Meeting the Challenge of Distributed Real-Time & Embedded (DRE) Systems

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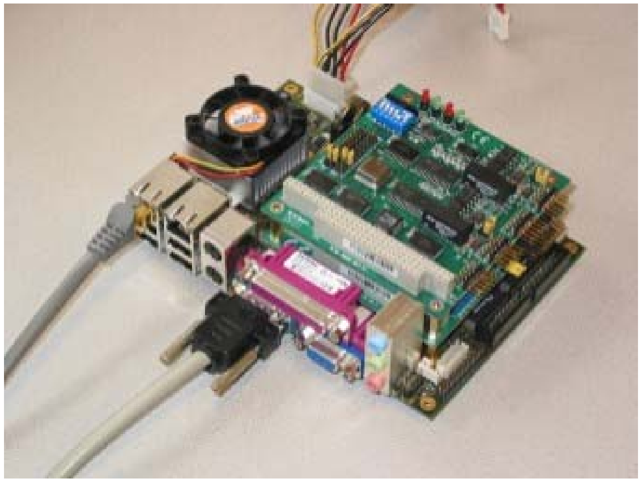
Evolution in DRE Systems

The Past



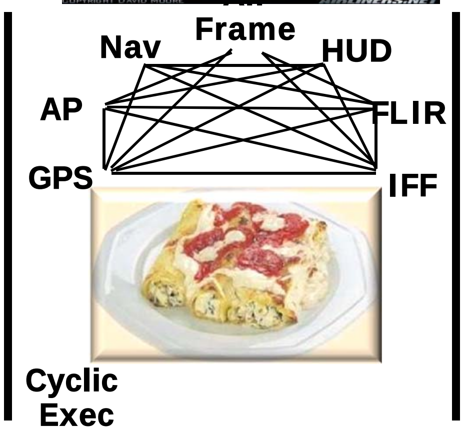
Standalone real-time & embedded systems
- Stringent quality of service (QoS) demands
  - e.g., latency, jitter, footprint
- Resource constrained

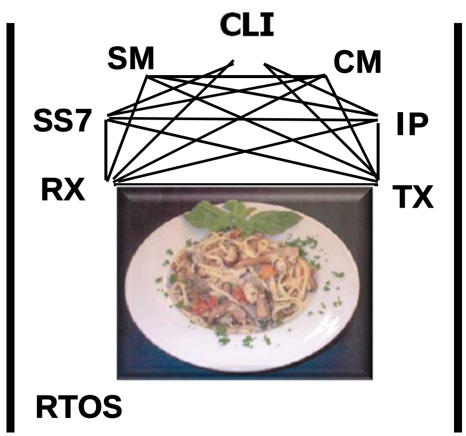
The Present

Distributed real-time & embedded (DRE) systems
- Net-centric systems-of-systems
- Stringent simultaneous QoS demands
  - e.g., dependability, security, scalability, etc.
- More fluid environments & requirements

This talk focuses on technologies & methods for enhancing DRE system QoS, producibility, & quality

Evolution of DRE Systems Development





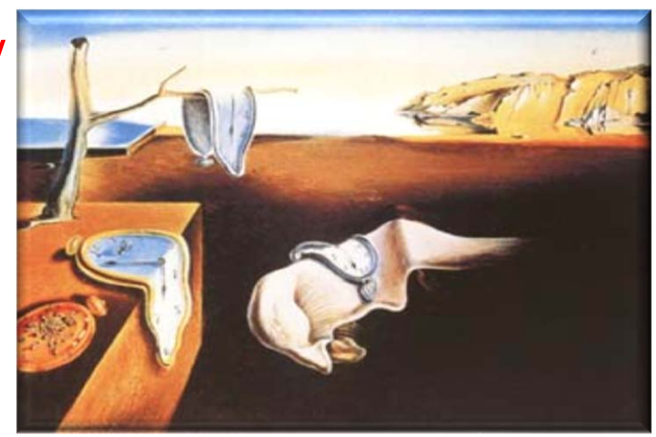
Technology Problems

- Legacy DRE systems are often:
  - Stovepiped
  - Proprietary
  - Brittle & non-adaptive
  - Expensive
  - Vulnerable

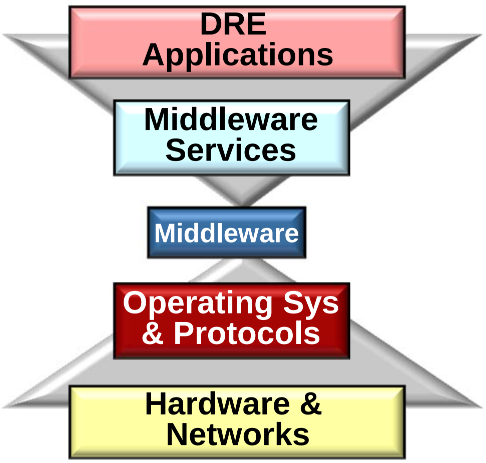
Mission-critical DRE systems have historically been built directly atop hardware, which is

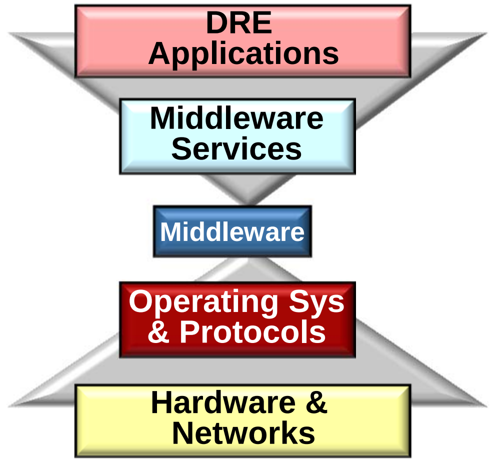
- Tedious
- Error-prone
- Costly over lifecycles

Consequence: Small changes to legacy software often have big (negative) impact on DRE system QoS & producibility



Evolution of DRE Systems Development





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Mission-critical DRE systems have historically been built directly atop hardware, which is

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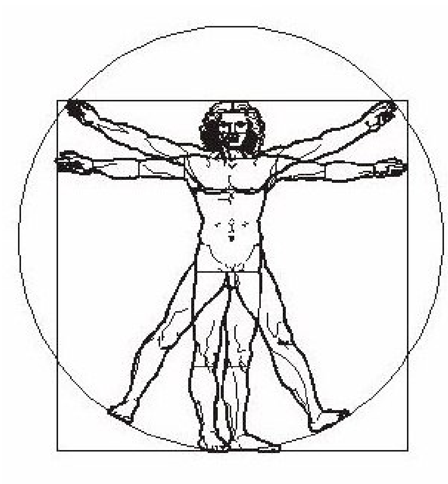
- Costly over lifecycles

What we need are the means to

- Enhance integrated DRE system capability at lower cost over the lifecycle & across the enterprise
- Reduce cycle time of developing & inserting new technologies into DRE systems

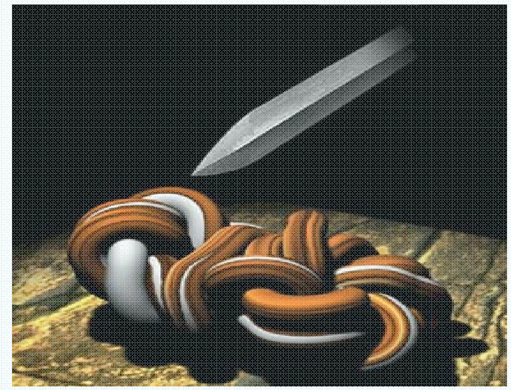
What’s So Hard About DRE Software?

Human Nature



- Organizational impediments
- Economic impediments
- Administrative impediments
- Political impediments
- Psychological impediments

Technical Complexities



Accidental Complexities

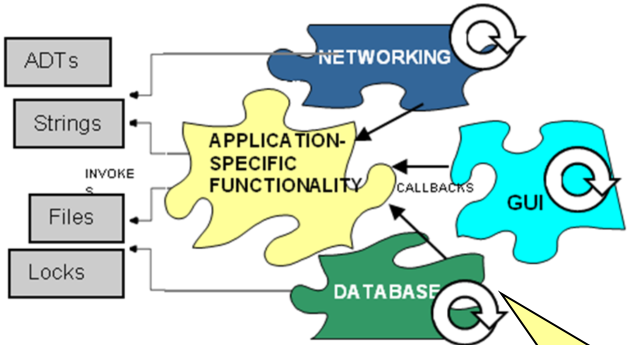
- Low-level APIs & debug tools
- Algorithmic decomposition

Inherent Complexities

- Quality attributes
- Causal ordering
- Scheduling & synchronization
- Deadlock avoidance
- ...

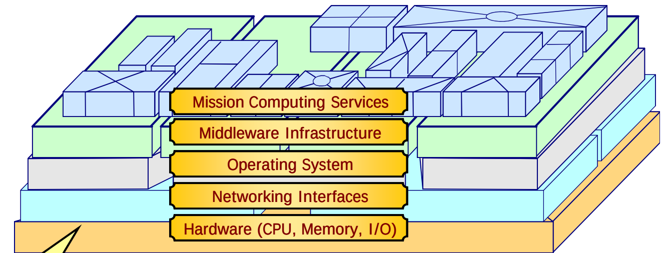
www.dre.vanderbilt.edu/~schmidt/reuse-lessons.html

Systematic Reuse Capabilities for DRE Systems

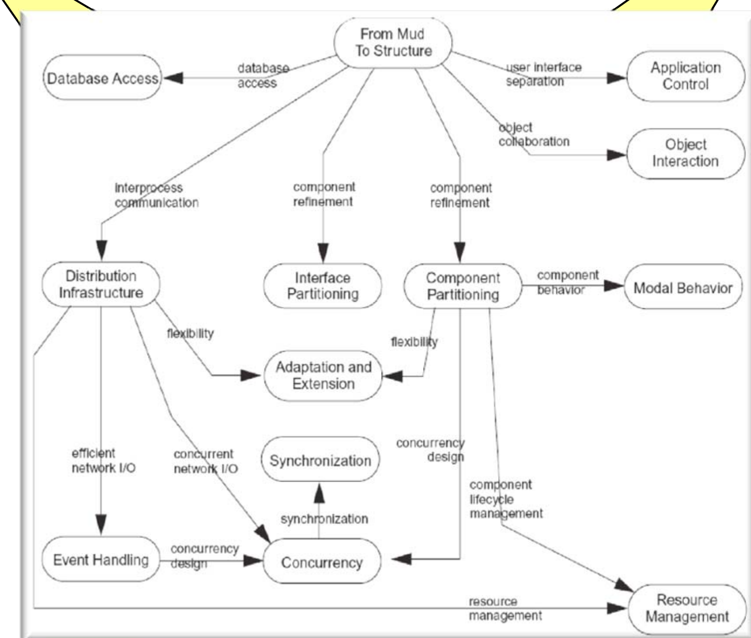


Frameworks

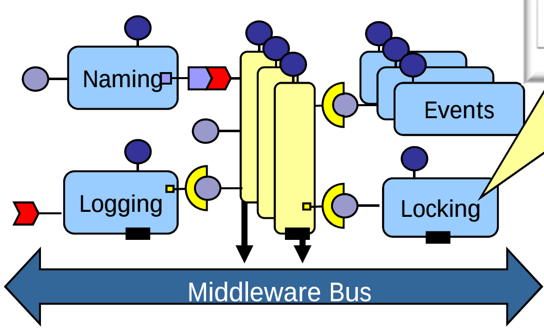
Patterns & Pattern Languages



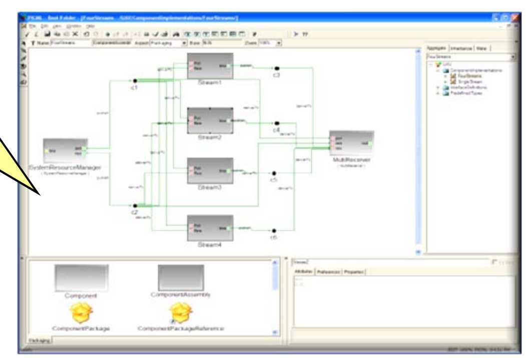
Software Product-lines



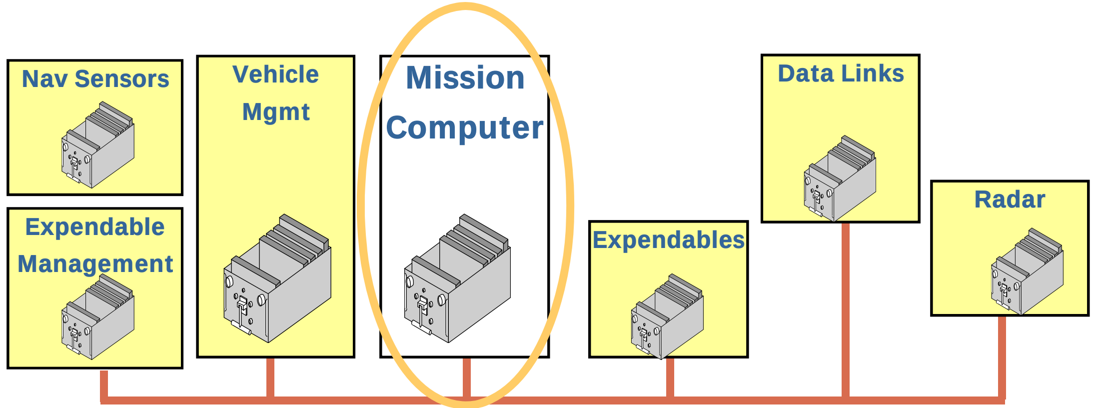
Component-based & Service-Oriented Middleware



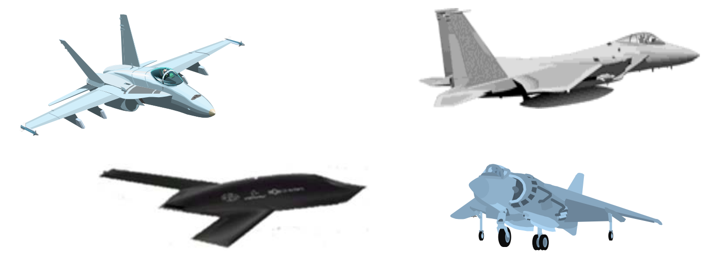
Model-Driven Engineering Tools

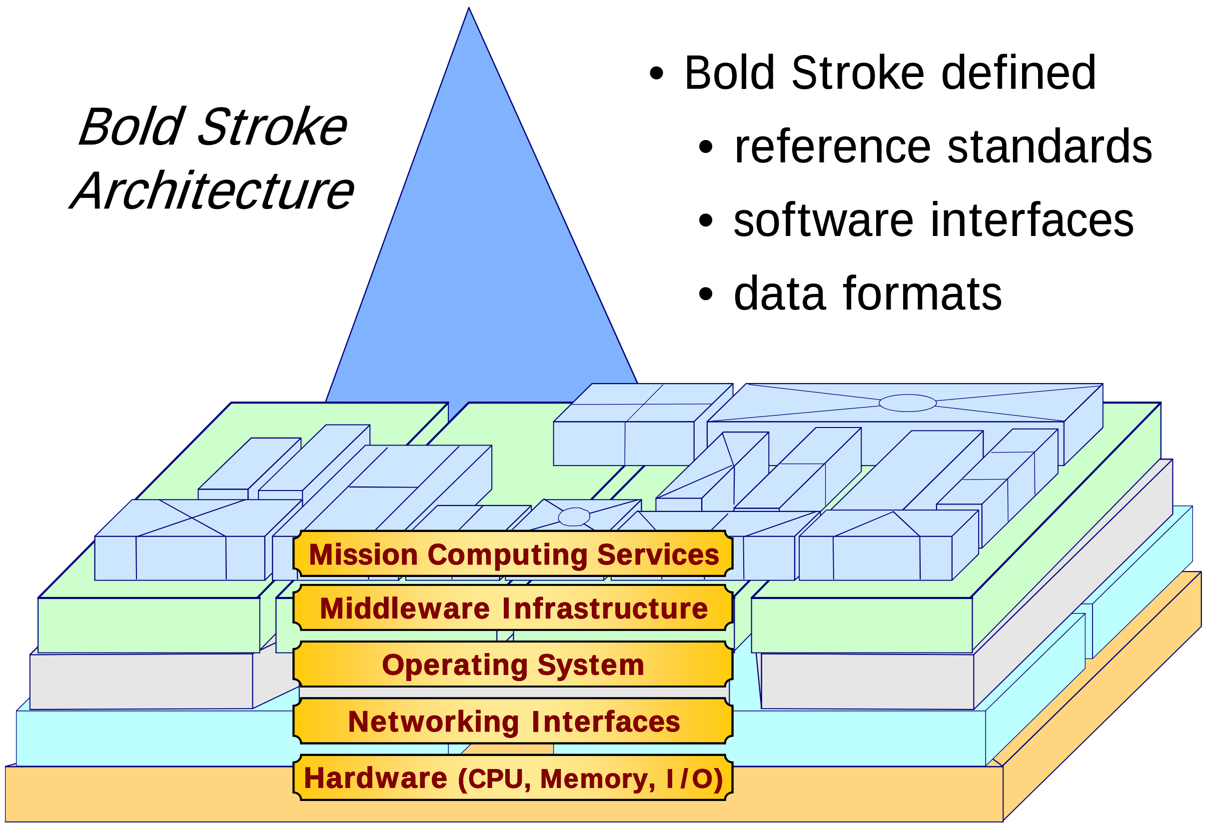


DRE System Case Study: Boeing Bold Stroke



- Systematic reuse platform for Boeing avionics mission computing



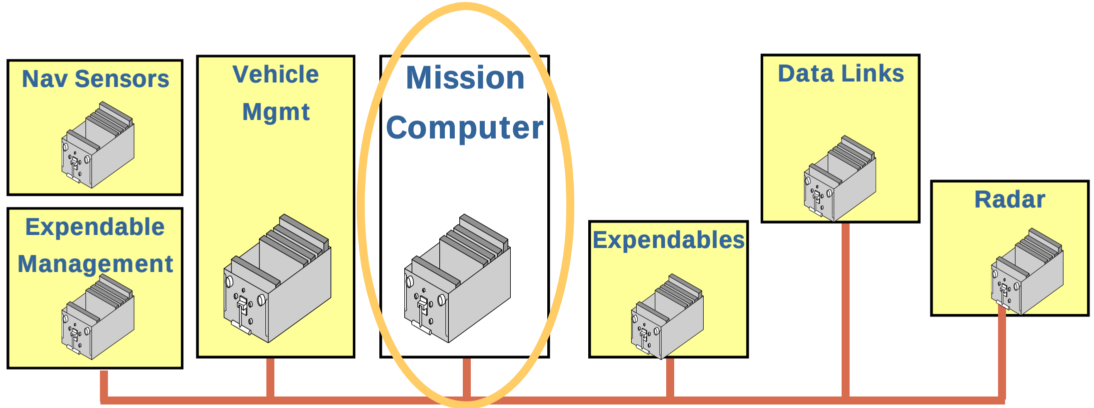


- Bold Stroke defined
  - reference standards
  - software interfaces
  - data formats
  - protocols
  - system services &
  - reusable components

  that enabled distributed computing & allowed distributed applications to coordinate, communicate, execute tasks, & respond to events in an integrated & dependable manner

splc.net/fame/boeing.html

DRE System Case Study: Boeing Bold Stroke



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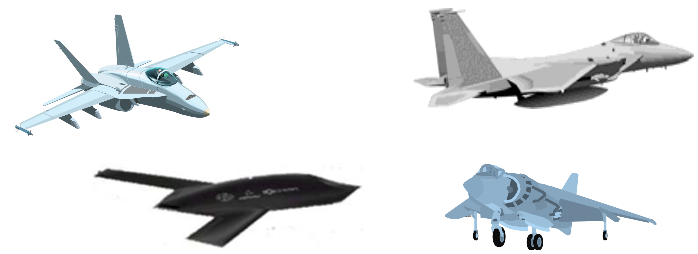

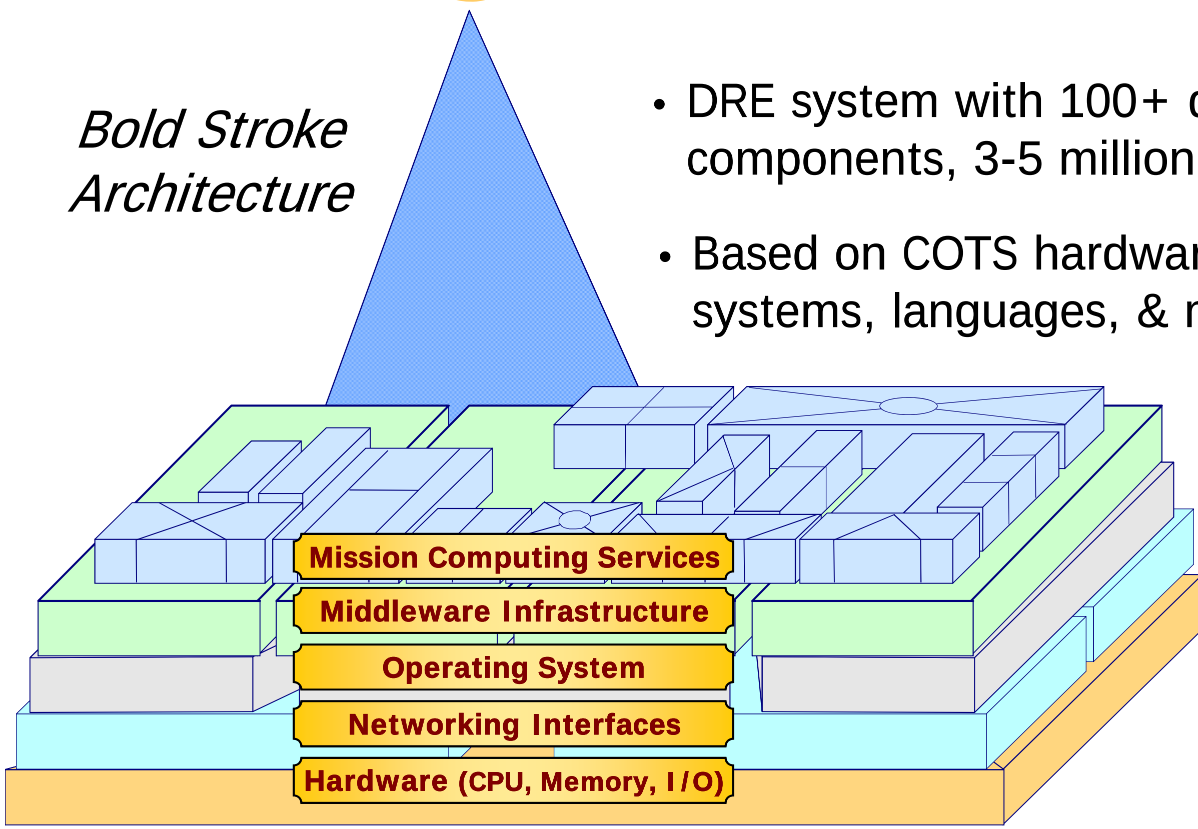

- DRE system with 100+ developers, 3,000+ software components, 3-5 million lines of C++/C/Ada/Java
- Based on COTS hardware, networks, operating systems, languages, & middleware
- Used as an Open Experimentation platform (OEP) for DARPA PCES, MoBIES, SEC, NEST, & MICA programs

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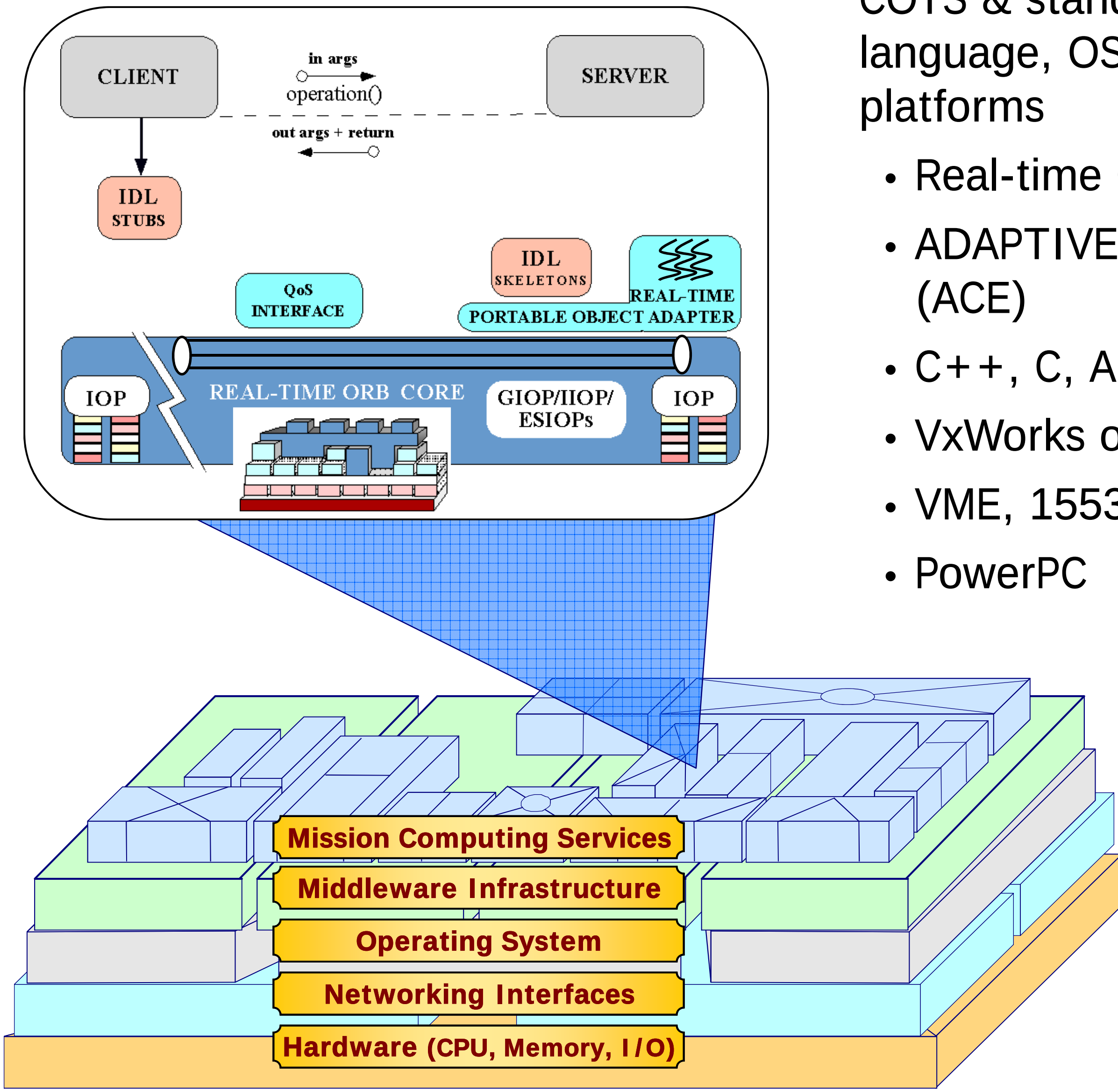
Applying COTS to Bold Stroke



