll()`**	**TCP Sockets + `select()/poll()`**

Leader/Followers Pattern Dynamics

1. *Leader thread demuxing*
2. *Follower thread promotion*
3. *Event handler demuxing & event processing*
4. *Rejoining the thread pool*



Pros & Cons of Leader/Followers Pattern

This pattern provides two **benefits**:

- ***Performance enhancements***
  - This can improve performance as follows:
    - It enhances CPU cache affinity & eliminates the need for dynamic memory allocation & data buffer sharing between threads
    - It minimizes locking overhead by not exchanging data between threads, thereby reducing thread synchronization
    - It can minimize priority inversion because no extra queueing is introduced in the server
    - It doesn't require a context switch to handle each event, reducing dispatching latency
- ***Programming simplicity***
  - The Leader/Follower pattern simplifies the programming of concurrency models where multiple threads can receive requests, process responses, & demultiplex connections using a shared handle set

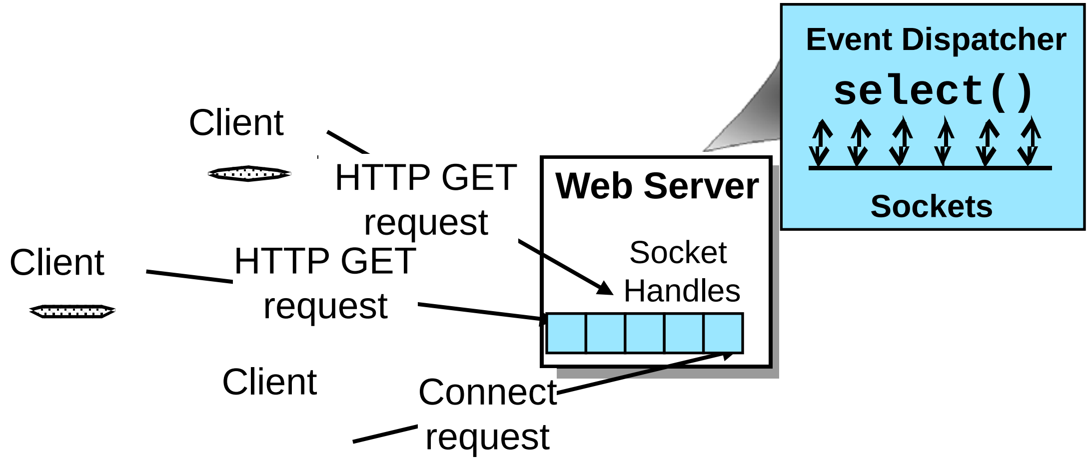
This pattern also incur **liabilities**:

- ***Implementation complexity***
  - The advanced variants of the Leader/ Followers pattern are hard to implement
- ***Lack of flexibility***
  - In the Leader/ Followers model it is hard to discard or reorder events because there is no explicit queue
- ***Network I/O bottlenecks***
  - The Leader/Followers pattern serializes processing by allowing only a single thread at a time to wait on the handle set, which could become a bottleneck because only one thread at a time can demultiplex I/O events

Decoupling Event Demuxing, Connection Management, & Protocol Processing (1/2)

Context

- Web servers can be accessed simultaneously by multiple clients
- They must demux & process multiple types of indication events arriving from clients concurrently
- A common way to demux events in a server is to use **`select()`**



Problem

- Developers often couple event-demuxing & connection code with protocol-handling code
- This code cannot then be reused directly by other protocols or by other middleware & applications

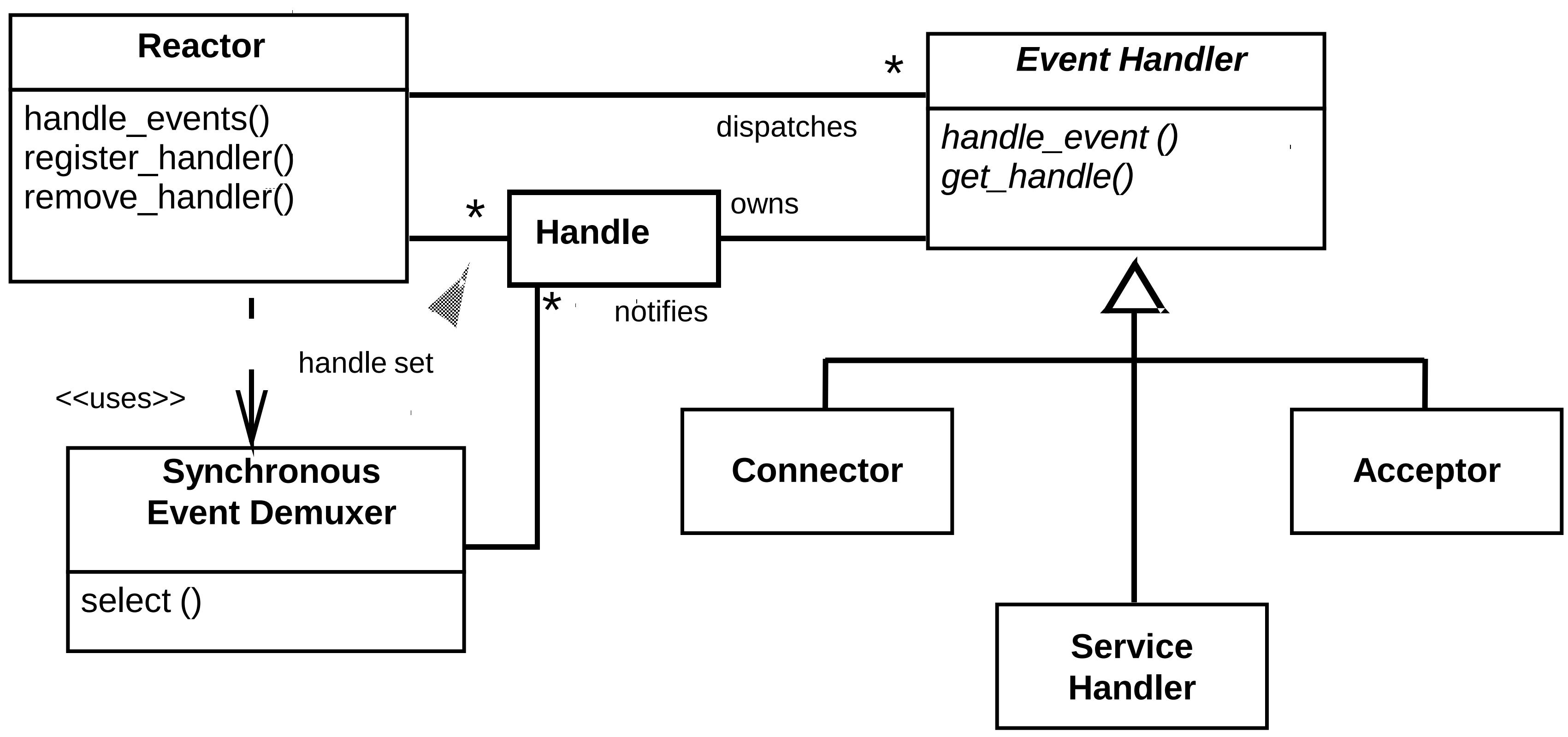
```
select (width, &read_handles, 0, 0, 0);
if (FD_ISSET (acceptor,  &ready_handles)) {
   int h;

   do {
     h = accept (acceptor, 0, 0);
     char buf[BUFSIZ];
     for (ssize_t i;  (i = read (h, buf, BUFSIZ)) > 0; )
        write (1, buf, i);
   } while (h != -1);
```

