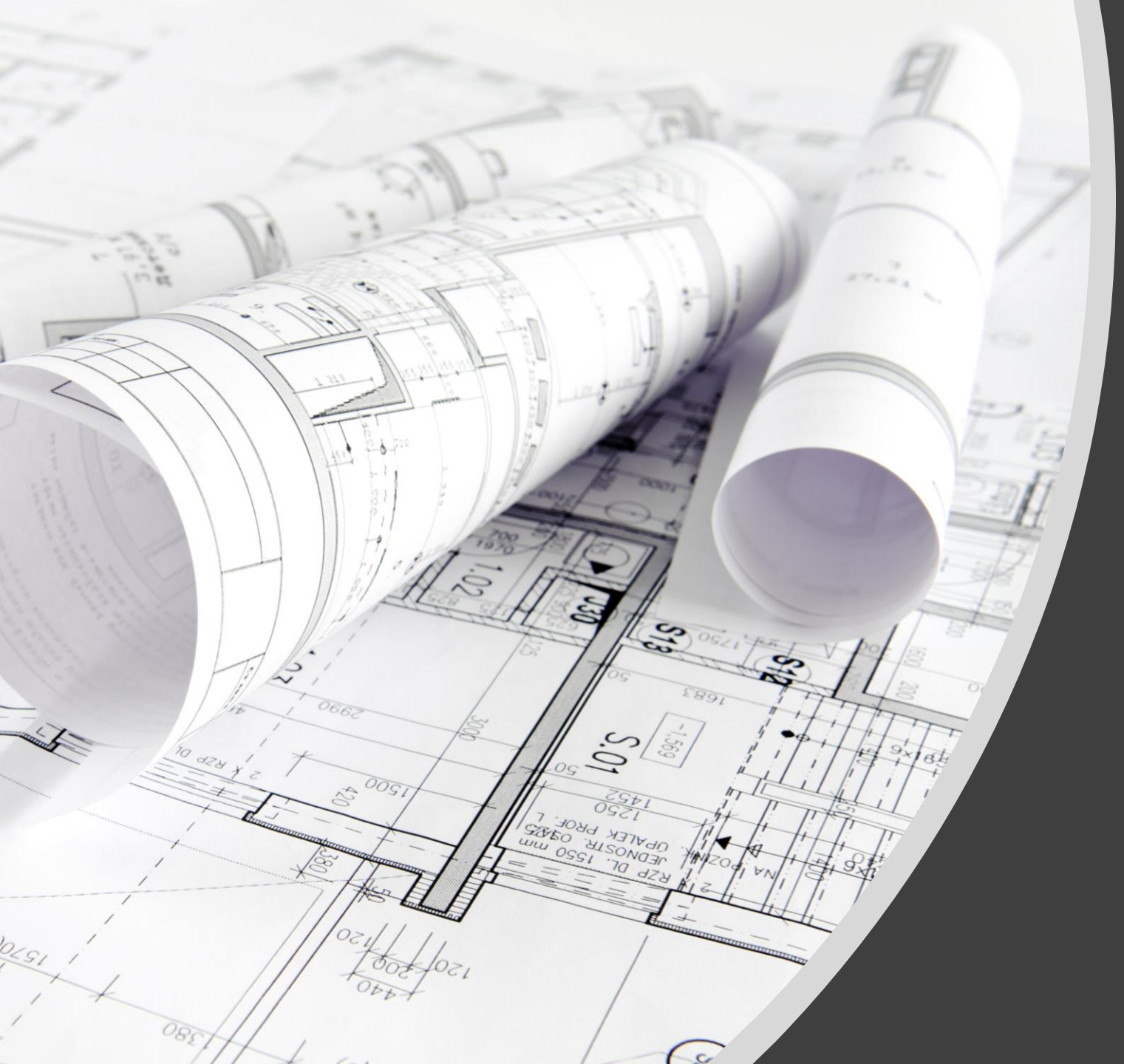


Lecture 10: Architecture

CS 5150, Spring 2022

Lecture goals

- Visualize structural models with deployment and interface diagrams
- Identify common architectural styles

