Software Architecture

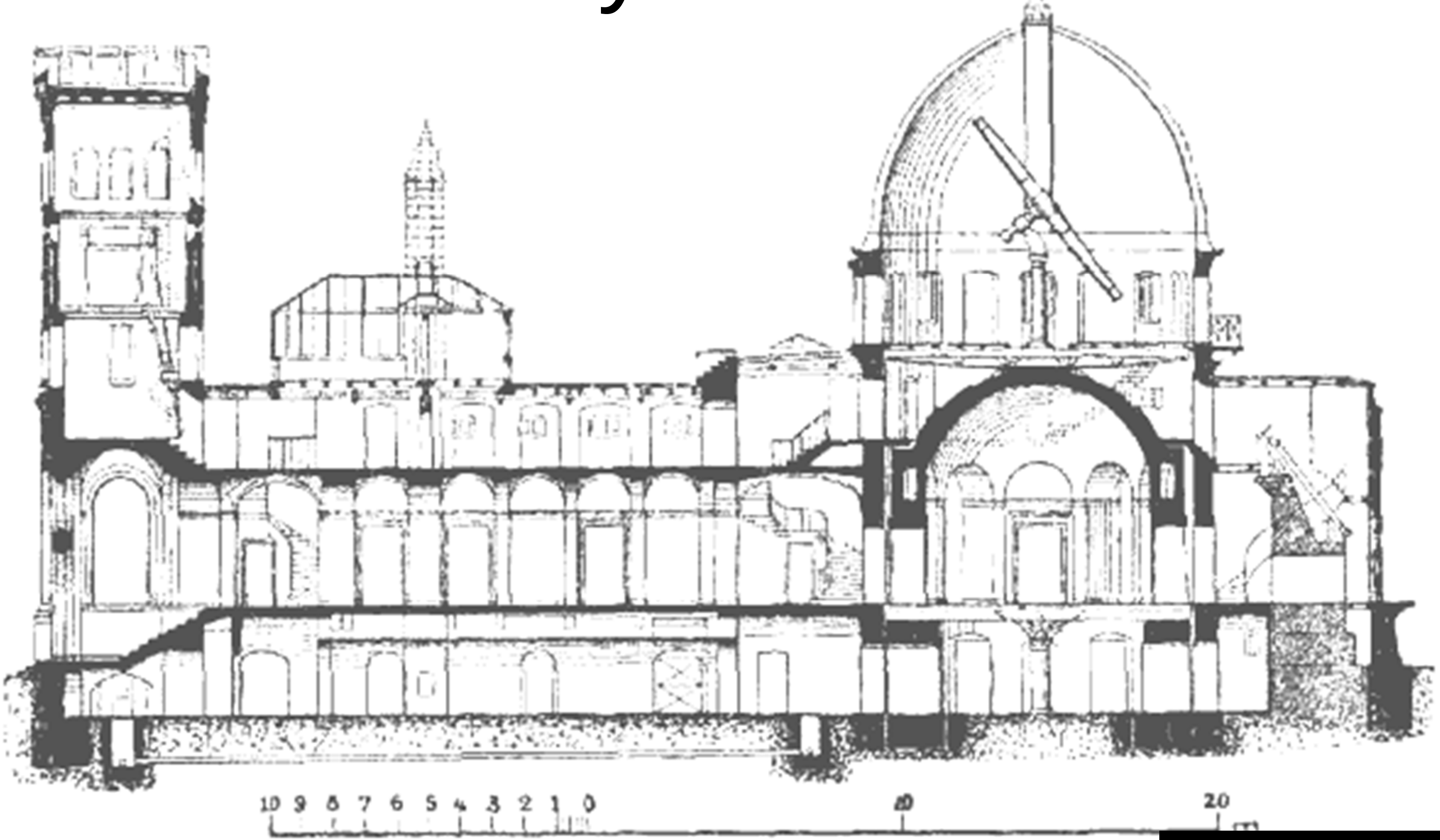
Jonathan Aldrich, Ph.D.
Associate Professor
Institute for Software Research
School of Computer Science
Carnegie Mellon University

January 2014

Outline

- **What is software architecture?**
- What are its benefits?
- How to develop a software architecture?
- How to document a software architecture?
- Conclusion and takeaways