Thus, changes to event-demuxing & connection code affects server protocol code directly & may yield subtle bugs, *e.g.*, when porting to use TLI or **`WaitForMultipleObjects()`**

Decoupling Event Demuxing, Connection Management, & Protocol Processing (2/2)

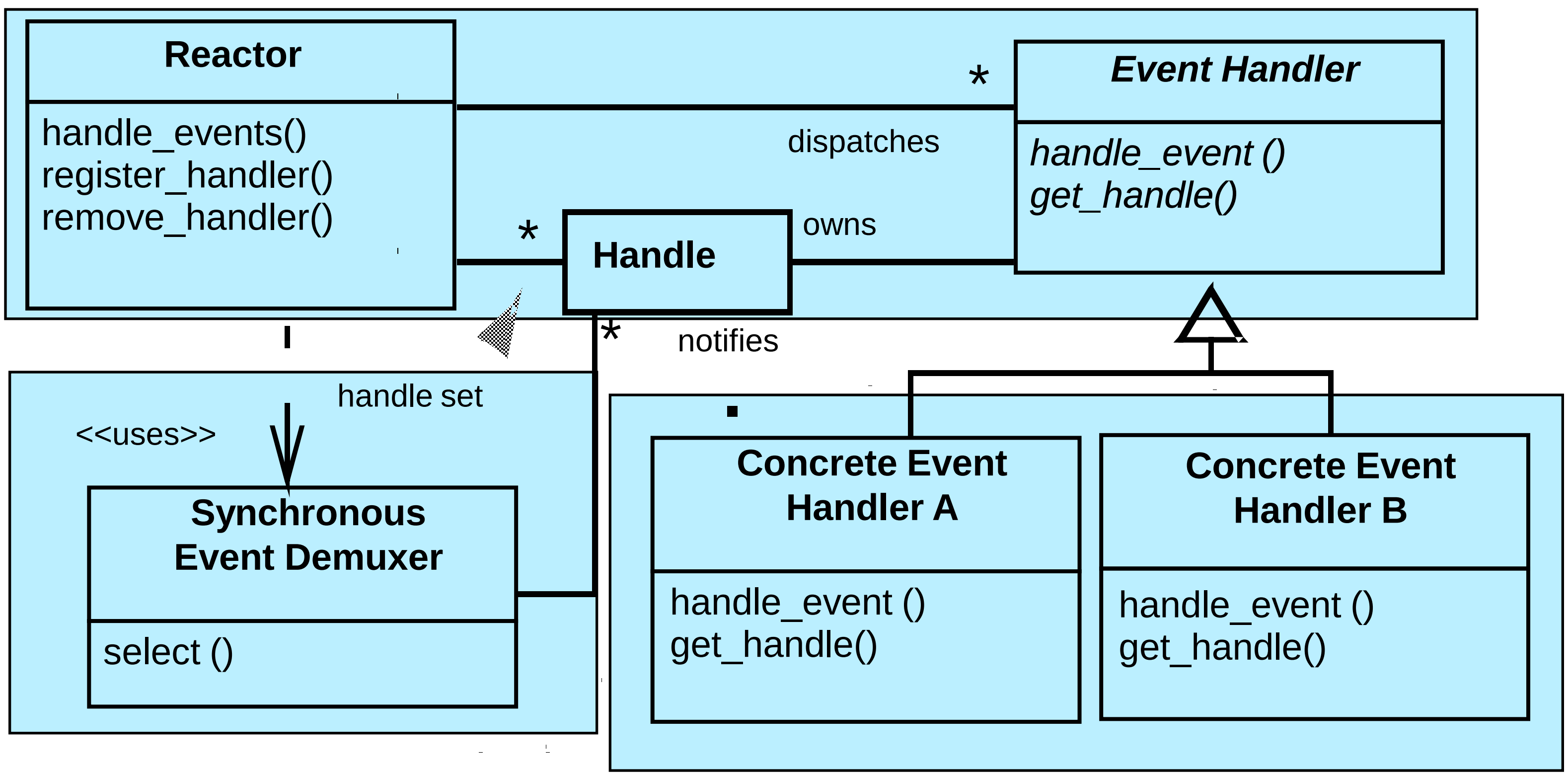
Solution

Apply the *Reactor* architectural pattern (P2) & the *Acceptor-Connector* design pattern (P2) to separate the generic event-demultiplexing & connection-management code from the web server’s protocol code