System design

Design steps

- Given requirements, must design a system to meet them
  - System architecture
  - User experience
  - Program design
- Ideal: requirements are independent of design (avoid implementation bias)
- Reality: working on design clarifies requirements
  - Methodology should allow feedback (strength of iterative & agile methods)

Design principles

- Design is an especially creative part of the software development process
  - More a "craft" than a science
  - Many tools are available; must select appropriate ones for a given project
- Strive for simplicity
  - Use modeling, abstraction to (hopefully) find simple ways to achieve complex requirements
  - Designs should be easy to implement, test, and maintain
- Easy to use correctly, hard to use incorrectly
- Low coupling, high cohesion

What is architecture?

- Brooks: Conceptual integrity is key to usability and maintainability; architect maintains conceptual integrity
- Johnson: *The shared understanding that expert developers have of the system / The decisions you wish you could get right early in a project*
- Sommerville: Dominant influence on non-functional system characteristics
- "Highest level" organization of system

Levels of abstraction

- Requirements
  - High level "what"
- Architecture
  - High-level "how"
  - Mid-level "what"
- Program design
  - Mid-level "how"
  - Low-level "what"
- Code
  - Low-level "how"

- Documentation for each step should respect its level of abstraction
  - Avoid biasing later steps
  - Avoid redundancy

Example

- Requirements:
  - Drone can hover
- Architecture
  - Sensing → navigation → control → actuation
  - Radio input
- Program design
  - PID controller, low-pass filter
  - Gain registry

- Code
  -
```
def lpf(x1, y0, a):
  """exp filter w/
smoothing factor a"""
  return a*x1 + (1-a)*y0
```

Architectural considerations

- Infrastructure
  - Hardware
  - Operating systems
  - Virtualization
- Interfaces
  - Networks/buses
  - Protocols
- Services
  - Databases
  - Authentication
- Operations
  - Testing
  - Logging/monitoring
  - Backups
  - Rolling deployment
- Product line

Architectual models

- Diagram **and** supporting specification
  - Be *specific* with notation
- Multiple perspectives
  - Conceptual
  - Static (subsystems)
  - Dynamic (data flow)
  - Physical (deployment)
- Appropriate level of detail
  - A single diagram should fit cleanly on one page
- Distinct from program models
  - Inheritance diagrams don’t show interactions

Examples

- Packing robot control system
  - See Sommerville, *Software Engineering, Tenth Edition*, Figure 6.1 (or Chapter 6 slides)

- Oscilloscope user interface
  - See Garlan & Shaw, "An Introduction to Software Architecture"

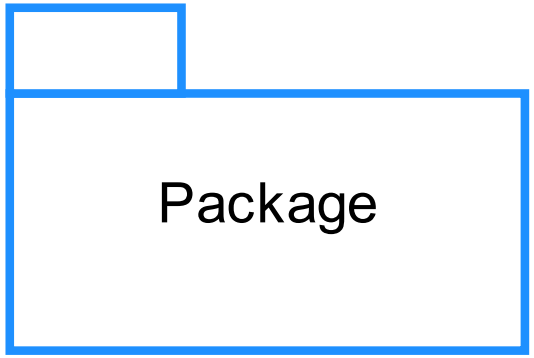
Subsystems

- Improve comprehensibility of system by decomposing into subsystems
- Group elements into subsystems to minimize coupling while maintaining cohesion

