Software Architecture

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About me

- Professor of Computer Science
  - At Carnegie Mellon University since 1990
  - Before then in industry (test and measurement)
- Research interests
  - Software architecture tools and techniques
  - Self-healing and self-adaptive systems
- Connection with NASA
  - Engagement since 2004
  - Sabbatical at JPL summer of 2006
  - On-going education offerings for several NASA Centers

This Talk

- What is Software Architecture?
  - Why is it important?
  - What are key principles and concepts of software architecture?
  - How can formal “architectural thinking” yield systems that better satisfy their requirements?
- Prospects for improving Fault Management through architectural design
  - How do these ideas relate to the themes of this workshop?

Examples of Software Architecture Descriptions

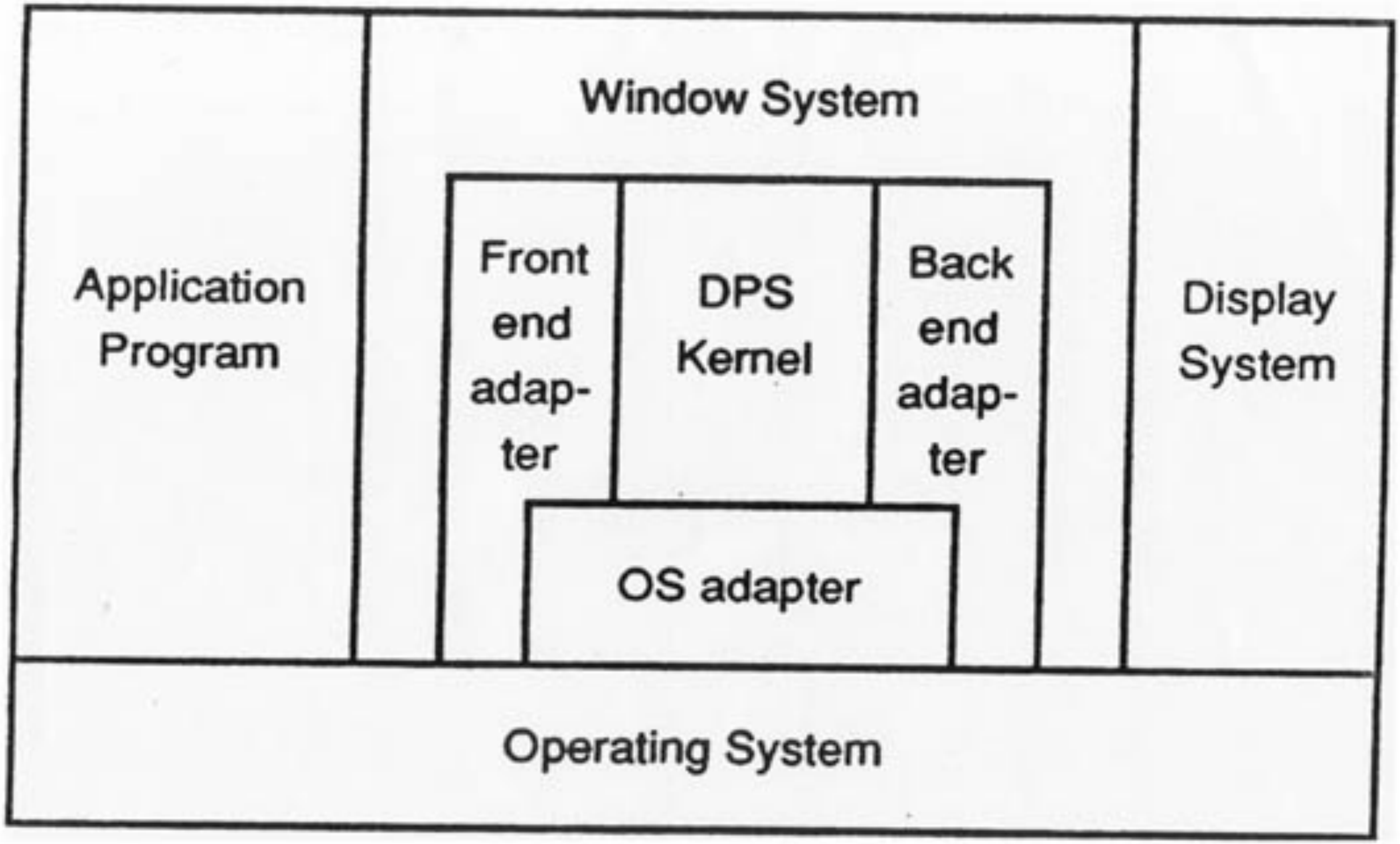
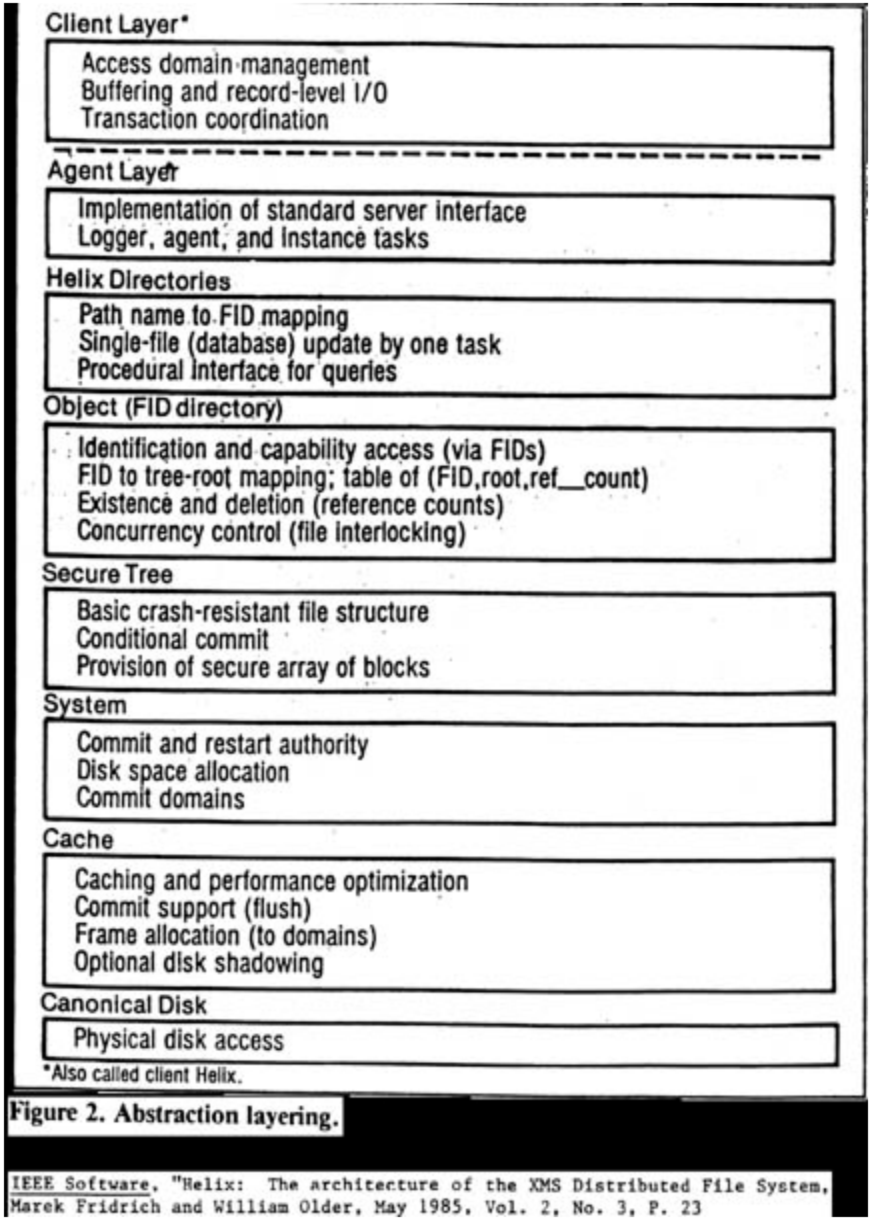