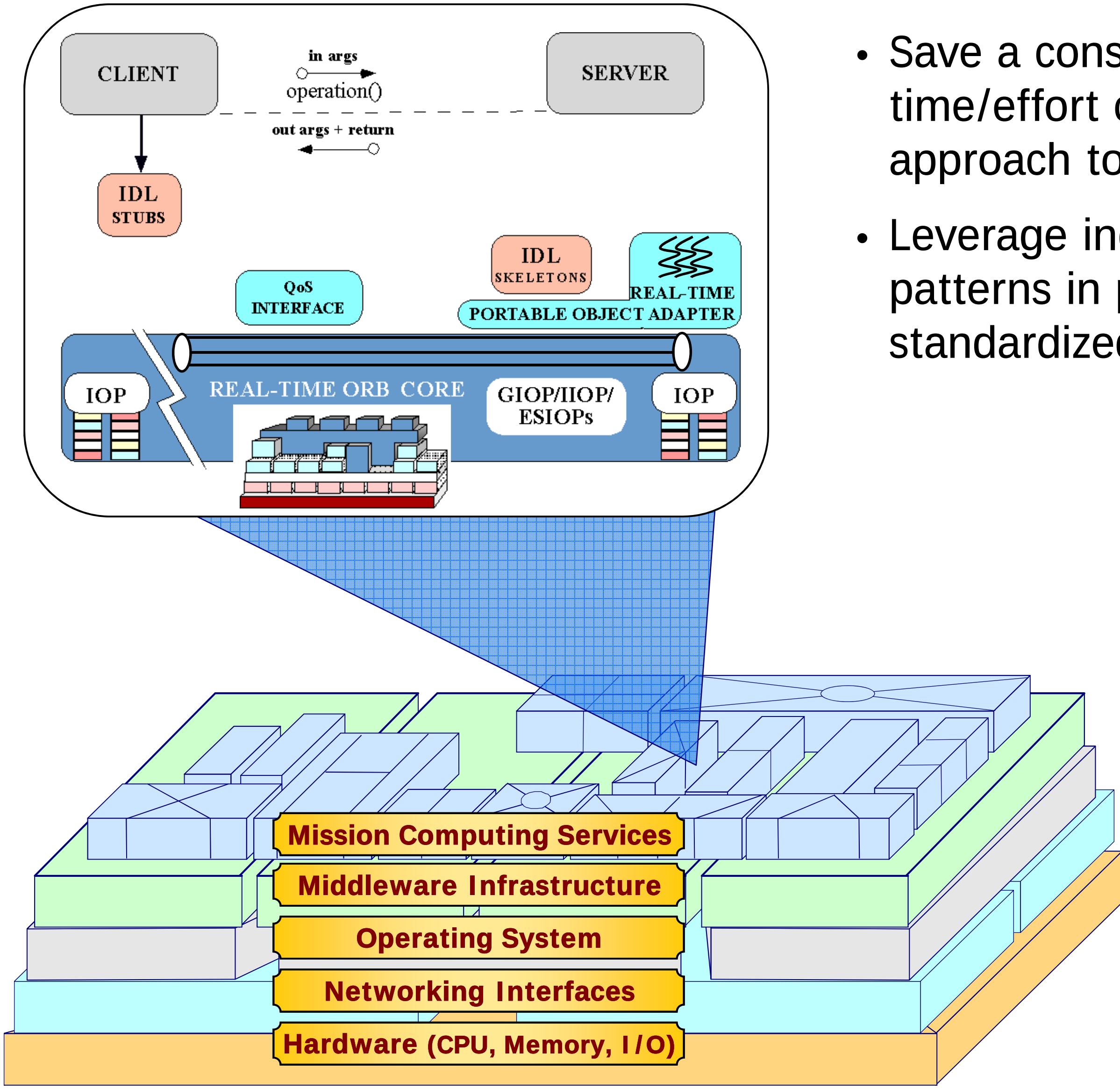
COTS & standards-based middleware, language, OS, network, & hardware platforms

- Real-time CORBA (TAO) middleware
- ADAPTIVE Communication Environment (ACE)
- C++, C, Ada, & Real-time Java
- VxWorks operating system
- VME, 1553, & Link16
- PowerPC

www.dre.vanderbilt.edu/ACE

www.dre.vanderbilt.edu/TAO

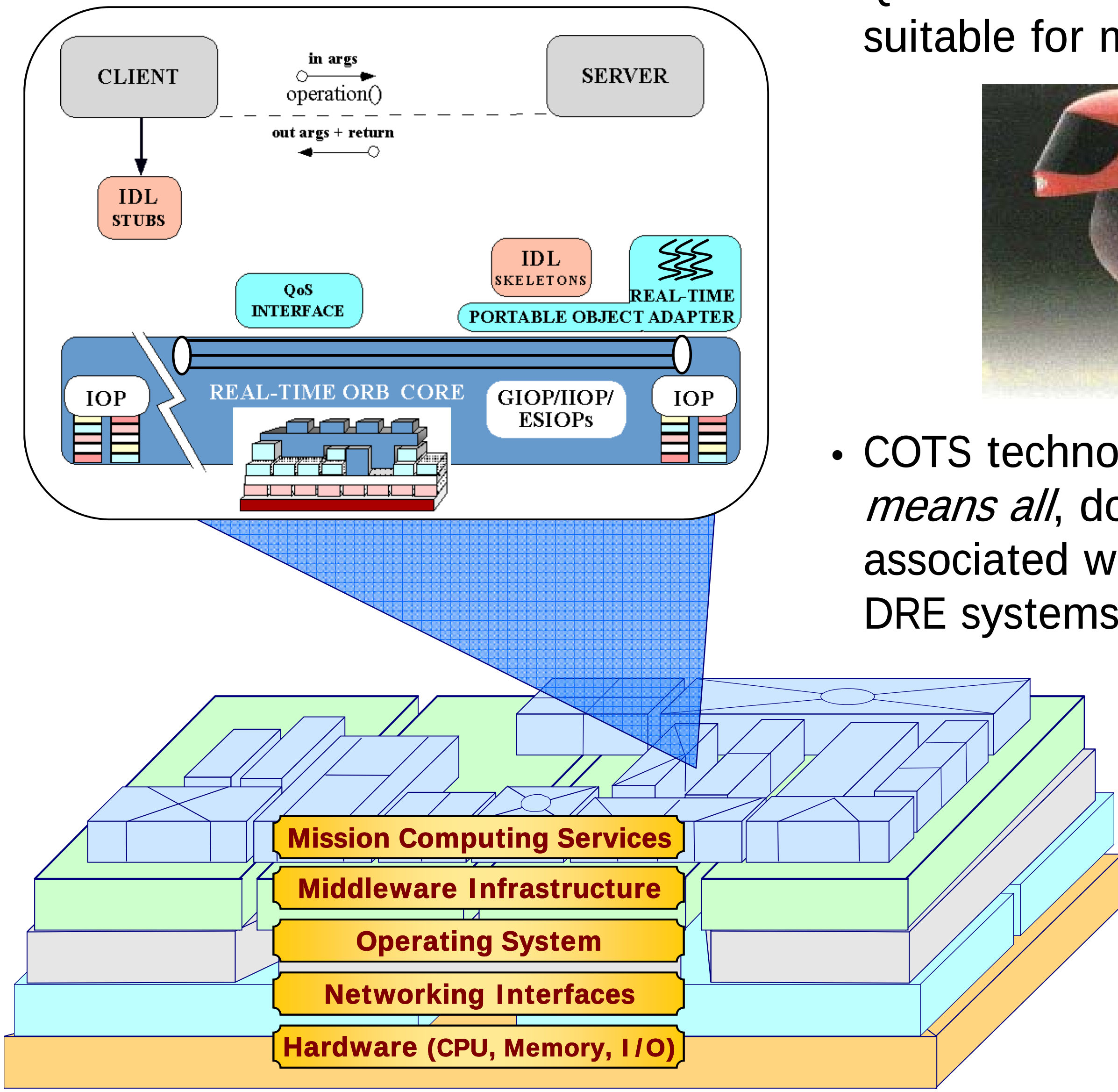
Benefits of Using COTS



- Save a considerable amount of time/effort compared with traditional approach to handcrafting capabilities
- Leverage industry "best practices" & patterns in pre-packaged (& ideally) standardized form

The use of COTS is essentially "outsourcing," with many of the associated pros & cons

Limitations of Using COTS

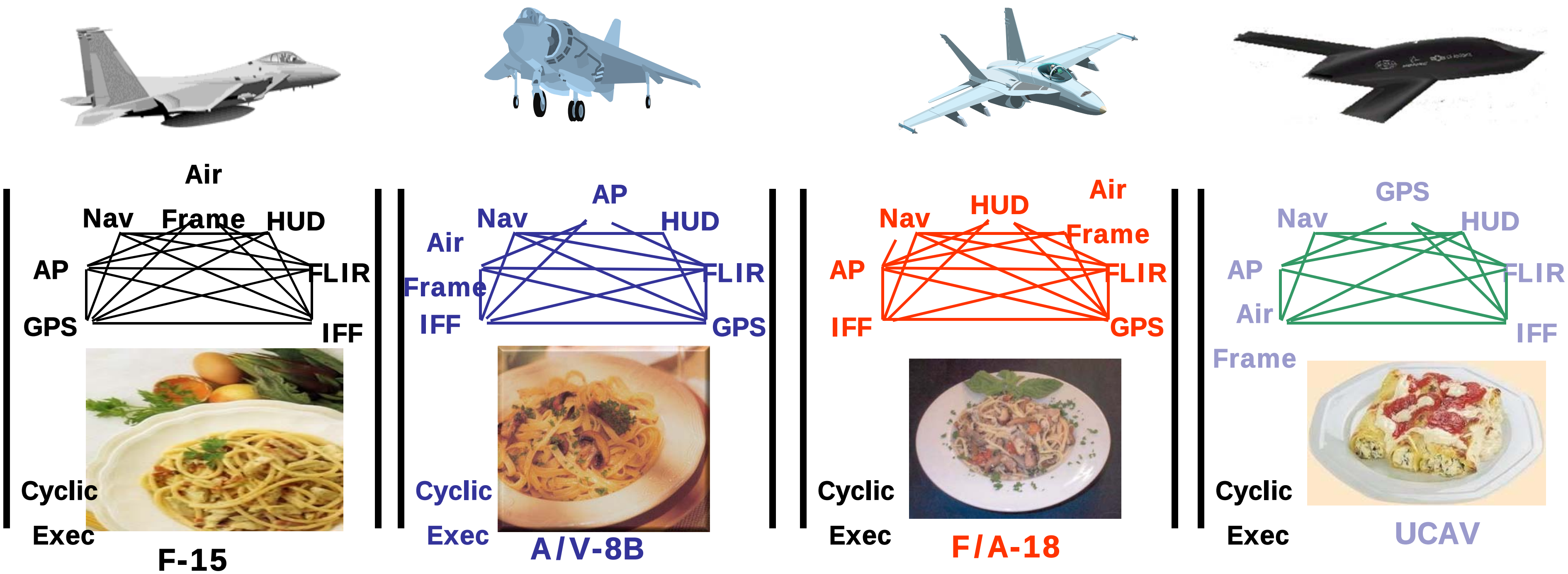


- QoS of COTS components is not always suitable for mission-critical DRE systems

- COTS technologies address some, *but by no means all*, domain-specific challenges associated with developing mission-critical DRE systems

What was needed was a systematic reuse technology for organizing & automating key roles & responsibilities in an application domain

Motivation for Software Product-lines (SPLs)



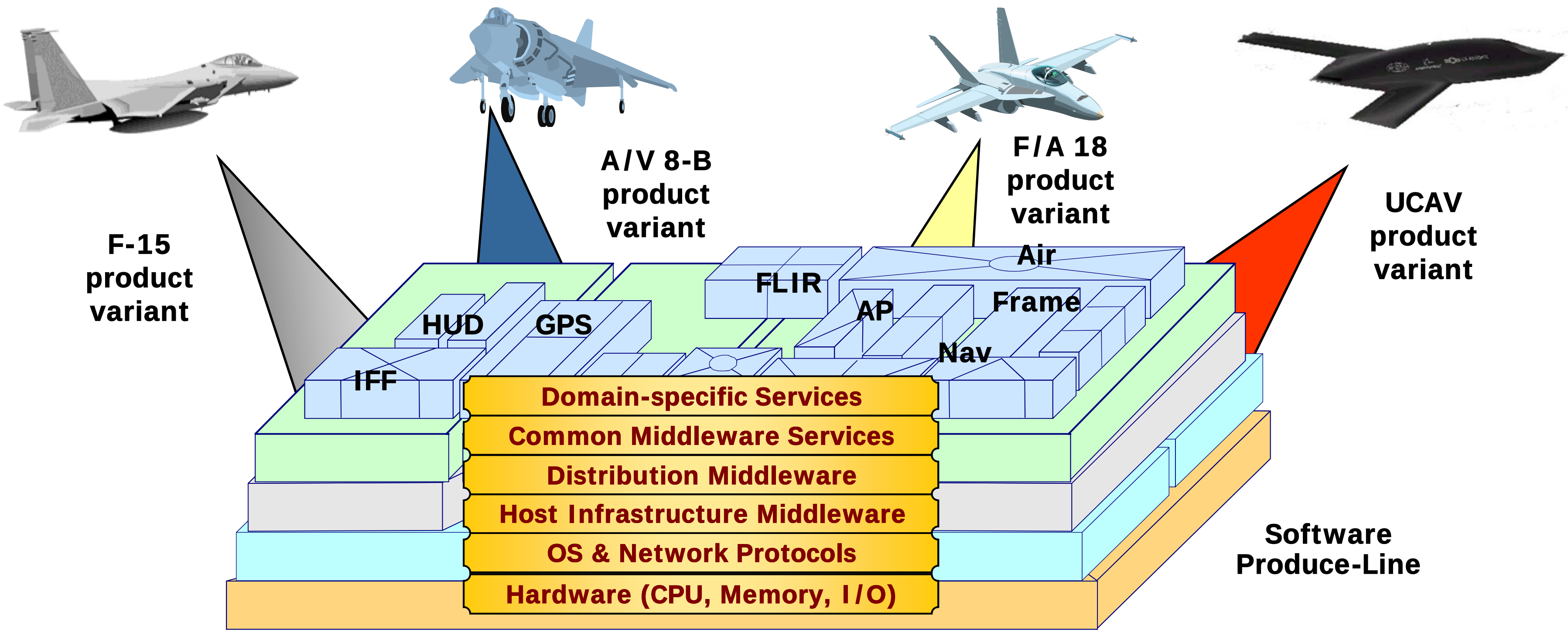
Legacy avionics mission computing systems are:

- Stovepiped
- Proprietary
- Brittle & non-adaptive
- Expensive
- Vulnerable

Consequences:

- Small changes to requirements & environments can break nearly anything
- Lack of any resource can break nearly everything

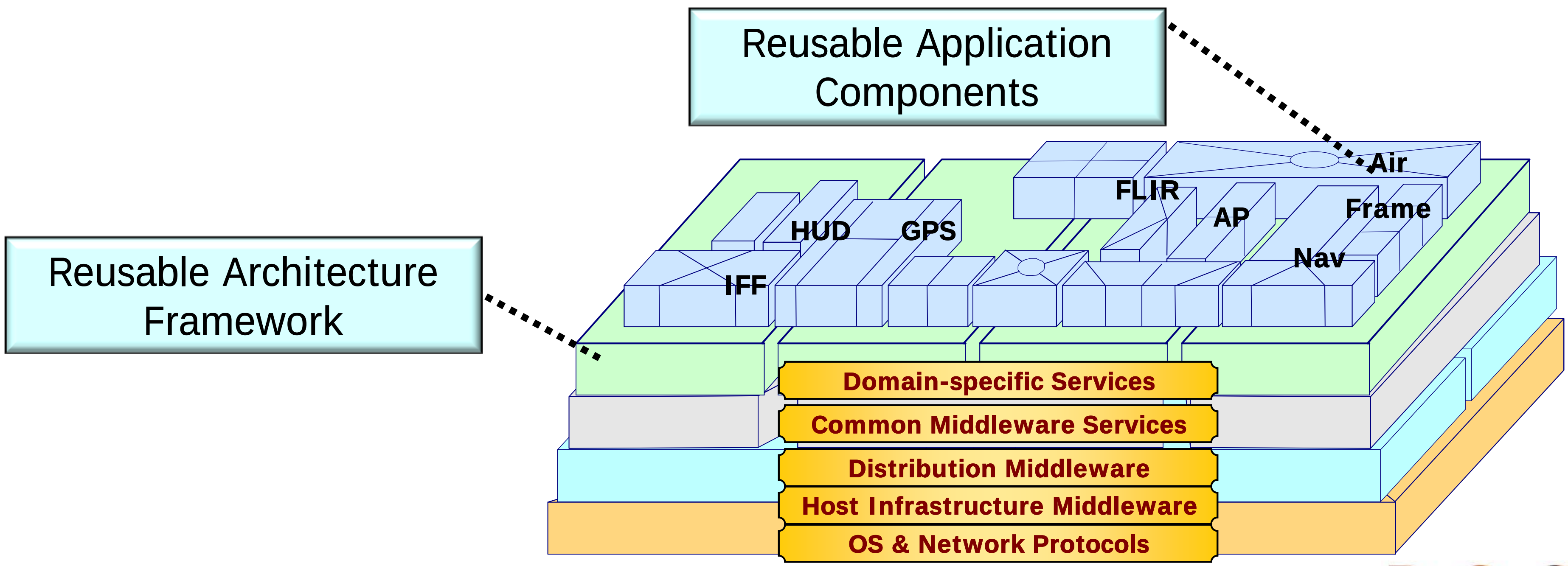
Motivation for Software Product-lines (SPLs)



- SPLs factor out general-purpose & domain-specific services from traditional application responsibility in DRE systems
- Manage software variation while reusing large amounts of code that implement common features within a particular domain
- SPLs offer many opportunities to configure product variants
  - e.g., component distribution & deployment, user interfaces & operating systems, algorithms & data structures, etc.

Overview of Software Product-lines (SPLs)

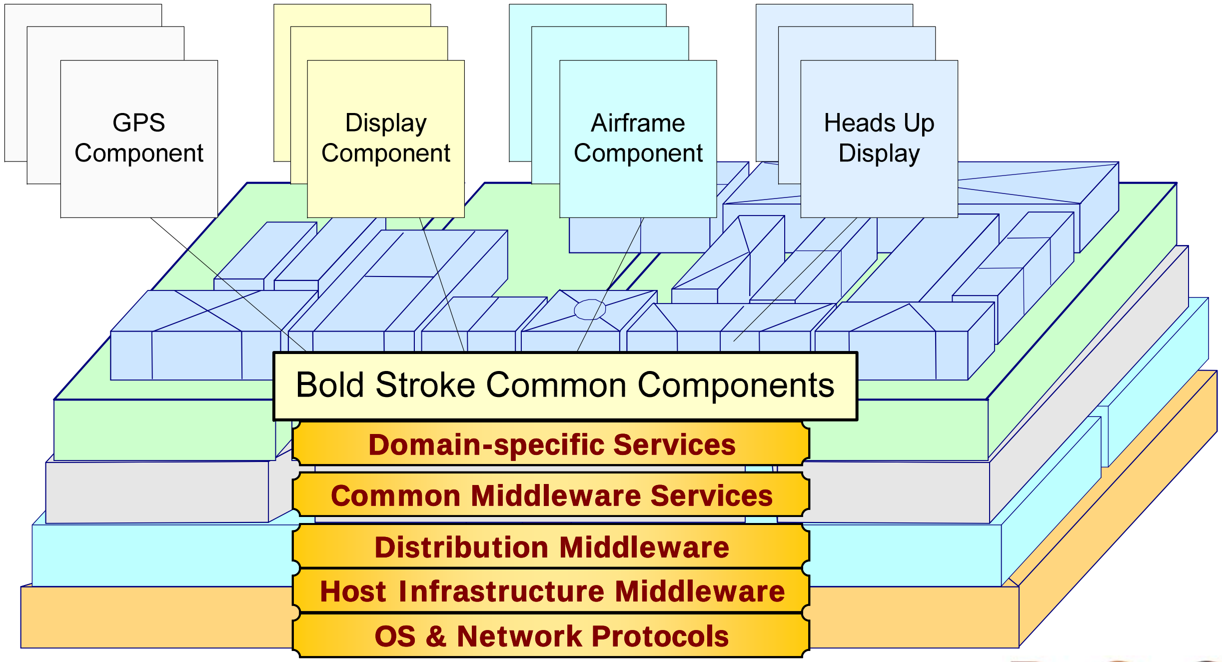
- SPL characteristics are captured via *Scope, Commonalities, & Variabilities (SCV) analysis*
  - This process can be applied to identify commonalities & variabilities in a domain to guide development of a SPL
- Applying SCV to Bold Stroke
  - Scope defines the domain & context of the SPL
    - e.g., Bold Stroke component architecture, object-oriented application frameworks, & associated components (GPS, Airframe, & Display)



Applying SCV to the Bold Stroke SPL

Commonalities describe the attributes that are common across all members of the SPL family

- Common object-oriented frameworks & set of component types
  - e.g., GPS, Airframe, Navigation, & Display components
- Common middleware infrastructure
- e.g., Real-time CORBA & Lightweight CORBA Component Model (CCM) variant called Prism