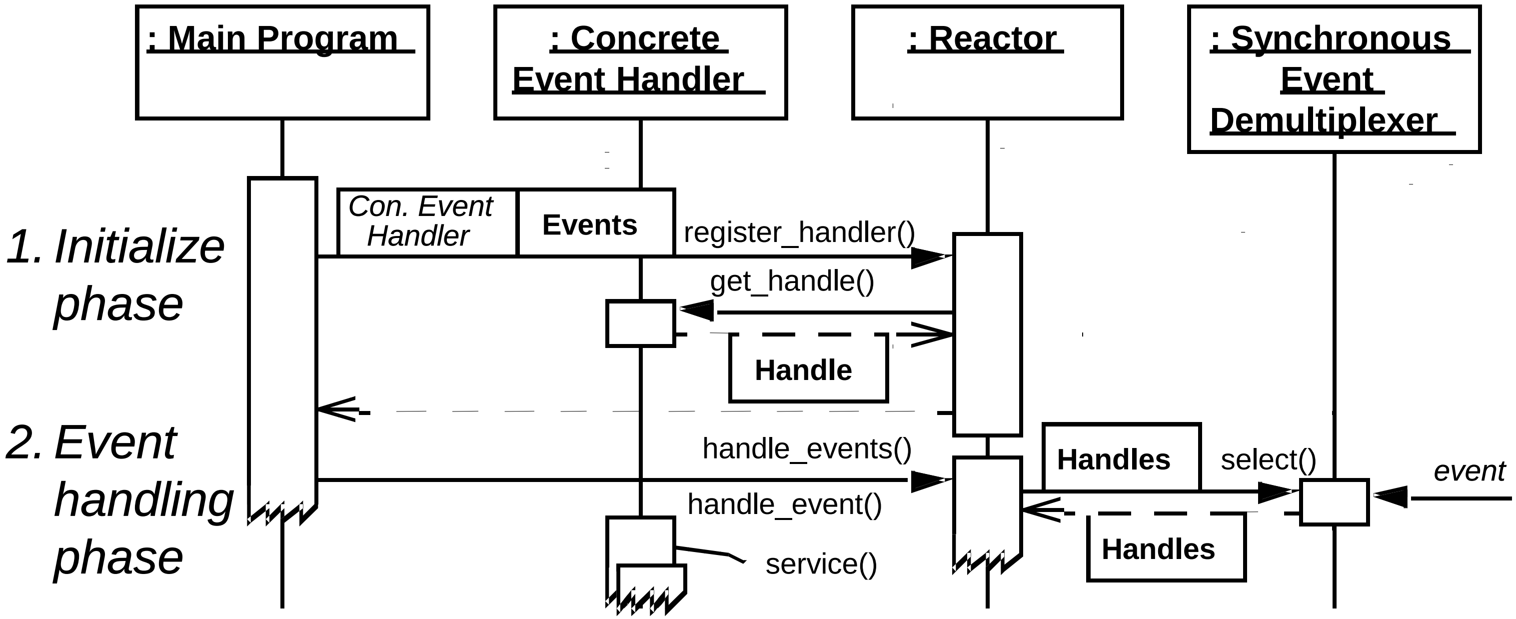


The Reactor Pattern

The *Reactor* architectural pattern allows event-driven applications to demultiplex & dispatch service requests that are delivered to an application from one or more clients



Reactor Pattern Dynamics



Observations

- Note inversion of control
- Also note how long-running event handlers can degrade the QoS since callbacks steal the reactor's thread!

Pros & Cons of the Reactor Pattern

This pattern offers four **benefits**:

- ***Separation of concerns***
  - This pattern decouples application-independent demuxing & dispatching mechanisms from application-specific hook method functionality
- ***Modularity, reusability, & configurability***
  - This pattern separates event-driven application functionality into several components, which enables the configuration of event handler components that are loosely integrated via a reactor
- ***Portability***
  - By decoupling the reactor's interface from the lower-level OS synchronous event demuxing functions used in its implementation, the Reactor pattern improves portability
- ***Coarse-grained concurrency control***
  - This pattern serializes the invocation of event handlers at the level of event demuxing & dispatching within an application process or thread

This pattern can incur **liabilities*:***

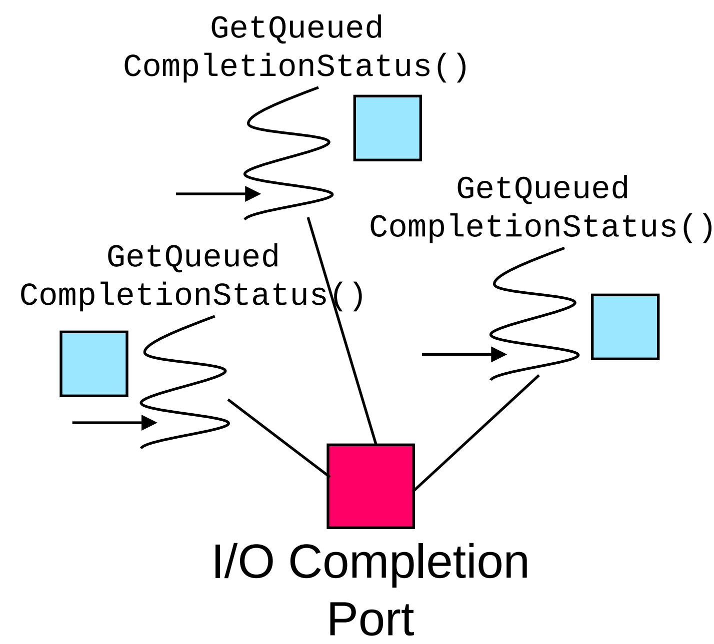
- ***Restricted applicability***
  - This pattern can be applied efficiently only if the OS supports synchronous event demuxing on handle sets
- ***Non-pre-emptive***
  - In a single-threaded application, concrete event handlers that borrow the thread of their reactor can run to completion & prevent the reactor from dispatching other event handlers
- ***Complexity of debugging & testing***
  - It is hard to debug applications structured using this pattern due to its inverted flow of control, which oscillates between the framework infrastructure & the method call-backs on application-specific event handlers

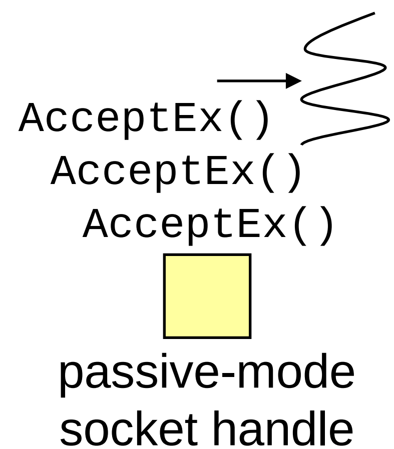
Using Asynchronous I/O Effectively

Context

- Synchronous multi-threading may not be the most scalable way to implement a Web server on OS platforms that support async I/O more efficiently than synchronous multi-threading

- For example, highly-efficient Web servers can be implemented on Windows NT by invoking async Win32 operations that perform the following activities:
  - Processing indication events, such as TCP CONNECT & HTTP GET requests, via **`AcceptEx()`** & **`ReadFile()`**, respectively
  - Transmitting requested files to clients asynchronously via **`WriteFile()`** or **`TransmitFile()`**
- When these async operations complete, WinNT
  1. Delivers the associated completion events containing their results to the Web server
  2. Processes these events & performs the appropriate actions before returning to its event loop