Figure 2. Display PostScript interpreter components.

An Overview of the DISPLAY POSTSCRIPT^{TM} System, Adobe Systems Incorporated, March 16, 1988, P. 10



Client Layer*

- Access domain management
- Buffering and record-level I/O
- Transaction coordination

Agent Layer

- Implementation of standard server interface
- Logger, agent, and instance tasks

Helix Directories

- Path name to FID mapping
- Single-file (database) update by one task
- Procedural interface for queries

Object (FID directory)

- Identification and capability access (via FIDs)
- FID to tree-root mapping; table of (FID,root,ref__count)
- Existence and deletion (reference counts)
- Concurrency control (file interlocking)

Secure Tree

- Basic crash-resistant file structure
- Conditional commit
- Provision of secure array of blocks

System

- Commit and restart authority
- Disk space allocation
- Commit domains

Cache

- Caching and performance optimization
- Commit support (flush)
- Frame allocation (to domains)
- Optional disk shadowing

Canonical Disk

- Physical disk access

*Also called client Helix.

Figure 2. Abstraction layering.

IEEE Software, "Helix: The architecture of the XMS Distributed File System, Marek Fridrich and William Older, May 1985, Vol. 2, No. 3, P. 23

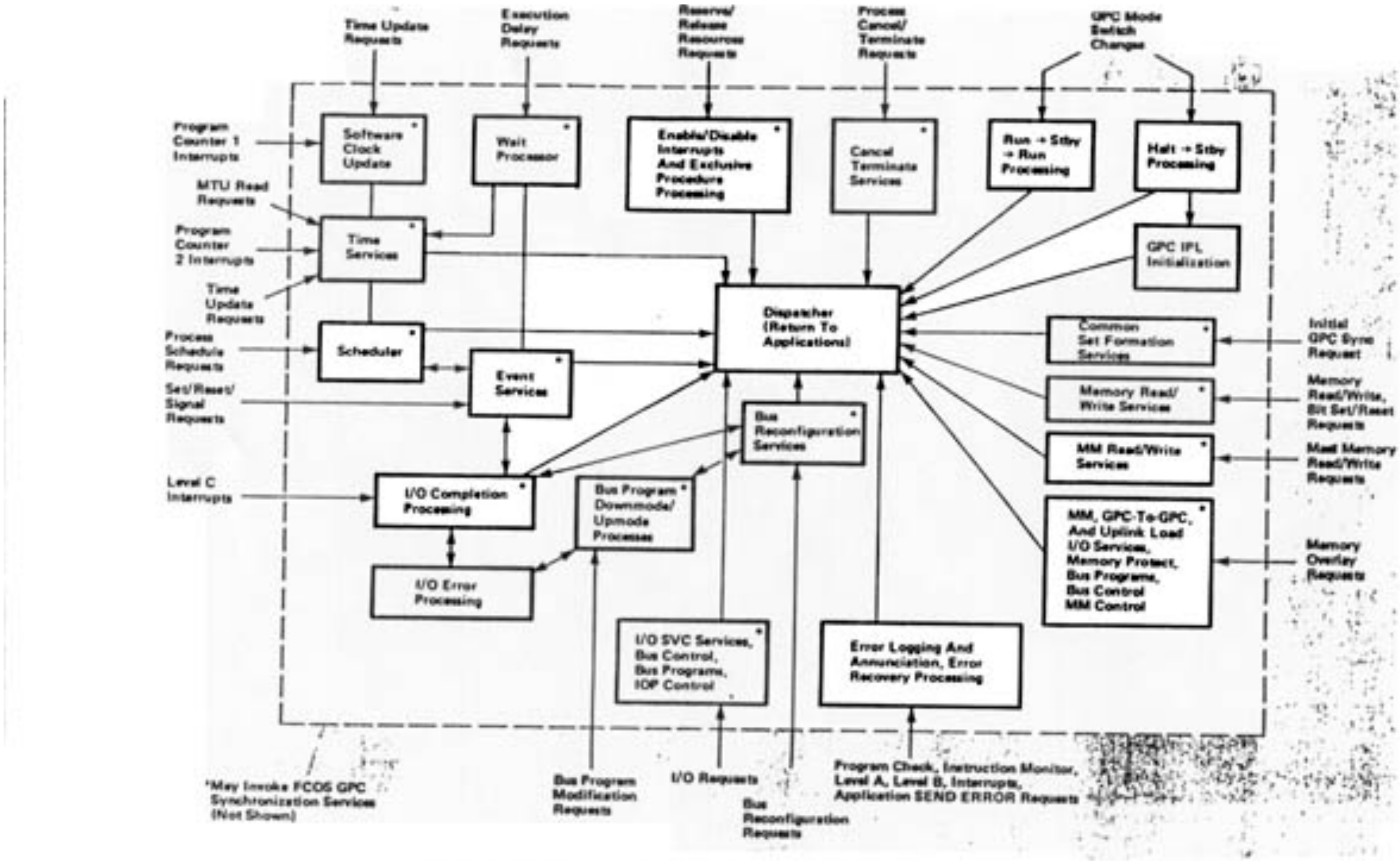
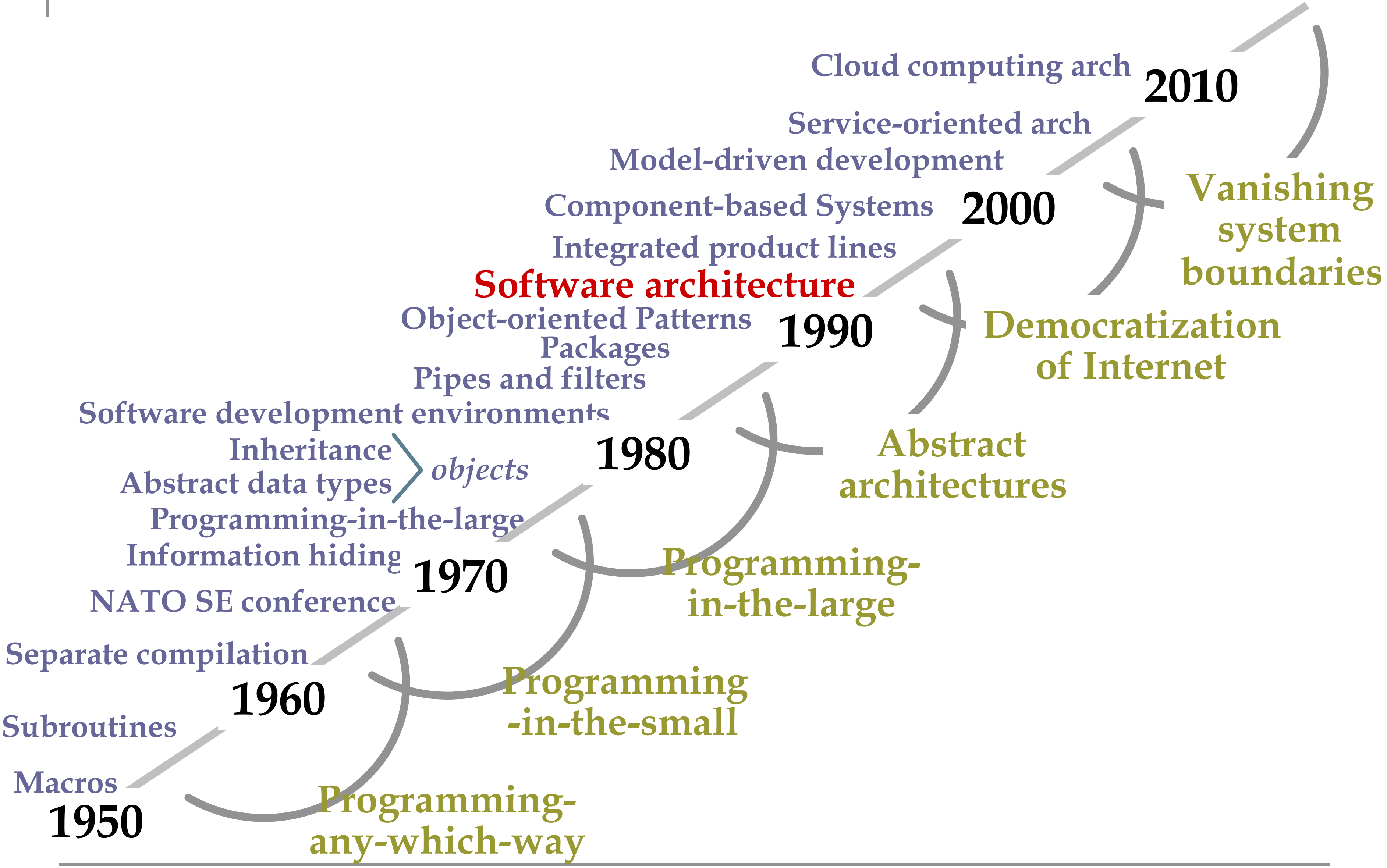

Time Update Requests
Execution Delay Requests
Reserve/ Release Resources Requests
Process Cancel/ Terminate Requests
GPC Mode Switch Changes
Program Counter 1 Interrupts