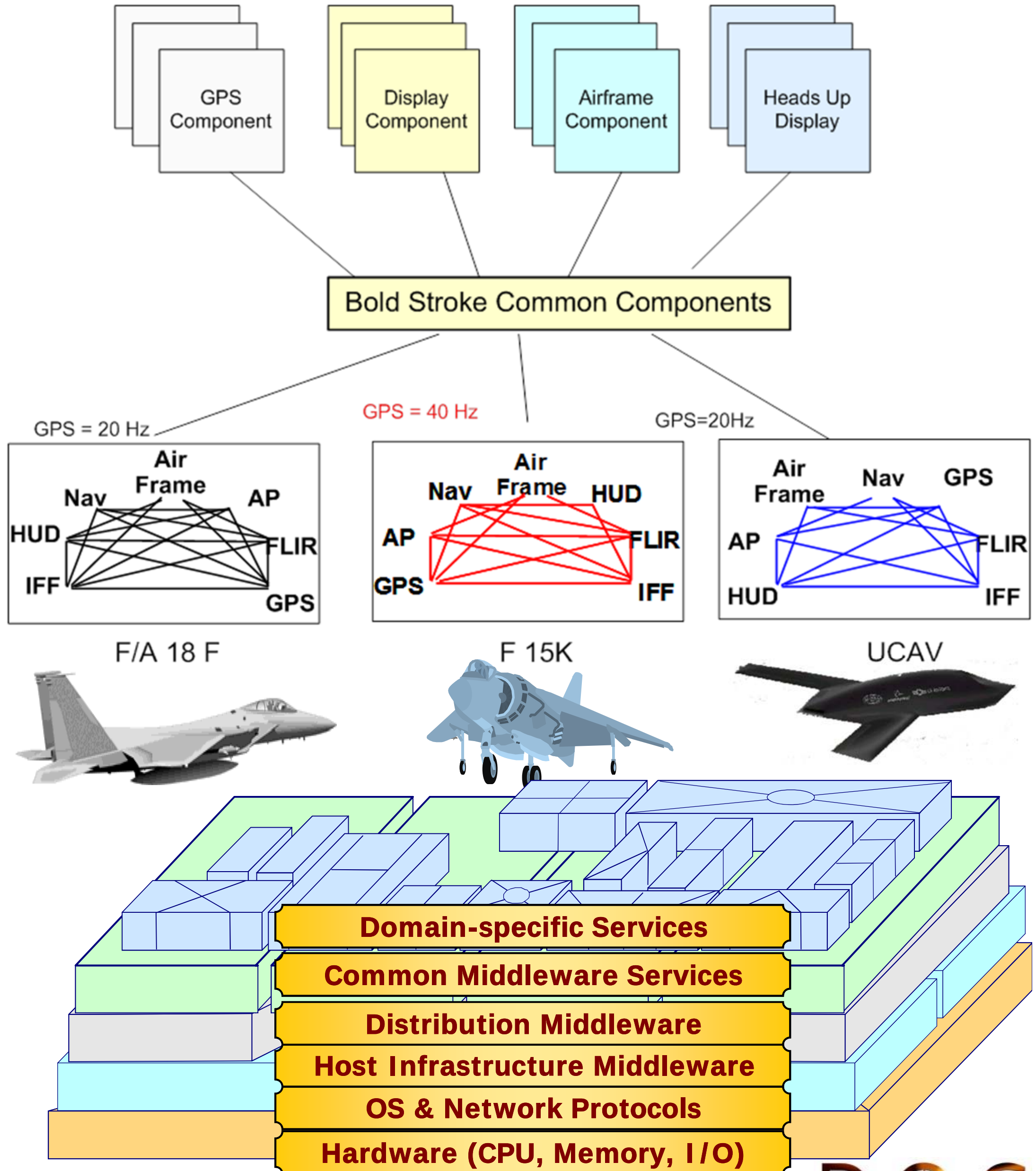


Applying SCV to the Bold Stroke SPL

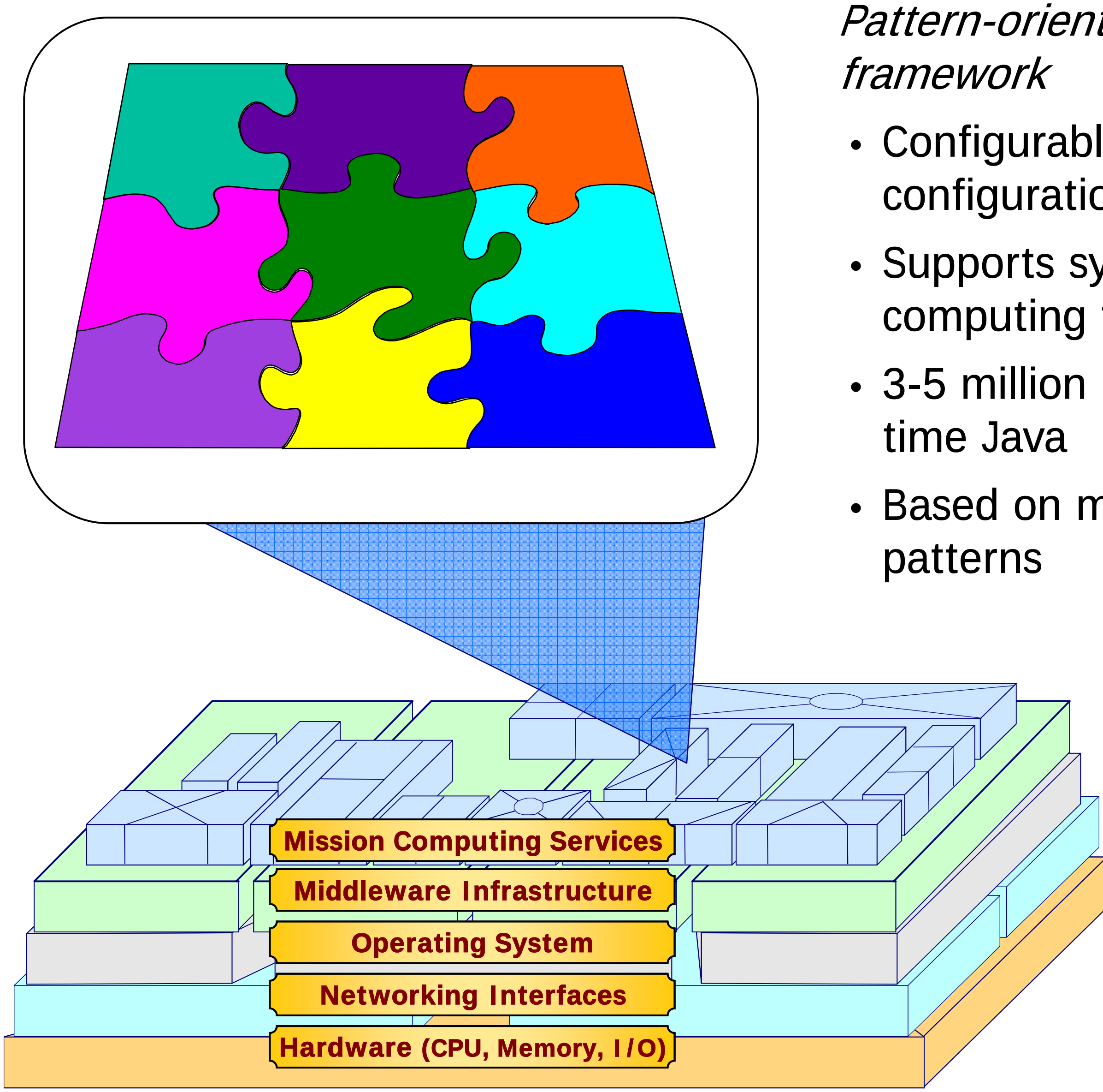
Variabilities describe the attributes unique to the different members of the family

- Product-dependent component implementations (GPS/INS)
- Product-dependent component connections
- Product-dependent component assemblies
  - e.g., different packages for different customers & countries
- Different hardware, OS, & network/bus configurations

Patterns & *frameworks* are essential for developing reusable SPLs



Applying Patterns & Frameworks to Bold Stroke



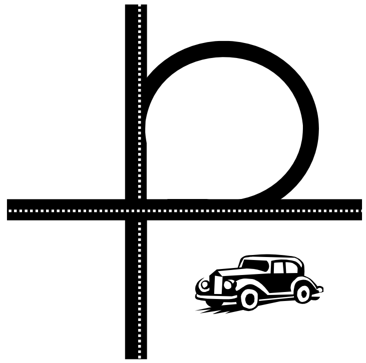
Pattern-oriented domain-specific application framework

- Configurable to variable infrastructure configurations
- Supports systematic reuse of mission computing functionality
- 3-5 million lines of C++, C, Ada, & Real-time Java
- Based on many architecture & design patterns

Patterns & frameworks are also used throughout Bold Stroke COTS software infrastructure

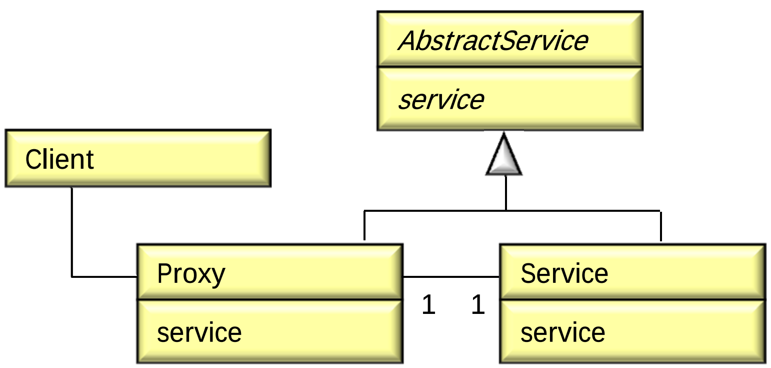
Overview of Patterns

- Present *solutions* to common software *problems* arising within a particular *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



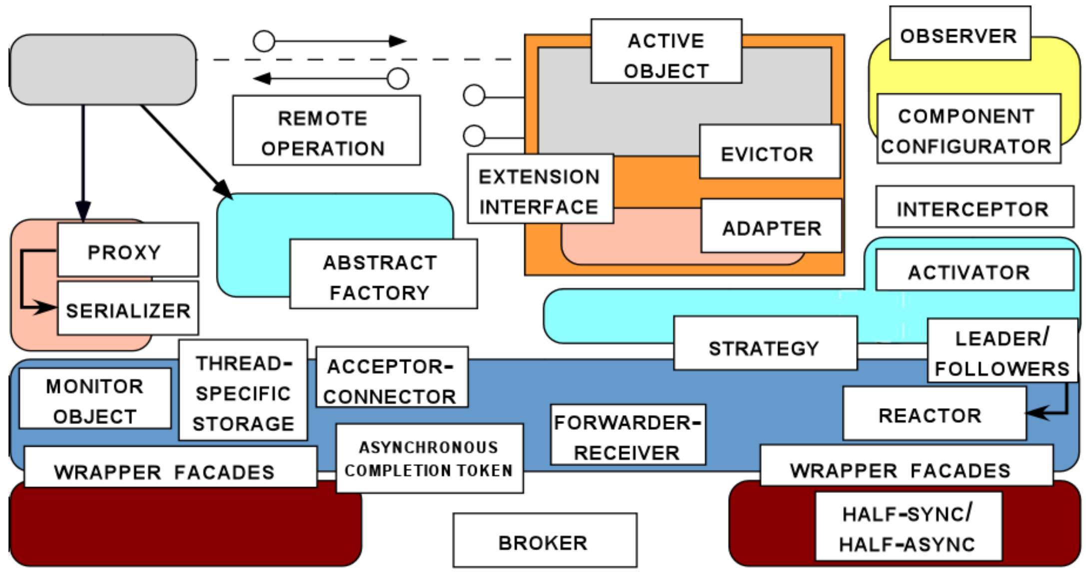
The Proxy Pattern

- Codify expert knowledge of design strategies, constraints, & best practices

Overview of Pattern Languages

Motivation

- Individual patterns & pattern catalogs are insufficient
- Software modeling methods & tools largely just illustrate *what/how* – not *why* – systems are designed



Benefits of Pattern Languages

- Define a *vocabulary* for talking about software development problems
- Provide a *process* for the orderly resolution of these problems
- Help to generate & reuse software *architectures*

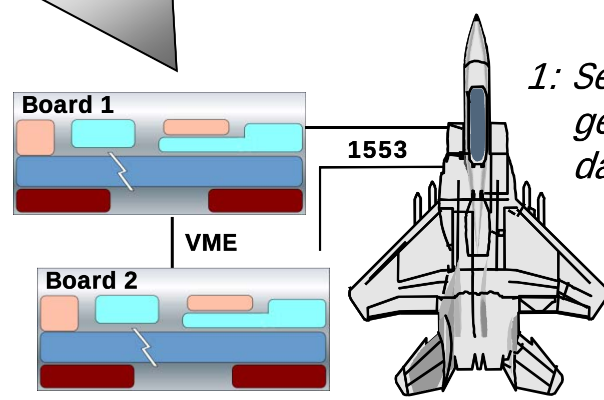
Legacy Avionics Architectures

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 disSPLy (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

Legacy Avionics Architectures

Key system characteristics

- Hard & soft real-time deadlines
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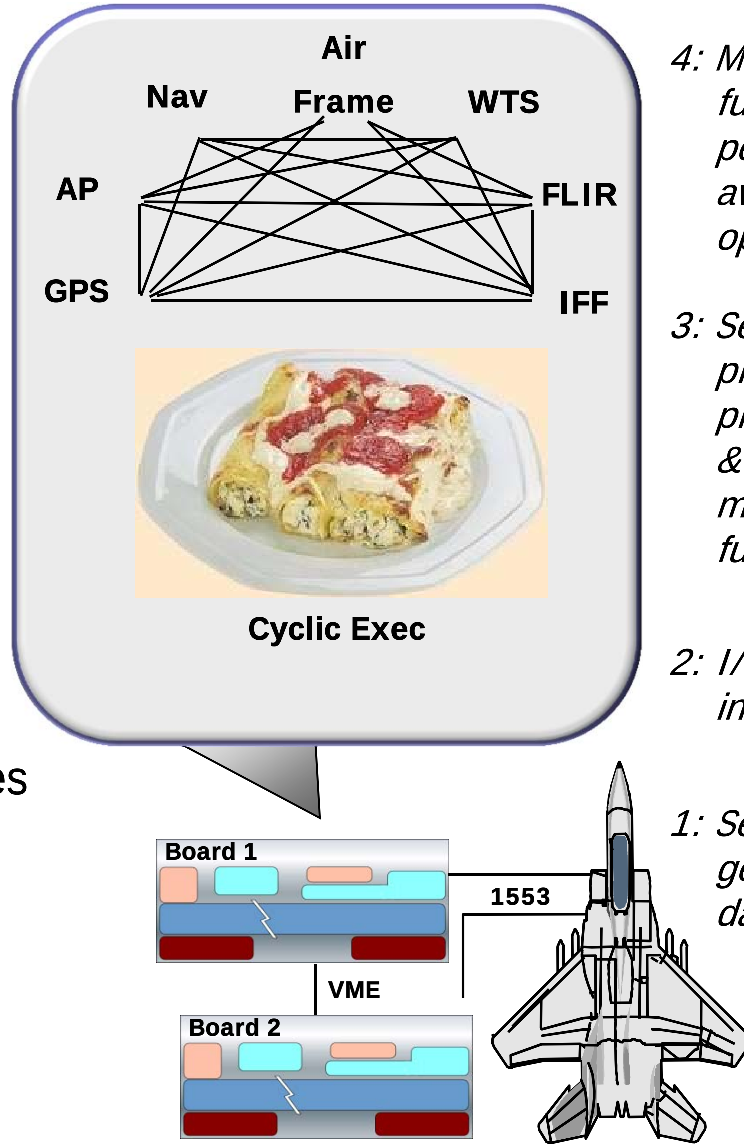

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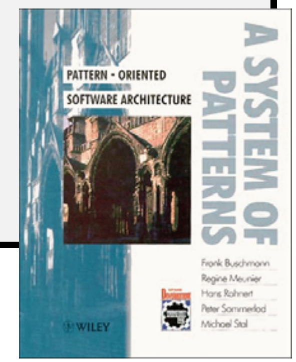
Limitations with legacy avionics architectures

- Stovepiped
- Proprietary
- Expensive
- Vulnerable

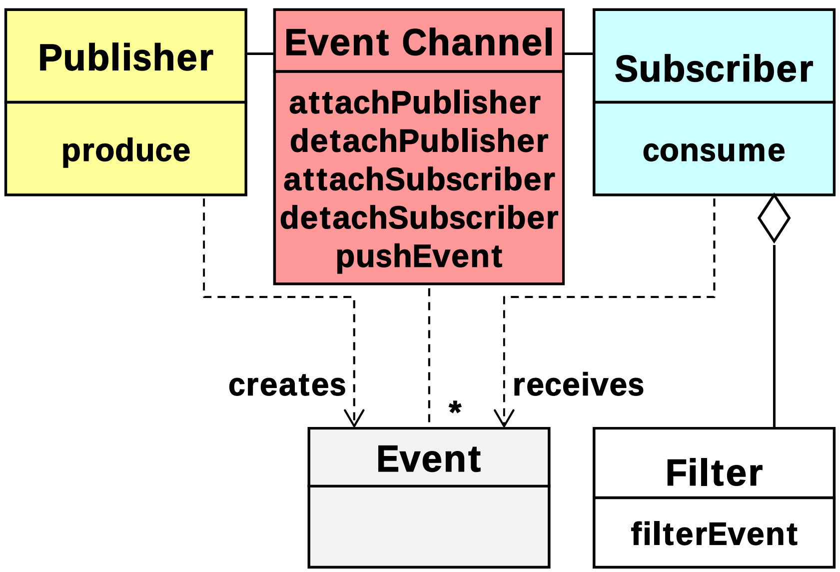
- *Tightly coupled*
- *Hard to schedule*
- *Brittle & non-adaptive*

Decoupling Avionics Components

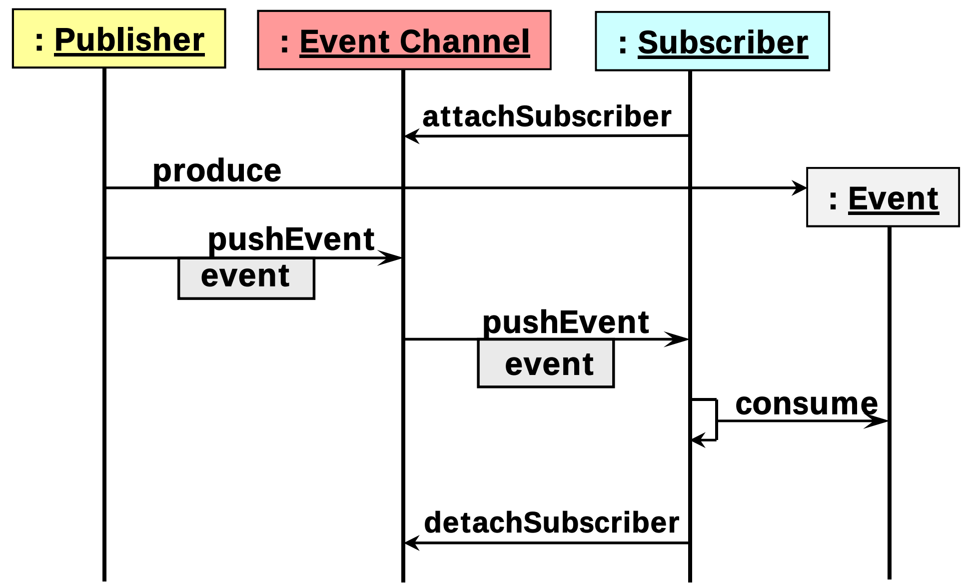
Context	Problems	Solution
• I/O driven DRE application • Complex dependencies • Real-time constraints	• Tightly coupled components • Hard to schedule • Expensive to evolve	• Apply the *Publisher-Subscriber* architectural pattern to distribute periodic, I/O-driven data from a single point source to a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



Structure



Dynamics



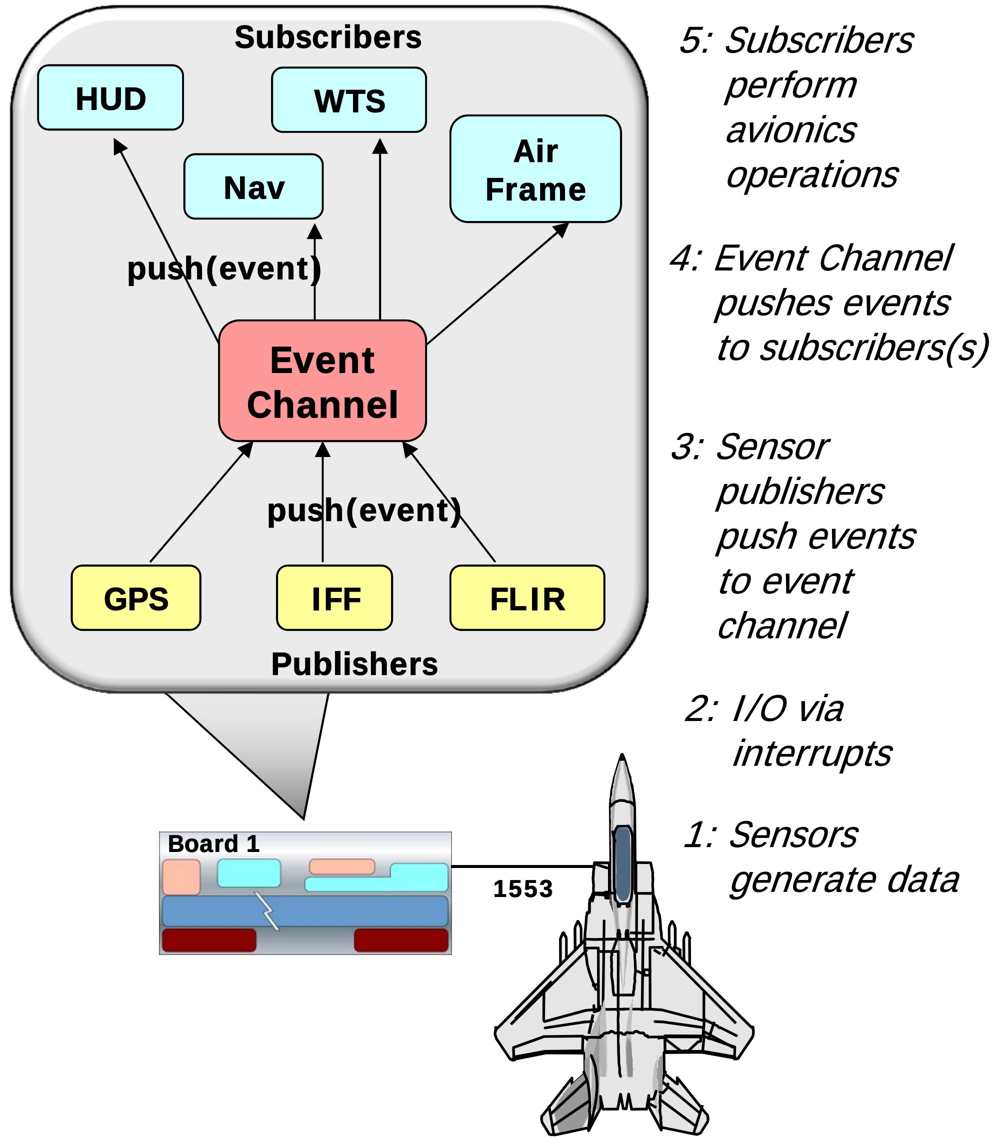
Applying Publisher-Subscriber to Bold Stroke

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

- Anonymous publisher & subscriber relationships
- Group communication
- Asynchrony

Implementing *Publisher-Subscriber* pattern for mission computing:

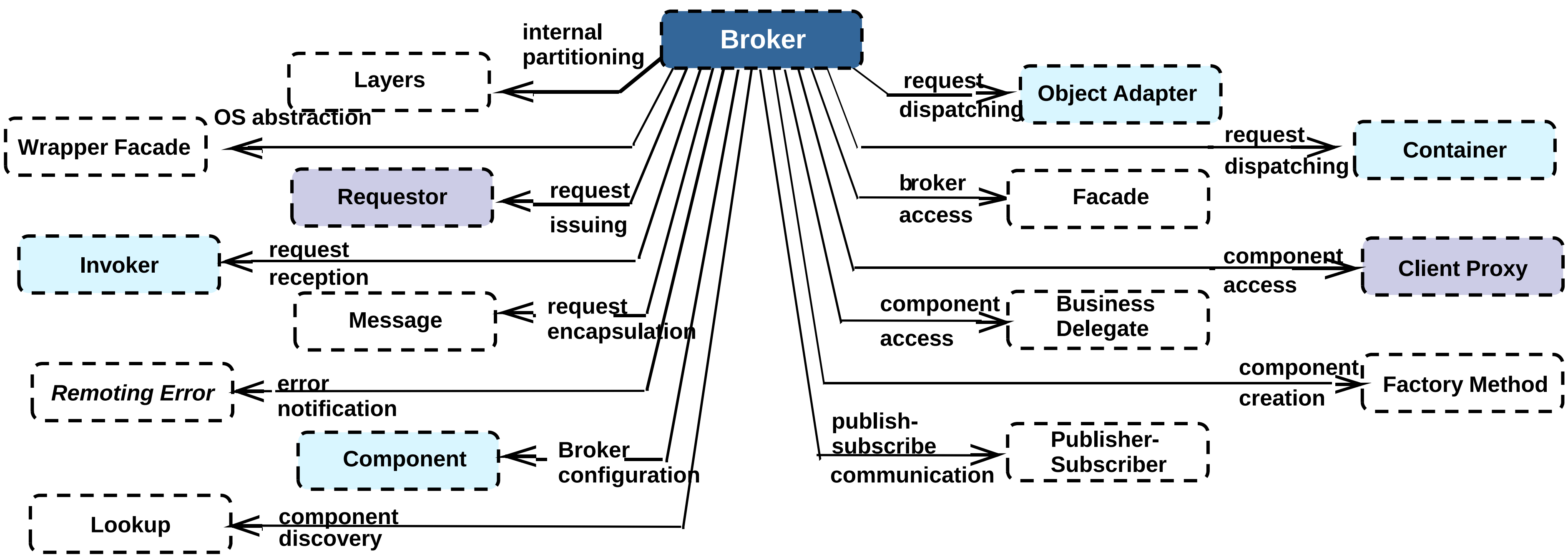
- *Event notification model*
  - Push control vs. pull data interactions
- *Scheduling & synchronization strategies*
  - e.g., priority-based dispatching & preemption
- *Event dependency management*
  - e.g., filtering & correlation mechanisms