The Proactor Pattern

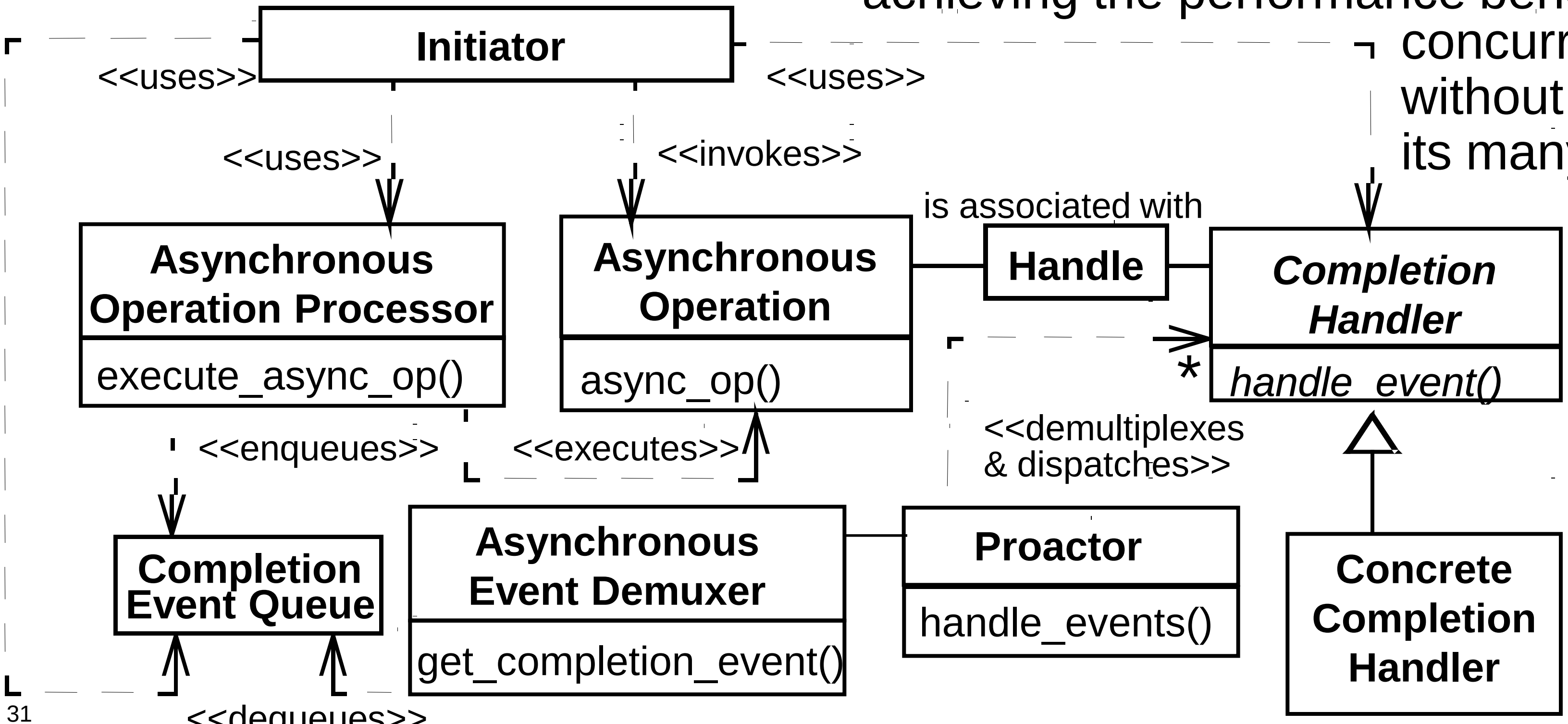
Problem

- Developing software that achieves the potential efficiency & scalability of async I/O is hard due to the separation in time & space of async operation invocations & their subsequent completion events

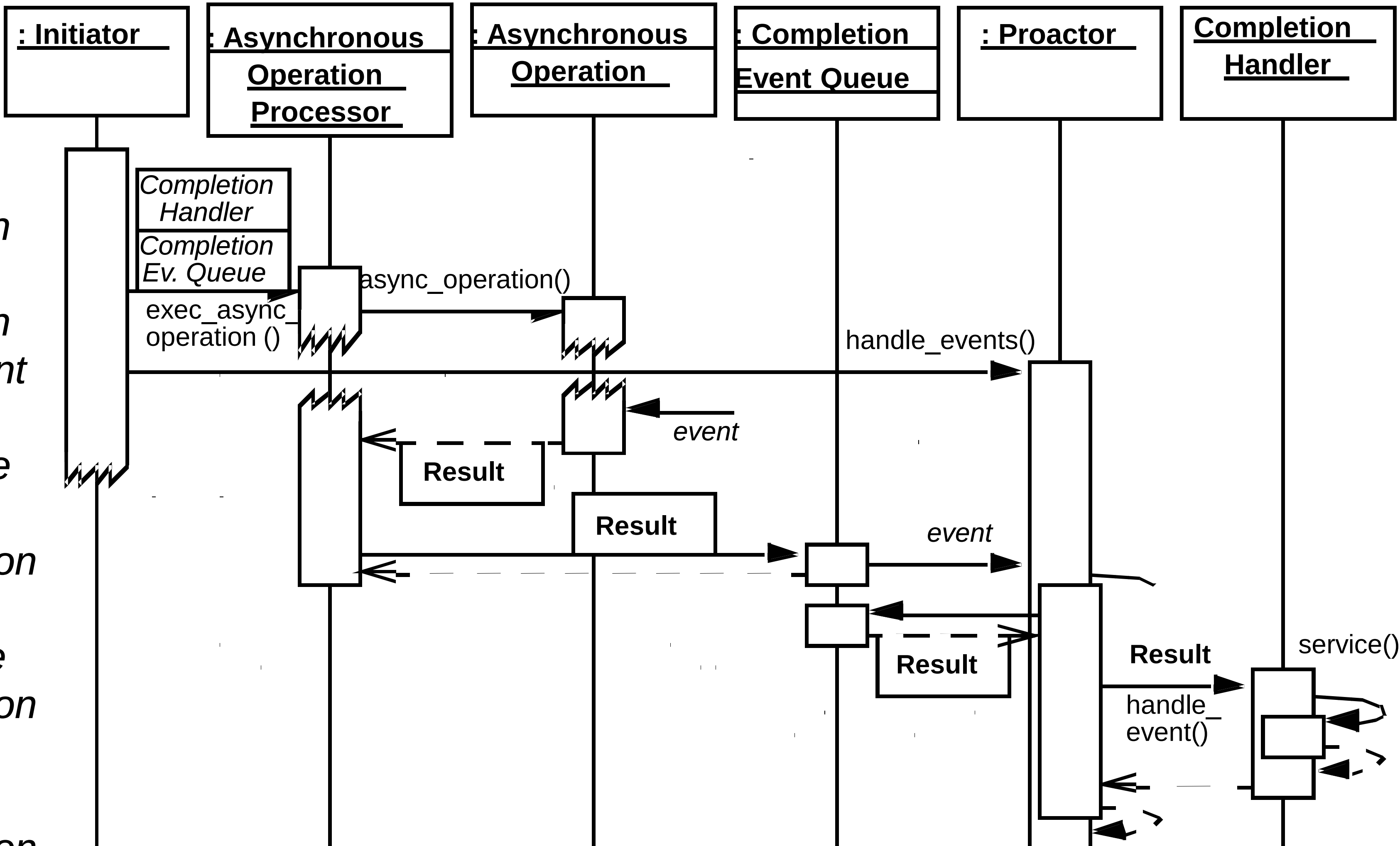
Solution

- Apply the *Proactor* architectural pattern (P2) to make efficient use of async I/O

This pattern allows event-driven applications to efficiently demultiplex & dispatch service requests triggered by the completion of async operations, thereby achieving the performance benefits of concurrency without incurring its many liabilities



Proactor Pattern Dynamics



1. *Initiate operation*
2. *Process operation*
3. *Run event loop*
4. *Generate & queue completion event*
5. *Dequeue completion event & perform completion processing*

Note *similarities* & *differences* with the Reactor pattern, *e.g.:*

- Both process events via callbacks
- However, it's generally easier to multi-thread a proactor

Pros & Cons of Proactor Pattern

This pattern offers five **benefits**:

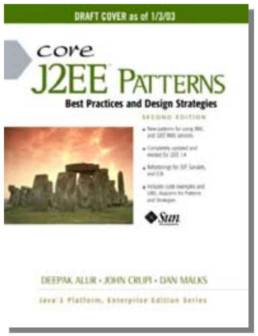
- ***Separation of concerns***
  - Decouples application-independent async mechanisms from application-specific functionality
- ***Portability***
  - Improves application portability by allowing its interfaces to be reused independently of the OS event demuxing calls
- ***Decoupling of threading from concurrency***
  - The async operation processor executes long-duration operations on behalf of initiators so applications can spawn fewer threads
- ***Performance***
  - Avoids context switching costs by activating only those logical threads of control that have events to process
- ***Simplification of application synchronization***
  - If concrete completion handlers spawn no threads, application logic can be written with little or no concern for synchronization issues

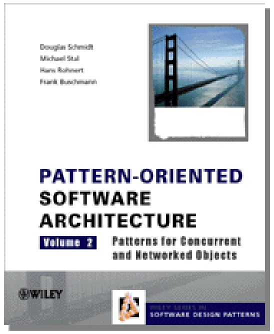
This pattern incurs some **liabilities**:

- ***Restricted applicability***
  - This pattern can be applied most efficiently if the OS supports asynchronous operations natively
- ***Complexity of programming, debugging, & testing***
  - It is hard to program applications & higher-level system services using asynchrony mechanisms, due to the separation in time & space between operation invocation & completion
- ***Scheduling, controlling, & canceling asynchronously running operations***
  - Initiators may be unable to control the scheduling order in which asynchronous operations are executed by an asynchronous operation processor

Architectural Patterns Resources

- Books





- Web sites

  http://www.enterpriseintegrationpatterns.com/ - patterns for enterprise systems and integrations

  http://www.cs.wustl.edu/~schmidt/POSA/ - patterns for distributed computing systems

  http://www.hillside.net/patterns/ - a catalog of patterns and pattern languages

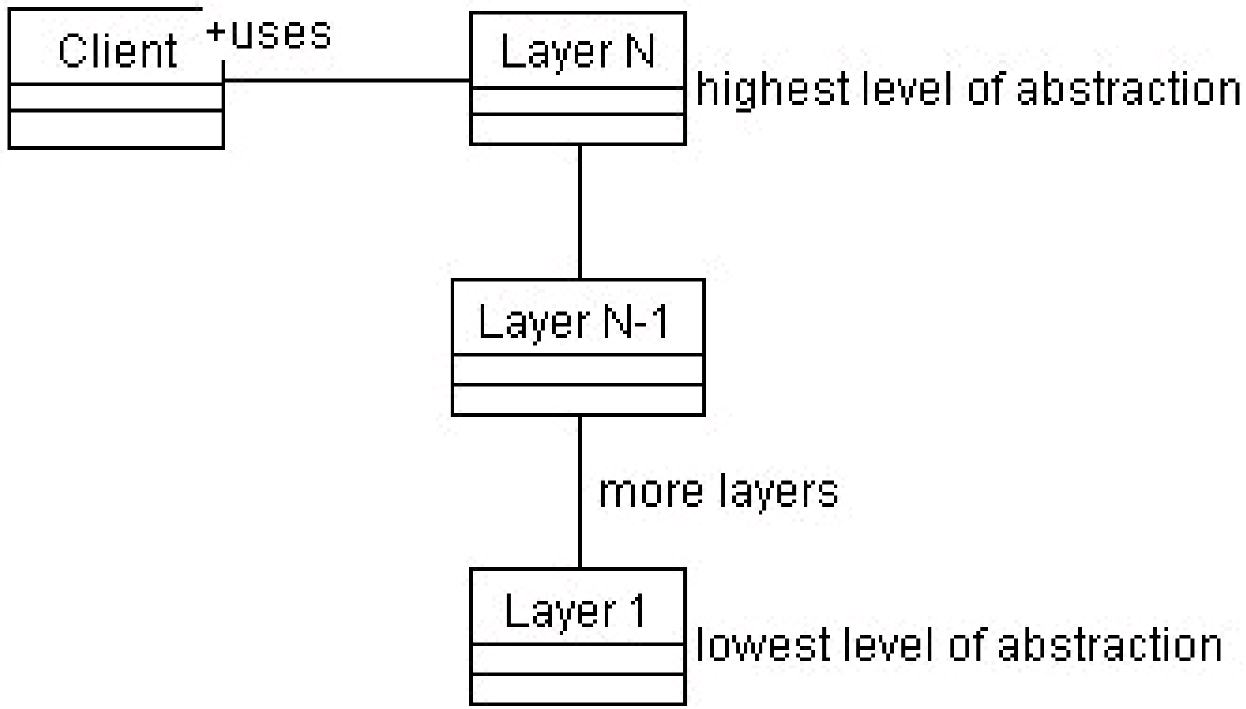
  http://www.opengroup.org/architecture/togaf8-doc/arch/chap28.html - architectural patterns

Layers Pattern Revisited

Context
- A large system that requires decomposition

Problem
- Managing a “sea of classes” that addresses various levels of abstraction

Solution
- Aggregate classes at the same level of abstraction into layers.

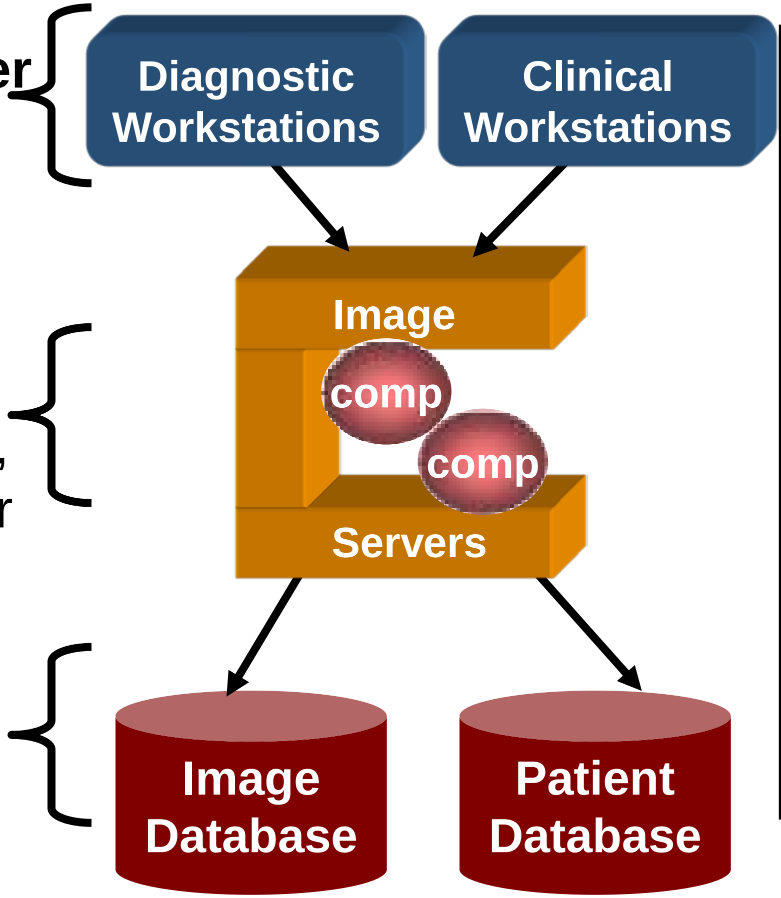


Applying the Layers Pattern to Image Acquisition

Presentation Tier
- *e.g.*, radiology clients

Middle Tier
- *e.g.*, image routing, security, & image transfer logic

Database Tier
- *e.g.*, persistent image data



Diagnostic & clinical workstations are presentation tier entities that:
- Typically represent sophisticated GUI elements
- Share the same address space with their clients
  - Their clients are containers that provide all the resources
- Exchange messages with the middle tier components

