# Architecture analysis:
# – The SAAM
# – ATAM



## When and Why To Analyze Architecture -1

- Analyzing for system qualities early in the life cycle allows for a comparison of architectural options.
- When building a system
  - » Architecture is the earliest artifact where trade-offs are visible.
  - » Analysis should be done when deciding on architecture.
  - » The reality is that analysis is often done during damage control, later in the project.

# When and Why To Analyze Architecture -2.

- When acquiring a system
  - » Architectural analysis is useful if the system will have a long lifetime within organization.
  - » Analysis provides a mechanism for understanding how the system will evolve.
  - » Analysis can also provide insight into other visible qualities.



# Qualities Are Too Vague for Analysis

- Is the following system modifiable?
  - » Background color of the user interface is changed merely by modifying a resource file.
  - » Dozens of components must be changed to accommodate a new data file format.
- A reasonable answer is
  - » yes with respect to changing background color
  - » no with respect to changing file format

# Qualities Are Too Vague for Analysis

- Qualities only have meaning within a context.
- SAAM specifies context through scenarios.



# Scenarios

- A scenario is a brief description of a stakeholder’s interaction with a system.
- When creating scenarios, it is important to consider all stakeholders, especially
  - » end users
  - » developers
  - » maintainers
  - » system administrators

# Steps of a SAAM Evaluation

- Identify and assemble stakeholders
- Develop and prioritize scenarios
- Describe candidate architecture(s)
- Classify scenarios as direct or indirect
- Perform scenario evaluation
- Reveal scenario interactions
- Generate overall evaluation



# Step 1: Identify and Assemble Stakeholders -1

| Stakeholder | Interest |
|---|---|
| Customer | Schedule and budget; usefulness of system; meeting customers' (or market's) expectations |
| End user | Functionality, usability |
| Developer | Clarity and completeness of architecture; high cohesion and limited coupling of parts; clear interaction mechanisms |
| Maintainer | Maintainability; ability to locate places of change |

# Step 1: Identify and Assemble Stakeholders -2

| Stakeholder | Interest |
|---|---|
| System administrator | Ease in finding sources of operational problems |
| Network administrator | Network performance, predictability |
| Integrator | Clarity and completeness of architecture; high cohesion and limited coupling of parts; clear interaction mechanisms |




# Step 1: Identify and Assemble Stakeholders -3.

| Stakeholder | Interest |
|---|---|
| Tester | Integrated, consistent error-handling; limited component coupling; high component cohesion; conceptual integrity |
| Application builder (if product line architecture) | Architectural clarity, completeness; interaction mechanisms; simple tailoring mechanisms |
| Representative of the domain | Interoperability |

# Step 2: Stakeholders Develop and Prioritize Scenarios

- Scenarios should be typical of the kinds of evolution that the system must support:
  - » functionality
  - » development activities
  - » change activities
- Scenarios also can be chosen to give insight into the system structure.
- Scenarios should represent tasks relevant to all stakeholders.
- Rule of thumb: 10-15 prioritized scenarios



# Step 3: Describe Candidate Architectures

- It is frequently necessary to elicit appropriate architectural descriptions.
- Structures chosen to describe the architecture will depend on the type of qualities to be evaluated.
- Code and functional structures are primarily used to evaluate modification scenarios.

# Step 4: Classify Scenarios

- There are two classes of scenarios.
  - » Direct scenarios are those that can be executed by the system without modification.
  - » Indirect scenarios are those that require modifications to the system.
- The classification depends upon both the scenario and the architecture.
- For indirect scenarios we gauge the order of difficulty of each change: e.g. a person-day, person-week, person-month, person-year.



# Step 5: Perform Scenario Evaluation

- For each indirect scenario
  - » identify the components, data connections, control connections, and interfaces that must be added, deleted, or modified
  - » estimate the difficulty of modification
- Difficulty of modification is elicited from the architect and is based on the number of components to be modified and the effect of the modifications.
- A monolithic system will score well on this step, but not on next step.

# Step 6: Reveal Scenario Interactions

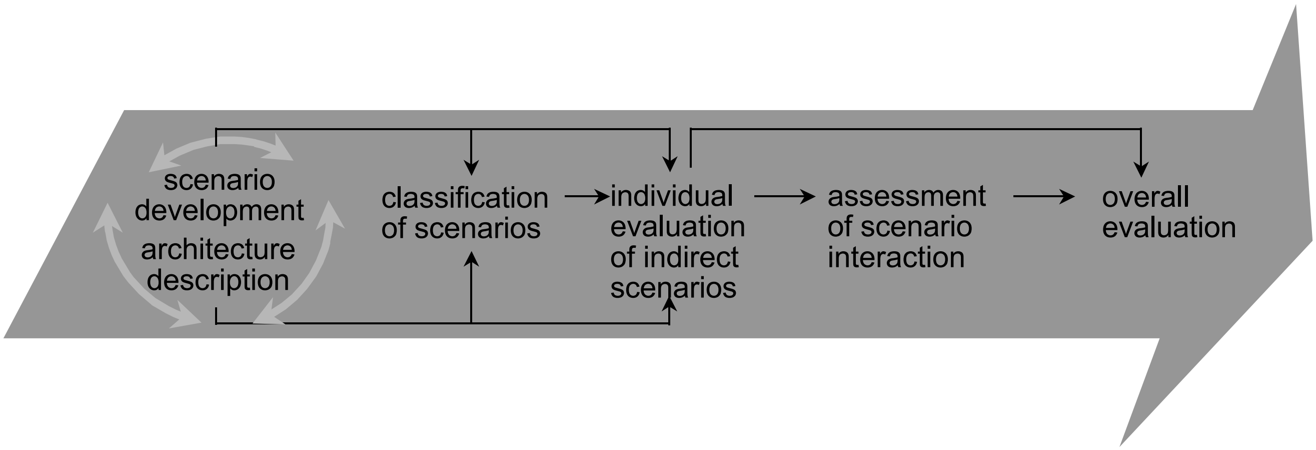
- When multiple indirect scenarios affect the same components, this could indicate a problem.
  - » could be good, if scenarios are variants of each other
    - – change background color to green
    - – change background color to red
  - » could be bad, indicating a potentially poor separation of concerns
    - – change background color to red
    - – port system to a different platform



# Step 7: Generate Overall Evaluation

- Not all scenarios are equal.
- The organization must determine which scenarios are most important.
- Then the organization must decide as to whether the design is acceptable “as is” or if it must be modified.