Distributing Avionics Components

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



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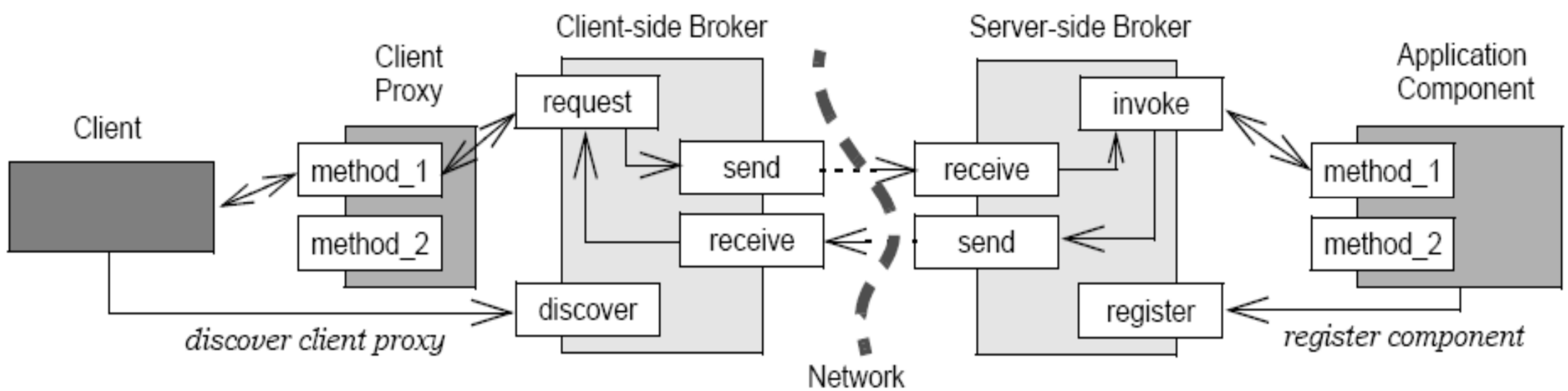
Structure & Dynamics



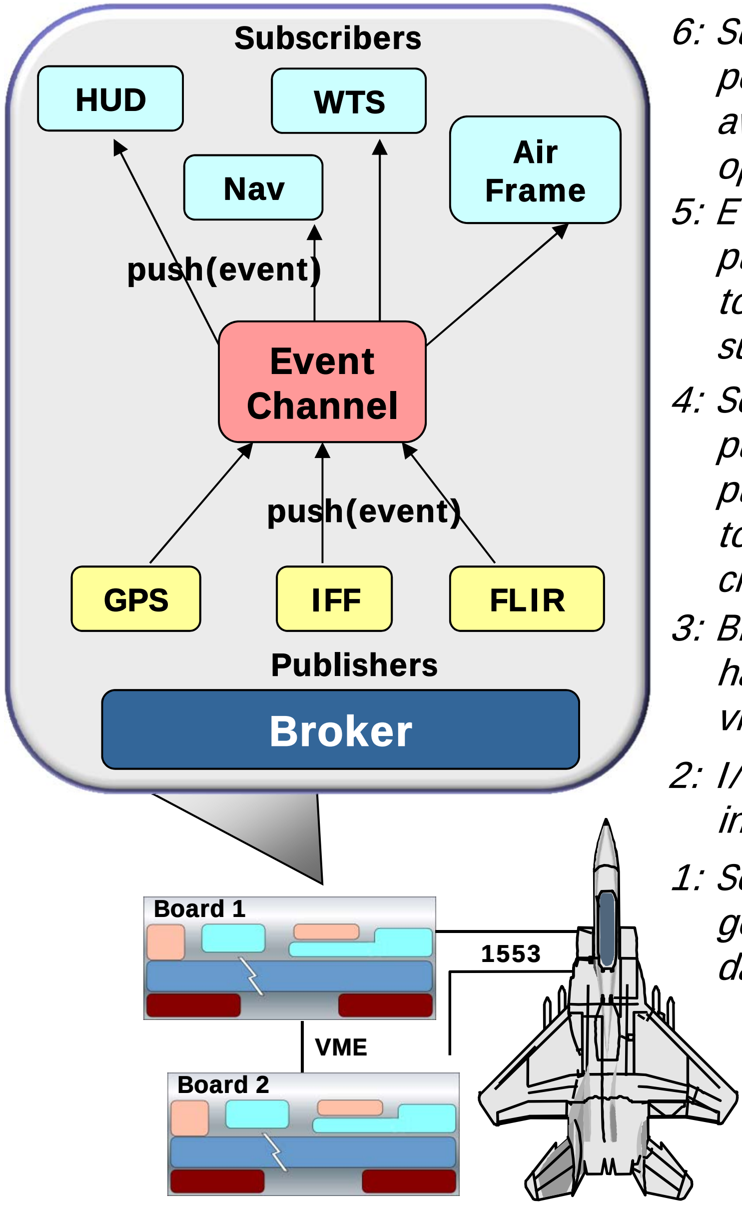
Applying the Broker Pattern to Bold Stroke

Bold Stroke uses the *Broker* pattern to shield distributed applications from environment heterogeneity, *e.g.,*

- Programming languages
- Operating systems
- Networking protocols
- Hardware

A key consideration for implementing the *Broker* pattern for mission computing applications is *QoS* support

- e.g., latency, jitter, priority preservation, dependability, security, etc.



6: Subscribers perform avionics operations

5: Event Channel pushes events to subscribers(s)

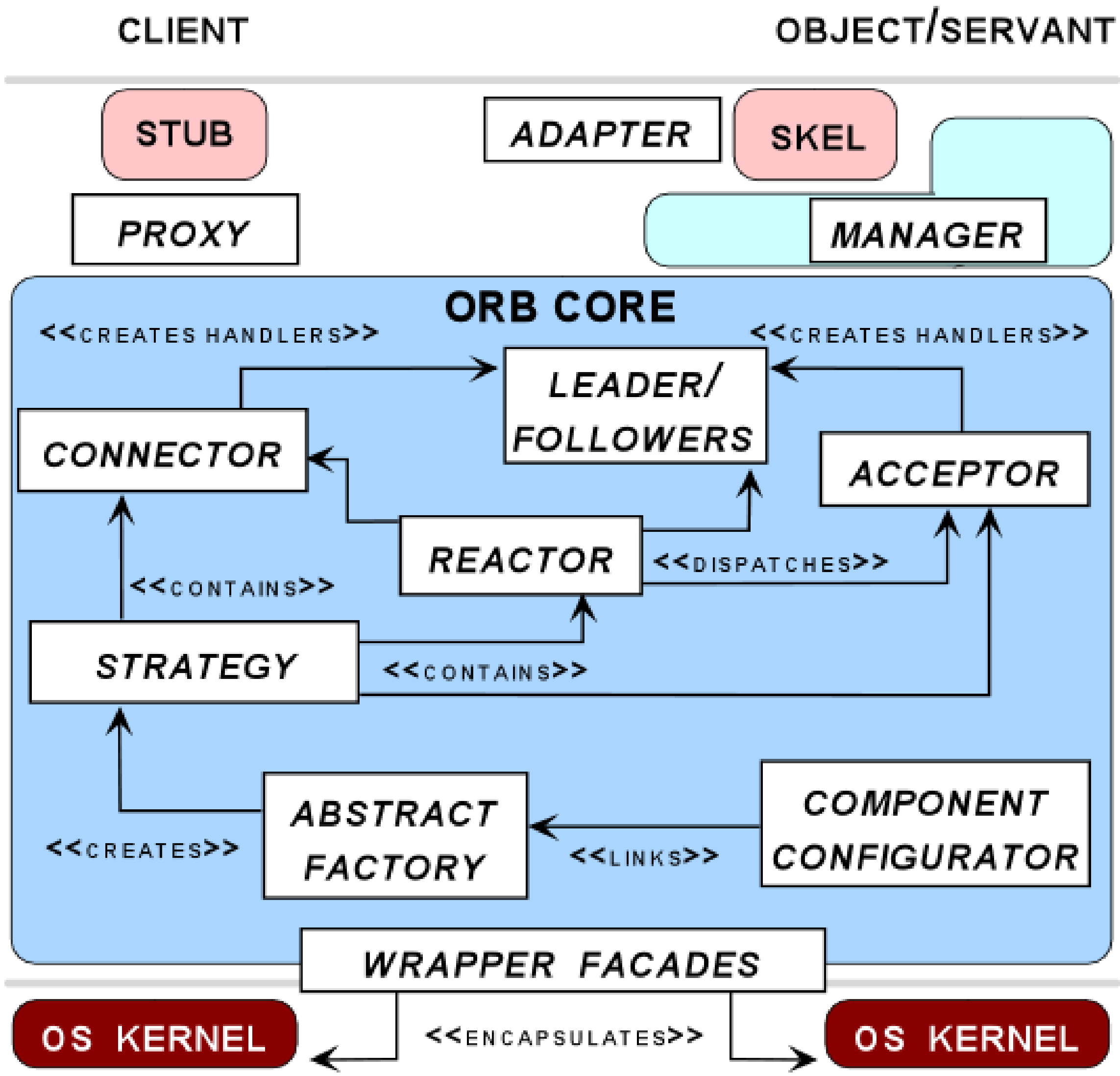
4: Sensor publishers push events to event channel

3: Broker handles I/O via upcalls

2: I/O via interrupts

1: Sensors generate data

Key Patterns Used to Implement Broker

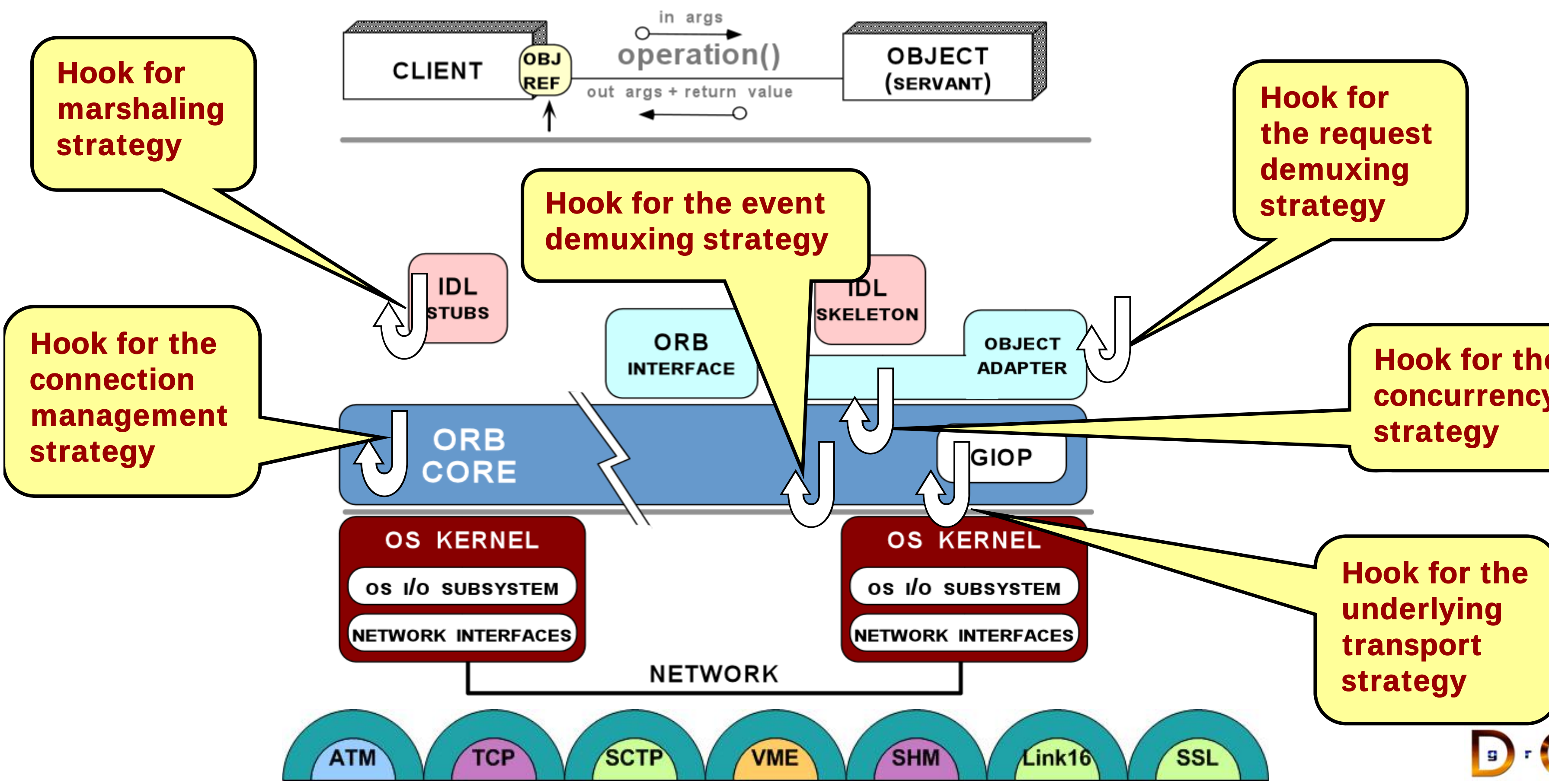


- *Wrapper facades* enhance portability
- *Proxies & adapters* simplify client & server applications, respectively
- *Component Configurator* dynamically configures *Factories*
- *Factories* produce *Strategies*
- *Strategies* implement interchangeable policies
- Concurrency strategies use *Reactor* & *Leader/Followers*
- *Acceptor-Connector* decouples connection management from request processing
- *Managers* optimize request demultiplexing

www.dre.vanderbilt.edu/~schmidt/PDF/ORB-patterns.pdf

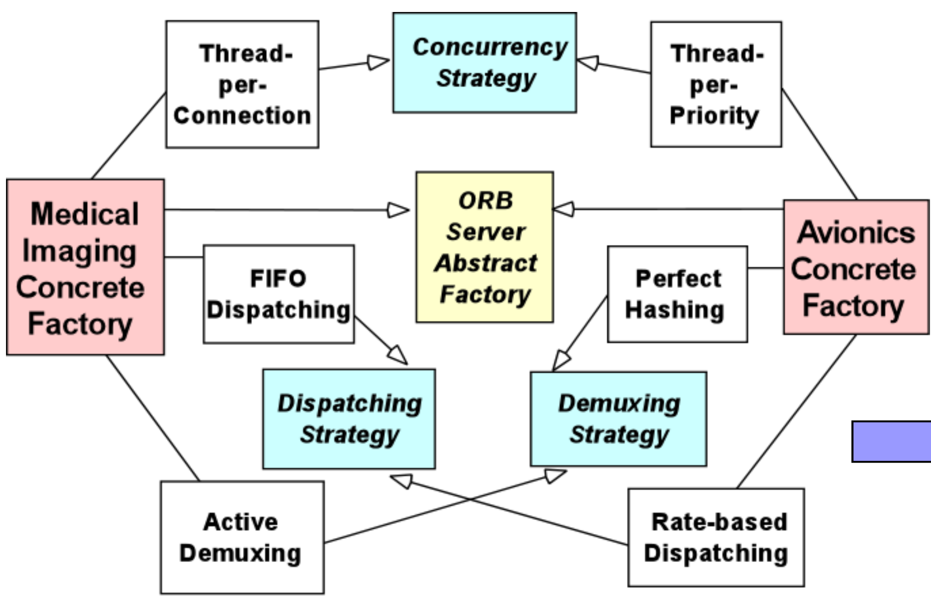
Enhancing Broker Flexibility with Strategy

Context	Problem	Solution
• Multi-domain reusable middleware Broker	• Flexible Brokers must support multiple policies for event & request demuxing, scheduling, (de)marshaling, connection mgmt, request transfer, & concurrency	• Apply the ***Strategy*** pattern to factory out commonality amongst variable Broker algorithms & policies

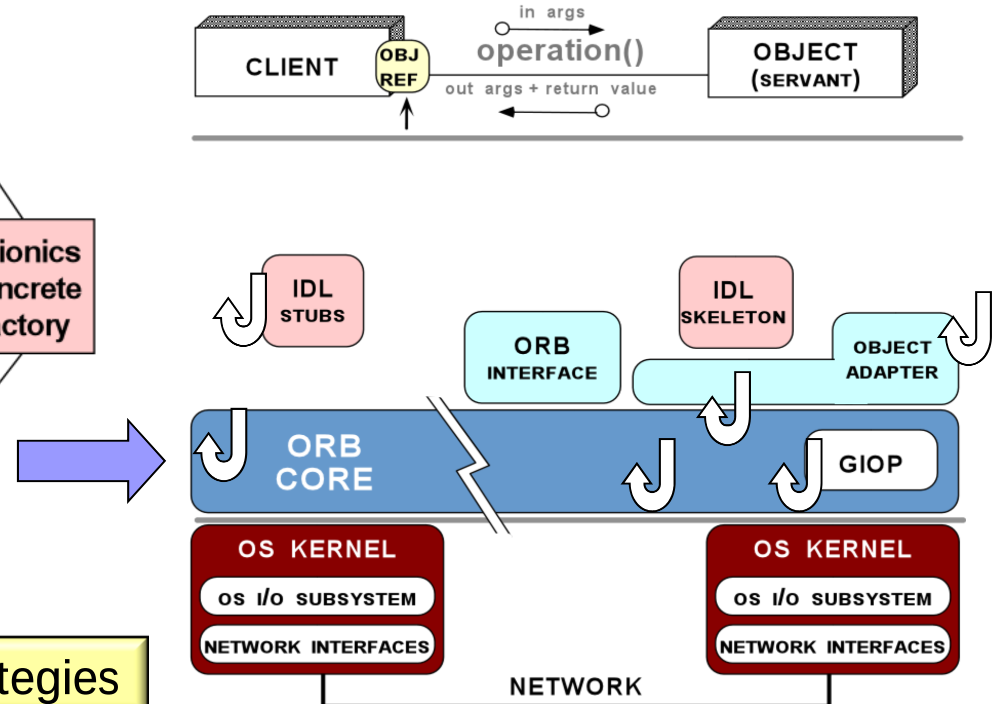


Consolidating Strategies with Abstract Factory

Context	Problem	Solution
• A heavily strategized framework or application	• Aggressive use of Strategy pattern creates a configuration nightmare • Managing many individual strategies is hard • It's hard to ensure that groups of semantically compatible strategies are configured	• Apply the ***Abstract Factory*** pattern to consolidate multiple Broker strategies into semantically compatible configurations

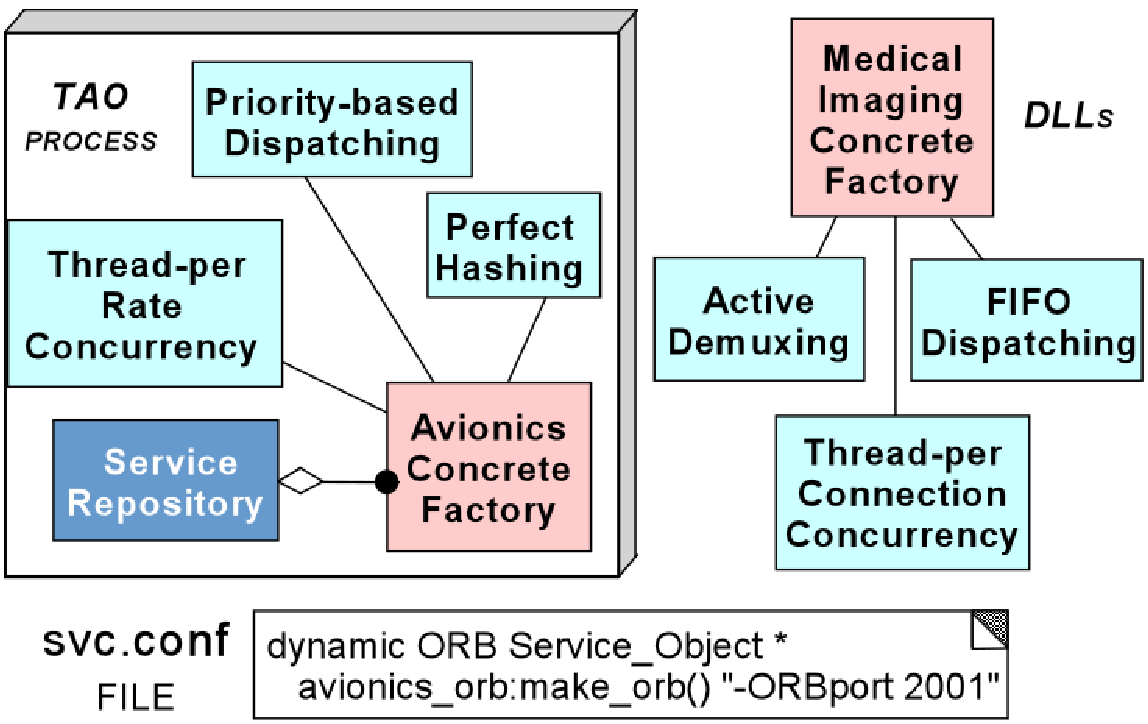


Concrete factories create groups of strategies



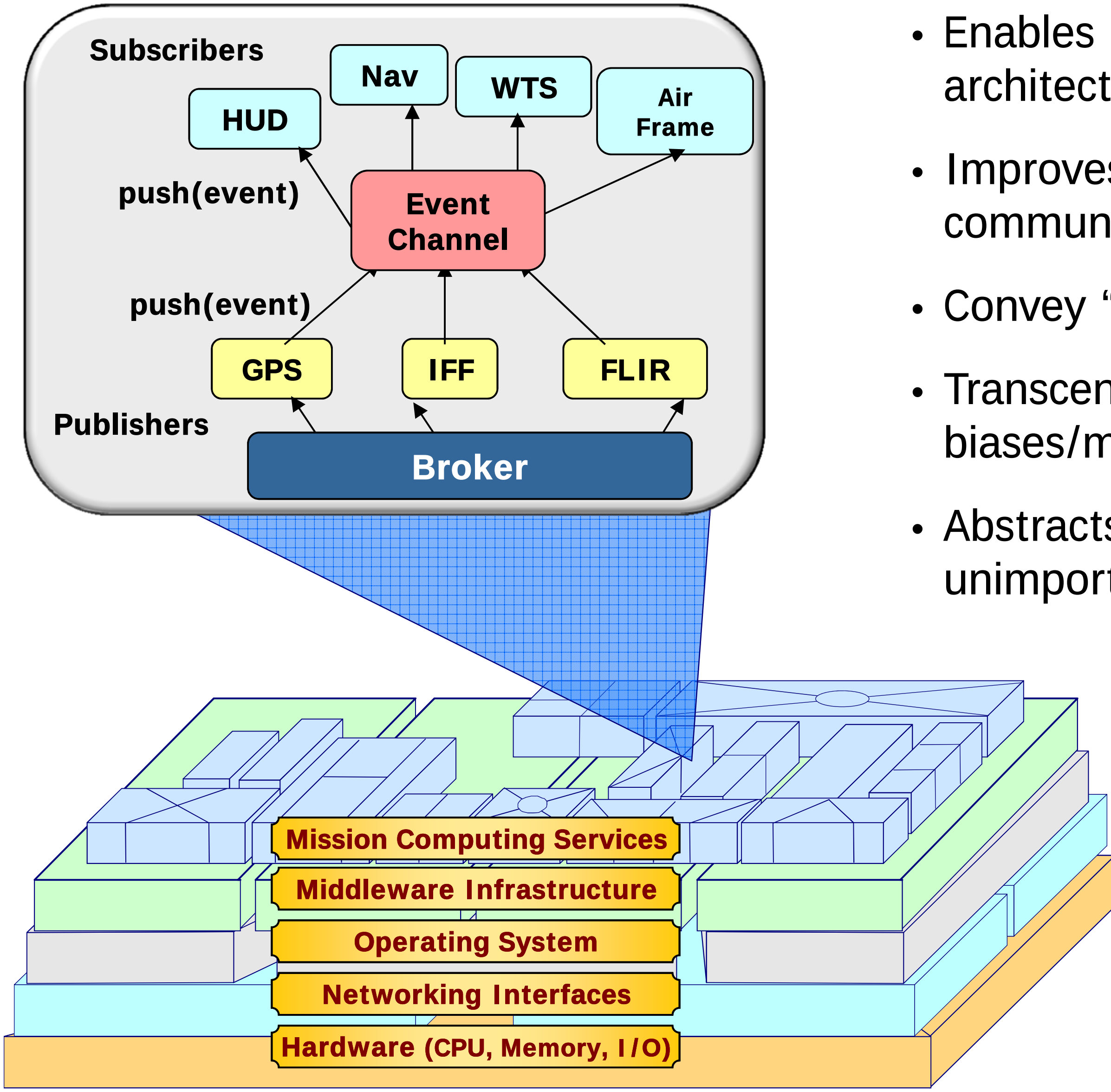
Configuring Factories w/ Component Configurator

Context	Problem	Solution
• Resource constrained systems	• Prematurely commiting to a Broker configuration is inflexible & inefficient • Certain decisions can't be made until runtime • Users forced to pay for components they don't use	• Apply the ***Component Configurator*** pattern to assemble the desired Broker factories & strategies more effectively



- Broker strategies are decoupled from when the strategy implementations are configured into Broker
- This pattern can reduce the memory footprint of Broker implementations