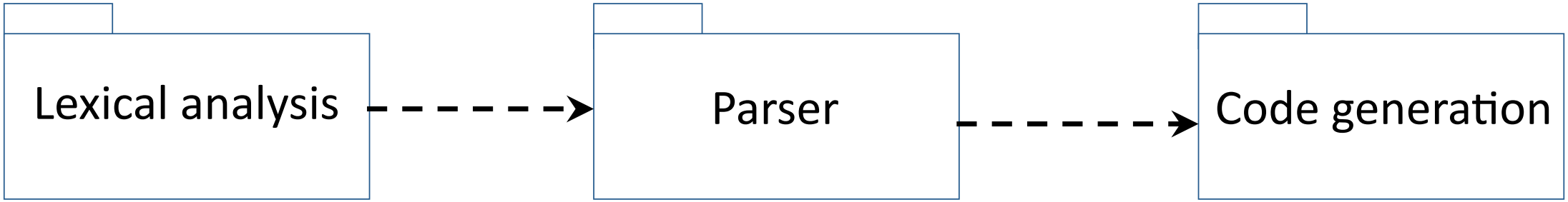
- Coupling: Dependencies *between* two subsystems
  - If coupling is high, can't change one without affecting the other
- Cohesion: Dependencies *within* a subsystem
  - High cohesion implies closely-related functionality

UML: Package

- General grouping of system elements
- Appropriate for denoting subsystem at conceptual level

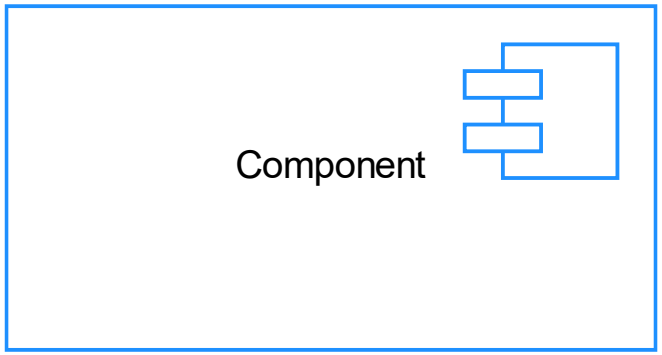


Example: conceptual diagram

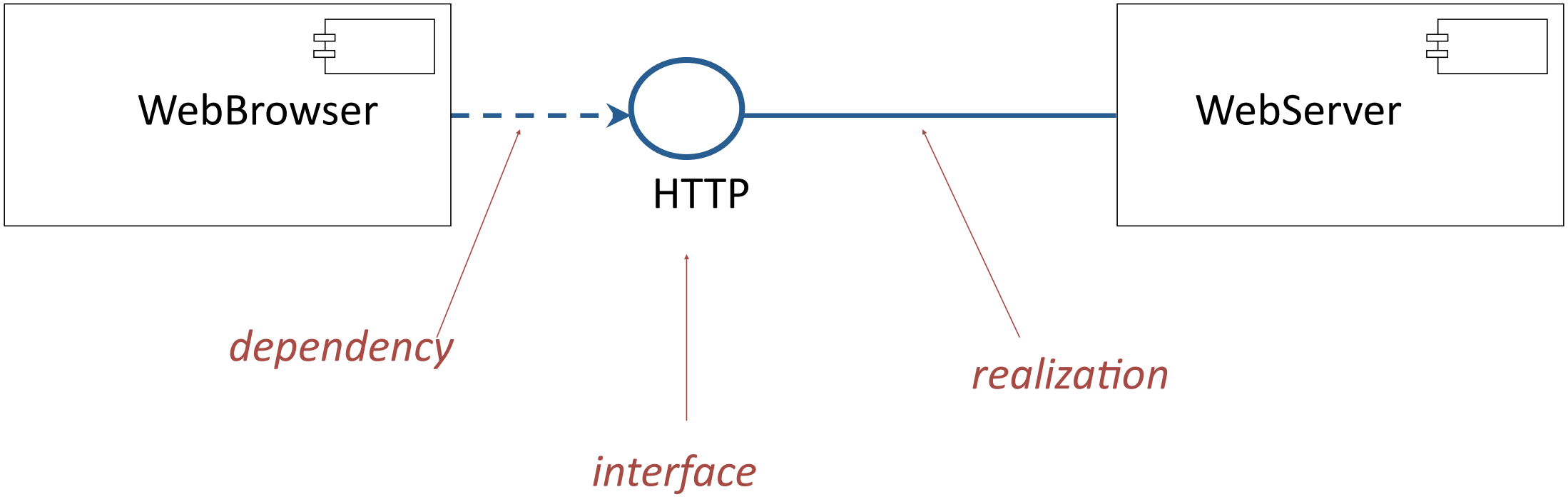


UML: Component

- Replaceable part of a system
  - Conforms to and realizes a set of interfaces
  - An implementation of a subsystem
  - Could be replaced by another component that realizes the same interfaces, and system would still function
- Distinct from classes
  - Classes may have fields, are assembled into programs
  - Components realize interfaces, are assembled into systems