# Interaction of SAAM Steps



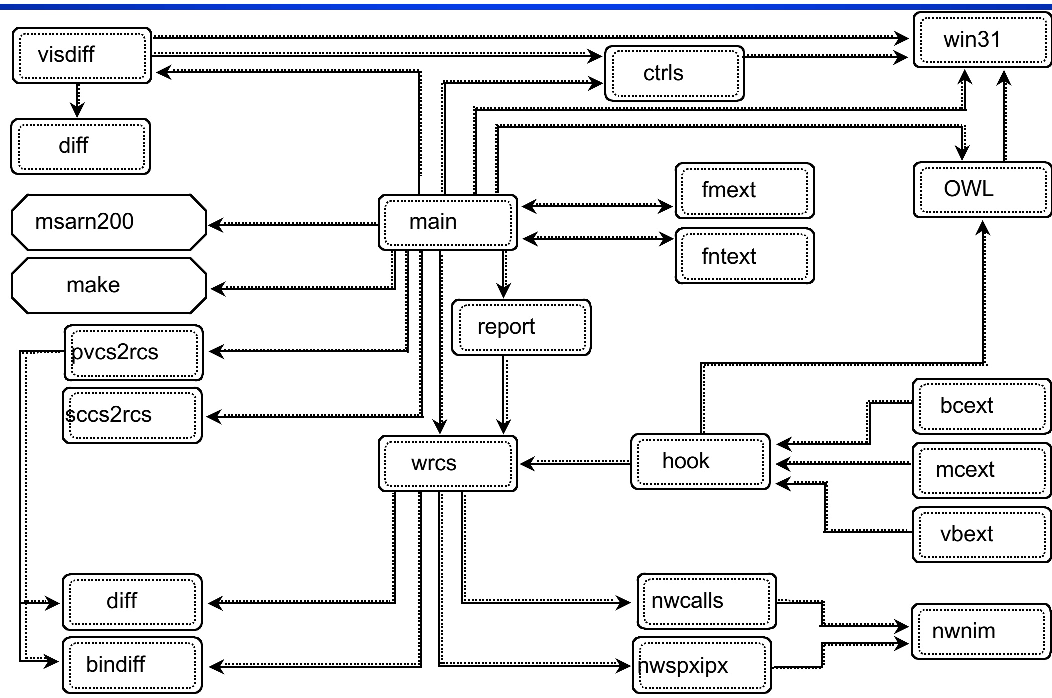




# Example: SAAM Applied to Revision Control System

- "WRCS" is a large, commercially-available revision control system.
- No documented system architecture existed prior to the evaluation.
- The purpose of the evaluation was to assess the impact of anticipated future changes.
- Three iterations were required to develop a satisfactory representation, alternating between
  - » development of scenarios
  - » representation of architecture

# Architectural Representation of WRCS






# Scenarios Used in WRCS

- User scenarios
  - » compare binary file representations
  - » configure the product's toolbar
- Maintainer
  - » port to another operating system
  - » make minor modifications to the user interface
- Administrator
  - » change access permissions for a project
  - » integrate with a new development environment

# Scenario Classification

- User scenarios
  - » compare binary file representations: *indirect*
  - » configure the product's toolbar: *direct*
- Maintainer
  - » port to another operating system: *indirect*
  - » make minor modifications to the user interface: *indirect*
- Administrator
  - » change access permissions for a project: *direct*
  - » integrate with a new development environment: *indirect*



# Scenario Interactions

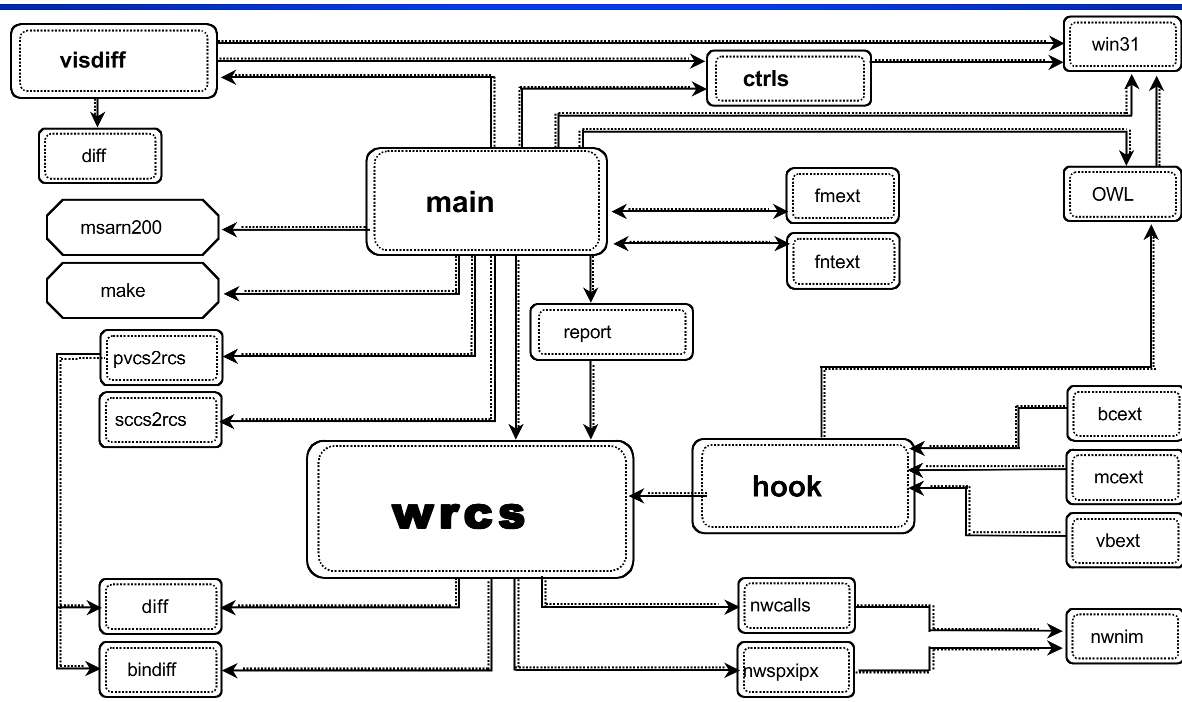
- Each indirect scenario necessitated a change in some modules. This can be represented either tabularly or visually.
- The number of scenarios that affected each module can be shown with a table or graphically, with a fish-eye view.
- A fish-eye view uses size to represent areas of interest.