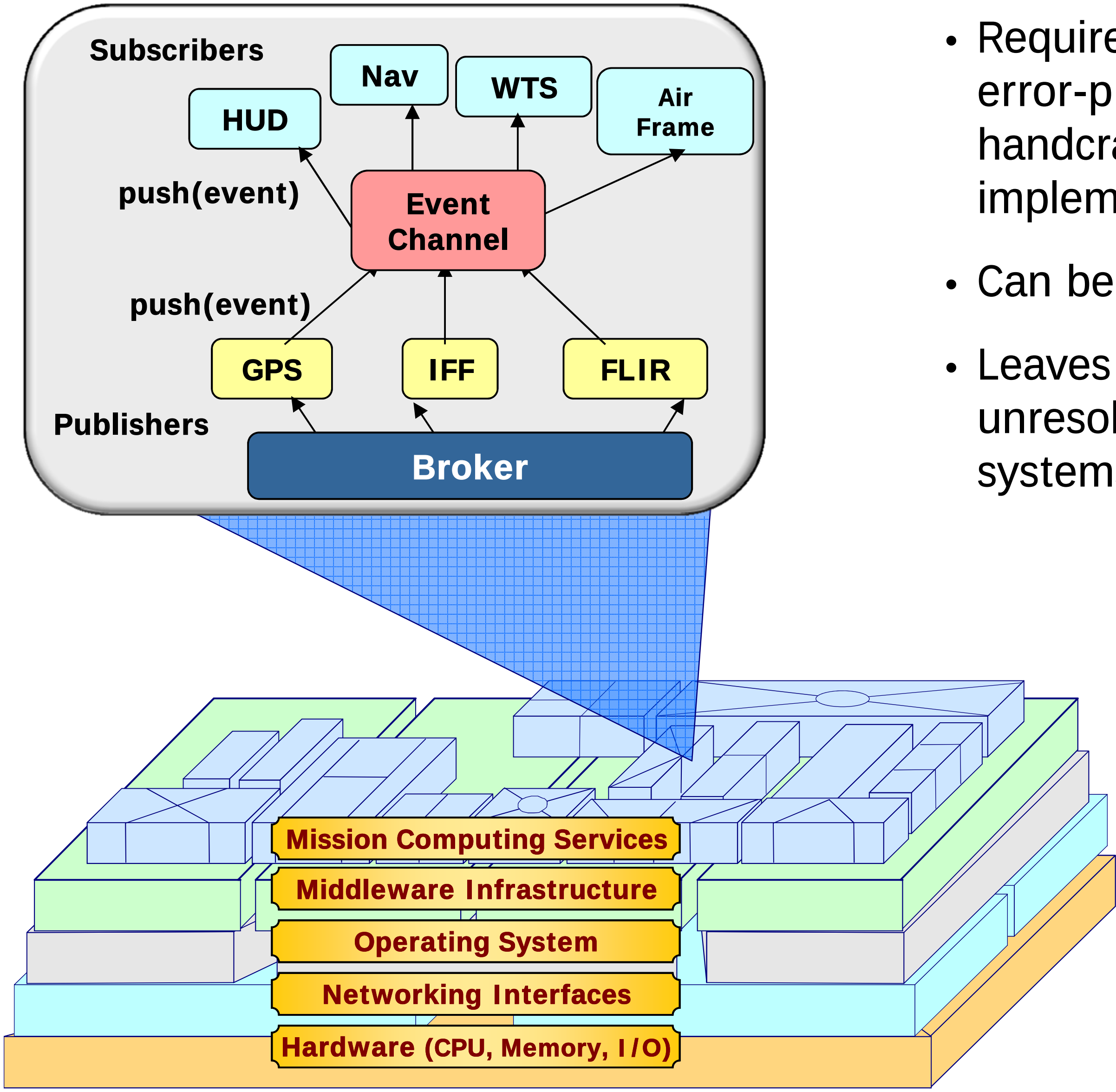
Benefits of Patterns



- 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.dre.vanderbilt.edu/~schmidt/patterns.html

Limitations of Patterns

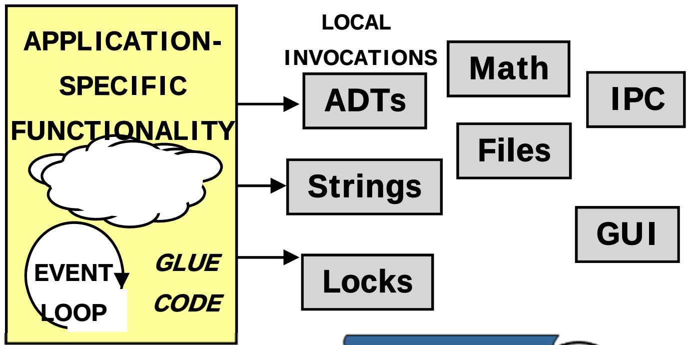


- Require significant tedious & error-prone human effort to handcraft pattern implementations
- Can be deceptively simple
- Leaves many important details unresolved, particularly for DRE systems

We therefore need more than just patterns to achieve effective systematic reuse

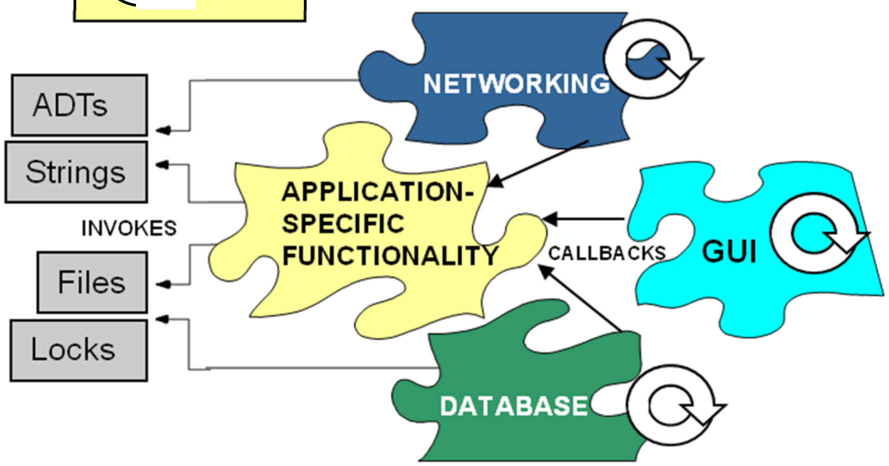
www.dre.vanderbilt.edu/~schmidt/patterns.html

Overview of Systematic Reuse Paradigms



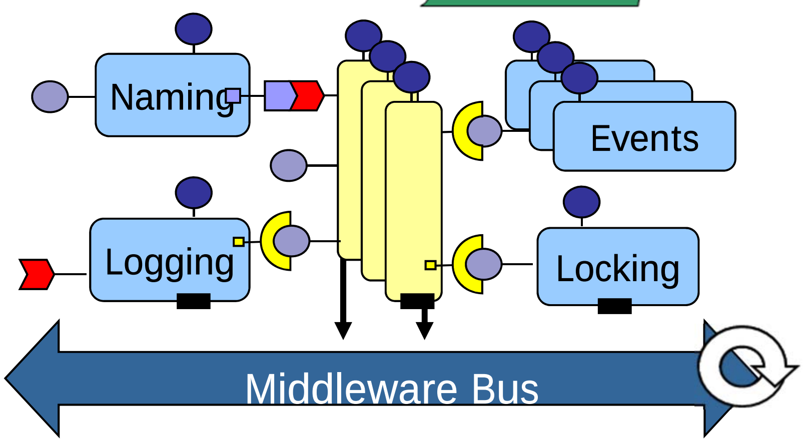
Class Library Architecture

- A *class* is a unit of abstraction & implementation in an OO programming language, i.e., a reusable *type* that often implements *patterns*
- Classes are typically *passive*



Framework Architecture

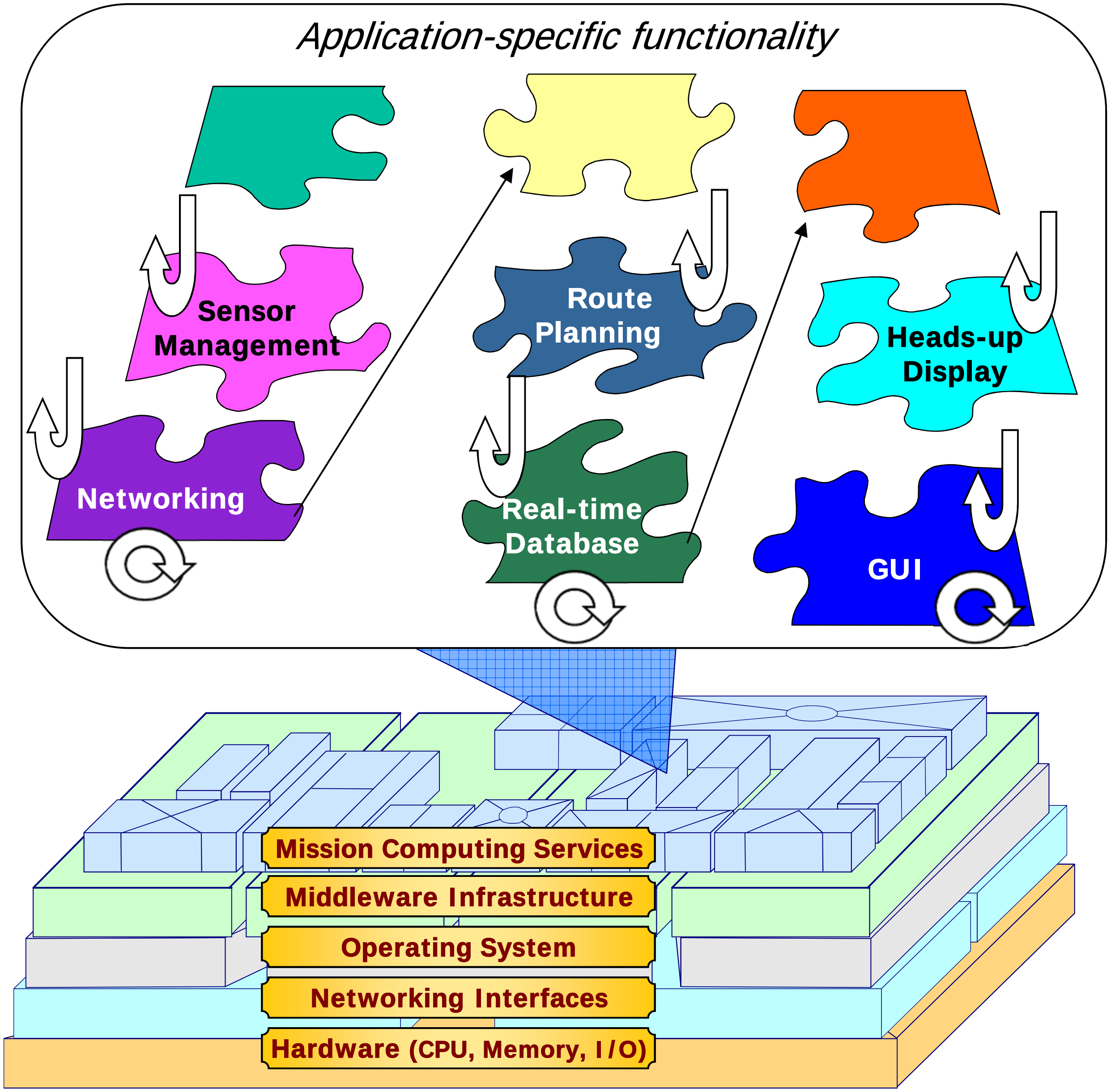
- A *framework* is an integrated set of classes that collaborate to produce a reusable architecture for a family of applications
- Frameworks implement *pattern languages*



Component / Service-Oriented Architecture

- A *component/service* is an encapsulation unit with one or more interfaces that provide clients with access to its services
- Components/services can be deployed & configured via *assemblies*

Applying Frameworks to Bold Stroke



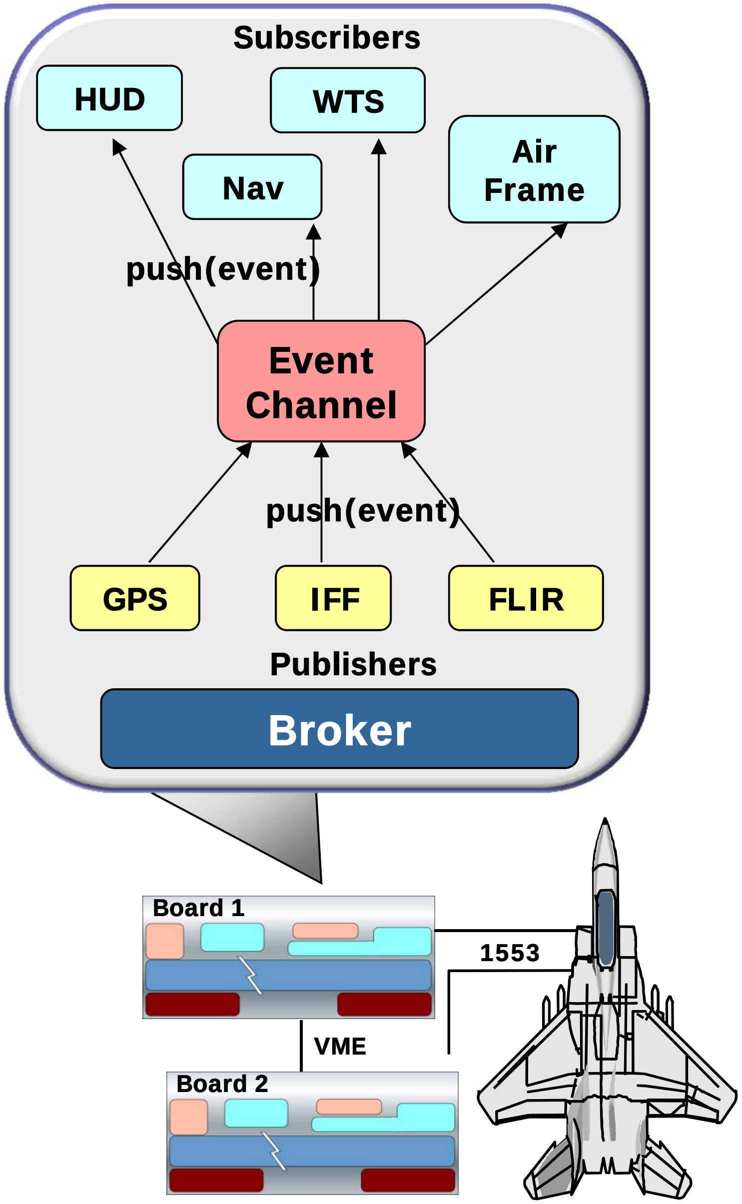
Framework characteristics

- Frameworks exhibit "inversion of control" at runtime via callbacks
- Frameworks provide integrated domain-specific structures & functionality
- Frameworks are "semi-complete" applications

www.dre.vanderbilt.edu/~schmidt/frameworks.html

Benefits of Frameworks

- Design reuse
  - e.g., by implementing patterns that guide application developers through the steps necessary to ensure successful creation & deployment of avionics software



Benefits of Frameworks

- Design reuse
  - e.g., by implementing patterns that guide application developers through the steps necessary to ensure successful creation & deployment of avionics software
- Implementation reuse
  - e.g., by amortizing software lifecycle costs & leveraging previous development & optimization efforts

```
package org.apache.tomcat.session;

import org.apache.tomcat.core.*;
import org.apache.tomcat.util.StringManager;
import java.io.*;
import java.net.*;
import java.util.*;
import javax.servlet.*;
import javax.servlet.http.*;

/**
 * Core implementation of a server session
 *
 * @author James Duncan Davidson [duncan@eng.sun.com]
 * @author James Todd [gonzo@eng.sun.com]
 */

public class ServerSession {

    private StringManager sm =
        StringManager.getManager("org.apache.tomcat.session");
    private Hashtable values = new Hashtable();
    private Hashtable appSessions = new Hashtable();
    private String id;
    private long creationTime = System.currentTimeMillis();;
    private long thisAccessTime = creationTime;
    private int inactiveInterval = -1;

    ServerSession(String id) { this.id = id; }

    public String getId() { return id; }

    public long getCreationTime() { return creationTime; }


    public ApplicationSession getApplicationSession(Context context,
        boolean create) {
        ApplicationSession appSession =
            (ApplicationSession)appSessions.get(context);

        if (appSession == null && create) {

            // XXX
            // sync to ensure valid?

            appSession = new ApplicationSession(id, this, context);
            appSessions.put(context, appSession);
        }

        // XXX
        // make sure that we haven't gone over the end of our
        // inactive interval -- if so, invalidate & create
        // a new appSession

        return appSession;
    }

    void removeApplicationSession(Context context) {
        appSessions.remove(context);
    }
```

Benefits of Frameworks

- Design reuse
  - e.g., by implementing patterns that guide application developers through the steps necessary to ensure successful creation & deployment of avionics software
- Implementation reuse
  - e.g., by amortizing software lifecycle costs & leveraging previous development & optimization efforts
- Validation reuse
  - e.g., by amortizing the efforts of validating application- & platform-independent portions of software, thereby enhancing software reliability & scalability

Build Scoreboard

Doxygen

Build Name	Last Finished	Config	Setup	Compile	Tests	Status
Doxygen	Sep 05, 2002 - 03:24	[Config]	[Full]	[Full] [Brief]		Inactive

Linux

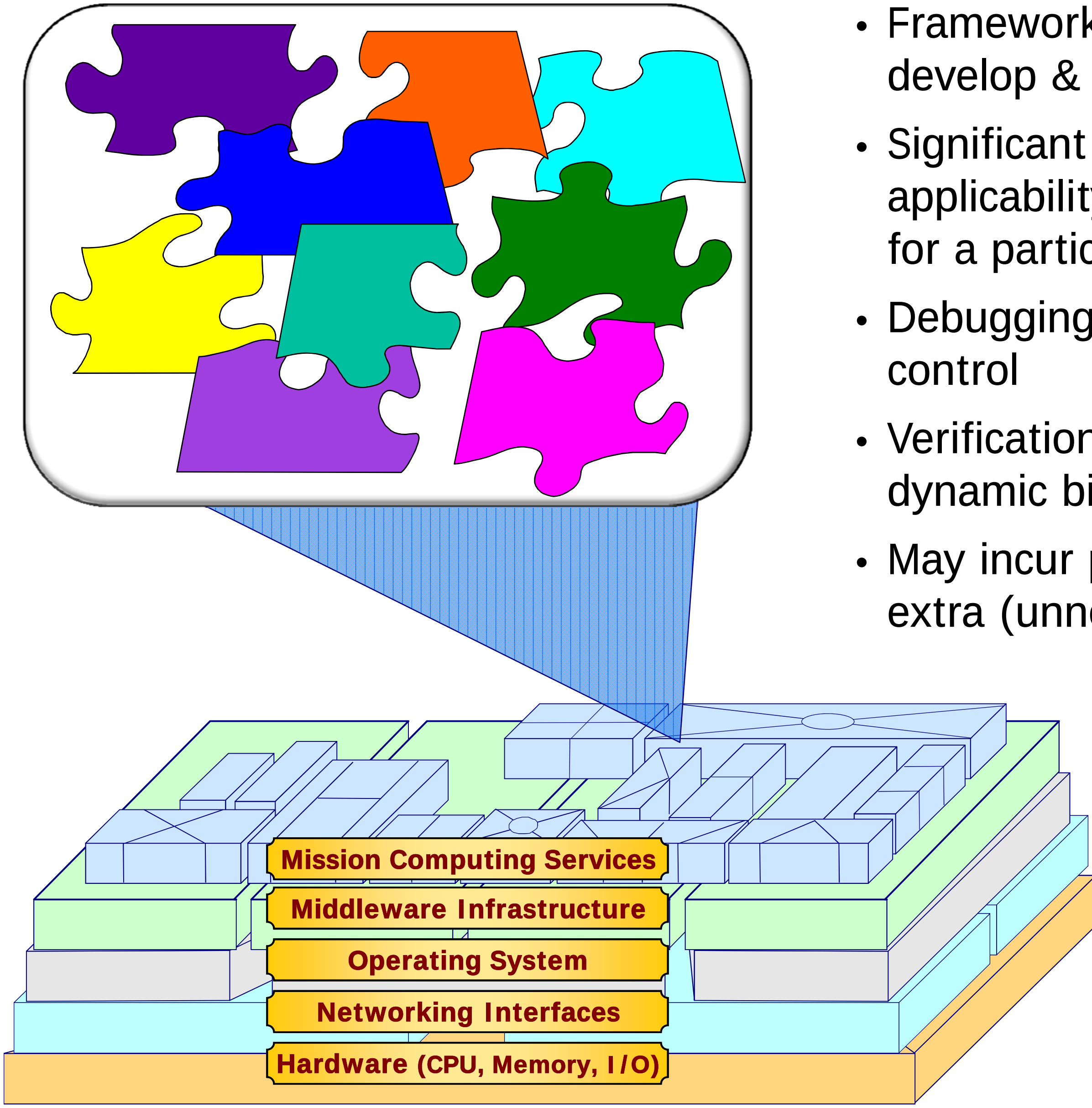
Build Name	Last Finished	Config	Setup	Compile	Tests	Status
Debian_Core	Sep 05, 2002 - 14:36	[Config]	[Full]	[Full]		Inactive
Debian_Full	Sep 05, 2002 - 12:19	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
Debian_Full_Reactors	Sep 05, 2002 - 11:59	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
Debian_GCC_3.0.4	Sep 05, 2002 - 13:45	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
Debian_Minimum	Sep 05, 2002 - 08:51	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
Debian_Minimum_Static	Sep 04, 2002 - 00:53	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Setup
Debian_NoInline	Sep 05, 2002 - 12:31	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
Debian_NoInterceptors	Sep 05, 2002 - 09:10	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
Debian_WChar_GCC_3.1	Sep 05, 2002 - 01:23	[Config]	[Full]	[Full]	[Full] [Brief]	Compile
RedHat_7.1_Full	Sep 04, 2002 - 02:34	[Config]	[Full]	[Full]	[Full] [Brief]	Setup
RedHat_7.1_No_AMI_Messaging	Sep 05, 2002 - 04:56	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
RedHat_Core	Sep 05, 2002 - 14:34	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
RedHat_Explicit_Templates	Sep 05, 2002 - 08:56	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
RedHat_GCC_3.2	Sep 05, 2002 - 06:53	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
RedHat_Implicit_Templates	Sep 03, 2002 - 06:25	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive
RedHat_Single_Threaded	Sep 05, 2002 - 10:55	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Compile
RedHat_Static	Sep 05, 2002 - 15:24	[Config]	[Full]	[Full] [Brief]	[Full] [Brief]	Inactive

Lynx

Build Name	Last Finished	Config	Setup	Compile	Tests	Status
Lynx_PPC	Sep 03, 2002 - 10:58	[Config]	[Full]	[Full] [Brief]		Setup

www.dre.vanderbilt.edu/scoreboard

Limitations of Frameworks



- Frameworks are powerful, but hard to develop & use effectively
- Significant time required to evaluate applicability & quality of a framework for a particular domain
- Debugging is tricky due to inversion of control
- Verification & validation is tricky due to dynamic binding
- May incur performance overhead due to extra (unnecessary) levels of indirection

We thus need something simpler than frameworks to achieve systematic reuse for DRE systems

The Evolution of Middleware

DRE Applications

Domain-Specific Services

Common Middleware Services

Distribution Middleware

Host Infrastructure Middleware

Operating Systems & Protocols

Hardware

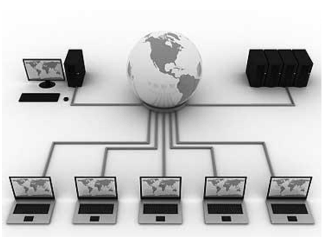
Historically, mission-critical DRE apps were built directly atop hardware & OS

- Tedious, error-prone, & costly over lifecycles

There are layers of middleware, just like there are layers of networking protocols

Standards-based COTS DRE middleware helps:

- Control end-to-end resources & QoS
- Leverage hardware & software technology advances
- Evolve to new environments & requirements
- Provide a wide array of reusable, off-the-shelf developer-oriented services

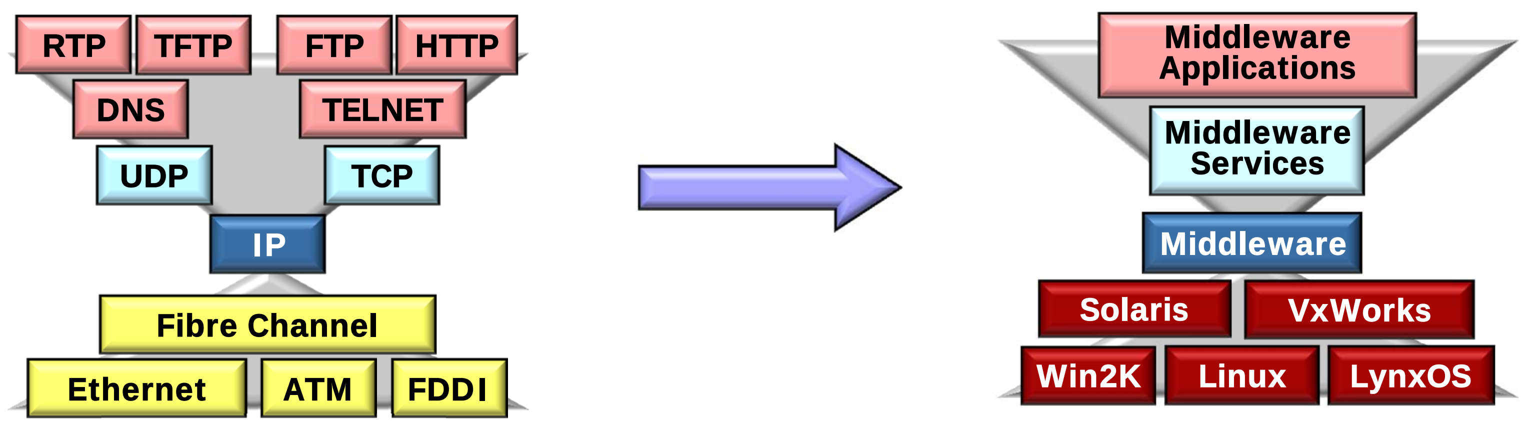


Middleware is pervasive in enterprise domain & is becoming pervasive in DRE domain

Operating System & Protocols

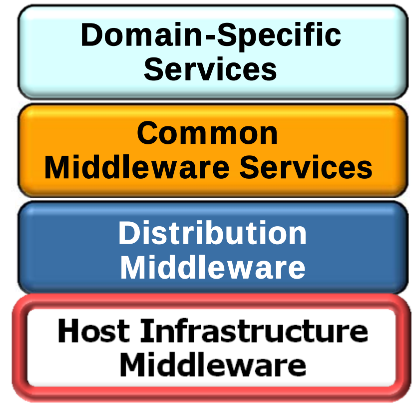
- Operating systems & protocols provide mechanisms to manage endsystem resources, e.g.,
  - CPU scheduling & dispatching
  - Virtual memory management
  - Secondary storage, persistence, & file systems
  - Local & remote interprocess communication (IPC)
- OS examples
  - UNIX/Linux, Windows, VxWorks, QNX, etc.
- Protocol examples
  - TCP, UDP, IP, SCTP, RTP, etc.