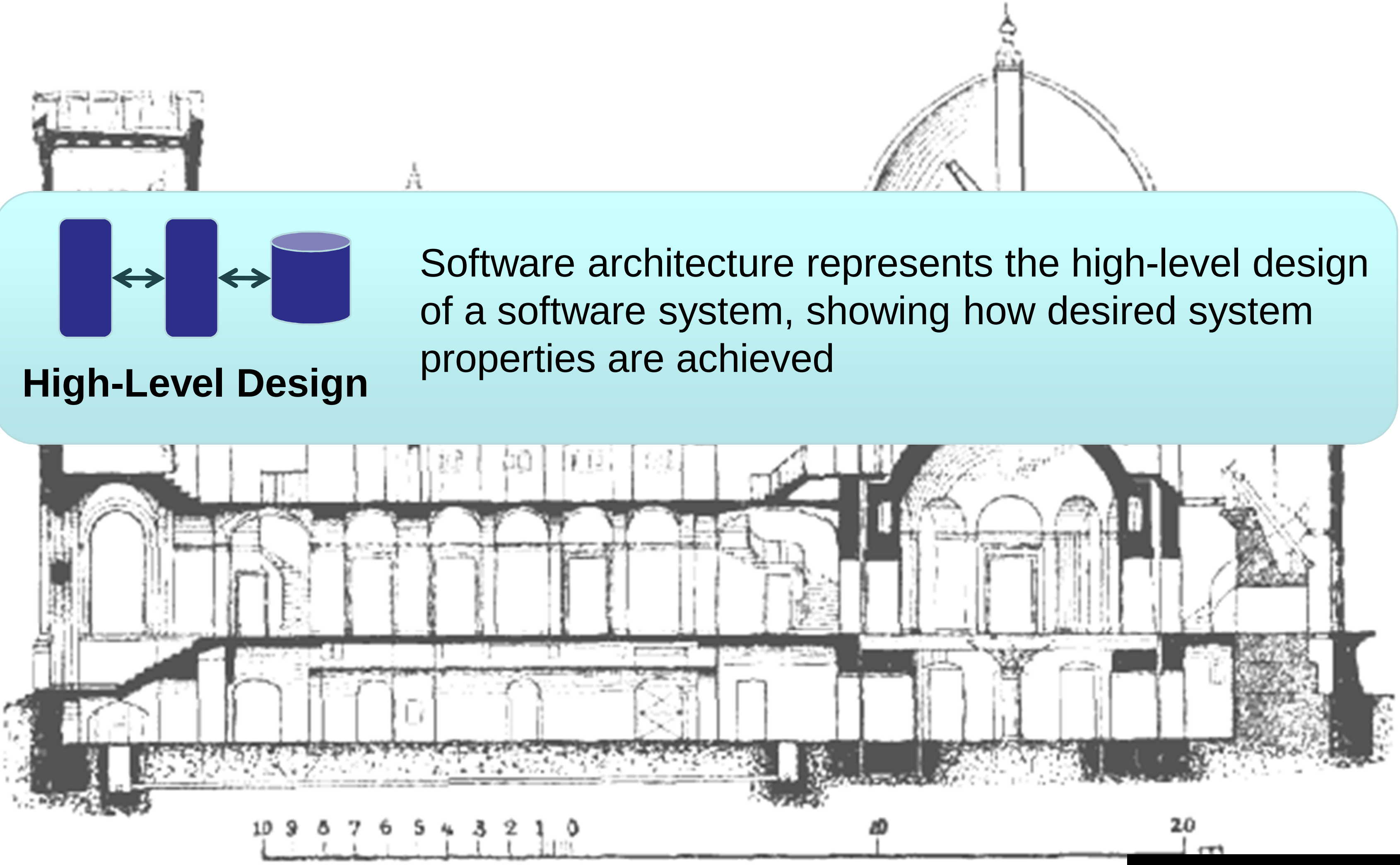
What is (Building) Architecture? And why is it useful?



Aſtrophyſikaliſches Inſtitut zu Potsdam.

Example Architecture:
Potsdam Observatorium

What is Software Architecture?



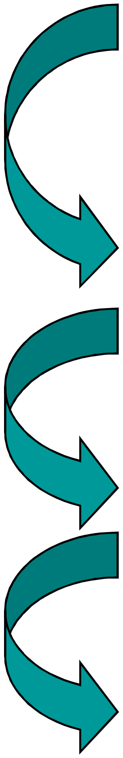
High-Level Design

Software architecture represents the high-level design of a software system, showing how desired system properties are achieved

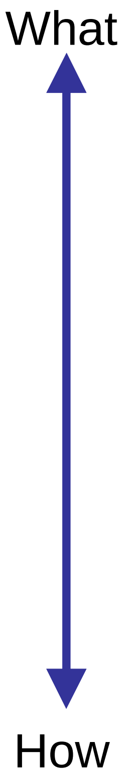
Aſtrophyſikaliſches Inſtitut zu Potsdam.

Example Architecture:
Potsdam Observatorium

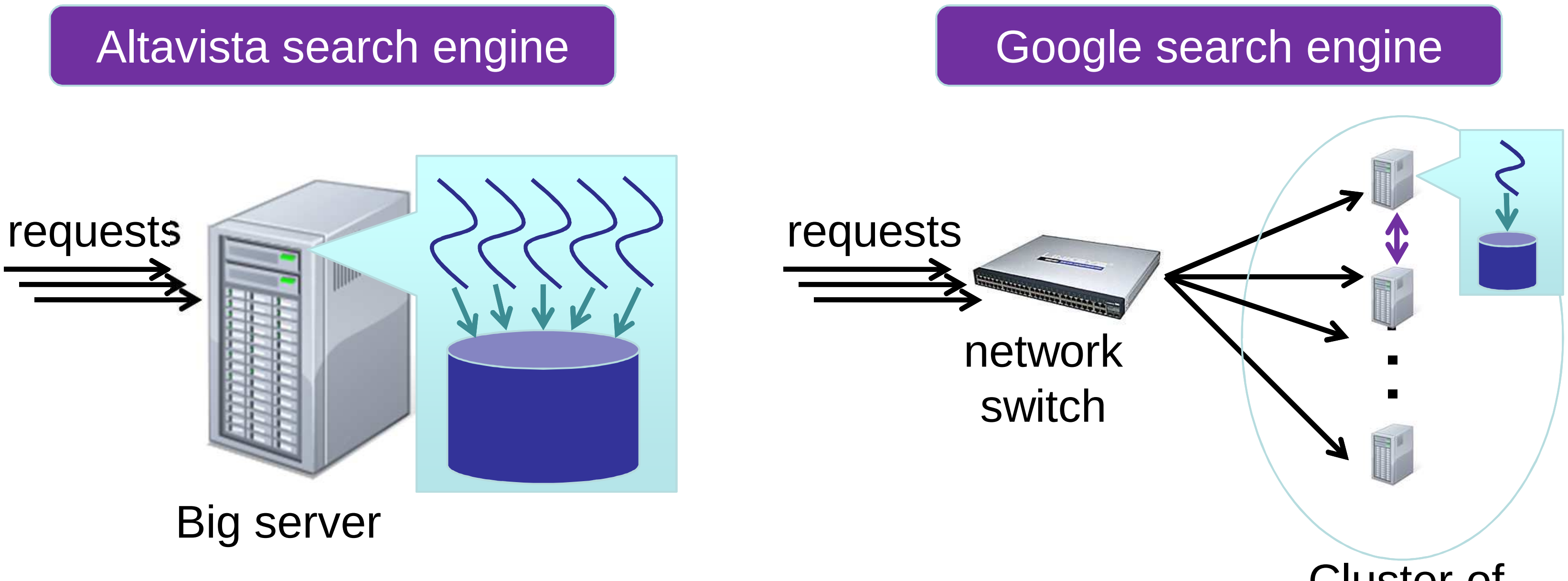
Where Architecture Fits



- Requirements
  - What the system should do
  - What properties it should have
- Architecture
  - High-level design, how properties are achieved
- Detailed design
  - Lower-level design, how system functions
- Code
  - How the system actually works