Software Clock Update *
Wait Processor *
Enable/Disable Interrupts And Exclusive Procedure Processing *
Cancel Terminate Services *
Run → Stby → Run Processing
Halt → Stby Processing
MTU Read Requests
Program Counter 2 Interrupts
Time Services *
Time Update Requests
GPC IPL Initialization
Dispatcher (Return To Applications)
Process Schedule Requests
Scheduler *
Event Services *
Common Set Formation Services *
Initial GPC Sync Request
Set/Reset/ Signal Requests
Memory Read/ Write Services *
Memory Read/Write, Bit Set/Reset Requests
Bus Reconfiguration Services *
MM Read/Write Services *
Mass Memory Read/Write Requests
Level C Interrupts
I/O Completion Processing *
Bus Program Downmode/ Upmode Processes *
MM, GPC-To-GPC, And Uplink Load I/O Services, Memory Protect, Bus Programs, Bus Control MM Control *
Memory Overlay Requests
I/O Error Processing
I/O SVC Services, Bus Control, Bus Programs, IOP Control *
Error Logging And Annunciation, Error Recovery Processing
*May Invoke FCOS GPC Synchronization Services (Not Shown)
Bus Program Modification Requests
I/O Requests
Bus Reconfiguration Requests
Program Check, Instruction Monitor, Level A, Level B, Interrupts, Application SEND ERROR Requests

FIGURE 7. **Flight Computer Operating System (The FCOS dispatcher coordinates and controls all work performed by the on-board computers.)**

Communications of the ACM, "Architecture of the Space Shuttle Primary Avionics Software Systems," Gene D. Carlow, September 1984, Vol. 27, No. 9, P. 933