INTERNETWORKING ARCH — *MIDDLEWARE ARCH*

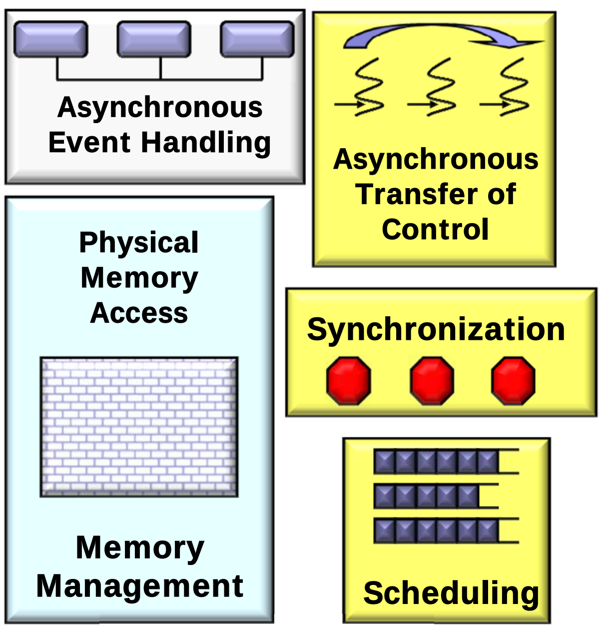


20th Century — **21st Century**

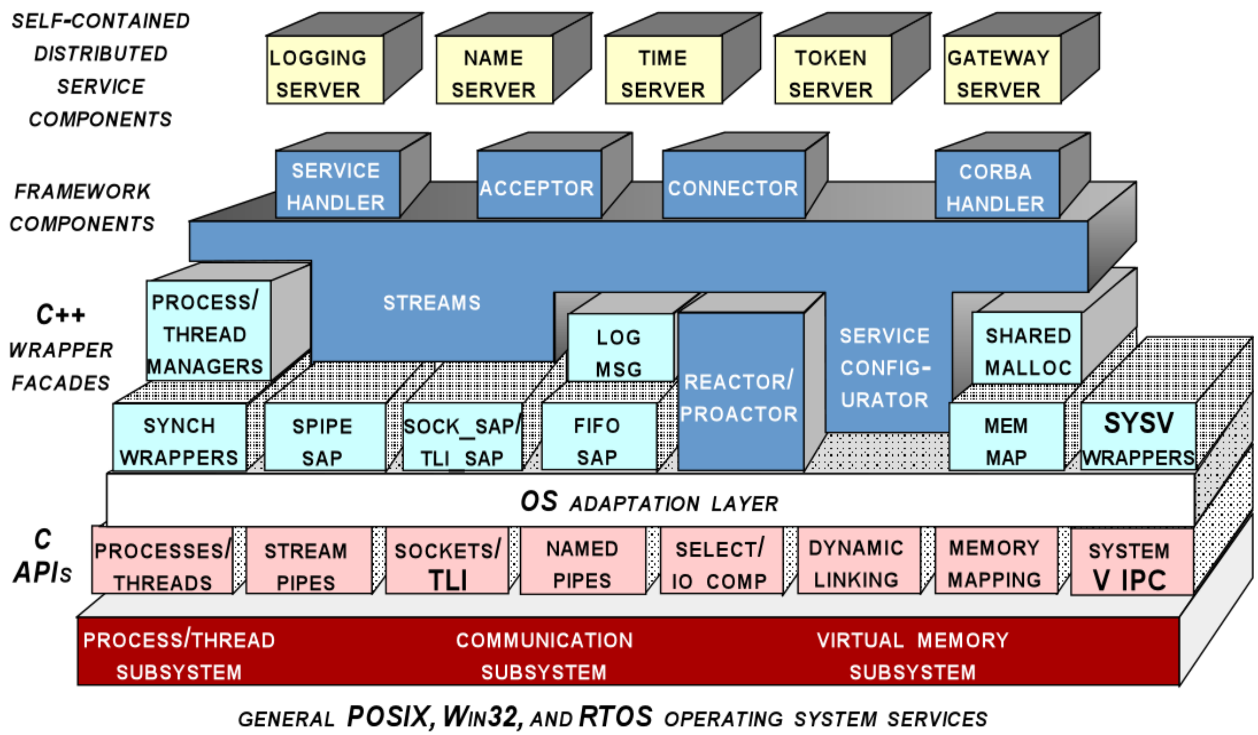
Host Infrastructure Middleware



- Host infrastructure middleware encapsulates & enhances native OS mechanisms to create reusable network programming objects
  - These components abstract away many tedious & error-prone aspects of low-level OS APIs
- Examples
  - Java Virtual Machine (JVM), Common Language Runtime (CLR), ADAPTIVE Communication Environment (ACE)

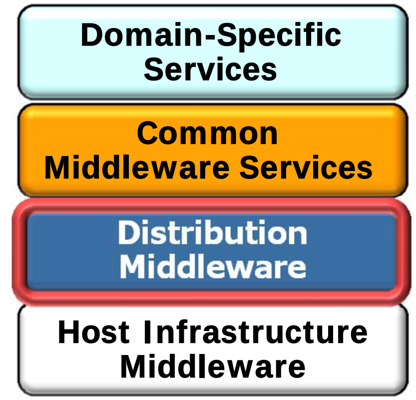


www.rtj.org

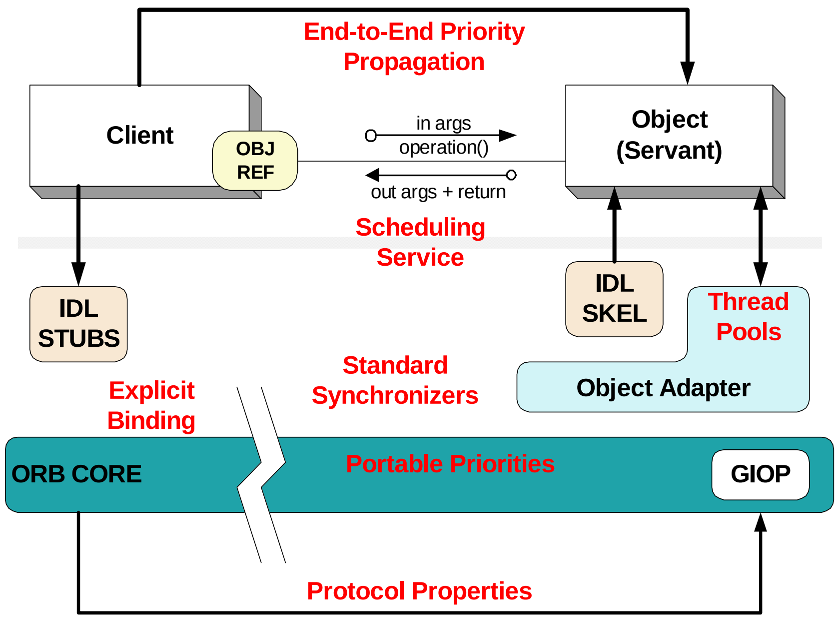


www.dre.vanderbilt.edu/~schmidt/ACE.html

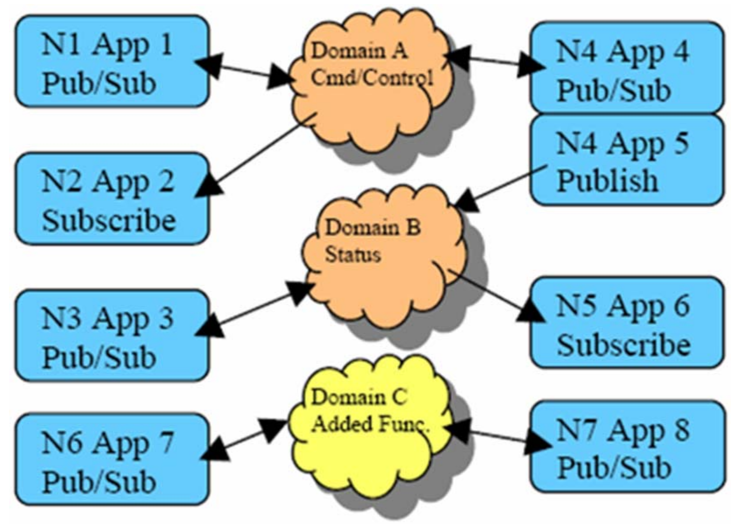
Distribution Middleware



- *Distribution middleware* defines higher-level distributed programming models whose reusable APIs & components automate & extend native OS capabilities
- Examples
  - OMG Real-time CORBA & DDS, Sun RMI, Microsoft DCOM, W3C SOAP



realtime.omg.org

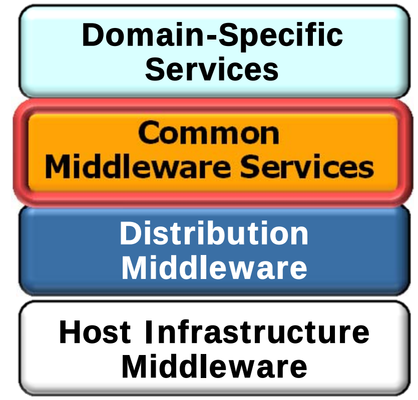


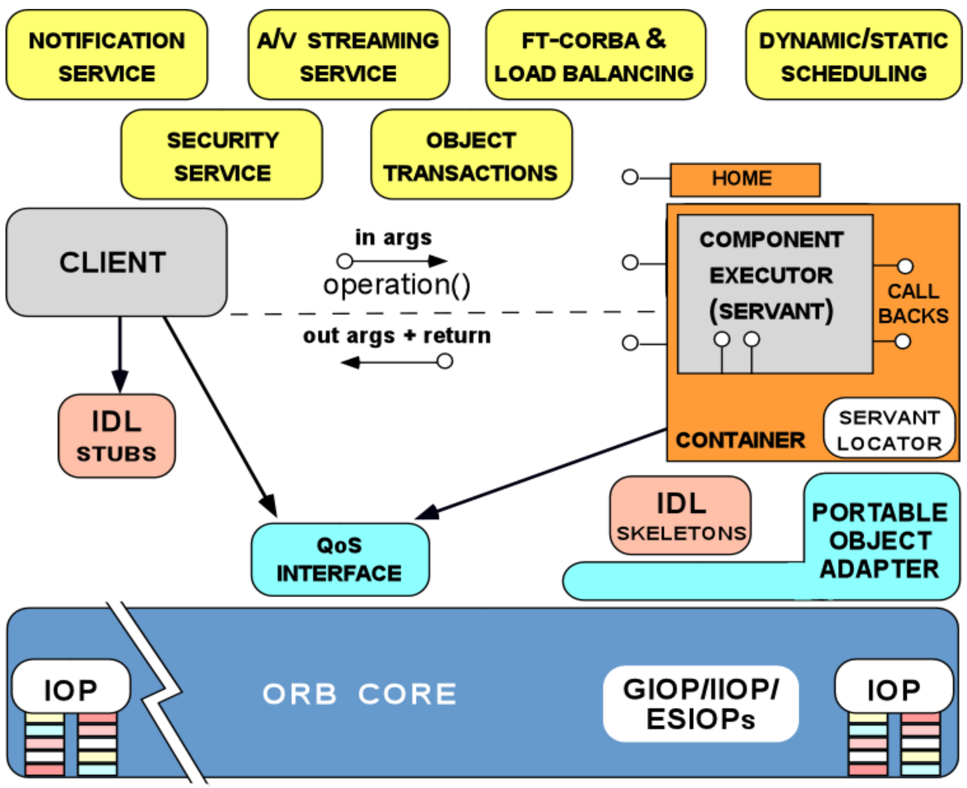
en.wikipedia.org/wiki/Data_Distribution_Service

Distribution middleware avoids hard-coding client & server application dependencies on object location, language, OS, protocols, & hardware

Common Middleware Services

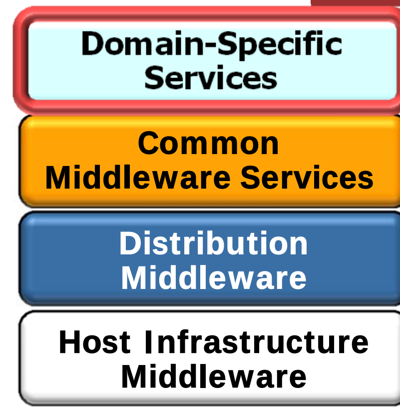
- *Common middleware services* augment distribution middleware by defining higher-level domain-independent services that focus on programming “business logic”
- Examples
  - W3C Web Services, CORBA Component Model & Object Services, Sun’s J2EE, Microsoft’s .NET, etc.





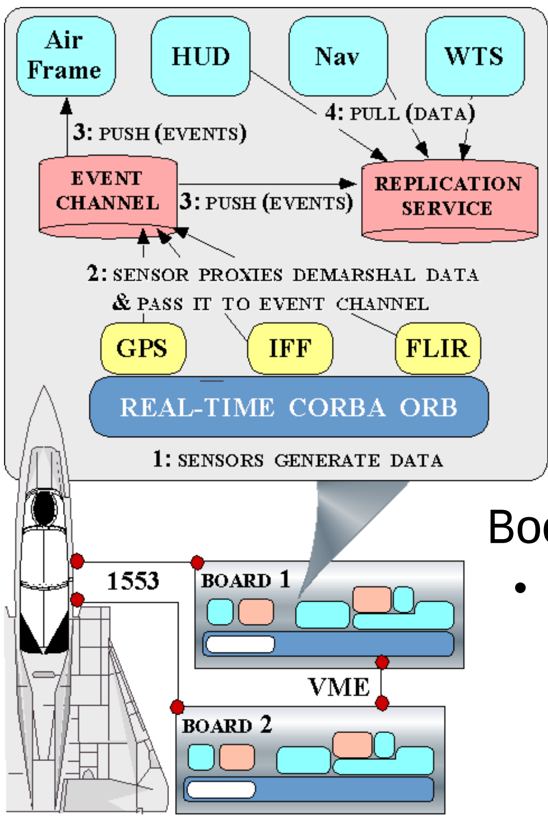
- Common middleware services support many recurring distributed system capabilities, e.g.,
  - Transactional behavior
  - Authentication & authorization,
  - Database connection pooling & concurrency control
  - Active replication
  - Dynamic resource management

Domain-Specific Middleware



- *Domain-specific middleware services* are tailored to the requirements of particular domains, such as telecom, e-commerce, health care, process automation, or aerospace

- Examples

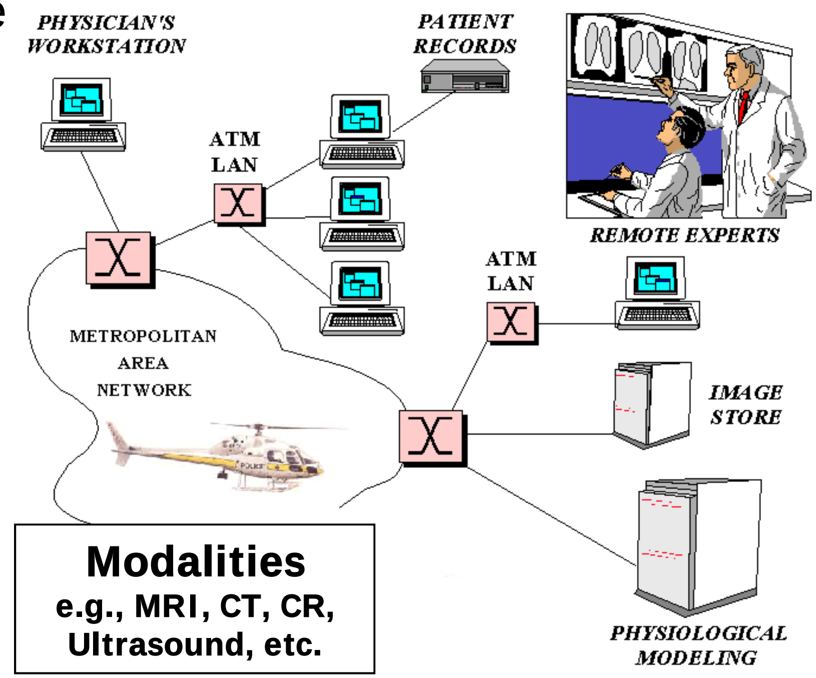


Siemens MED Syngo

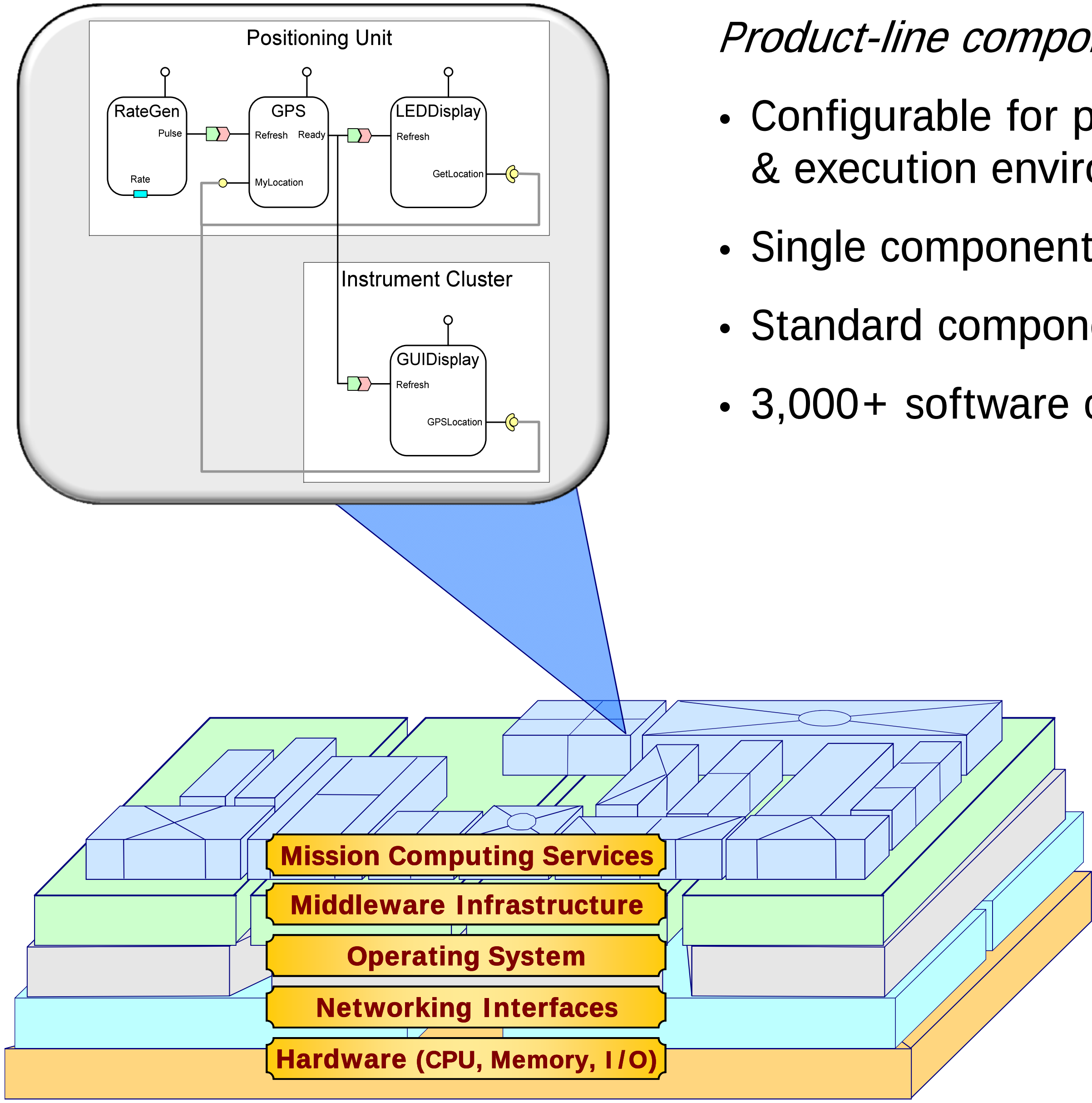
- Common software platform for distributed electronic medical systems
- Used by all Siemens MED business units worldwide

Boeing Bold Stroke

- Common software platform for Boeing avionics mission computing systems



Applying Component Middleware to Bold Stroke

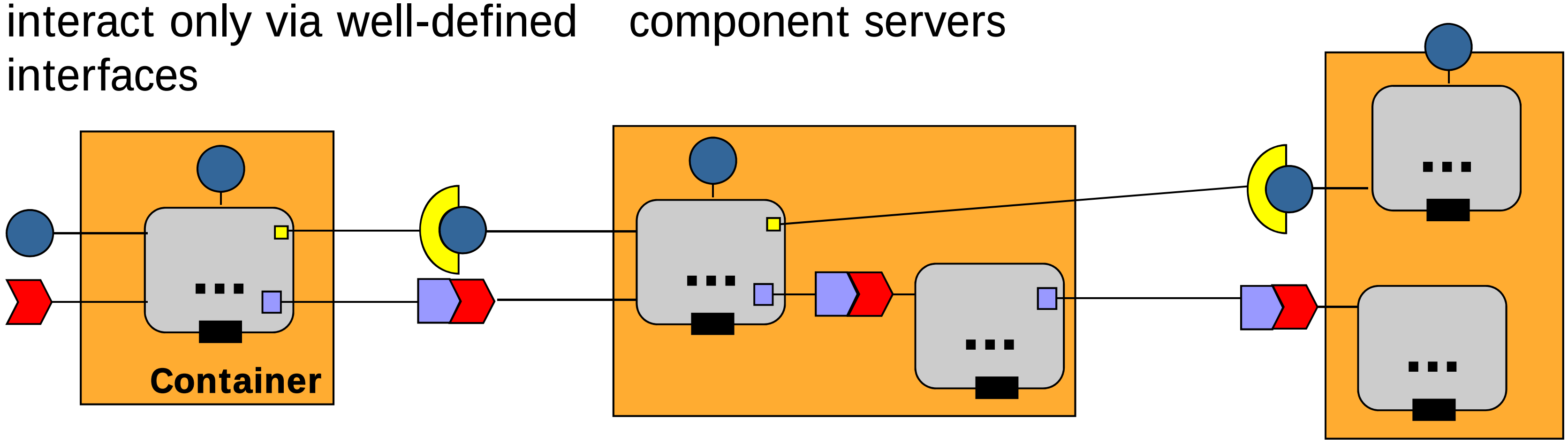


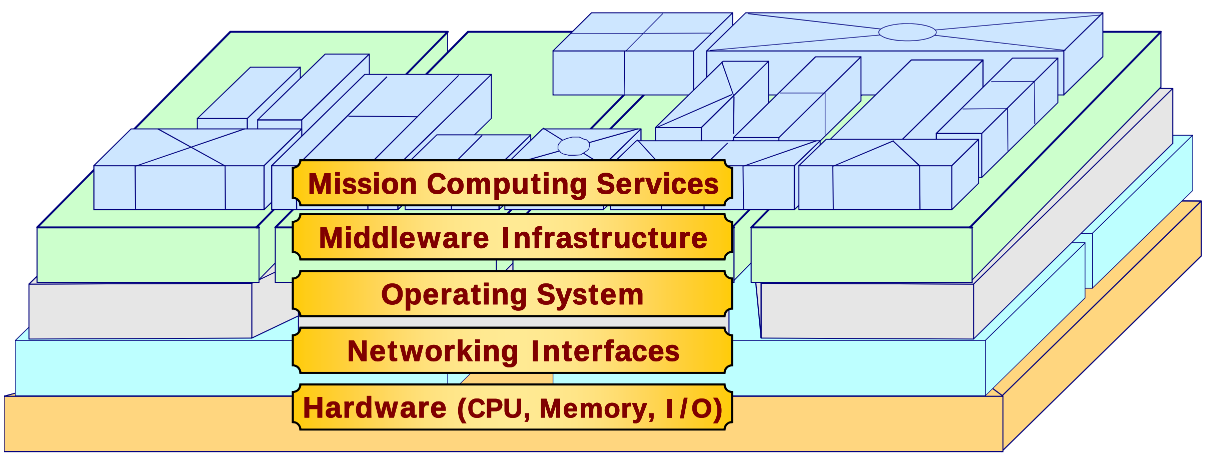
Product-line component model

- Configurable for product-specific functionality & execution environment
- Single component development policies
- Standard component packaging mechanisms
- 3,000+ software components