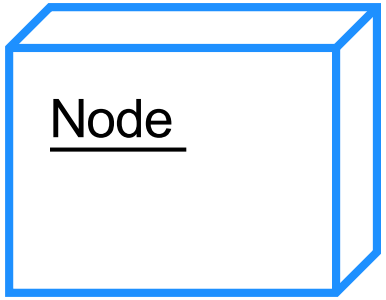


Example: interface diagram

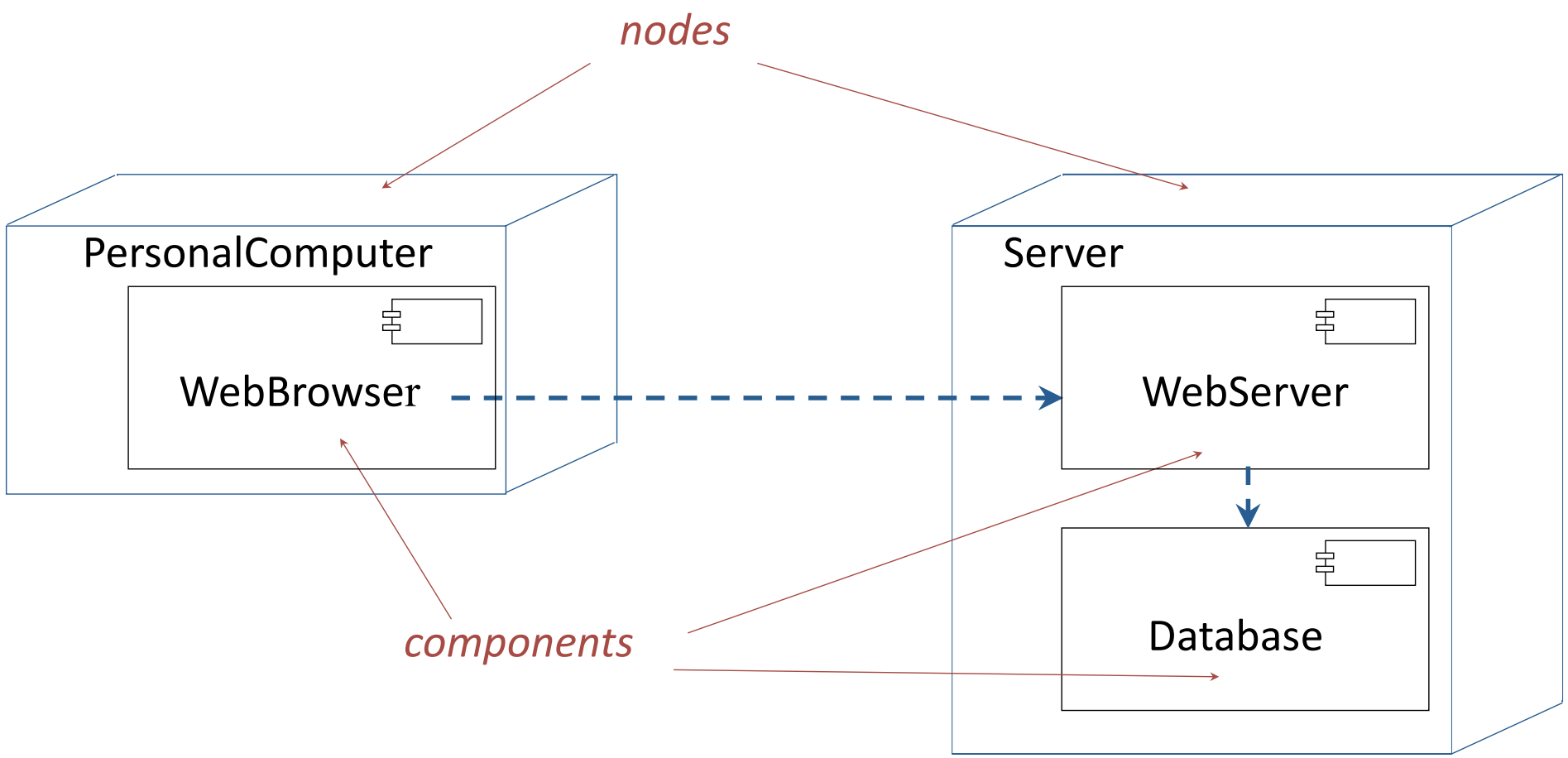


Node

- Physical element that exists at runtime, provides a computational resource
  - Computer
  - Smartphone
  - Network router
- Components live on nodes



Example: deployment diagram



Deployment environments

- Development

- Production
- Staging
- (Acceptance testing)

Example: simulator

- Vehicle state propagated by integrator
- Integrated equations affected by physics models, actuators
- Sensors read vehicle state
- Sensors and actuators communicate with controller via streams and/or registers
- Register values aggregated by a registry server communicating with registry clients

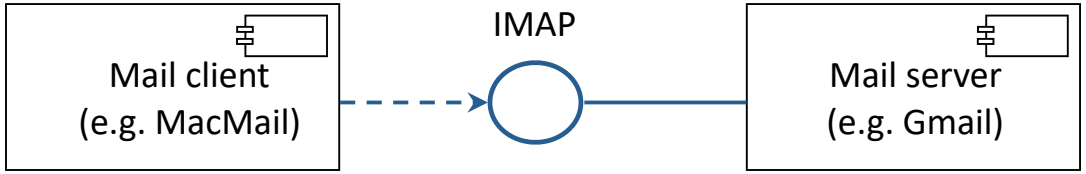
- Simulator process consists of integrator, models, sensors & actuators, and registry server
- Controller's registry client reads/writes controller's registers via shared memory
- Registry server communicates with clients via UDP
- Streams are sent via TCP
- Controller runs on virtual machine