Two Architectures for Web Search



Altavista search engine

requests

Big server

Google search engine

requests

network switch

Cluster of commodity servers

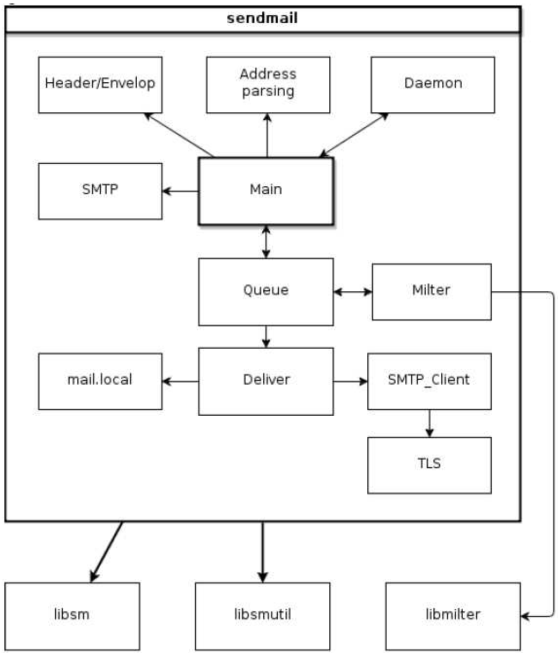
How does architecture affect system **properties**?

- Modifiability / ease of change
- Consistency of results
- System cost
- Scalability of system
- Reliability of system

Two Architectures for Sending Email

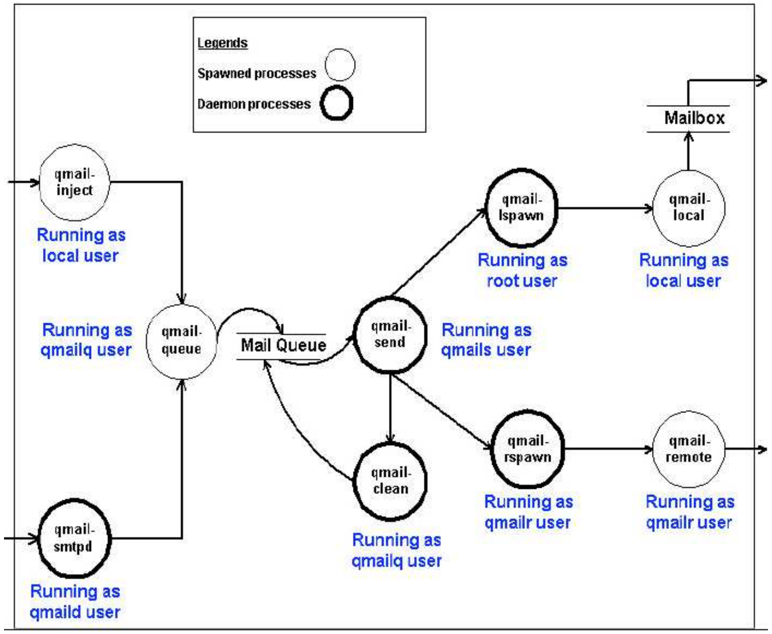
sendmail

Modules within sendmail process



qmail

Processes implementing qmail



Which architecture was better in 1980? Which was better in 2000?

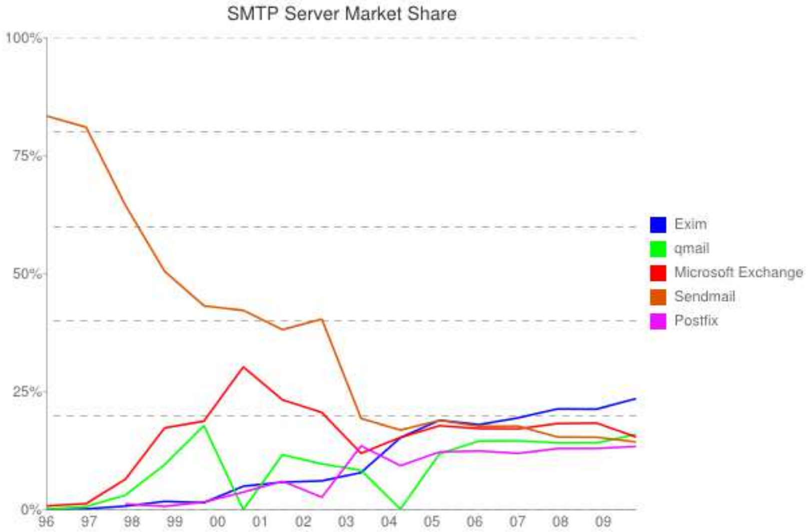
Factors to consider

- Simplicity
- Efficiency
- Security

Two Architectures for Sending Email

sendmail

qmail



- Sendmail was the dominant email client from 1982 until 2000.
- In 1988 the Morris worm, the first internet worm, took advantage of a sendmail vulnerability; many other vulnerabilities have been found since.
- By 2000 sendmail had begun a steep and permanent decline, and qmail was growing exponentially.

Architecture is an Abstraction

- Focus on **principal** design decisions
  - **Structure** – components and connections
  - **Behavior** – responsibilities of each component, high level algorithms
  - **Interaction** – rules governing how components communicate
  - **Quality attributes** – strategy for achieving
  - **Implementation** – language, platform, libraries, etc.