Benefits of Component Middleware

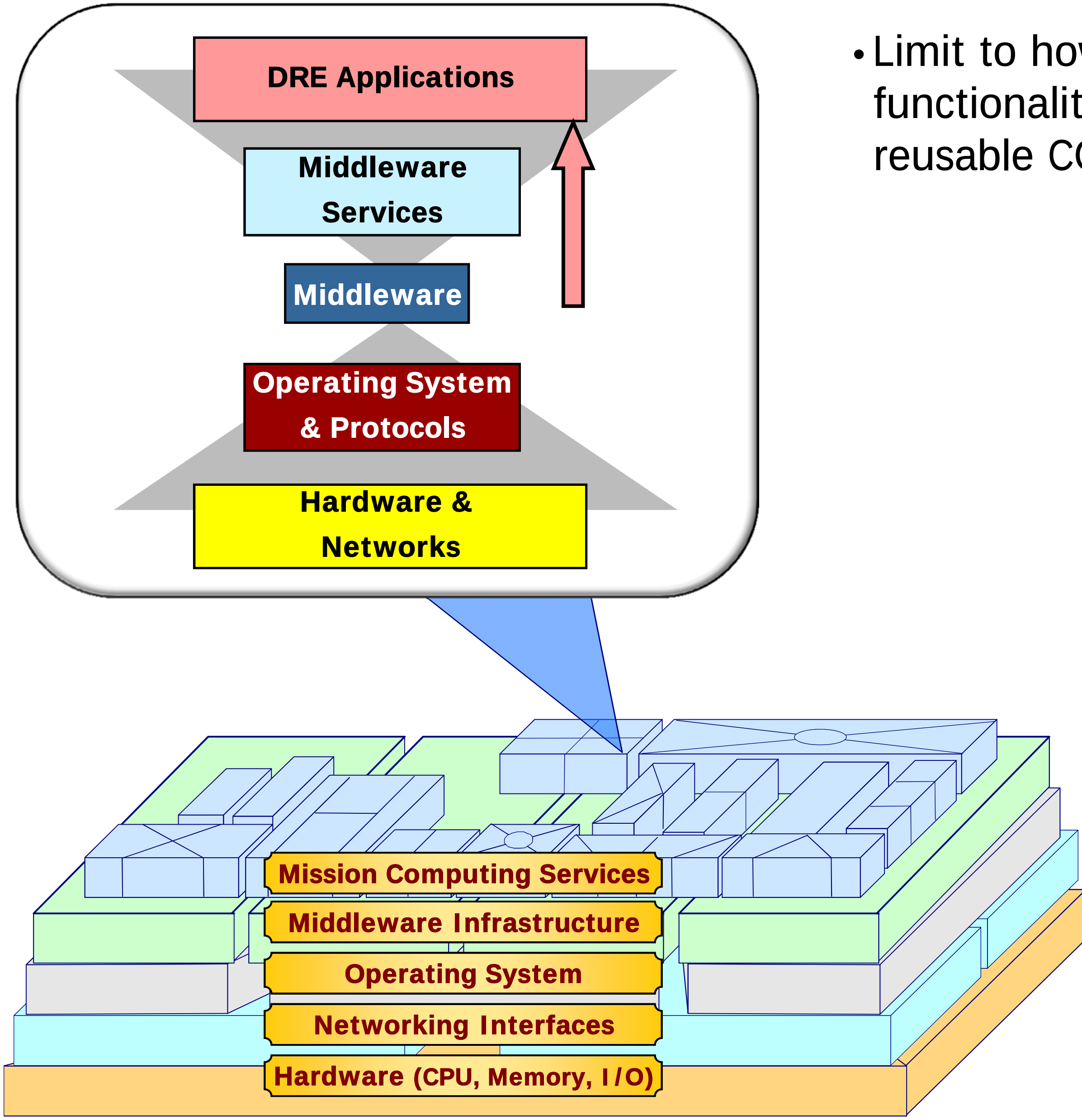
- Creates a standard "virtual boundary" around application component implementations that interact only via well-defined interfaces
- Define standard container mechanisms needed to execute components in generic component servers
- Specify the infrastructure needed to configure & deploy components thruout a distributed system





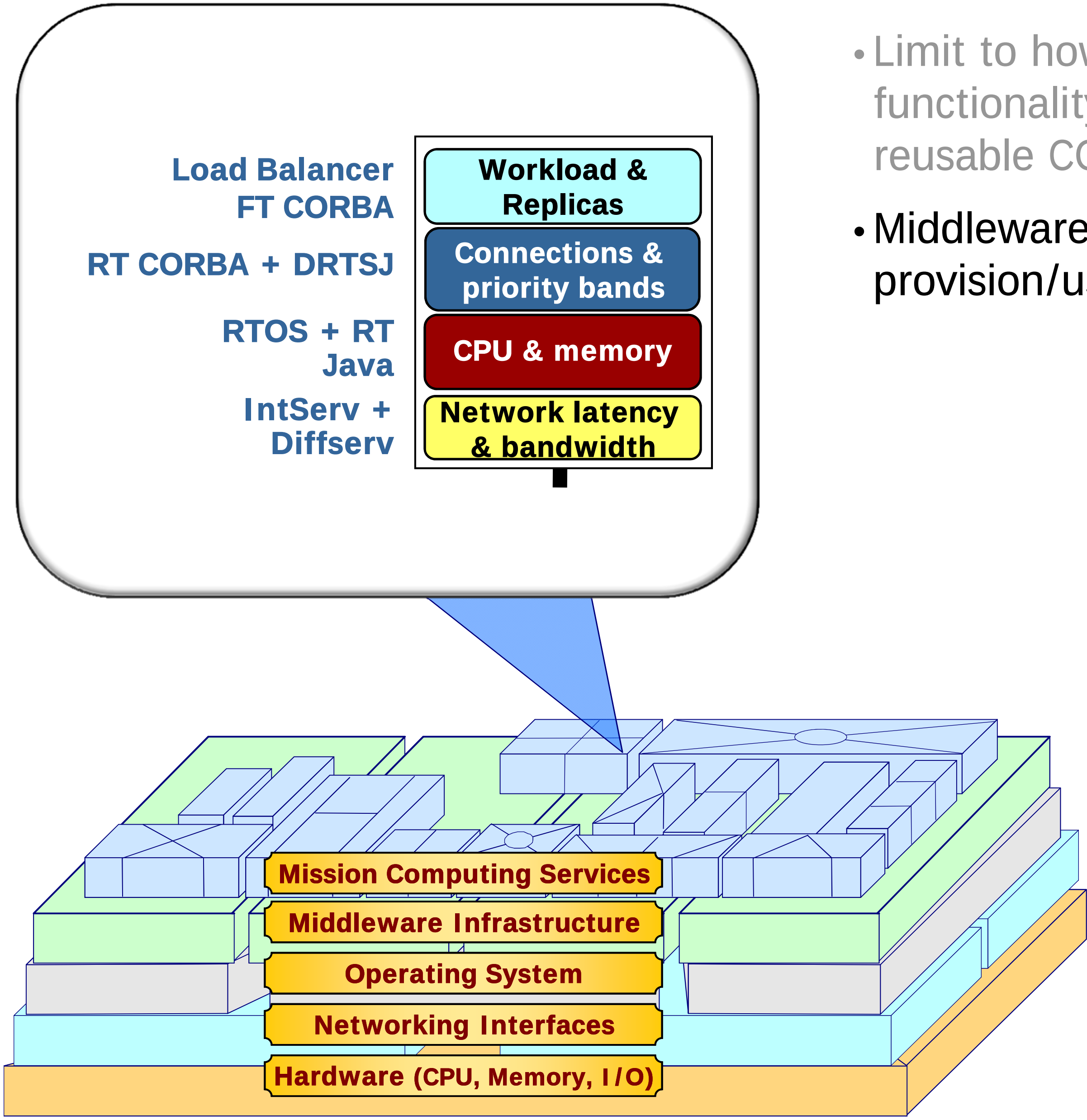

```
<ComponentAssemblyDescription id="a_HUDDisSPLy"> ...
 <connection>
   <name>GPS-RateGen</name>
<internalEndPoint><portName>Refresh</portName><instance>a_GPS<
/instance>
   </internalEndPoint>
   <internalEndPoint>
     <portName>Pulse</portName><instance>a_RateGen</instance>
   </internalEndPoint>
  </connection>
  <connection>
    <name>NavDisSPLy-GPS</name>
<internalEndPoint><portName>Refresh</portName><instance>a_NavDi
sSPLy</instance>
    </internalEndPoint>
<internalEndPoint><portName>Ready</portName><instance>a_GPS</i
nstance>
    </internalEndPoint>
  </connection> ...
</ComponentAssemblyDescription>
```

Limitations of Component Middleware



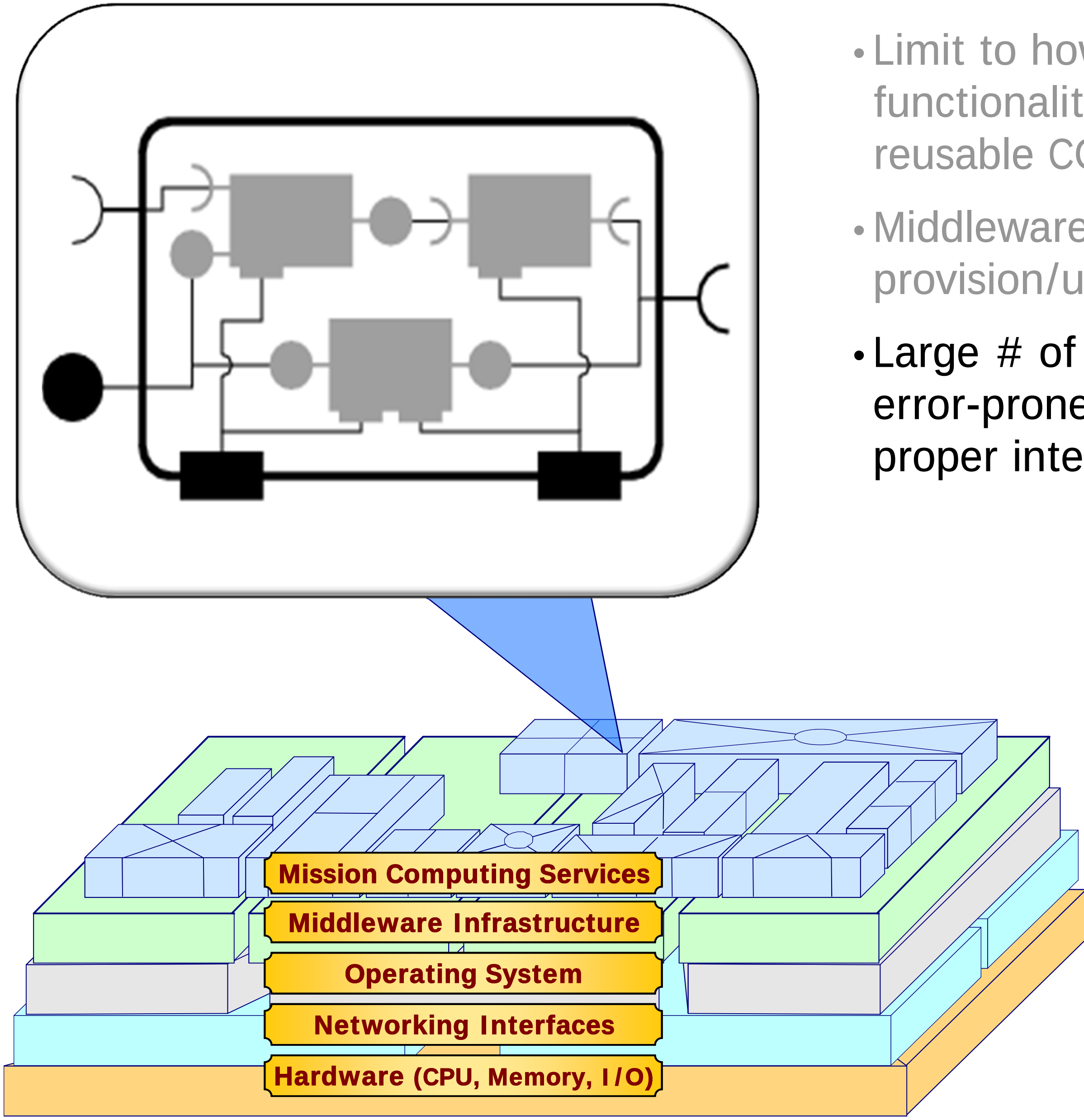
- Limit to how much application functionality can be refactored into reusable COTS component middleware

Limitations of Component Middleware



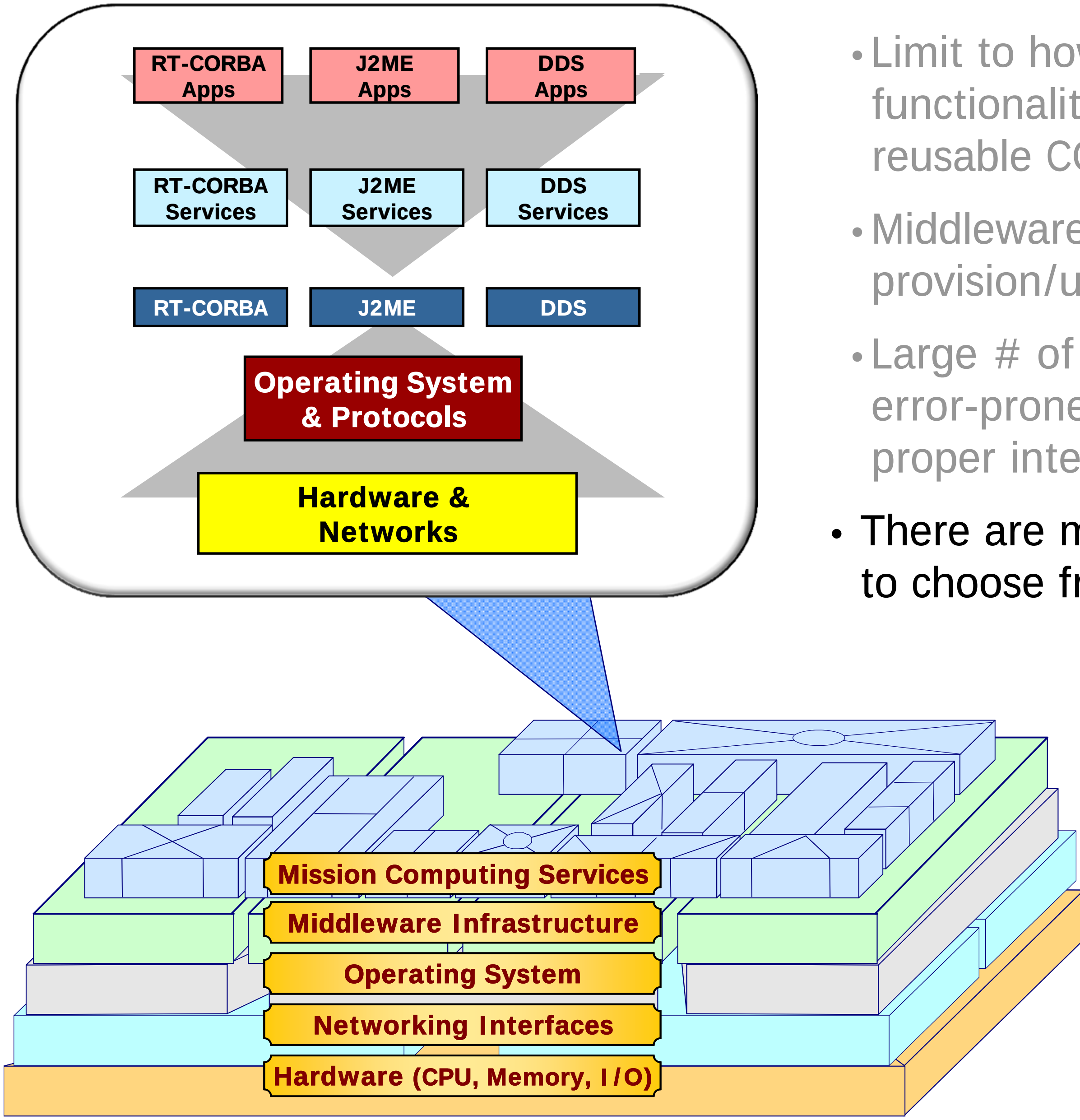
- Limit to how much application functionality can be refactored into reusable COTS component middleware
- Middleware itself has become hard to provision/use

Limitations of Component Middleware



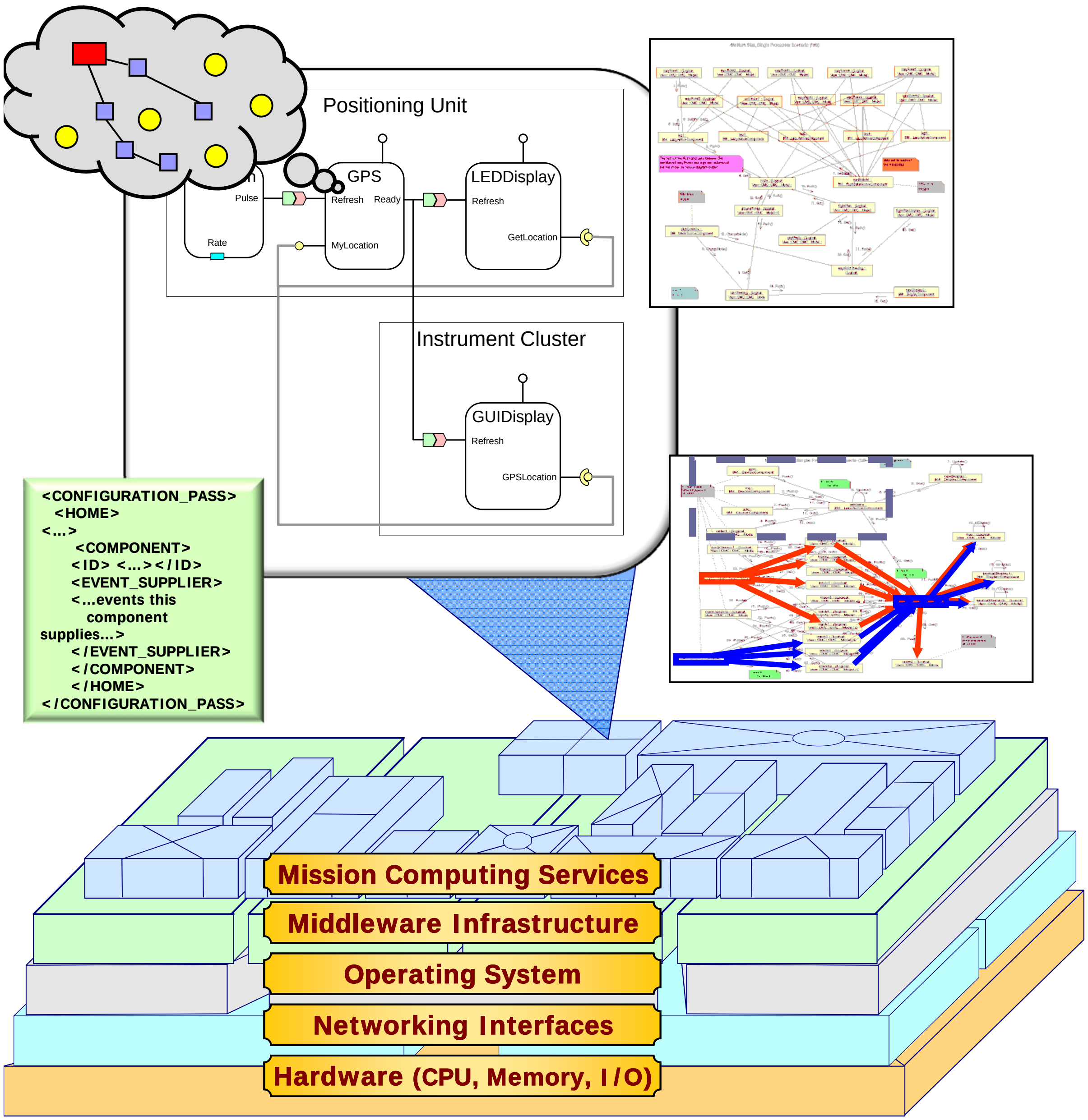
- Limit to how much application functionality can be refactored into reusable COTS component middleware
- Middleware itself has become hard to provision/use
- Large # of components can be tedious & error-prone to configure & deploy without proper integration tool support

Limitations of Component Middleware



- Limit to how much application functionality can be refactored into reusable COTS component middleware
- Middleware itself has become hard to provision/use
- Large # of components can be tedious & error-prone to configure & deploy without proper integration tool support
- There are many middleware technologies to choose from

Applying MDE to Bold Stroke



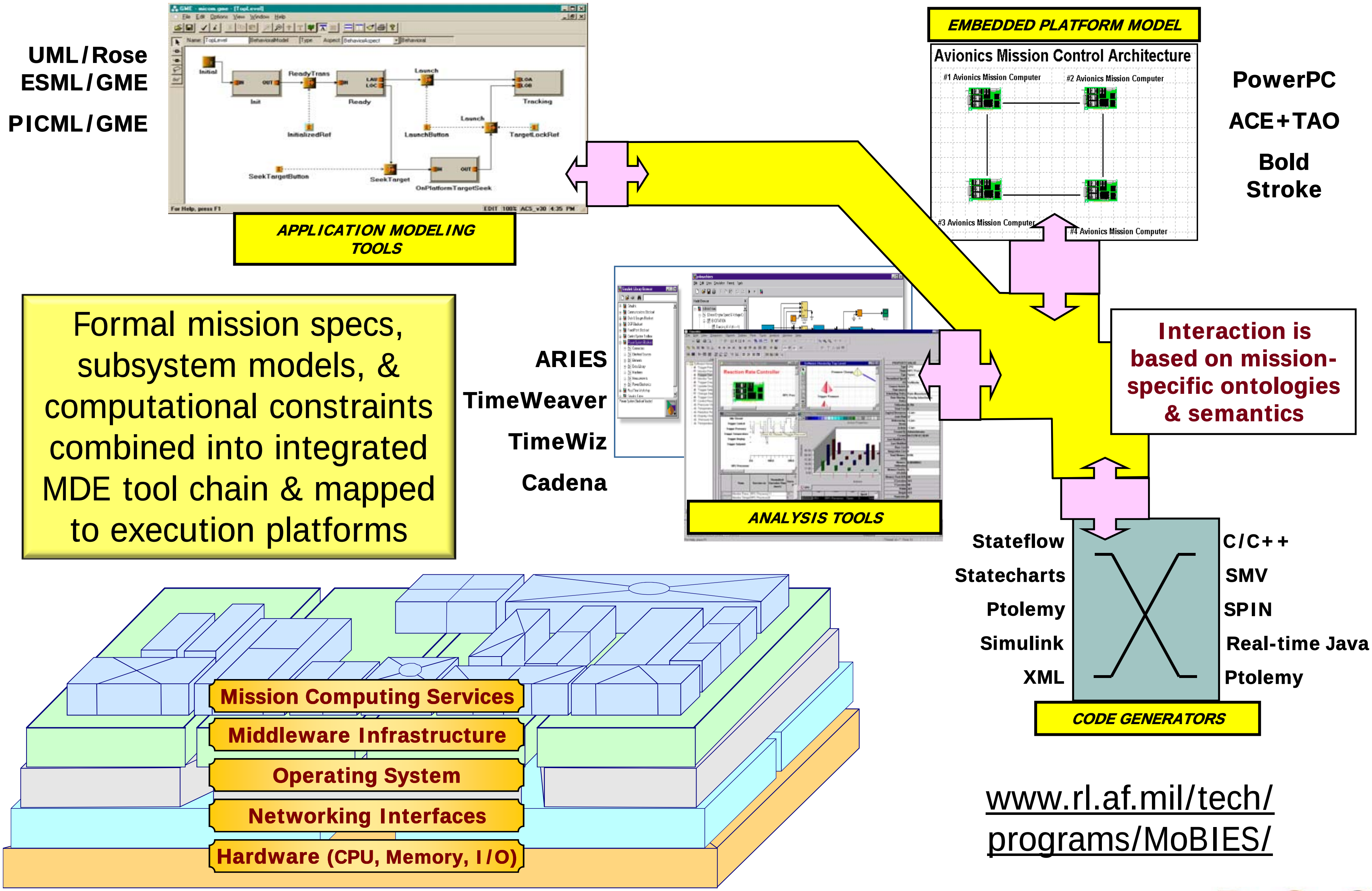
Model-driven engineering (MDE)