Software Architecture in Context



1950

Macros

Subroutines

Programming-any-which-way

1960

Separate compilation

NATO SE conference

Programming-in-the-small

1970

Information hiding

Programming-in-the-large

Abstract data types

Inheritance

objects

Programming-in-the-large

1980

Software development environments

Pipes and filters

Packages

Object-oriented Patterns

Abstract architectures

1990

Software architecture

Integrated product lines

Component-based Systems

Democratization of Internet

2000

Model-driven development

Service-oriented arch

Vanishing system boundaries

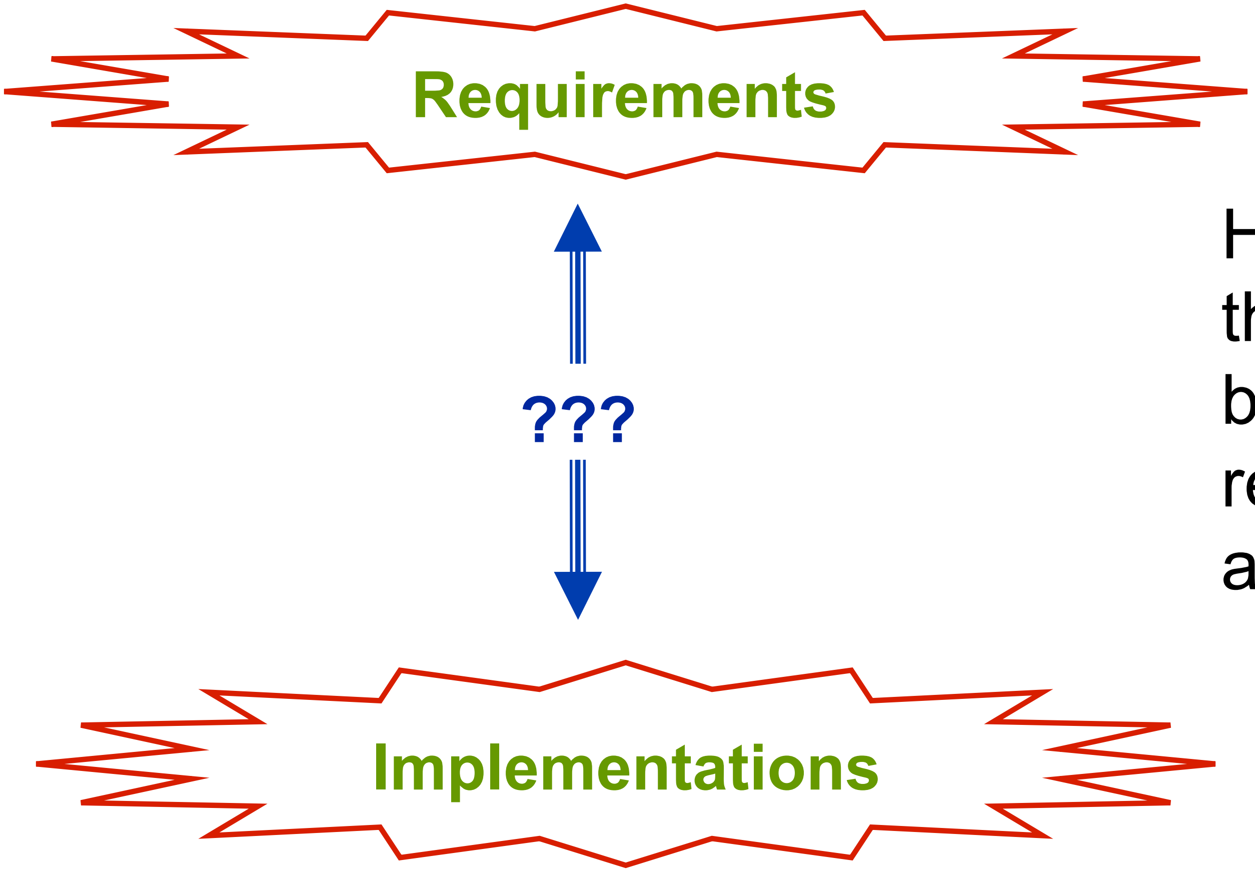
2010

Cloud computing arch

The Promise

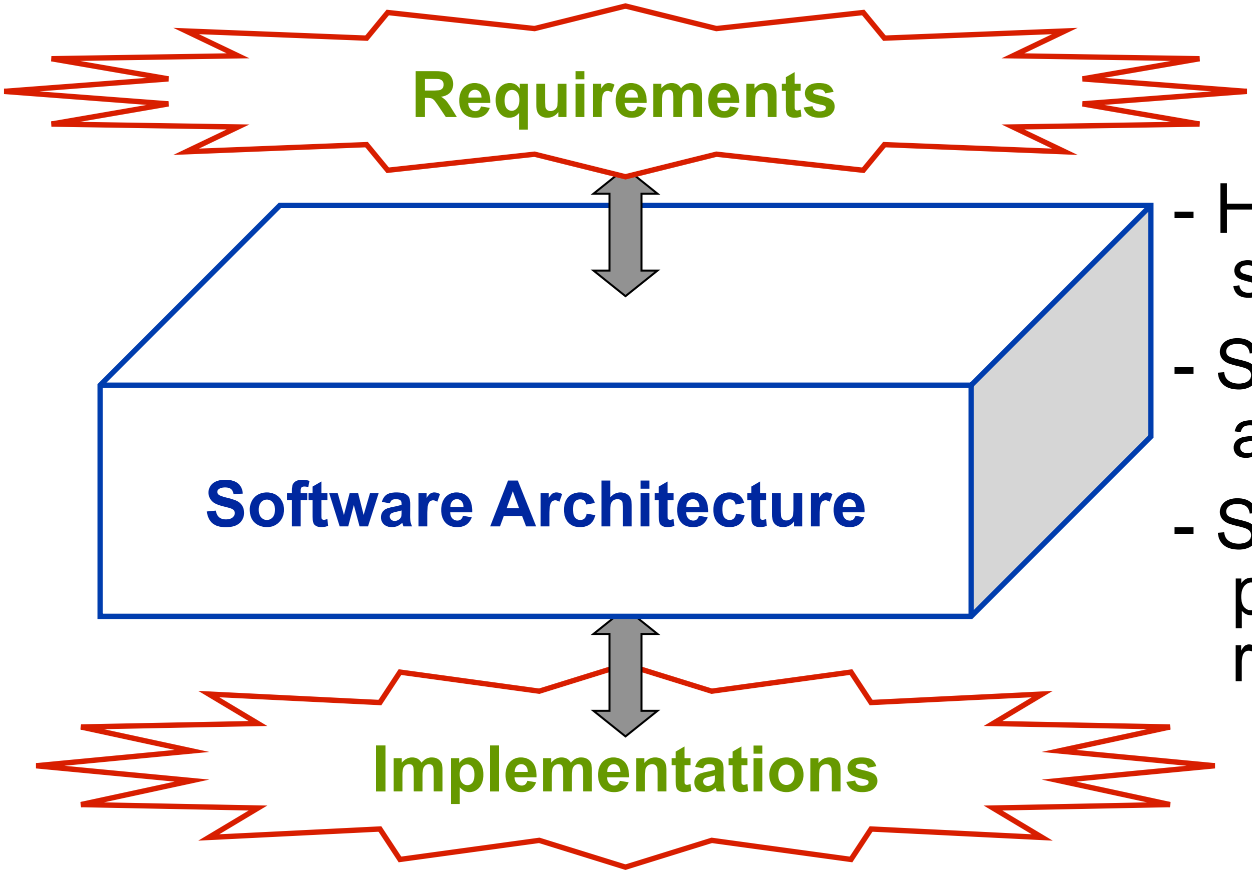
- Software Architecture as critical element of an effective *engineering discipline*
  - from ad hoc definition to codified principles
- Develop systems *"architecturally"*
  - improve system quality through conceptual integrity and coherence
  - support trade-off analysis & appropriate selection of architectural approaches
  - assure that the system will have desired properties by design
  - manage essential complexity; hide accidental complexity