Architectural styles

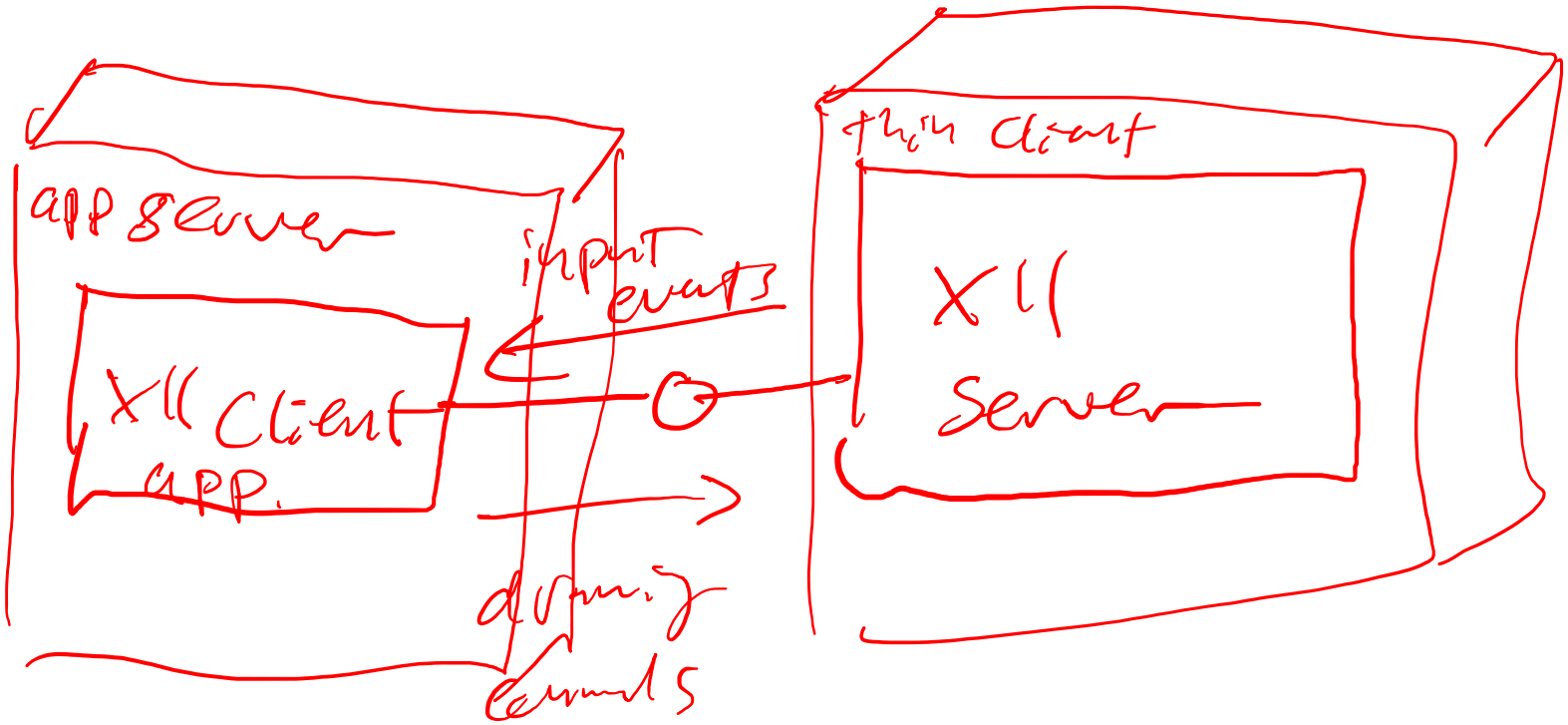
System architecture (or portion thereof) that recurs in many different applications

Client/server

- Control flow in client and server are independent
- Communication follows a protocol
- If protocol is fixed, either side can be replaced independently
- Peer-to-peer: same component can act as both client and server



Example: X Window System (X11)



Layered

- Partition subsystems into stack of layers
  - Layer provides services to layer directly above
  - Layer relies on services to layer directly below
- Advantage: constrains coupling
- Danger: leaky abstractions
  - May need services of multiple lower layers