- Apply MDE tools to
  - Model
  - Analyze
  - Synthesize
  - Provision

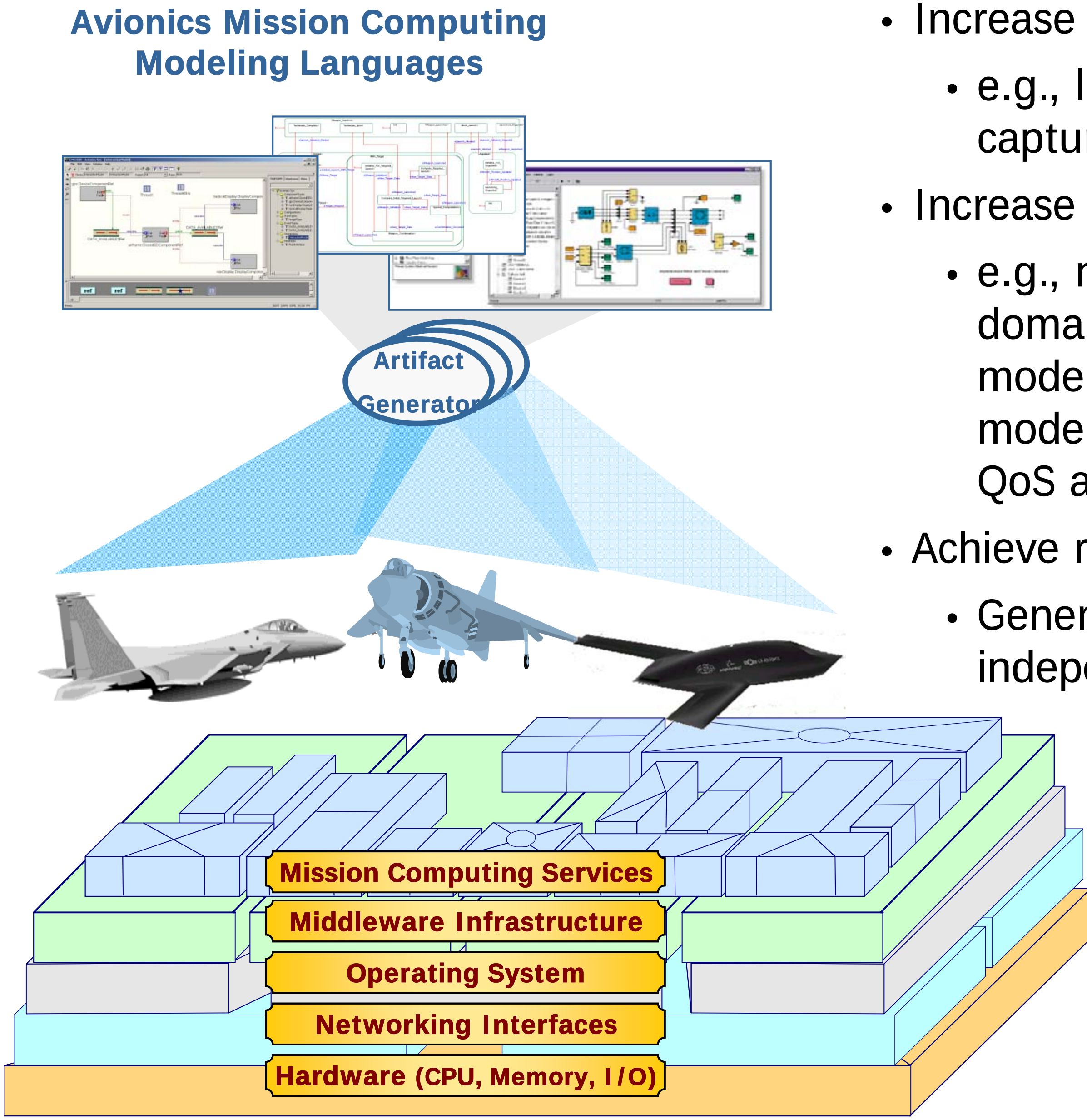
  middleware & application components
- Configure product variant-specific component assembly & deployment environments
- Model-based component integration policies

www.isis.vanderbilt.edu/projects/mobies

Applying MDE to Bold Stroke

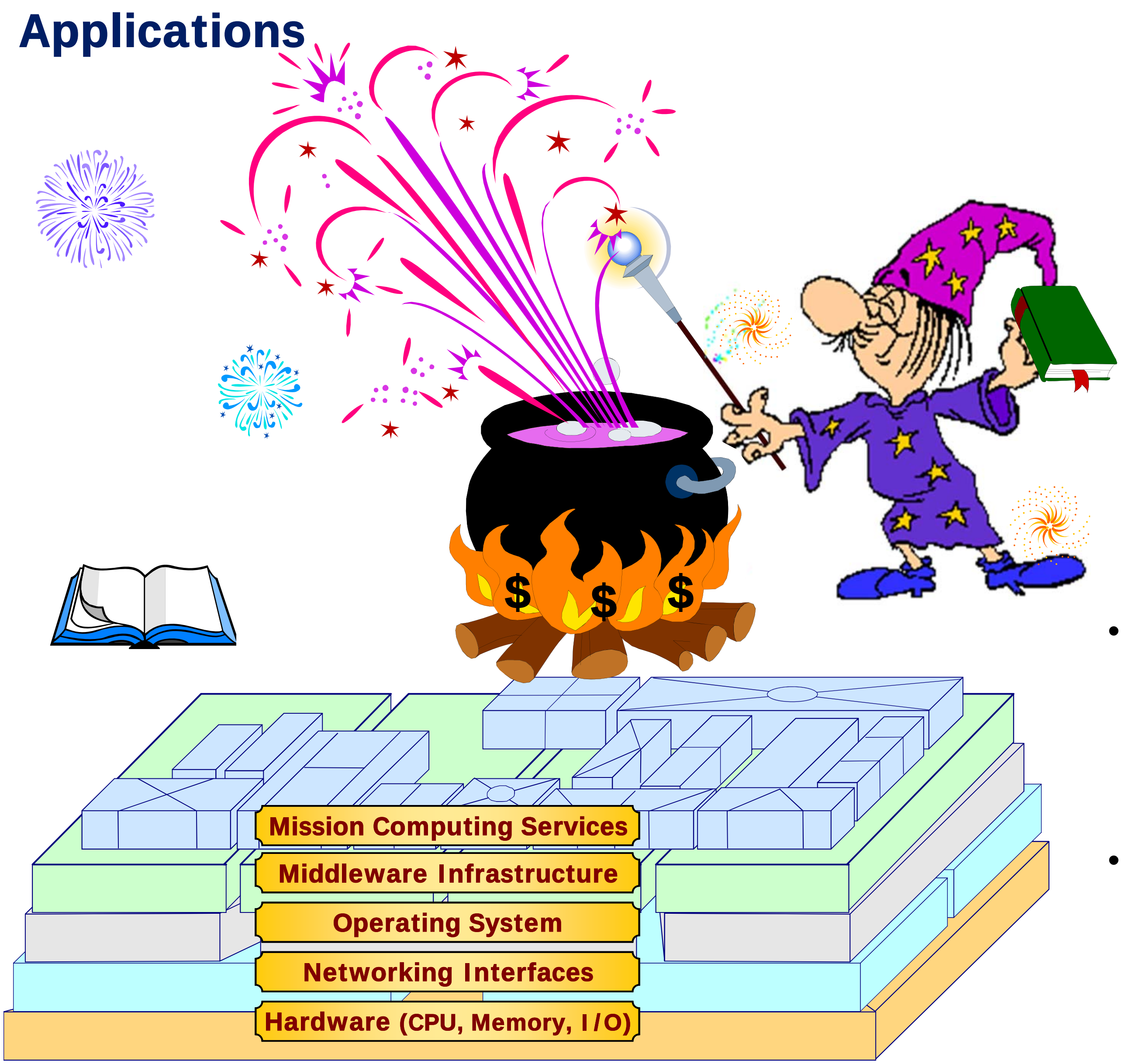


Benefits of MDE



- Increase expressivity
  - e.g., linguistic support to better capture design intent
- Increase precision
  - e.g., mathematical tools for cross-domain modeling, synchronizing models, change propagation across models, modeling security & other QoS aspects
- Achieve reuse of domain semantics
  - Generate code that's more "platform-independent" (or not)!
    - Support DRE system development & evolution

Limitations of MDE

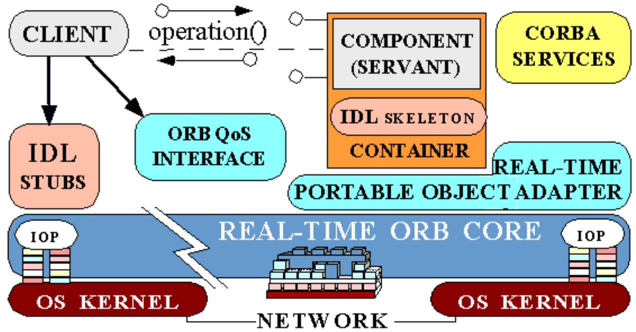


- Modeling technologies are still maturing & evolving
  - i.e., non-standard tools
- Magic (& magicians) are still necessary for success

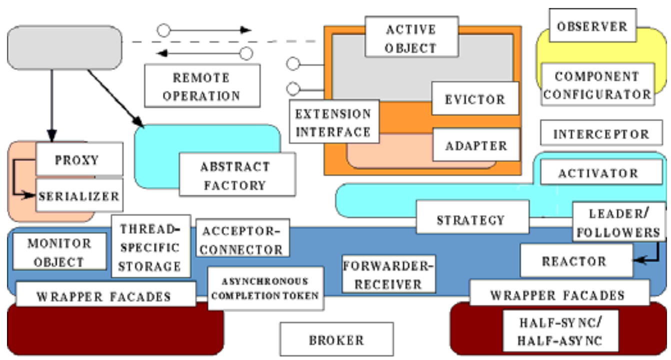
Ingredients for Success with Systematic Reuse

Key Technologies

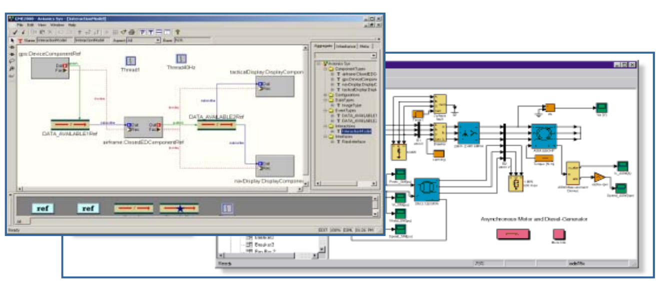
Standard Middleware, Frameworks, & Components



Patterns & Pattern Languages



Model-driven Software Development



Experienced Senior Architects

- Responsible for communicating completeness, correctness, & consistency of all parts of the software architecture to the stakeholders

Solid Key Developers

- Design responsibility (maintenance, evolution) for a specific architectural topic

Enlightened Managers

- Must be willing to defend the sacrifice of some short-term investment for long-term payoff

Accepted Business Drivers

- i.e., need a "succeed or die" mentality

It's crucial to have an effective process for growing architects & key developers

Traits of Dysfunctional Software Organizations

Process Traits

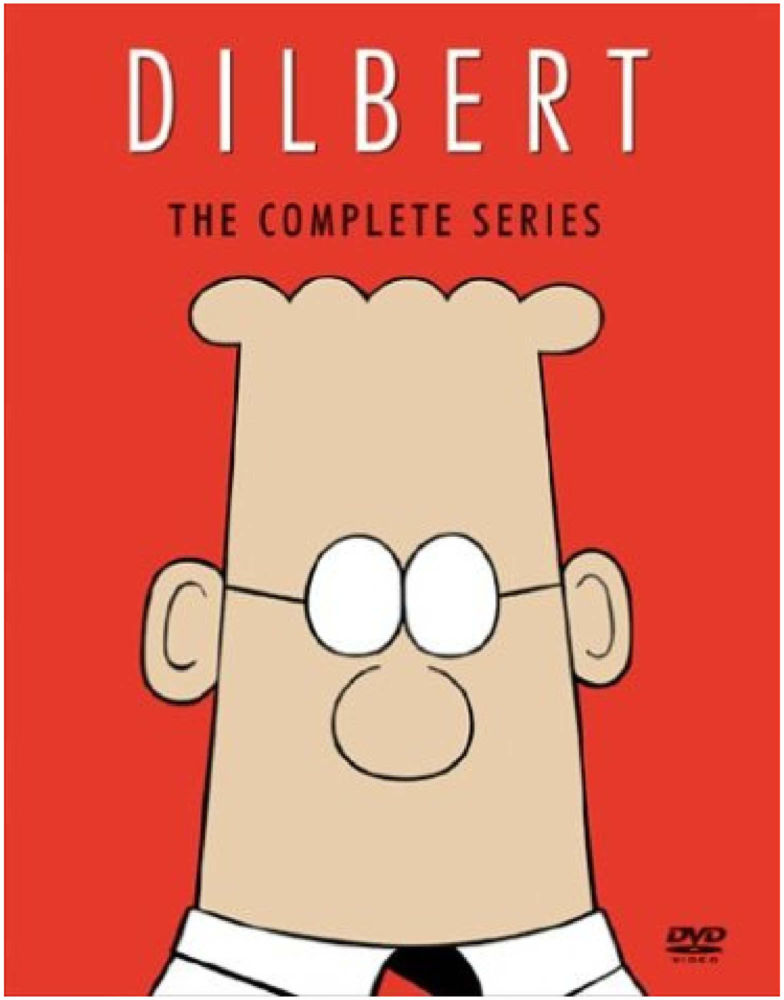
- Death through quality
  - “Process bureaucracy”
- Analysis paralysis
  - “Zero-lines of code seduction”
- Infrastructure churn
  - e. g., programming to low-level APIs

Organizational Traits

- Disrespect for quality developers
  - “Coders vs. developers”
- Top-heavy bureaucracy

Sociological Traits

- The “Not Invented Here” syndrome
- Modern method madness



www.dre.vanderbilt.edu/~schmidt/editorials.html

Traits of Highly Successful Software Organizations

Strong leadership in business & technology

- e.g., understand the role of software technology
- Don't wait for "silver bullets"

Clear architectural vision

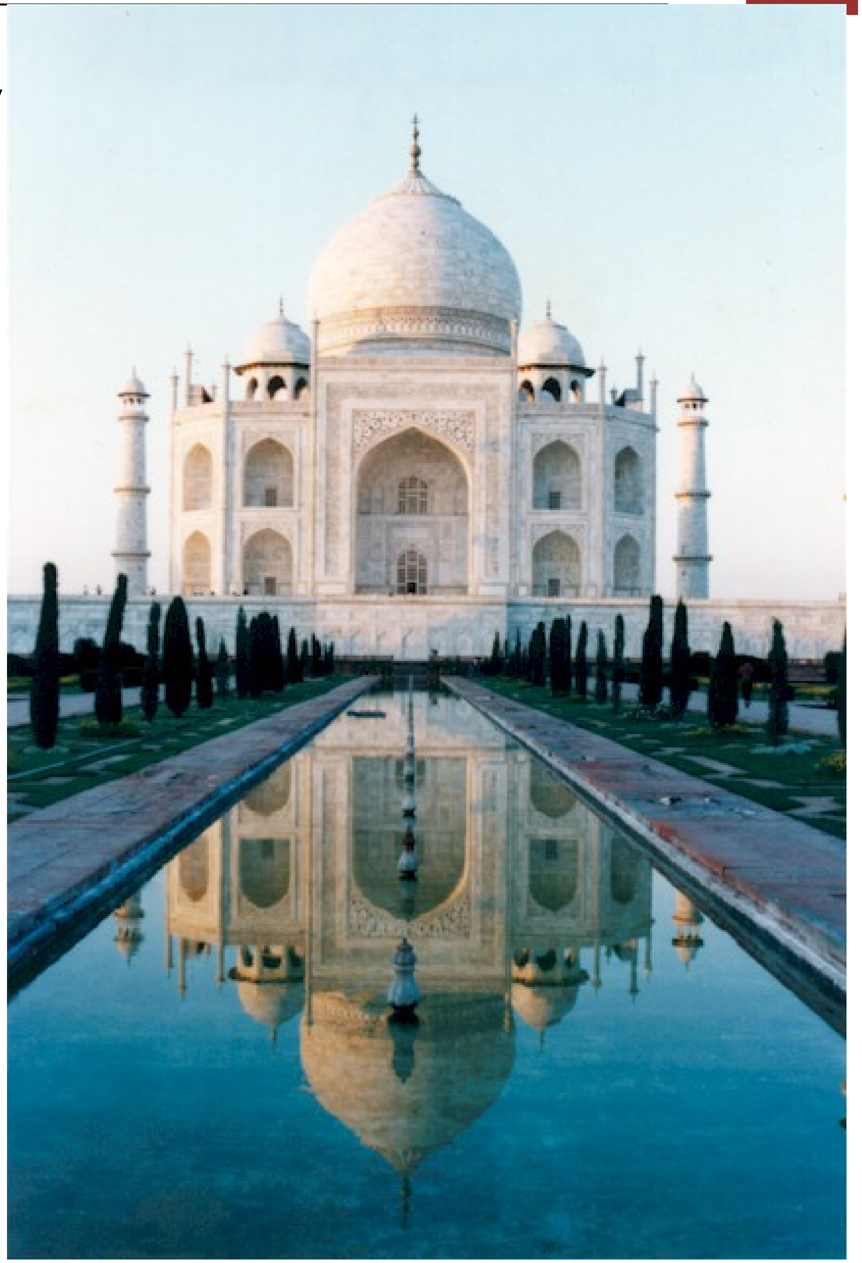
- e.g., know when to buy vs. build
- Avoid worship of specific tools & technologies

Effective use of prototypes & demos

- e.g., reduce risk & get user feedback

Commitment to/from skilled developers

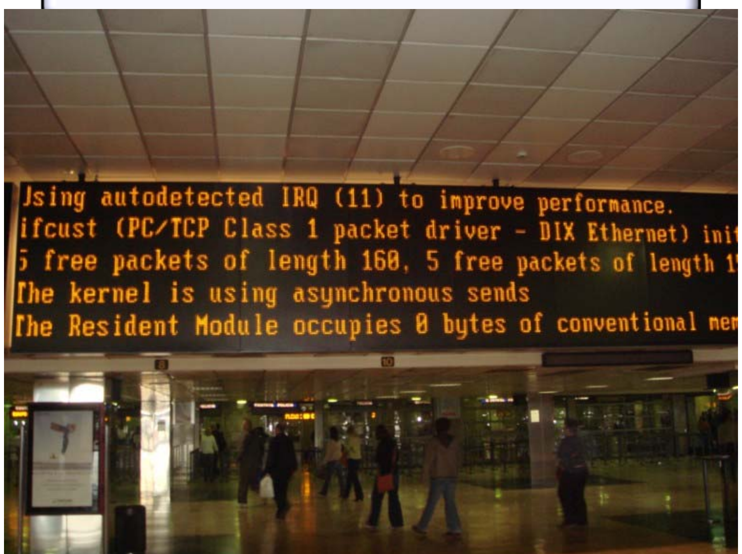
- e.g., know how to motivate software developers & recognize the value of thoughtware



Consequences of COTS & IT Commoditization

Applications

Domain-Specific Services



& Protocols

Hardware

- More emphasis on integration rather than programming
- Increased technology convergence & standardization
- Mass market economies of scale for technology & personnel
- More disruptive technologies & global competition
- Lower priced—but often lower quality—hardware & software components
- The decline of internally funded R&D
- Potential for complexity cap in next-generation complex systems

Not all trends bode well for long-term competitiveness of traditional leaders

Ultimately, competitiveness depends on success of long-term R&D on *complex* distributed real-time & embedded (DRE) systems

Concluding Remarks

- The growing size & complexity of DRE systems requires significant innovations & advances in processes, methods, platforms, & tools
- Not all technologies provide precision of legacy real-time & embedded systems
- Advances in Model-Driven Engineering & component/SOA-based DRE system middleware are needed to address future challenges
- Significant groundwork laid in DARPA & NSF programs

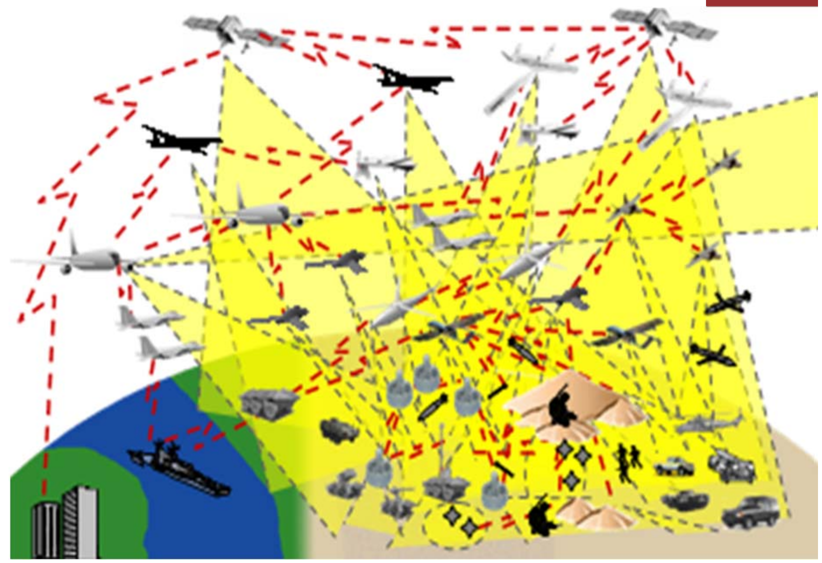
- Much more R&D needed to assure key quality attributes of DRE systems

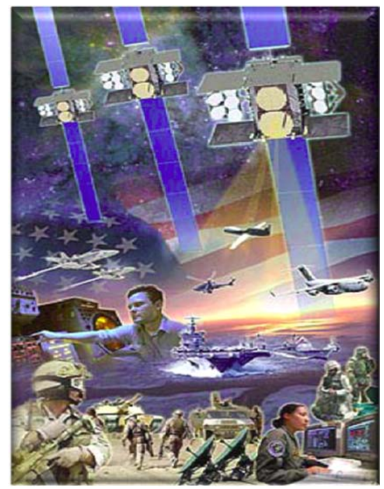
See blog.sei.cmu.edu for coverage of SEI R&D activities

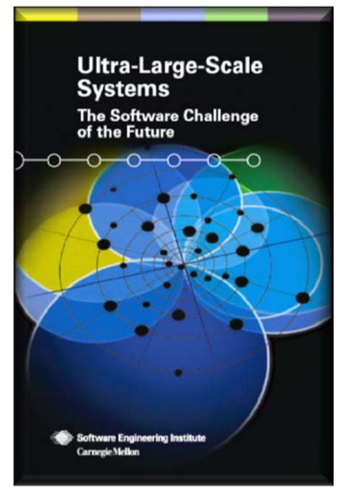
Further Reading

ULS systems are socio-technical ecosystems comprised of software-reliant systems, people, policies, cultures, & economics that have unprecedented scale in the following dimensions:

- # of lines of software code & hardware elements
- # of connections & interdependencies
- # of computational elements
- # of purposes & user perception of purposes
- # of routine processes & "emergent behaviors"
- # of (overlapping) policy domains & enforceable mechanisms
- # of people involved in some way
- Amount of data stored, accessed, & manipulated
- ... etc ...







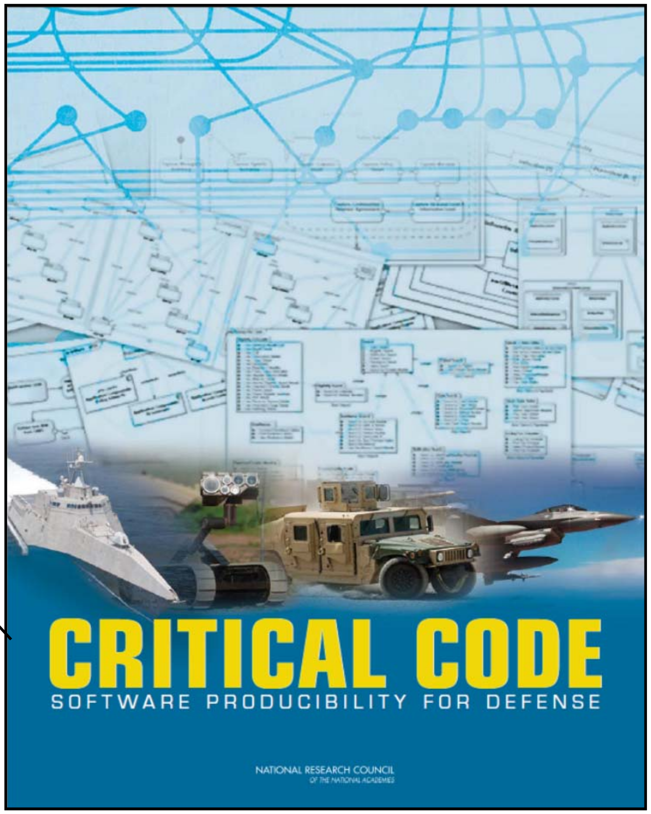
www.sei.cmu.edu/uls

See blog.sei.cmu.edu for discussions of software R&D activities

Further Reading

NRC Report *Critical Code: Software Producibility for Defense* (2010)

Focus of the report is on ensuring the DoD has the technical capacity & workforce to design, produce, assure, & evolve innovative software-reliant systems in a predictable manner, while effectively managing risk, cost, schedule, & complexity



Sponsored by Office of the Secretary of Defense (OSD) with assistance from the National Science Foundation (NSF), & Office of Naval Research (ONR), www.nap.edu/openbook.php?record_id=12979&page=R1

See blog.sei.cmu.edu for discussions of software R&D activities