# Scenario Interaction Table

| Module | No. changes |
|---|---|
| main | 4 |
| wrcs | 7 |
| diff | 1 |
| bindiff | 1 |
| pvcs2rcs | 1 |
| sccs2rcs | 1 |
| nwcalls | 1 |
| nwspxipx | 1 |
| nwnlm | 1 |
| hook | 4 |
| report | 1 |
| visdiff | 3 |
| ctrls | 2 |



# Scenario Interaction Fish-Eye



# Lessons Learned from WRCS

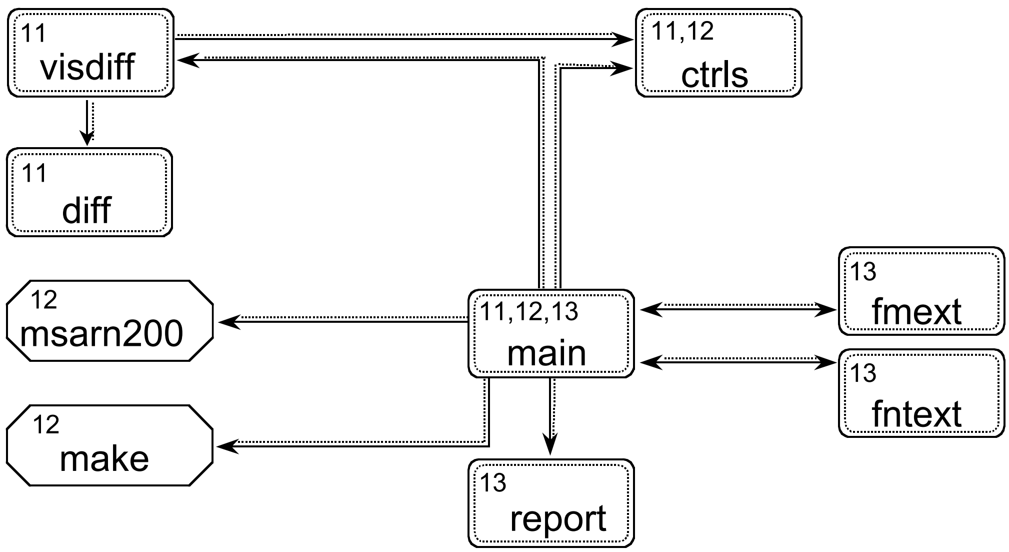
- Granularity of architectural description
- Interpretation of scenario interactions



# Proper Granularity of Architectural Description

- The level of detail of architectural description is determined by the scenarios chosen.
- The next slide shows what an architect thought was an appropriate level of detail.
- Components are annotated with the numbers of indirect scenarios that affect them.

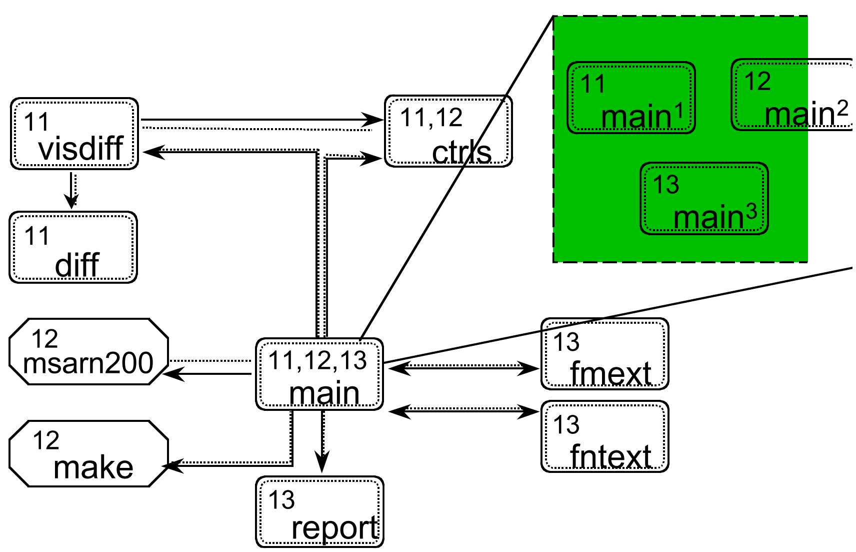
# Original Representation of WRCS






# The “main” Scenario Interactions

- Possibilities:
  - » Scenarios are all of the same class.
  - » Scenarios are of different classes and “main” cannot be subdivided.
  - » Scenarios are of different classes, and “main” *can* be subdivided.



# WRCS: What did we learn?

- We identified severe limitations in achieving the desired portability and modifiability. A major system redesign was recommended.
- The evaluation itself obtained mixed results.
  - » Senior developers/managers found it important and useful.
  - » Developers regarded this as just an academic exercise.
- SAAM allowed insight into capabilities and limitations that weren't easily achieved otherwise.
- This was accomplished with only scant knowledge of the internal workings of WRCS.



# Lessons from SAAM -1

- Direct scenarios provide a
  - » first-order differentiation mechanism for competing architectures
  - » mechanism for eliciting and understanding structures of architectures (both static and dynamic)
- It is important to have stakeholders present at evaluation meetings.
  - » Stakeholders find it to be educational.
  - » Architectural evaluators may not have the experience to keep presenters "honest."

# Lessons from SAAM -2.

- SAAM and traditional architectural metrics
  - » Coupling and cohesion metrics do not represent different patterns of use.
  - » High scenario interaction shows low cohesion.
  - » A scenario with widespread hits shows high coupling.
  - » Both are tied to the context of use.
  - » SAAM provides a means of sharpening the use of coupling and cohesion metrics.




# Summary

- A SAAM evaluation produces
  - » technical results: provides insight into system capabilities
  - » social results
    - – forces some documentation of architecture
    - – acts as communication vehicle among stakeholders

# Architecture analysis: The ATAM



# Outline

- Why analyze an architecture?
- ATAM Steps
- An example
- Summary and Status

# Why Analyze an Architecture?

- *All* design involves tradeoffs.
- A software architecture is the earliest life-cycle artifact that embodies significant design decisions: choices and tradeoffs.



# The ATAM

- We have been developing the Architecture Tradeoff Analysis Method (ATAM) for over two years.
- The purpose of ATAM is: *to assess the consequences of architectural decision alternatives in light of quality attribute requirements*.

# Purpose of ATAM - 1

- We need a method in which the right questions are asked *early to:*
  - » Discover *risks* -- alternatives that might create future problems in some quality attribute
  - » Discover *sensitivity points* -- alternatives for which a slight change makes a significant difference in some quality attribute
  - » Discover *tradeoffs* -- decisions affecting more than one quality attribute



# Purpose of ATAM - 2.

- The purpose of an ATAM is NOT to provide precise analyses . . . the purpose IS to discover risks created by architectural decisions.
- We want to find *trends:* correlation between architectural decisions and predictions of system properties.
- Discovered risks can then be made the focus of mitigation activities: e.g. further design, further analysis, prototyping.

# ATAM Benefits

- There are a number of benefits from performing ATAM analyses:
  - » Clarified quality attribute requirements
  - » Improved architecture documentation
  - » Documented basis for architectural decisions
  - » Identified risks early in the life-cycle
  - » Increased communication among stakeholders
- The results are improved architectures.