The Big Problem



How to bridge the gap between requirements and solutions?

The Role of Software Architecture



- High level of system design
- System-level abstractions
- Satisfy high priority requirements

What is Software Architecture?

The software architecture of a computing system is the set of structures needed to reason about the system, which comprise software elements, relations among them and properties of both.

Documenting Software Architecture: Views and Beyond, 2nd Ed., Clements et al. 2010.

Issues Addressed by Architectural Design

- Structure: decomposition of a system into interacting components
  - assignment of function to components
  - selection of component interaction/coordination mechanisms
- Quality attributes: emergent system properties
  - performance, reliability, security, evolvability, testability, cost of maintenance
  - tradeoffs
- Design principles: conceptual integrity
  - vocabulary and rules for system composition
  - "load-bearing walls"
  - use of codified design idioms, styles, and tactics

Example: Google

Quality Attributes

- **Performance**
- **Cost**
- **Availability**

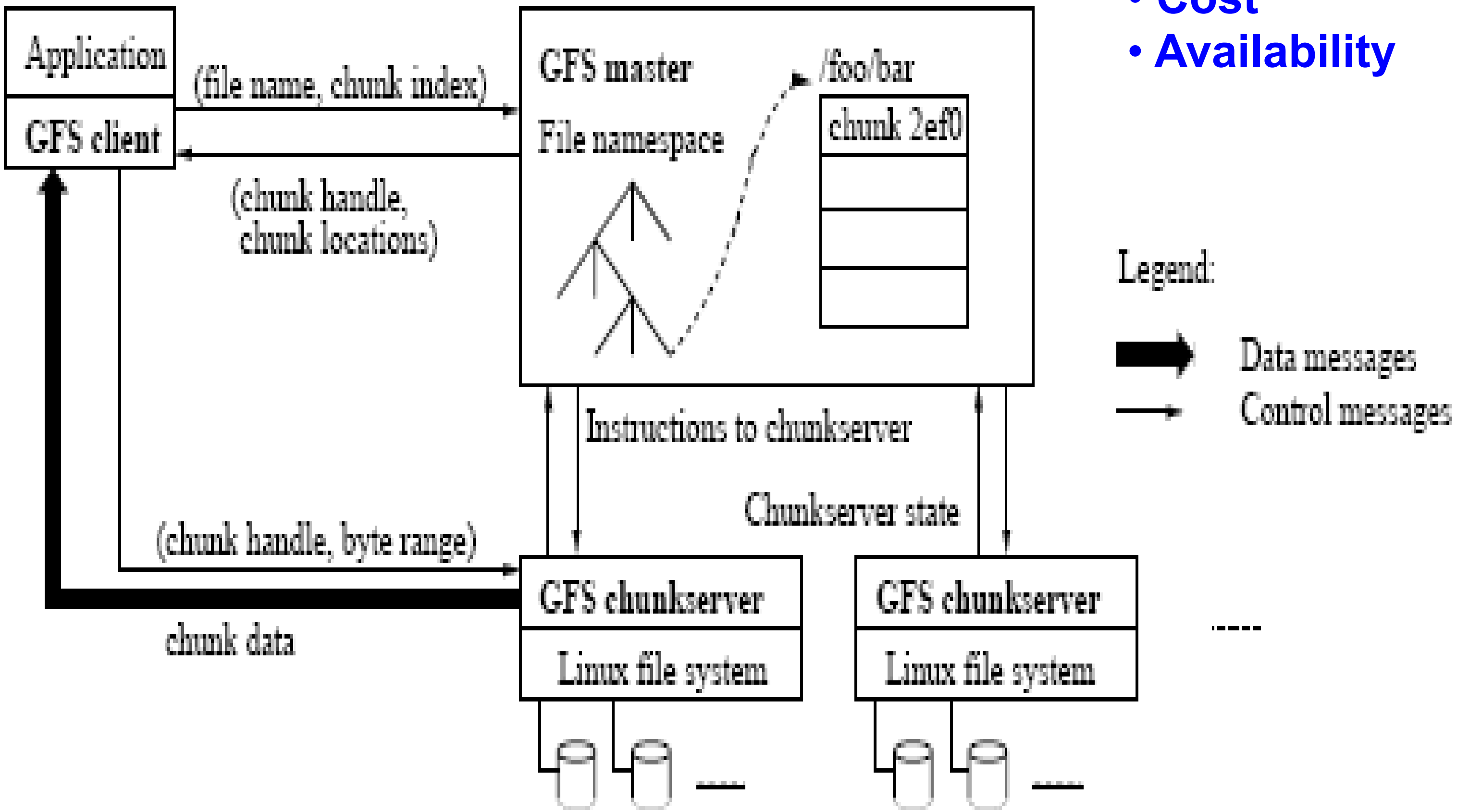
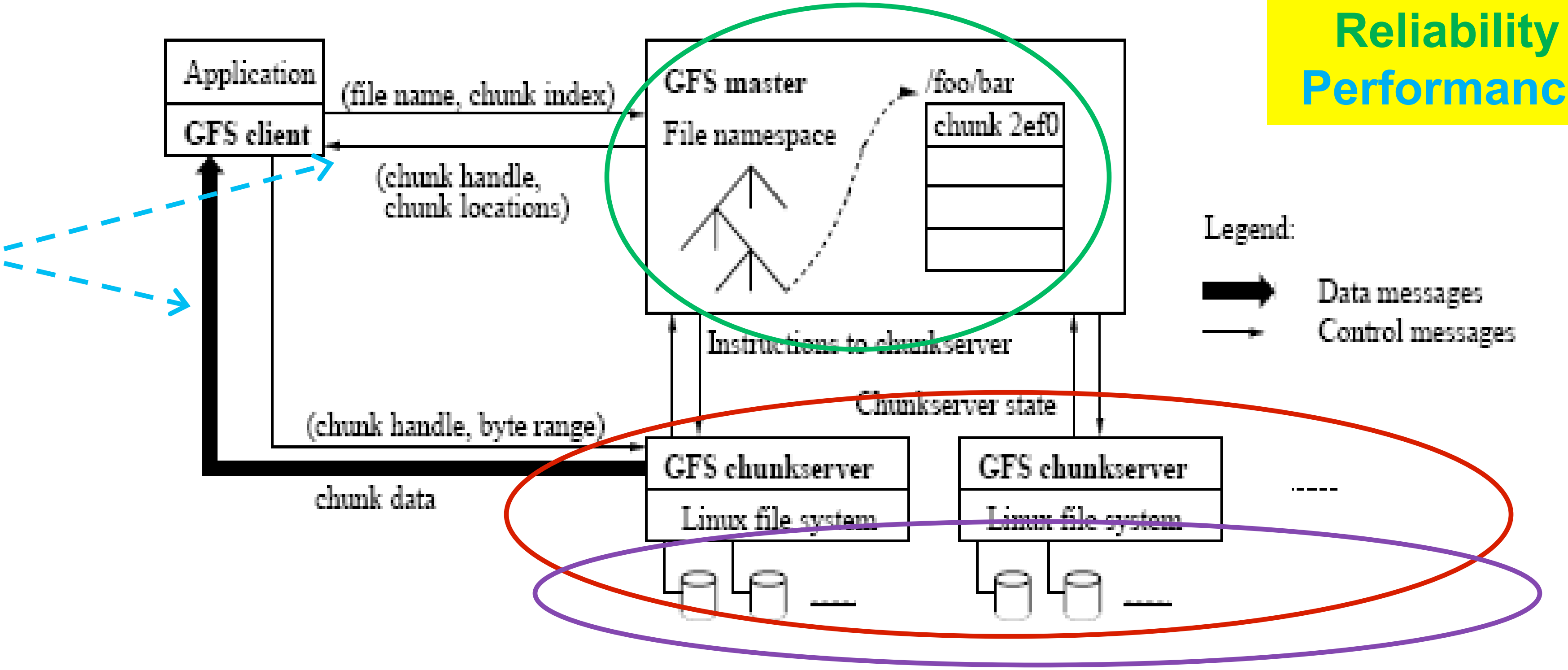