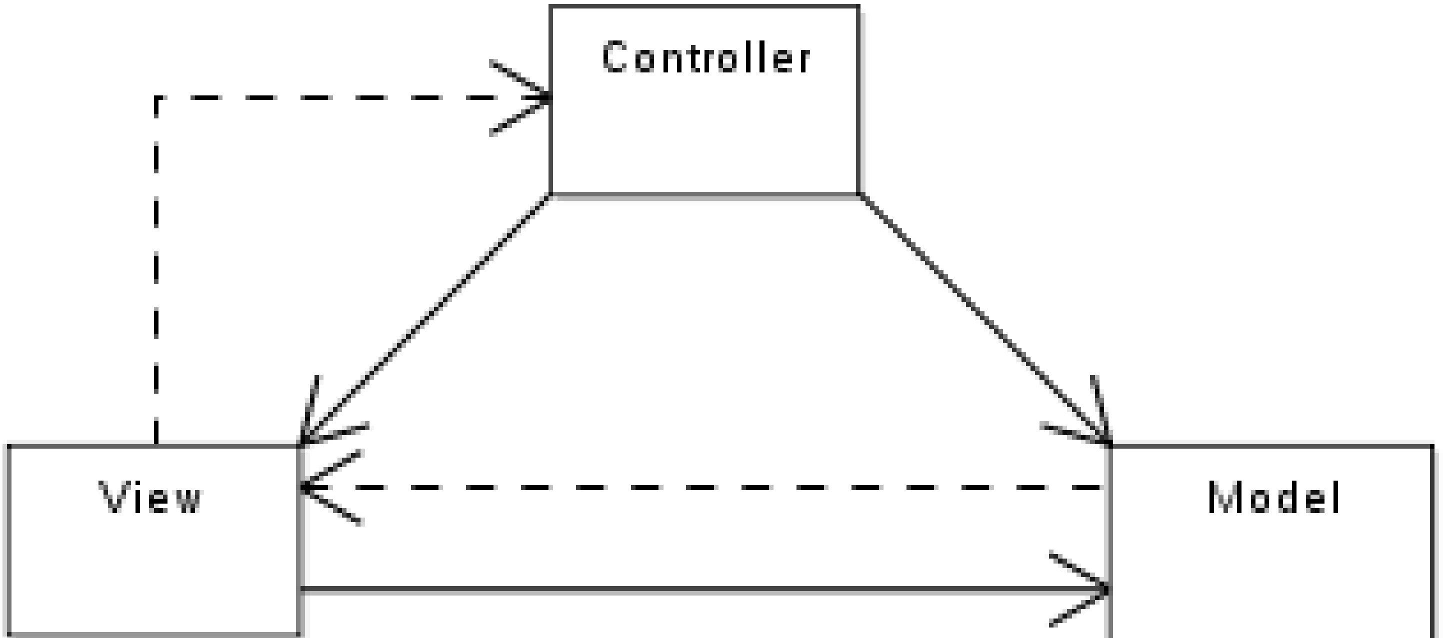
Image servers are middle tier entities that:
- Provide server-side functionality
  - *e.g.*, they are responsible for scalable concurrency & networking
- Can run in their own address space
- Are integrated into containers that hide low-level OS platform details

Model View Controller Revisited

Context
- Interactive applications with a flexible human-computer interface

Problem
- Managing different & changing presentations of the same data
- Updating the presentations when the data changes

Solution
- Decouple core data and functionality from output representations or input behavior