  - ***Any decision that impacts key stakeholder concerns or has global impact on the program***

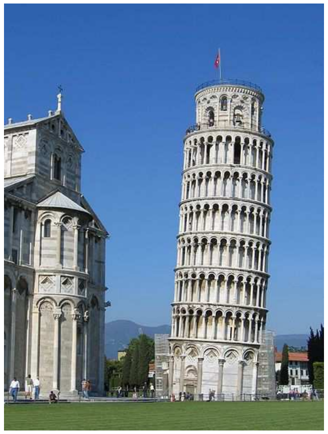
- Elide unimportant details
  - Decisions that are **internal to a component**
    - i.e. which other components cannot depend on
    - e.g. internal algorithms, data structures, local design patterns
  - AND do not impact **key stakeholder concerns**

Architecture is design, but not all design is architectural

Outline

- What is software architecture?
- **What are its benefits?**
- How to develop a software architecture?
- How to document a software architecture?
- Conclusion and takeaways

Architecture Benefits: System Properties



- Architecture is not about a system's **function**, but rather the system's **properties**

- Some properties and their consequences
  - **Fitness**: performance, reliability, security → **competitive advantage**
  - **Modifiability**/ease of changing → business **agility**
  - **Reuse** of code → reduced **cost**

Business Case: Cell Phones [M. Bass]

- Market is driven by killer products
  - e.g. Razr, iPhone
- Most profit is made at initial release
  - Premium charged on initial sales
  - Drops rapidly when copycats arrive
- Business model
  - Be first to market with new features
- Software quality attributes
  - Ability to change rapidly and at low cost
- True story: effect of architecture
  - Leading cell phone manufacturer
    - not enough new products
    - starts to lose market share, decides to release faster
    - leads to trouble: e.g. tone so loud it damages hearing ➔ recalls
  - Analysis
    - software structure did not enable rapid change
    - too costly to rewrite software from scratch
    - eventually left cell phone business entirely

Telecom Architecture Scenario

- Context: telecommunications wholesaler
  - Provides services both to end users and resellers
  - 8 legacy applications built with different interfaces, technologies
- Challenges
  - Duplicate functionality between end user / reseller channels
  - Several manual steps in process; difficult to automate
  - Difficult to roll out new services
  - Need to free reserved resources when an operation is canceled
- What would you do?

Telecom Architecture Solution

- Service-Oriented Architecture
  - Wrap legacy applications with a standard web services interface
  - Automate tasks using scripting (BPEL)
  - Share common operations, services between the different channels
  - Incorporate undoing reservations into the script
- Impacts
  - Common interface enabled automation → lower cost
  - Also facilitates replacing components → agility
  - Scripts make business operation changes easier → agility
  - Reuse of common components → lower cost
  - Built-in undo avoids wasting resources → reliability, lower cost