Figure 1: GFS Architecture

Source: “The Google File System” Sanjay Ghemawat, Howard Gobioff, and Shun-Tak Leung

Example: Google

Scalability
Cost
Reliability
Performance



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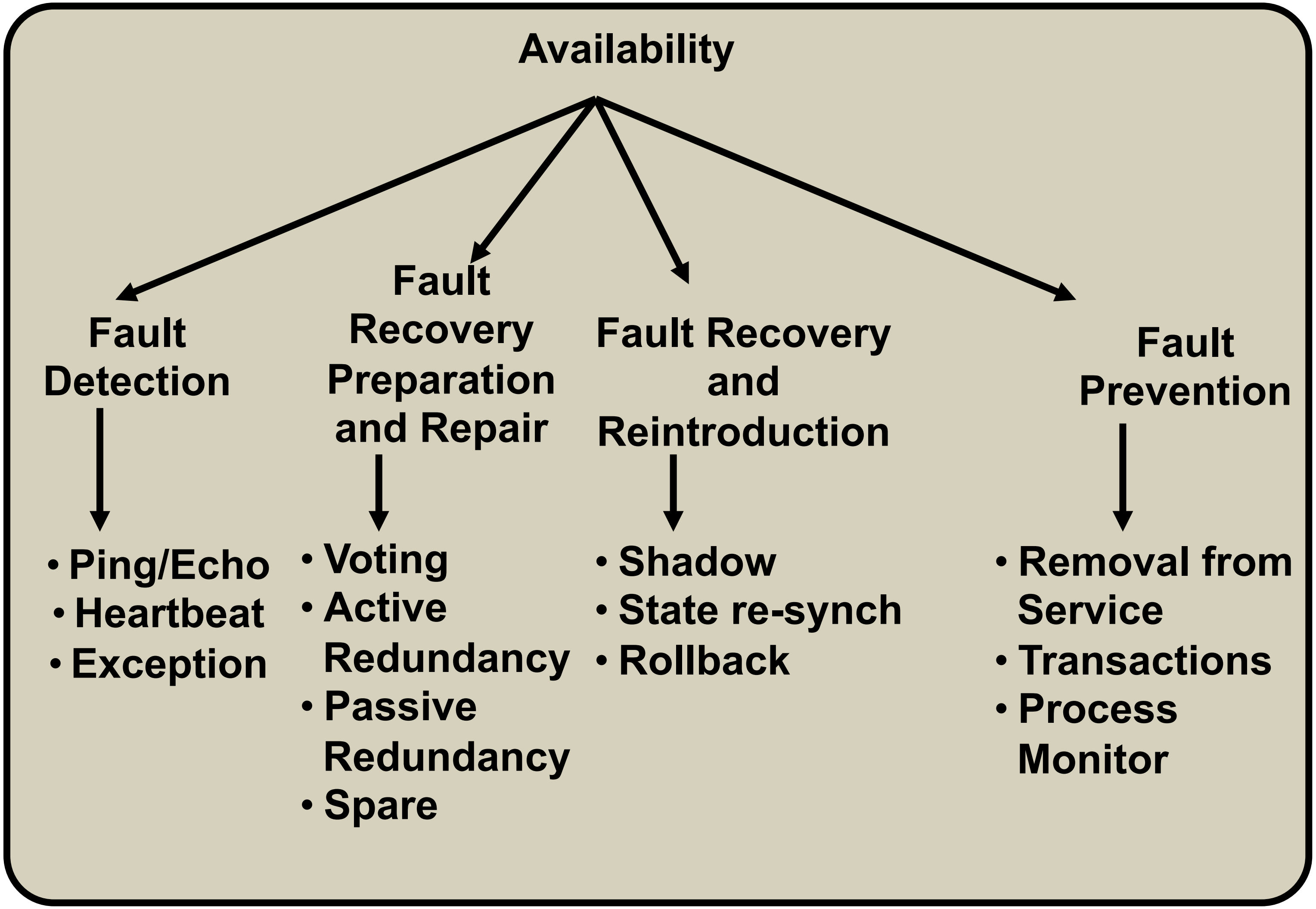
Principles of Architectural Design