Applying the Layers & MVC Patterns to Image Acquisition

Layer 3

Presentation Tier

- *e.g.*, radiology clients

Layer 2

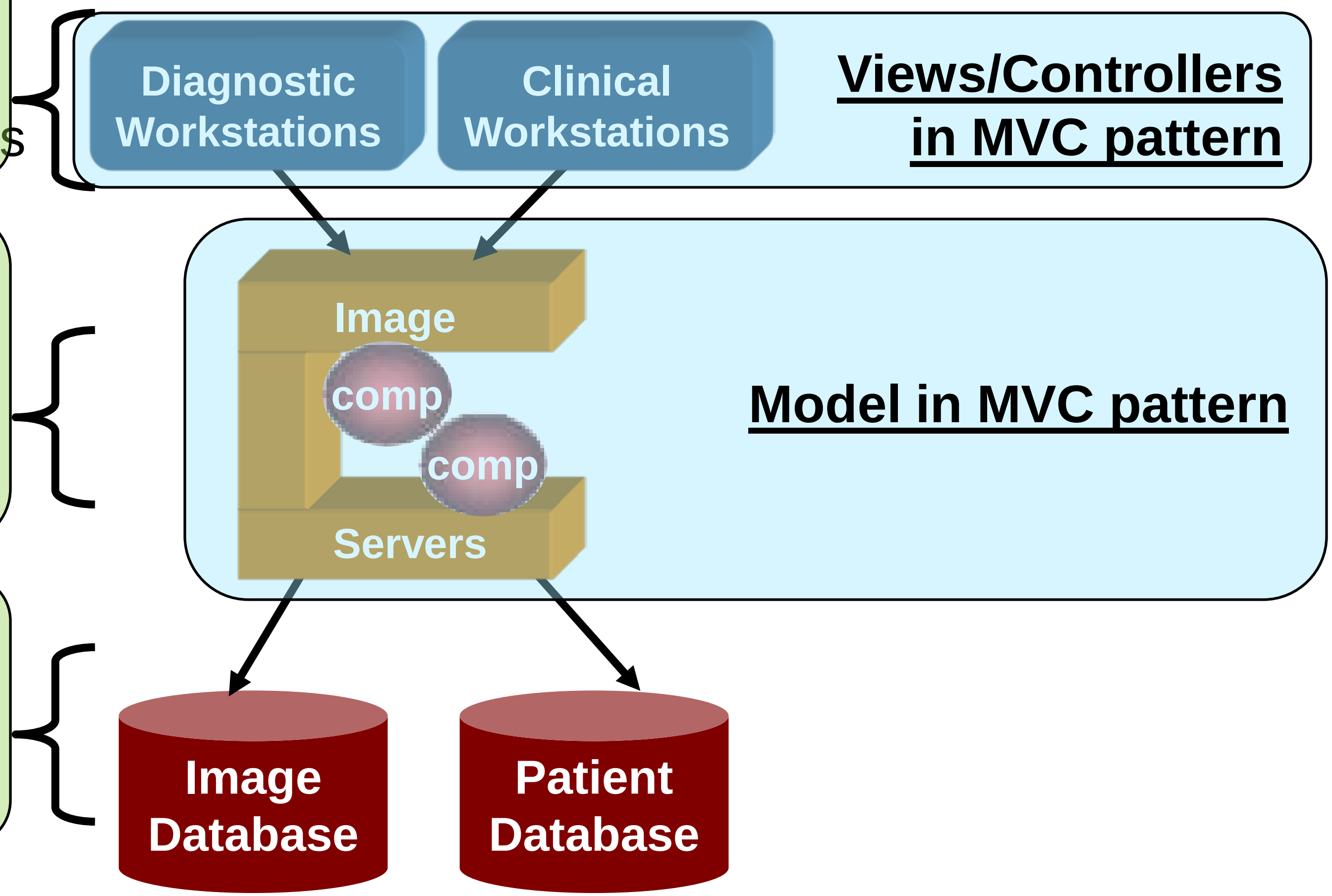
Middle Tier

- *e.g.*, image routing, security, & image transfer logic

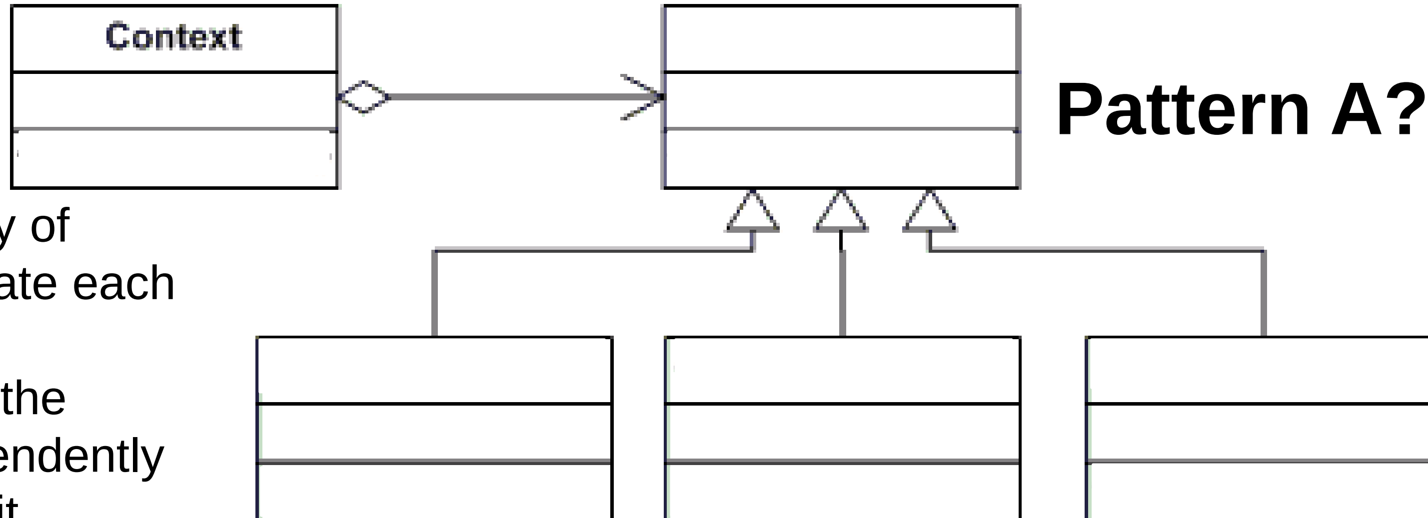
Layer 1

Database Tier

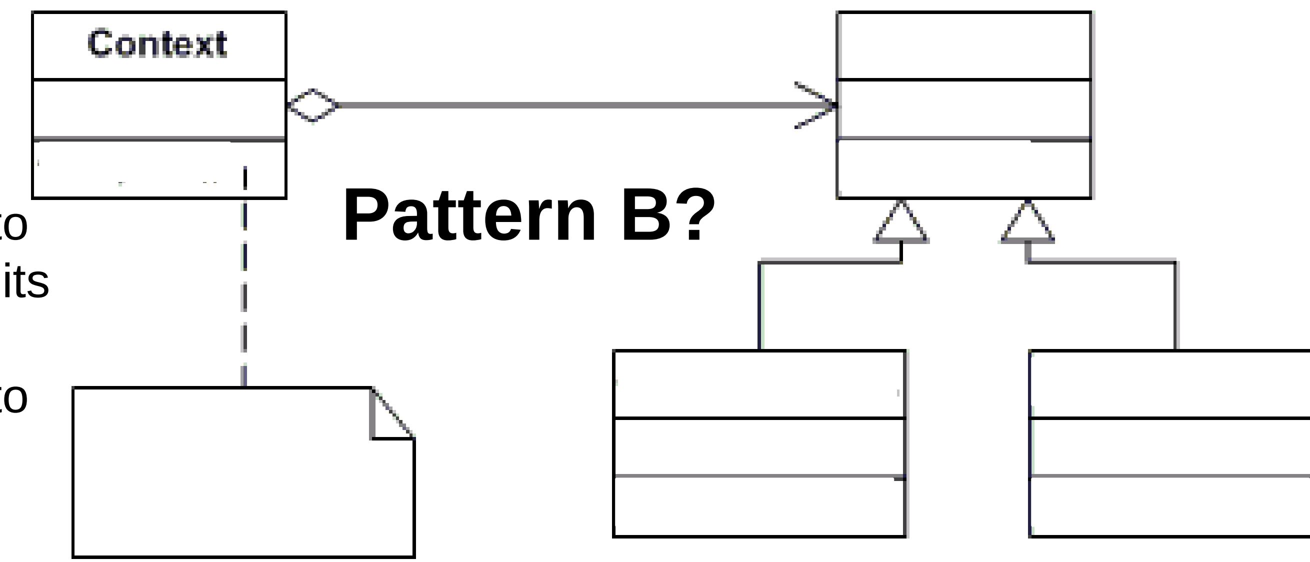
- *e.g.*, persistent image data



Patterns Are More Than Structure

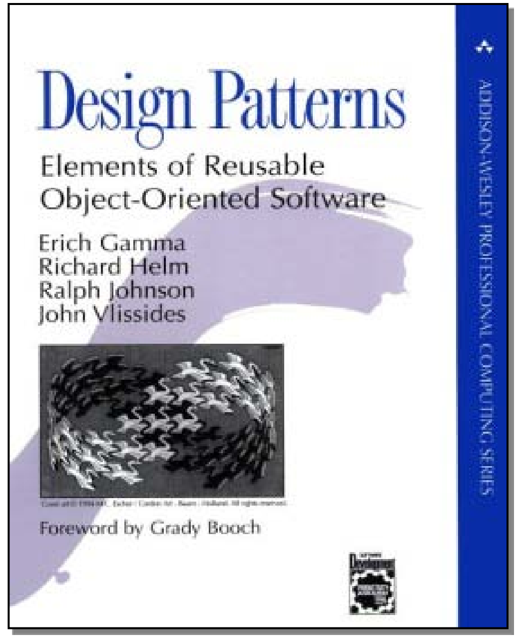


Intent: Define a family of algorithms, encapsulate each one, and make them interchangeable. Let the algorithm vary independently from clients that use it.