# Outline

- Why analyze an architecture?
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# ATAM Steps

- 1. Present ATAM
- 2. Present business drivers
- 3. Present architecture
- 4. Identify architectural styles
- 5. Generate quality attribute utility tree
- 6. Elicit and analyze architectural styles
- 7. Generate seed scenarios
- 8. Brainstorm and prioritize scenarios
- 9. Map scenarios onto styles
- 10. Present out-brief and/or write report






# 1. Present ATAM

- Evaluation Team presents an overview of ATAM including:
  - » ATAM steps in brief
  - » techniques
    - – utility tree generation
    - – style-based elicitation/analysis
    - – scenario brainstorming/mapping
  - » outputs
    - – scenarios
    - – architectural styles
    - – quality attribute questions
    - – risks and “non-risks
    - – utility tree

# 2. Present Business Drivers

- ATAM customer representative describes the system's business drivers including:
  - » business context for the system
  - » high-level functional requirements
  - » high-level quality attribute requirements
    - – architectural drivers: quality attributes that "shape" the architecture
    - – critical requirements: quality attributes most central to the system's success






# 3. Present Architecture

- Architect presents an overview of the architecture including:
  - » technical constraints such as an OS, hardware, or middle-ware prescribed for use
  - » other systems with which the system must interact
  - » architectural approaches used to meet quality attribute requirements
- Evaluation team begins probing for:
  - » risks
  - » architectural styles

# 4. Identify Architectural Styles

- High-level overview of architecture is completed by itemizing architectural styles found in the architecture.
- Examples:
  - » client-server
  - » 3-tier
  - » pipeline
  - » publish-subscribe

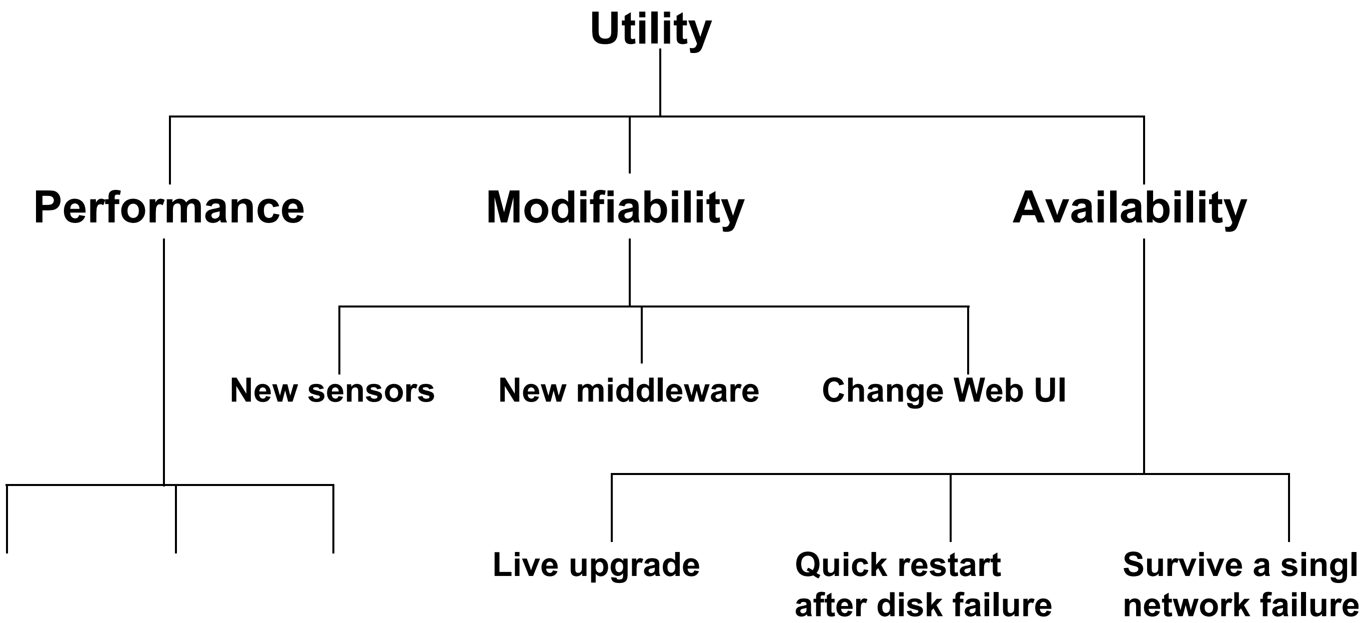





# 5. Generate Quality Attribute Utility Tree

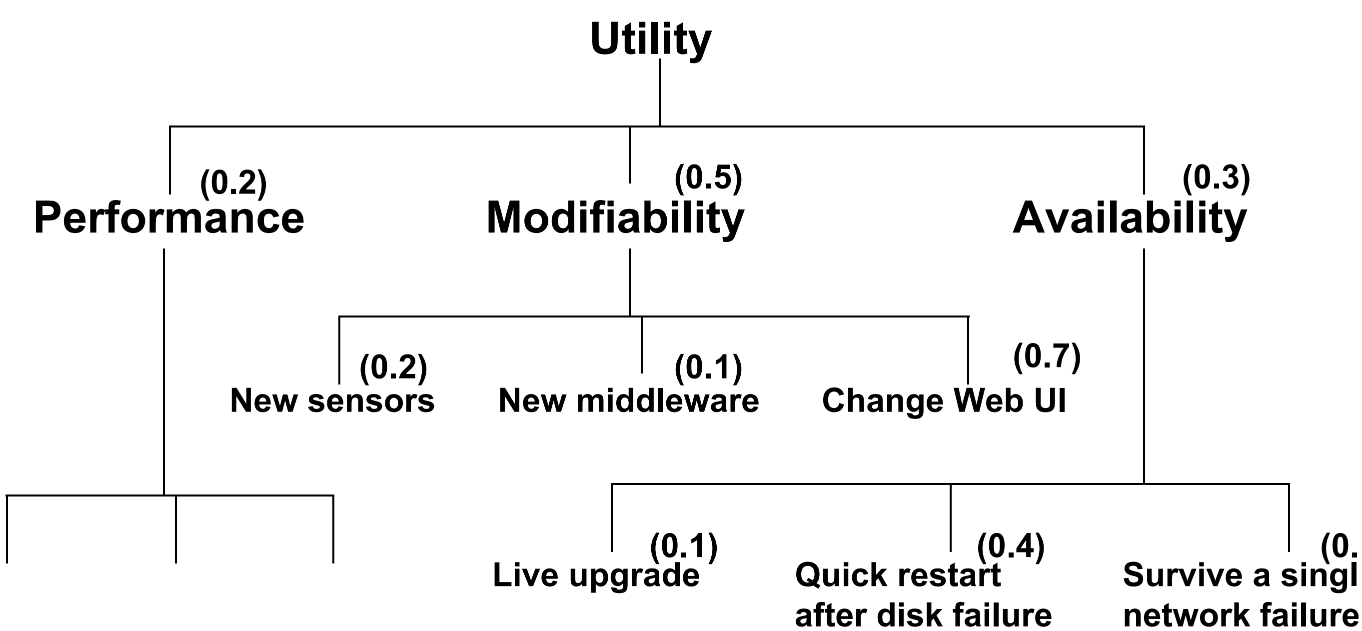
- Identify, prioritize and refine the most important quality attribute goals by building a *utility tree*.
  - » a utility tree is an AHP (analytic hierarchy process)-like model of the “driving” attribute-specific requirements
  - » typically performance, modifiability, security, and availability are the high-level nodes
  - » scenarios are leaves of utility tree
- Output: a prioritization of specific quality attribute requirements.