- Understand architectural drivers
  - functional; quality attributes (QA); constraints
- Identify relevant architectural approaches
  - Styles, idioms, patterns, tactics
- Understand how those approaches impact achievement of quality attributes
  - Consider tradeoffs in achieving multiple QAs
- Select the set of approaches that are optimal for the particular system

Example QA: Availability Tactics



Availability

Fault Detection

- Ping/Echo
- Heartbeat
- Exception

Fault Recovery Preparation and Repair

- Voting
- Active Redundancy
- Passive Redundancy
- Spare

Fault Recovery and Reintroduction

- Shadow
- State re-synch
- Rollback

Fault Prevention

- Removal from Service
- Transactions
- Process Monitor

This Workshop

- What architectural approaches are currently used for FM today?
- What factors influence that decision?
- What are the tradeoffs in picking one FM architecture over another?
- What can we learn by looking at positive and negative experiences of prior FM architectures?
- How can we address future challenges in FM through better understanding of architectural principles?

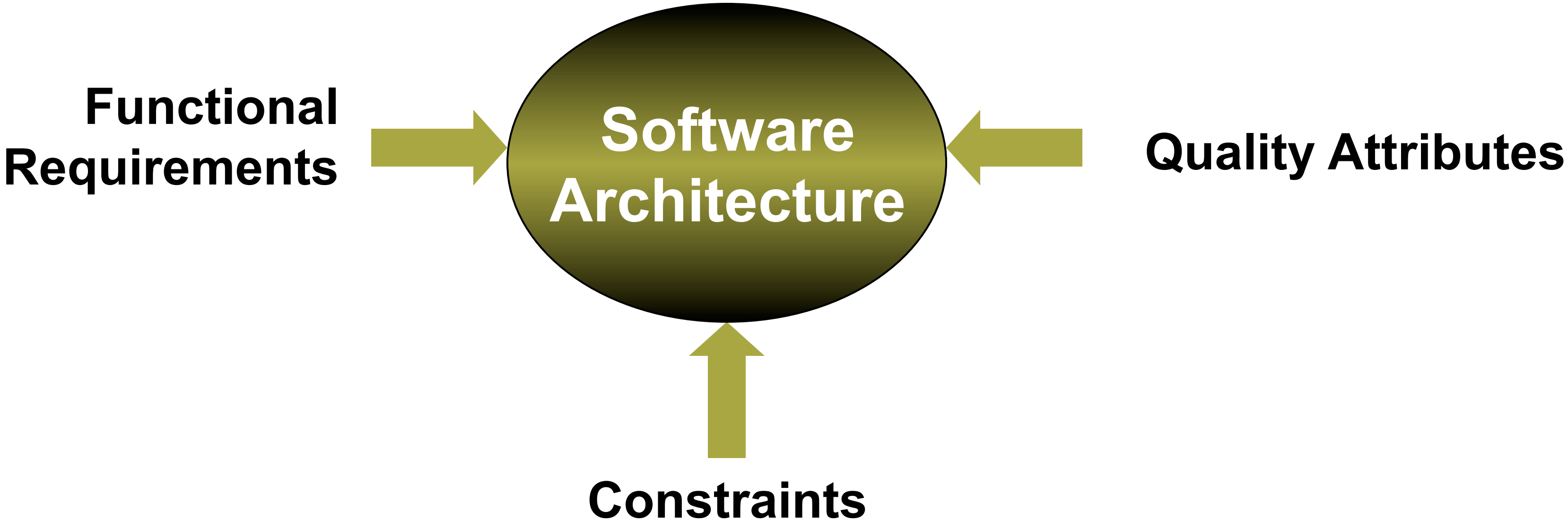
The End

Supplementary Slides

- Architecture Drivers
- Quality Attributes
- Styles and Tactics
- Architecture tradeoff analysis

Architectural Drivers – 1

- Architectural drivers are requirements that shape the software architecture



Functional Requirements

Software Architecture

Quality Attributes

Constraints

Architectural Drivers – 2

- Functional Requirements – what the system must do.
  - In architectural design we are concerned with high level function not implementation details.
- Constraints – design decisions already made for the designers.
  - Business/organizational (e.g., schedule)
  - Technical (e.g., required use of legacy platform)
- Quality Attributes – characteristics the system must possess in addition to the functionality.

Quality Attributes

- Example QAs
  - availability
  - modifiability
  - performance
  - security
- Important notes
  - There is no standard taxonomy/definitions of QA
  - Each QA has multiple aspects
  - System-level QA requirements may induce functional requirements on a subsystem

Example: Availability – 1

- Definition: Availability is concerned with system failure and its associated consequences. A system failure occurs when a system no longer delivers a service that is consistent with its specification.