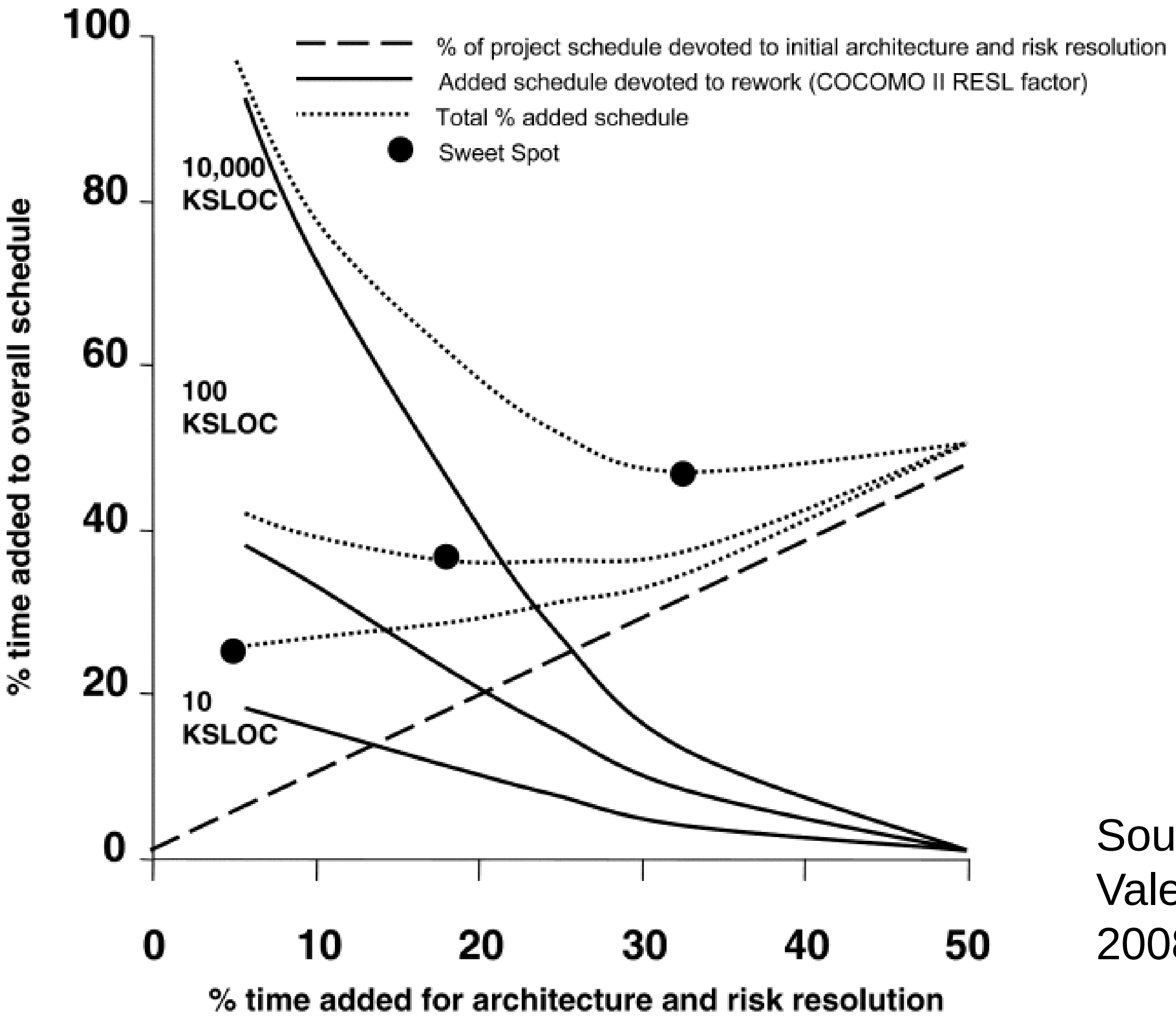
Outline

- What is software architecture?
- What are its benefits?
- **How to develop a software architecture?**
- How to document a software architecture?
- Conclusion and takeaways

How to Develop a Software Architecture

- Investment driven by **complexity** and **scale**
- Fitness evaluated by key **risks**
- Design appropriate for the **domain**
- Structure aligned with the **organization**

Tradeoffs in Architecture Investment



Source: Boehm, Valerdi, Honour 2008

Driving Architecture via Risks

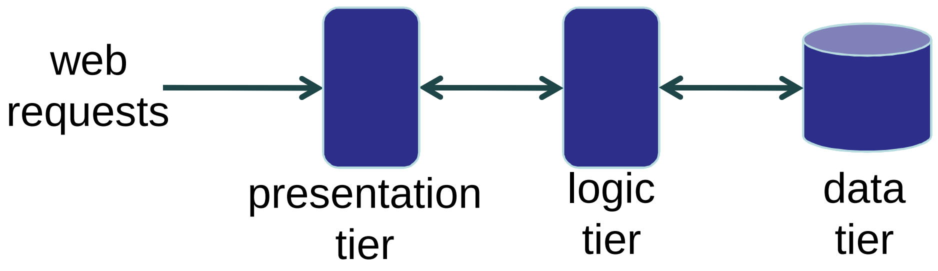
- Low risk ➔ little investment needed
  - Typically use a reference architecture (e.g. 3-tier web)
  - Reference architectures capture ("hoist") known domain risks

- Otherwise, evaluate architecture **fitness** using **risks**

- Major risks are ***architectural drivers***
- Example drivers and architectural analysis approaches
  - Maintainability/Reuse: variation, interface standards
  - Performance: queuing theory, real-time analysis
  - Security: threat modeling
  - Distributed development: interfaces between teams

Domain-Specific Architectures

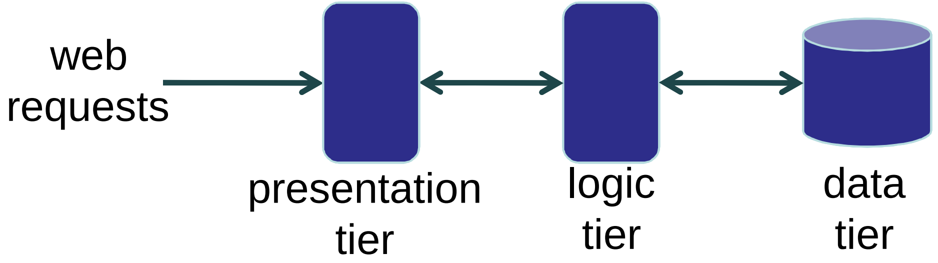
- Pattern: A reusable solution to a recurring architecture design problem



- Example: **3-tier web applications**
  - Data tier stores data in a database
  - Logic tier implements business logic
  - Presentation tier handles web requests
  - ***Benefits?***

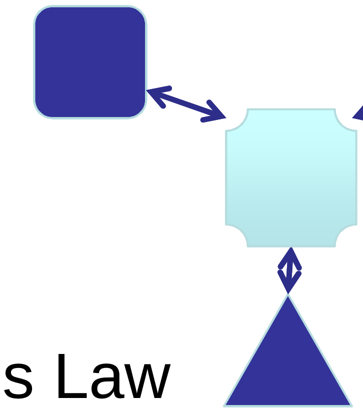
Domain-Specific Architectures

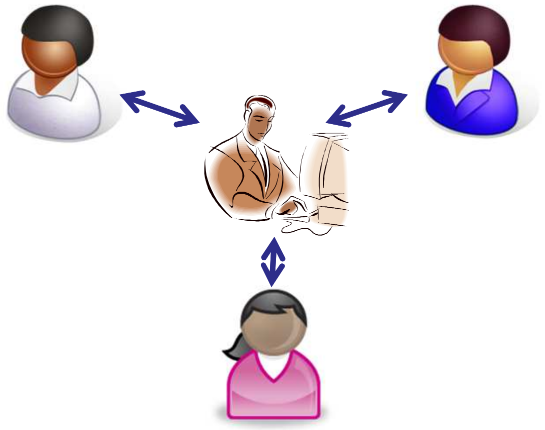
- Pattern: A reusable solution to a recurring architecture design problem



- Example: **3-tier web applications**
  - Data tier stores data in a database
  - Logic tier implements business logic
  - Presentation tier handles web requests
  - Benefits include **modifiability**, **scalability**

Architecture-Organization Alignment





- Conway's Law

  Any organization that designs a system...will inevitably produce a design whose structure is a copy of the organization's communication structure (Conway, 1968)

- Case example: product line
  - Applications initially developed independently
  - Desired reusable library to reduce cost, increase agility
  - Failed to build library using existing teams
  - Success required a team dedicated to the core library.