# Utility Tree Construction -1






# Utility Tree Construction -2

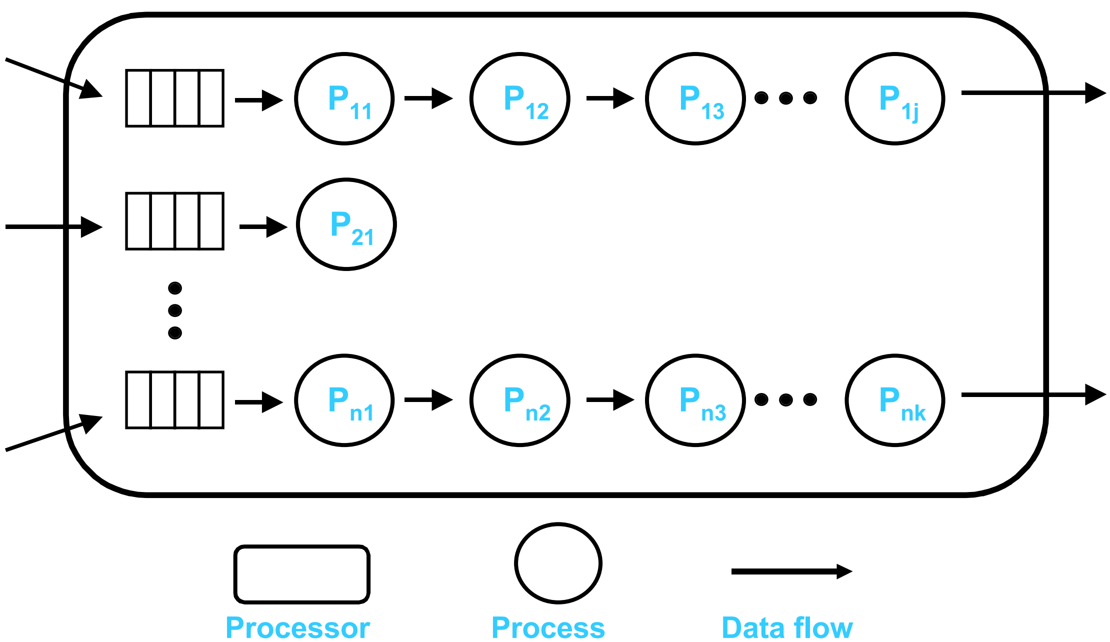


# 6. Elicit and Analyze Architecture Styles

- Evaluation Team probes architectural styles from the point of view of specific quality attributes to identify risks.
  - » Identify the styles which pertain to the highest priority quality attribute requirements
  - » Generate quality-attribute specific questions for highest priority quality attribute requirement
  - » Ask quality-attribute specific questions
  - » Identify and record risks and non-risks




# Concurrent Pipelines Style



# Quality Attribute Questions

- Quality attribute questions probe styles to elicit architectural decisions which bear on quality attribute requirements.
- Performance
  - » How are priorities assigned to processes?
  - » What are the message arrival rates?
- Modifiability
  - » Are there any places where layers/facades are circumvented ?
  - » What components rely on detailed knowledge of message formats?



# Risks and Non-Risks -1

- While risks are potentially problematic architectural decisions, …
- Non-risks are good decisions relying on implicit assumptions.
- Risk and non-risk constituents
  - » architectural decision
  - » quality attribute requirement
  - » rationale
- Sensitivity points are candidate risks and risks are candidate tradeoff points.

# Risks and Non-Risks -2

- Example risk
  - » Rules for writing business logic modules in the second tier of your 3-tier style are not clearly articulated. This could result in replication of functionality thereby compromising modifiability of the third tier.
- Example non-risk
  - » Assuming  message arrival rates of once per second, a processing time of less than 30 ms, and the existence of one higher priority process, a 1 second soft deadline seems reasonable.





# 7. Generate Seed Scenarios

- *Scenarios*  are example stimuli used to
  - » Represent *stakeholders*' interests
  - » Understand quality attribute requirements
- Seed scenarios are sample scenarios
- Scenarios are specific
  - » anticipated uses of (use cases),
  - » anticipated changes to (growth scenarios), or
  - » unanticipated stresses (exploratory) to the system.

# 8. Brainstorm and Prioritize Scenarios

- Stakeholders generate scenarios using a brainstorming process.
- Each stakeholder is allocated a number of votes roughly equal to 0.3 x #scenarios
- Prioritized scenarios are compared with the utility tree and differences are reconciled.




# Example Scenarios

- Use case
  - » *Remote user comes via the web to access report database.*
- Growth scenario
  - » *Add a new data server to reduce latency by 50%.*
- Exploratory scenario
  - » *Half of the servers go down during operation.*

=> Scenarios should be as specific as possible.

# 9. Map Scenarios onto Styles



- Identify styles and components within styles impacted by each scenario.
- Continue identifying risks and non-risks.
- Continue annotating architectural information.




# 10. Present Out-Brief/Write Report



- Recapitulate steps of ATAM
- Present ATAM outputs
  - » styles
  - » scenarios
  - » questions
  - » utility tree
  - » risks
  - » non-risks
- Offer recommendations

# Outline

- Why analyze_an architecture?
- ATAM Steps
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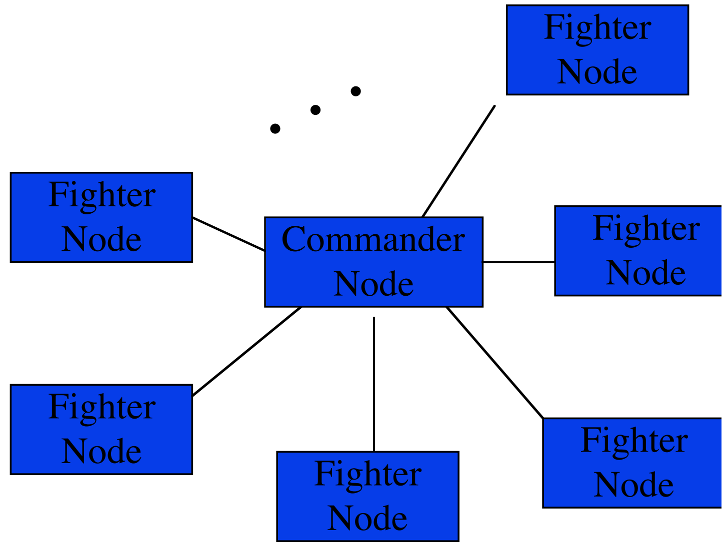
Presentation

# 2. Present Business Drivers

- A distributed battlefield management system (BMS)
  - » One mobile central commander node
  - » A set of mobile fighter nodes under commander
  - » Information from many sources/sensors
  - » Messages of different types (maps, orders)
- Stakeholders wanted to understand how the system would perform and adapt to changes

# 3. Present Architecture

- *Physical view*: "*customer-providers*", where the commander node is the customer and the fighter nodes are providers.
- Detailed information also collected for *concurrency* and *code* views.