Example: Availability – 2

- Areas of concern include
  - preventing catastrophic system failures
  - detecting system failures
  - recovering successfully from system failures
  - the amount of time needed to recover from system failures
  - the frequency of system failures
  - degraded modes of operation due to system failures

Styles and Tactics

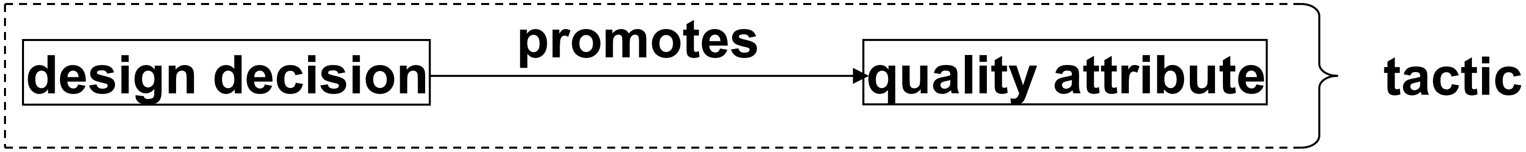
- Architectural design can be improved by reusing prior architectural approaches that have well-understood properties
- Two of the most common forms of reuse are
  - Styles: general families of systems based on overall compositional structure
  - Tactics: techniques for improving quality attributes

A (Partial) Catalogue of Styles

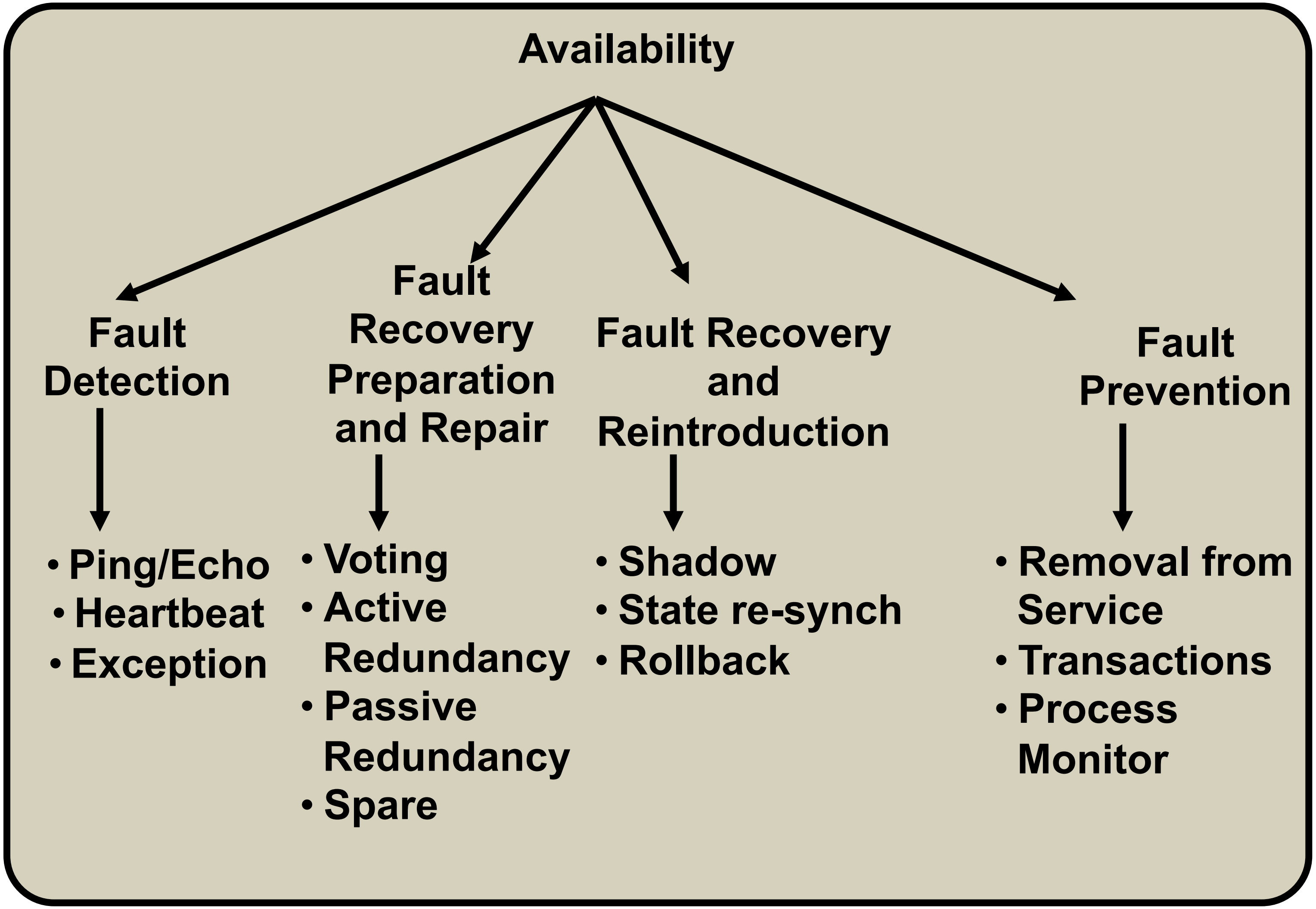
- Data flow
  - batch sequential
  - pipes and filters
  - process control
- Call-return
  - main program-subroutine
  - object-oriented
  - component-based
  - peer-to-peer
  - service-oriented
  - N-tiered
- Event-based
  - asynchronous messaging
  - publish-subscribe
  - implicit invocation
  - data-triggered
- Data-centered
  - repository
  - blackboard
  - shared variable

Tactics

- A *tactic* is a design decision that refines a high level style and is influential in the control of a quality attribute response.



Example QA: Availability Tactics



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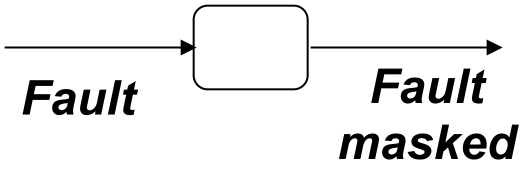
Availability Tactics – 2



Fault

Fault masked

- Fault detection
  - ping/echo: when one component issues a ping and expects to receive an echo within a predefined time from another component
  - heartbeat: when one component issues a message periodically while another listens for it
  - exceptions: using exception mechanisms to raise faults when an error occurs

Architecture Tradeoff Analysis

- A tactic is usually selected because it will improve a particular QA
- But at the same time it will have an impact on other QA or other aspects of the same QA
- Example: Detection Tactics for Availability
  - Performance: number of messages, timeliness of detection
  - Testability: complexity, non-determinism
  - Modifiability: distributed/localized responsibility