Intent: Allow an object to alter its behavior when its internal state changes. The object will appear to change its class.

Patterns Are Abstract



The **solution** describes the elements that make up the design, their relationships, responsibilities, and collaborations. The solution doesn't describe a particular concrete design or implementation, because a pattern is like a template that can be applied in many different situations. Instead, the pattern provides an abstract description of a design problem and how a general arrangement of elements (classes and objects in our case) solves it.

- Design Patterns: Elements of Reusable Object-Oriented Software

Taxonomy of Patterns & Idioms

Type	Description	Examples
Idioms	Restricted to a particular language, system, or tool	Scoped locking
Design patterns	Capture the static & dynamic roles & relationships in solutions that occur repeatedly	Active Object, Bridge, Proxy, Wrapper Façade, & Visitor
Architectural patterns	Express a fundamental structural organization for software systems that provide a set of predefined subsystems, specify their relationships, & include the rules and guidelines for organizing the relationships between them	Half-Sync/Half-Async, Layers, Proactor, Publisher-Subscriber, & Reactor
Optimization principle patterns	Document rules for avoiding common design & implementation mistakes that degrade performance	Optimize for common case, pass information between layers

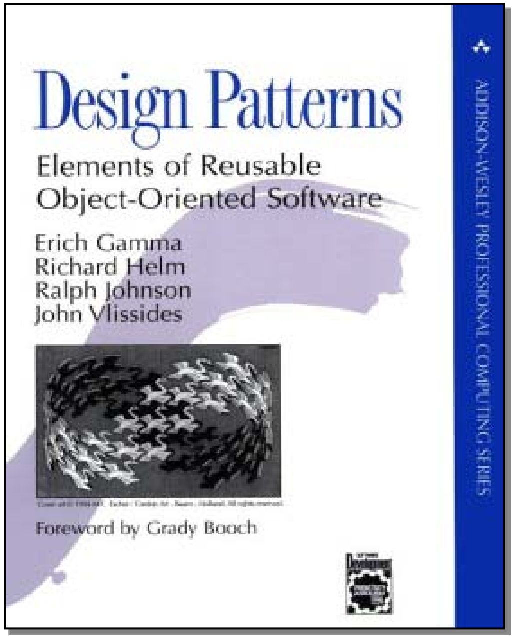
Seminal Design Patterns Book

<u>Design Patterns: Elements of Reusable Object-Oriented Software</u>
by Erich Gamma, Richard Helm, Ralph Johnson, & John Vlissides ("Gang of Four")

Written in 1995

Documents 23 design patterns outlining:

- Intent
- Motivation
- Applicability
- Structure
- Collaborations
- Consequences
- Implementation
- Known uses
- Related patterns



Patterns grouped as:

- Creational,
- Structural, or
- Behavioral

Managing Global Objects Effectively

Goals:

– Centralize access to objects that should be visible globally, e.g.:
  - command-line options that parameterize the behavior of the program
  - The object (Reactor) that drives the main event loop

Constraints/forces:

– Only need one instance of the command-line options & Reactor

– Global variables are problematic in C++

```
% tree-traversal -v
format [in-order]
expr [expression]
print [in-order|pre-order|post-order|level-order]
eval [post-order]
quit
> format in-order
> expr 1+4*3/2
> eval post-order
7
> quit
```

Verbose mode

```
% tree-traversal
> 1+4*3/2
7
```

Succinct mode

Solution: Centralize Access to Global Instances

Rather than using global variables, create a central access point to global instances, e.g.:

```
int main (int argc, char *argv[])
{
  // Parse the command-line options.
  if (!Options::instance ()->parse_args (argc, argv))
    return 0;

  // Dynamically allocate the appropriate event handler
  // based on the command-line options.
  Expression_Tree_Event_Handler *tree_event_handler =
    Expression_Tree_Event_Handler::make_handler
      (Options::instance ()->verbose ());

  // Register event handler with the reactor.
  Reactor::instance ()->register_input_handler
    (tree_event_handler);
  // ...
```

Singleton Description (1/2)

Singleton object creational

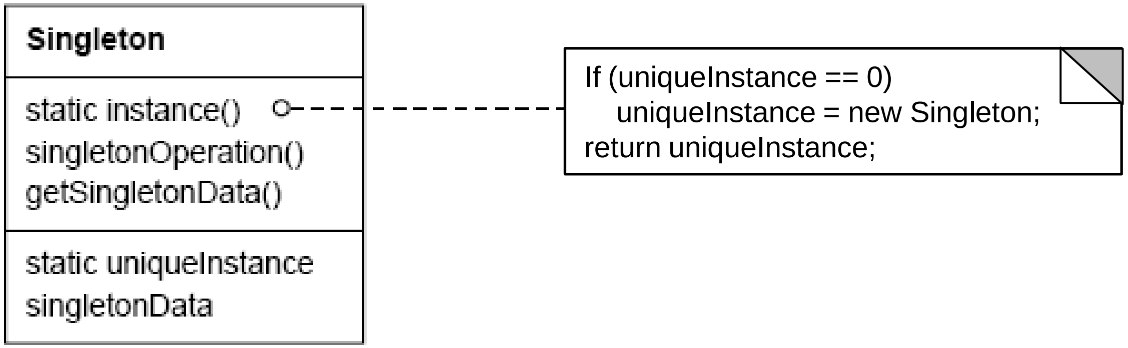
Intent

ensure a class only ever has one instance & provide a global point of access

Applicability

- when there must be exactly one instance of a class, & it must be accessible from a well-known access point
- when the sole instance should be extensible by subclassing, & clients should be able to use an extended instance without modifying their code

Structure



Singleton Description (2/2)

Singleton — object creational

Consequences

+ reduces namespace pollution
+ makes it easy to change your mind & allow more than one instance
+ allow extension by subclassing

– same drawbacks of a global if misused
– implementation may be less efficient than a global
– concurrency pitfalls strategy creation & communication overhead

Implementation

– static instance operation
– registering the singleton instance
– deleting singletons

Known Uses

– Unidraw's Unidraw object
– Smalltalk-80 ChangeSet, the set of changes to code
– InterViews Session object

See Also

– Double-Checked Locking Optimization pattern from POSA2
– "To Kill a Singleton" www.research.ibm.com/designpatterns/pubs/ph-jun96.txt