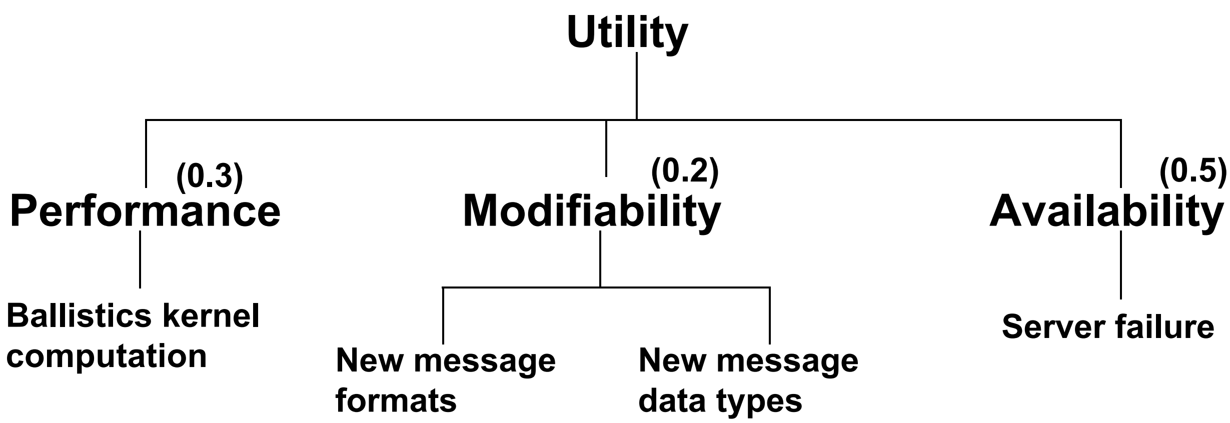


# 4. Identify Architectural Styles

- We elicited information on the architectural approaches with respect to modifiability, availability, and performance.
  - » For availability, a *backup commander* scheme was described.
  - » For modifiability, *standard subsystem organizational patterns* were described.
  - » For performance, an *independent communicating components* style was described..

# 5. Generate Quality Attribute Utility Tree





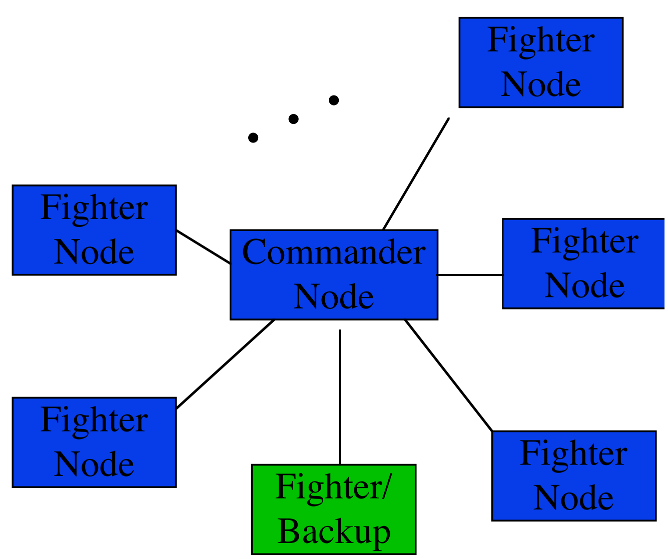




# 6. Elicit and Analyze Architecture Styles



- The repair time for the system is the time to turn the backup into the commander node.
- Communication between the commander node and the backup keeps the backup "in sync".



# Availability Analysis - 1

- $Q_A$ = the fraction of time the system is working
- The system is considered to be working if there is a working commander node and one or more fighter nodes.
- When the commander node fails the system has failed.
- Provisions have been made in the BMS architecture to turn a designated fighter (backup) node into a commander node.



# Availability Analysis - 2

- Availability can be seen as:

  $Q_A = h(\lambda_c, \lambda_b, \mu_c, \mu_b)$

where $\lambda_c$ = failure rate of the commander

$\lambda_b$ = failure rate of the backup

$\mu_c$ = repair rate of the commander

$\mu_b$ = repair rate of the backup

- Problem! The backup has no backup, i.e. in the BMS architecture, $\mu_b = 0$
- We discovered this problem via qualitative analysis questions that focused on failure and repair rates.

# Availability Analysis - 3

- Hence, two well-aimed hits (or hardware failures) disable the entire system!
- The solution was to turn more fighter nodes into potential backups.
- Alternatives could be:
  - » Acknowledging backups (*n*)
  - » Passive backups (*m*)
  - » Passive backups (*m*) + update



# Availability: Sensitivity/Risk Identification

- The availability of the system can now be seen as:

$Q_A = j(n, m)$

- *n* and *m* are architectural availability *sensitivity points*
- Since availability is a key attribute for the battle management mission, some choices of n and m present *availability risks*

# 7. Generate Seed Scenarios

- Initial set of seed scenarios were too general
  - » "System fails"
- Seed scenarios were later refined
  - » "Command node is destroyed and the Backup node takes over as the Commander node"






# 8. Brainstorm and Prioritize Scenarios

- 46 scenarios were collected, covering modifiability, scalability, availability, performance, portability.
- Examples:
  - » Modifiability: map data formats change
  - » Performance: the number of simultaneous missions doubles
  - » Availability: the commander is disable by a direct hit

# Scenario Prioritization

- The stakeholders suggested groupings of scenarios.
- The stakeholders used preference-voting to prioritize scenarios.
- The result was 15 high priority scenarios.



Testing

# 9. Map Scenarios onto Styles

- The architects mapped each of the high-priority scenarios onto the BMS architecture.
- During this stage we:
  - » Gathered attribute-specific information qualitative attribute questions
  - » Clarified our understanding of the architecture and the scenarios
  - » Documented the answers

# Performance Analysis - 1

- We discovered a performance problem via a qualitative attribute questions that asks about the relative speeds of communication and processing.

- The problem uncovered was: the nodes in the BMS architecture communicated via slow modems.




# Performance Analysis -2

- End-to-end latency calculations showed that the overall latency was highly sensitive to the number and size of transmitted messages.

- Communication load came from:
  - » The normal operations communication overhead
  - » The number of backups (both acknowledging and passive)

# Performance: Sensitivity/Risk Identification

- Thus, system performance can be characterized as:
- $Q_P = k(n, m, CO)$
- Communications overhead was a constant.
- *n* and *m* are architectural performance *sensitivity* points.