Outline

- What is software architecture?
- What are its benefits?
- How to develop a software architecture?
- **How to document a software architecture?**
- Conclusion and takeaways

Architectural Views

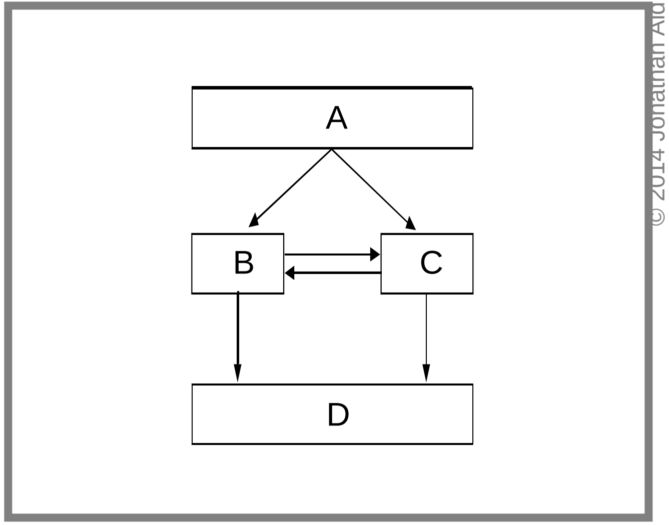
- Many possible “views” of architecture
  - Implementation structures
    - Modules, packages
    - Modifiability, Independent construction, …
  - Run-time structures
    - Components, connectors
    - Interactions, dynamism, reliability, …
  - Deployment structures
    - Hardware, processes, networks
    - Security, fault tolerance, …

Why Document Architecture?

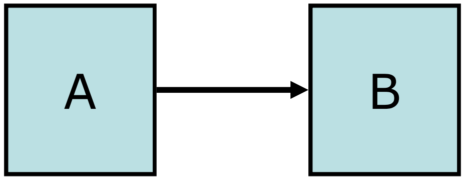
- Blueprint for the system
  - Artifact for early analysis
  - Primary carrier of quality attributes
  - Key to post-deployment maintenance and enhancement
- Documentation speaks for the architect, today and 20 years from today
  - As long as the system is built, maintained, and evolved according to its documented architecture

What is Wrong Today?

- In practice today's documentation consists of
  - Ambiguous box-and-line diagrams
  - Inconsistent use of notations
  - Confusing combinations of viewtypes
- Many things are left unspecified:
  - What kind of elements?
  - What kind of relations?
  - What do the boxes and arrows mean?
  - What is the significance of the layout?

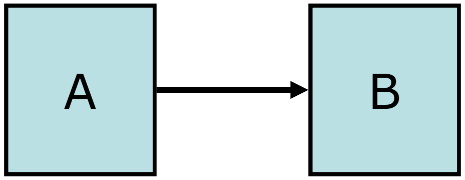


What could the arrow mean?

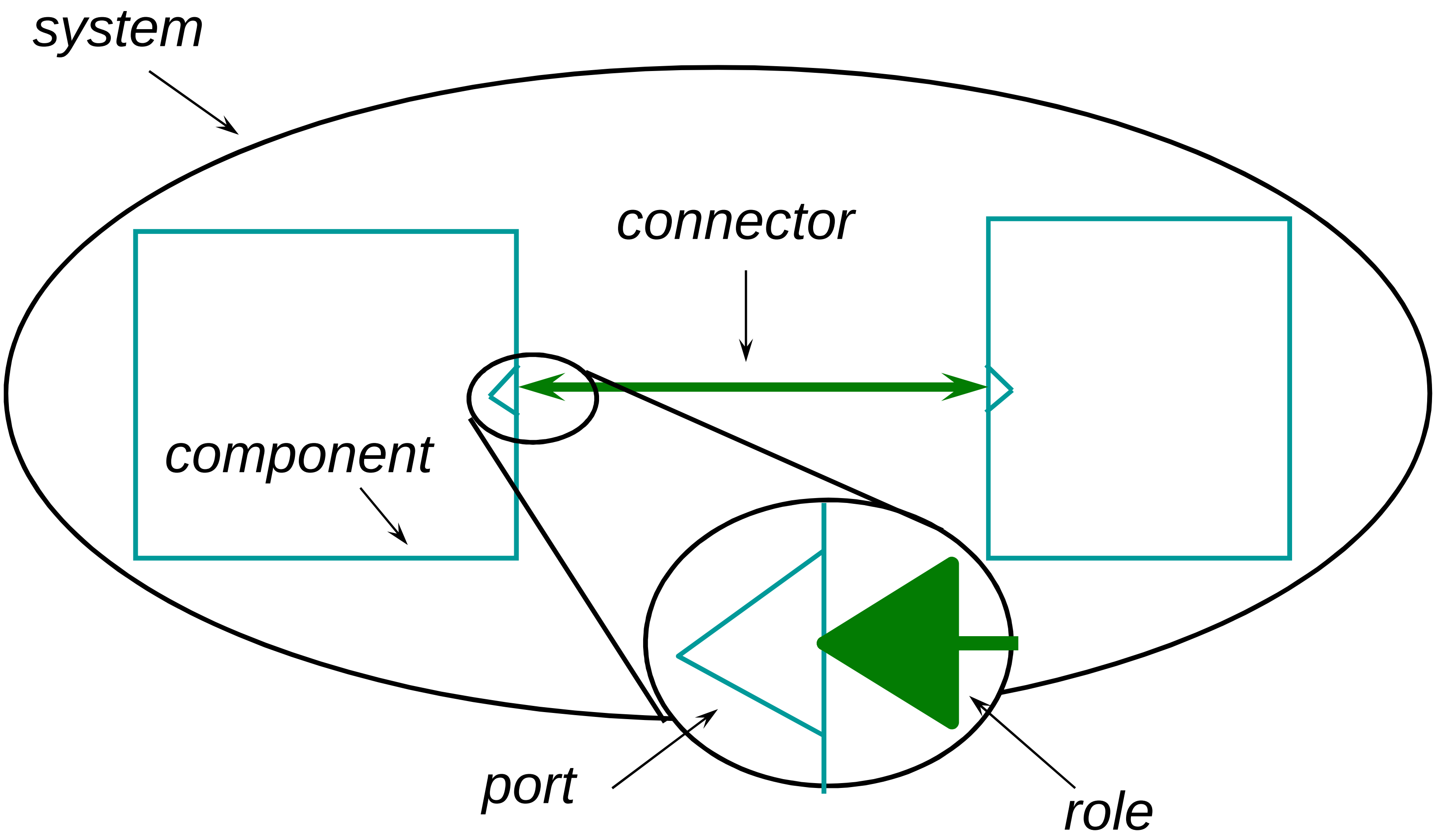


What could the arrow mean?