# Tradeoff Identification

- Increasing the number of backups increases availability, but also increases average latency (because these backups must be kept up-to-date by the commander).
- Hence, the number of active and passive backups (*n* and *m*) is a tradeoff point in the BMS architecture.
- The designers had *not* been aware of the tradeoff inherent in their design.

# 10. Present Out-Brief/Write Report

- Presentation and written report detailed the potential modifiability, performance, and availability problems, and …
- delineated new architecture options and their costs:
  - » Acknowledging backups
  - » Passive backups
  - » Passive backups + updates




# Results of the BMS ATAM

- Greatly improved architectural documentation
- Stakeholder buy-in
- Discovery of missing performance and availability requirements
- Highlighting of a previously unknown tradeoff point in the architecture
- Delineation of recommendations to mitigate the risks of this tradeoff

# Outline

- Why analyze an architecture?
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# Summary - 1

- ATAM is a method for evaluating an architecture with respect to multiple quality attributes.
- It is an effective risk mitigation strategy to avoid the disastrous consequences of a poor architecture. ATAM:
  - » can be done early
  - » requires stakeholder participation
- The key to the method is looking for *trends*, not in making precise analyses.

# Summary - 2

- ATAM relies critically on
  - » Clearly-articulated quality attribute requirements
  - » Active stakeholder participation
  - » Active participation by the architect
  - » Familiarity with architectural styles and analytic models



# Appendix A

# Overview of architectural styles

# Overview of architectural styles*)

» Data-centered:
- Repository
- Blackboard

» Data-flow:
- Pipes & filters
- Batch/sequential

» Call-and-return:
- Top down
- OO
- layered

» Virtual machine:
- Interpreter
- Rule-based

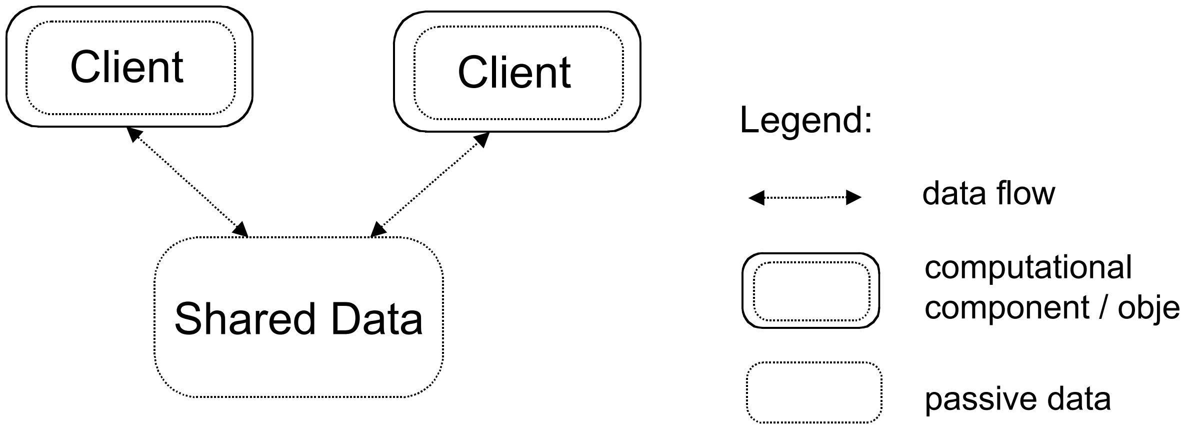
» Independent components:
- Communicating processes
- Event systems
  - implicit invocation
  - explicit invocation

*) The presentation is based on *Software Architecture in Practice* (Bass et al.; Addison-Wesley, 1998) and *Software Architecture: Perespectives on an Emerging Discipline* (Shaw, Garlan; Prentice Hall, 1996)



# Data-centered (I)

**Access to shared data** represents the core characteristic of data-centered architectures. The data integrability forms the principal goal of such systems.



# Data-centered (II)

The means of communication between the components distinguishes the subtypes of the data-centered architectural style:

» **Repository: passive data** (see schematic representation of previous slide)

» **Blackboard: active data**
A blackboard sends notification to subscribers when relevant data change (→ Observer pattern)




# Data-centered (III)

\+ clients are quite independent of each other
=> clients can be modified without affecting others

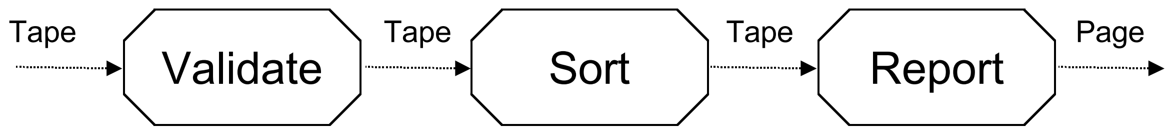
coupling between clients might increase performance but lessen this benefit

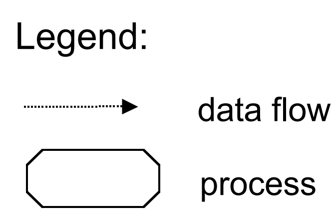
\+ new clients can be easily added

No rigid separation of styles: When clients are independently executing processes: client/server architectural style

# Data-flow

The system consists of a **series of transformations on successive pieces of (input) data.** Reuse and modifiability form the principal goals of such architectures.





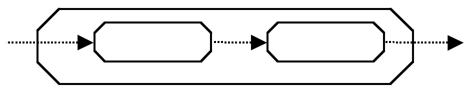


# Data-flow substyles

- **Batch sequential** (→ sample on previous slide)
  - components (= processing steps) are independent programs
  - **each step runs to completion before the next step starts**, i.e., each batch of data is transmitted as a whole between steps
- **Pipe-and-filter** (→ UNIX pipes & filters)
  - **incremental transformation of data** based on streams
  - filters are stream transducers and use little contextual information and retain no state information between instantiations
  - pipes are stateless and just move data between filters

# Pros and cons of pipes-and-filters

- \+ no complex component interactions to manage
- \+ filters are black boxes
- \+ pipes and filters can be hierarchically composed



- – batch mentality => hardly suitable for interactive applications
- – filter ordering can be difficult; filters cannot interact cooperatively to solve a problem
- – performance is often poor

  parsing/unparsing overhead due to lowest common denominator data representation
- – filters which require all input for output production have to create unlimited buffers



# Virtual machine (I)

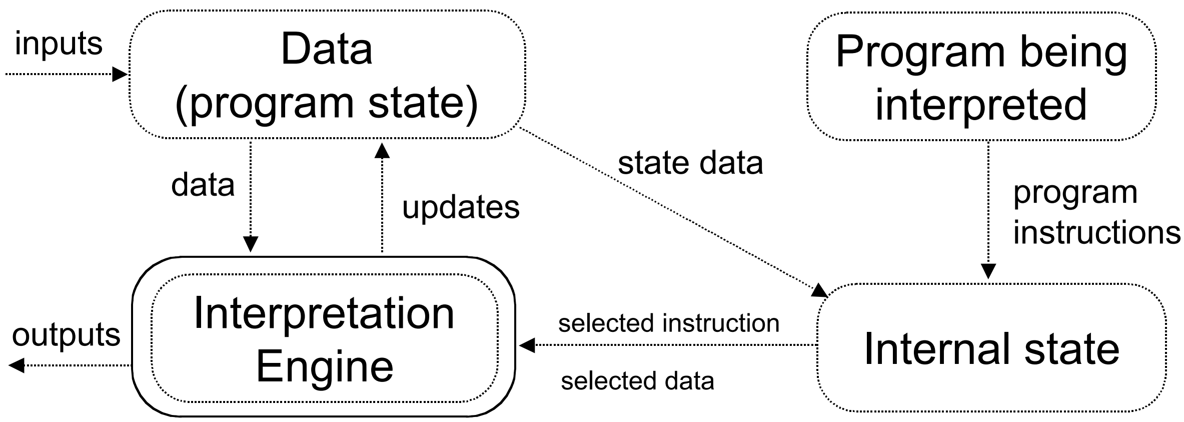
Virtual machines **simulate some functionality that is not native to the hardware/software on which it is implemented.** This supports achieving the quality attribute of **portability**.

Examples:

- » interpreters
- » command language processors
- » rule-based systems

# Virtual machine (II)

**Schematic representation:**





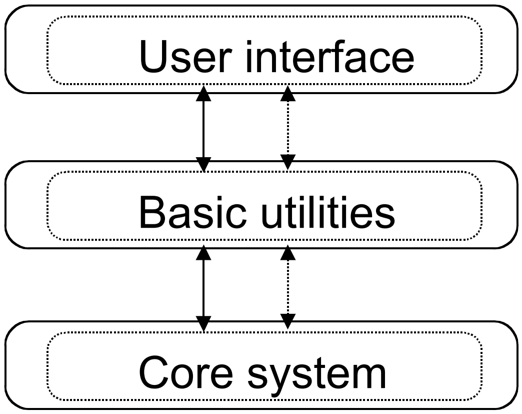

# Call-and-return

Call-and-return architectures rely on the well-known abstraction of procedures/functions/methods. Shaw and Garlan discern between the following substyles:

- » main-program-and-subroutine style
  - – remote-procedure-call systems also belong to this category but are decomposed in parts that live on computers connected via a network
- » object-oriented or abstract-data-type style
- » layered style

# Layered style

Components belong to layers. In pure layered systems **each level should communicate only with its immediate neighbors.**



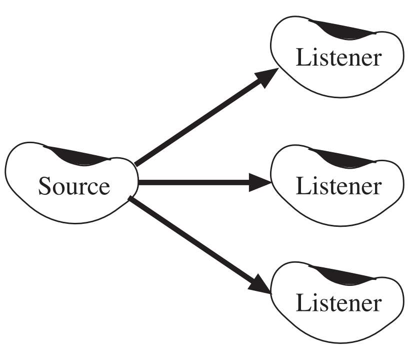

Each successive layer is built on its predecessor, hiding the lower layer and providing some services that the upper layers make use of. Upper layers often form virtual machines.

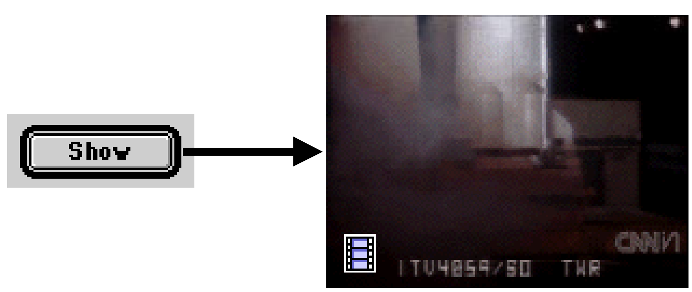


# Event systems

Publish/subscribe (observer) pattern: Components can register an interest in notifications.

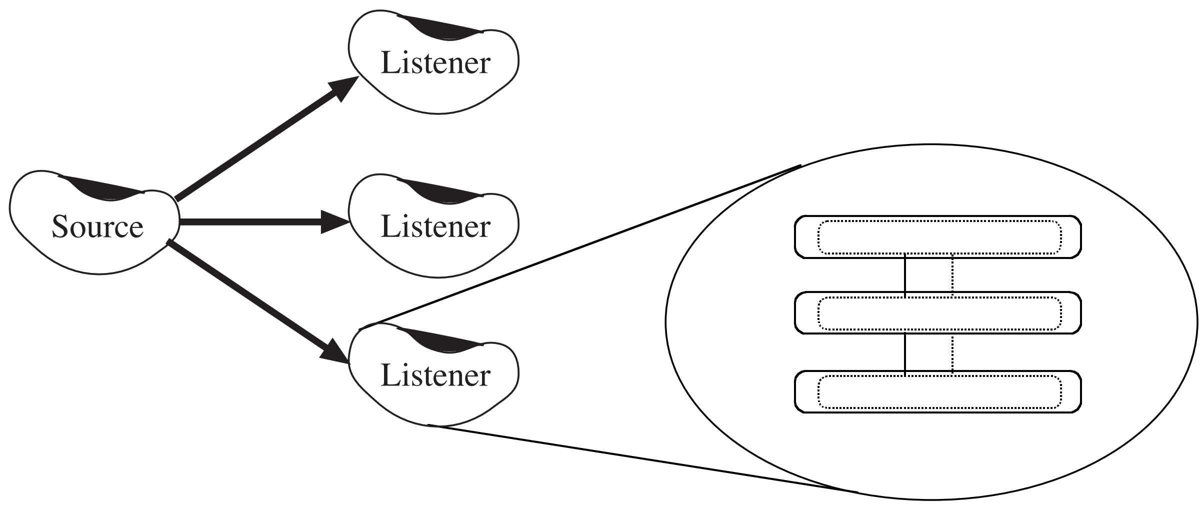
Example: coupling between JavaBeans



# Heterogeneous styles (I)

Example: event system + layered style






# Heterogeneous styles (II)

In general, the presented architectural styles do not clearly categorize architectures. Styles exist as cognitive aids and communication cues.

- » The data-centered style, composed out of thread-independent clients is like an independent component architecture.
- » The layers in a layered architecture might be objects/ADTs.
- » The components in a pipe-and-filter architecture are usually independently operating processes and thus also correspond to an independent component architecture.
- » Commercial client/server systems with a CORBA-based infrastructure could be described as layered object-based process systems, i.e., a hybrid of three styles.

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