- Many possibilities
  - A passes control to B
  - A passes data to B
  - A gets a value from B
  - A streams data to B
  - A sends a message to B
  - A creates B
  - …



Representing C&C Views



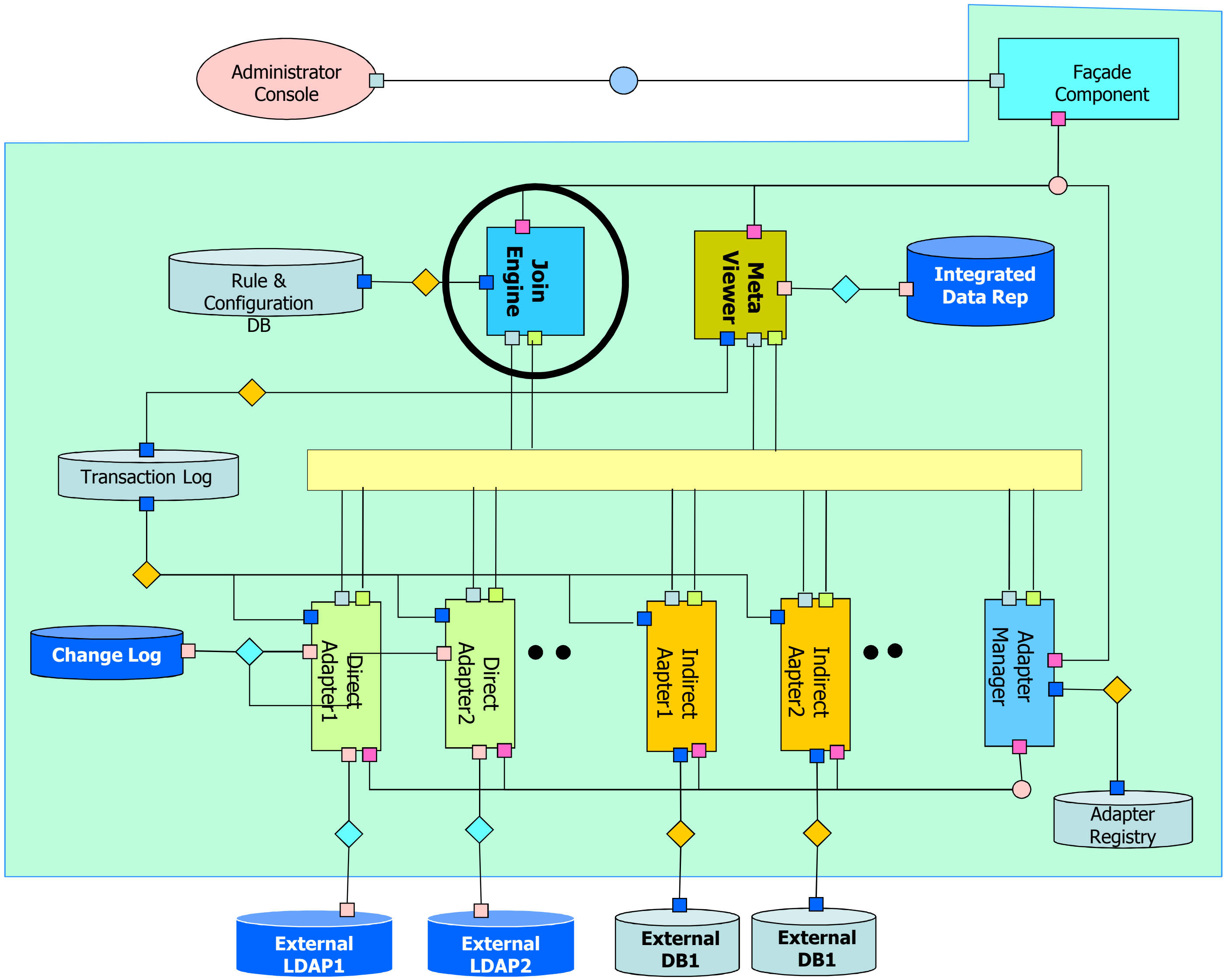
Guidelines: Avoiding Ambiguity

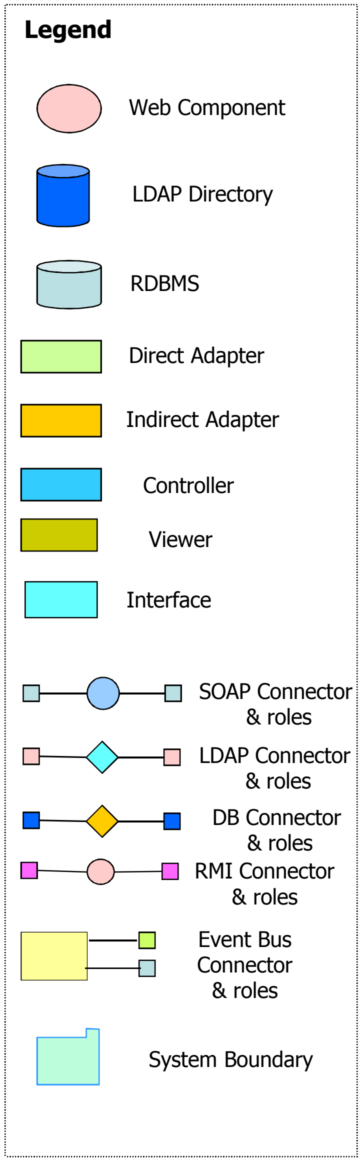
- **Always include a legend**
- Define precisely what the boxes mean
- Define precisely what the lines mean
- Don't mix viewtypes unintentionally
  - Recall: Module (classes), C&C (components)
- Supplement graphics with explanation
  - Very important: rationale (architectural intent)
- Do not try to do too much in one diagram
  - Each view of architecture should fit on a page
  - Use hierarchy

Technique: Hierarchy

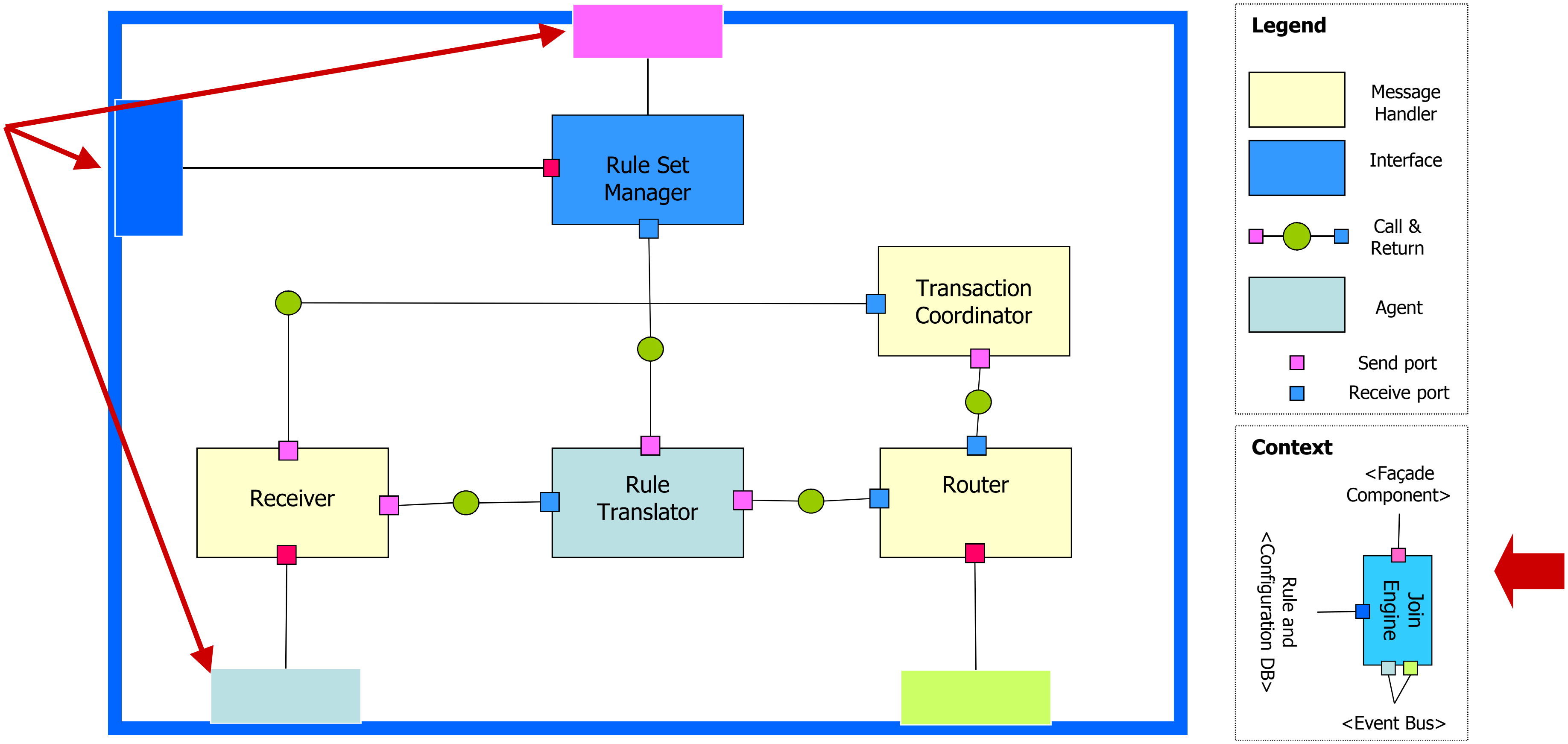
- Use hierarchy to define elements in more detail in separate views
- Helps keep an architectural description manageable

Top-level C&C View





Showing Details of Component



Outline

- What is software architecture?
- What are its benefits?
- How to develop a software architecture?
- How to document a software architecture?
- **Conclusion and takeaways**

Conclusion: Key Takeaways

- Architecture captures **high-level design** of software
  - Structure and communication
  - Key design decisions

- Enables desired **properties** of system
  - **Reuse** → reduce cost
  - **Modifiability** → business agility
  - **Fitness for use** → competitive advantage

Extra: Architecture Research at CMU

- Architecture modeling and analysis
  - Verify security, performance properties
  - Ensure an architecture is realizable
- Architecture adaptation models
  - React to breakdowns, security breaches
  - Adapt to changing resources (e.g. network bandwidth)
- Architecture-based development
  - Synchronizing code and architecture
  - Verifying constraints at architectural interfaces

References and Further Reading

References

- **Software Architecture: Perspectives on an Emerging Discipline.** Mary Shaw and David Garlan. Prentice Hall, 1996.
- **Software Architecture: Foundations, Theory, and Practice.** Taylor, Medvidovic, and Dashofy. Wiley, 2009.

Further Reading

- **Software Architecture in Practice**. Bass, Clements, and Kazman. Addison-Wesley, 2003.
- **Just Enough Software Architecture**. George Fairbanks. Marshall & Brainerd, 2006.