- See Sommerville, *Software Engineering, Tenth Edition*, Figure 6.8 (or Chapter 6 slides)

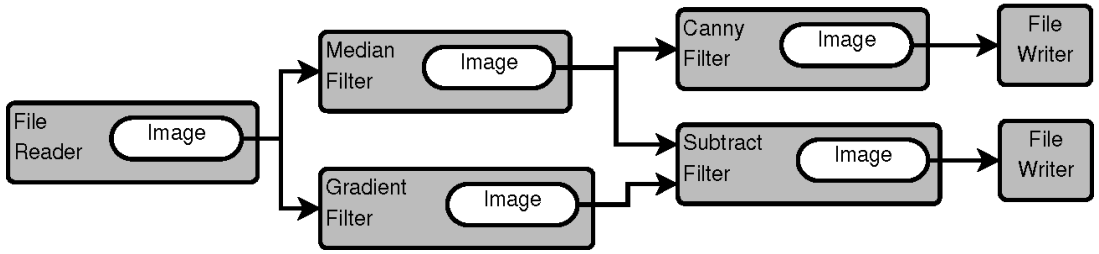
Examples

- OSI reference model architecture
  - See Sommerville, *Software Engineering, Tenth Edition*, Web sections: Reference Architectures

- Oscilloscope: Layered approach
  - See Garlan & Shaw, "An Introduction to Software Architecture"

Pipe and filter

- Transformation components process inputs to produce outputs
  - Subsystems coupled via data exchange
  - Good match for data flow models
  - May be dynamically assembled
- Applications:
  - Streaming media
  - Graphics shaders
  - Signal processing
- Caveats:
  - Awkward to handle events (interactive systems)
  - Rate mismatches if branches merge



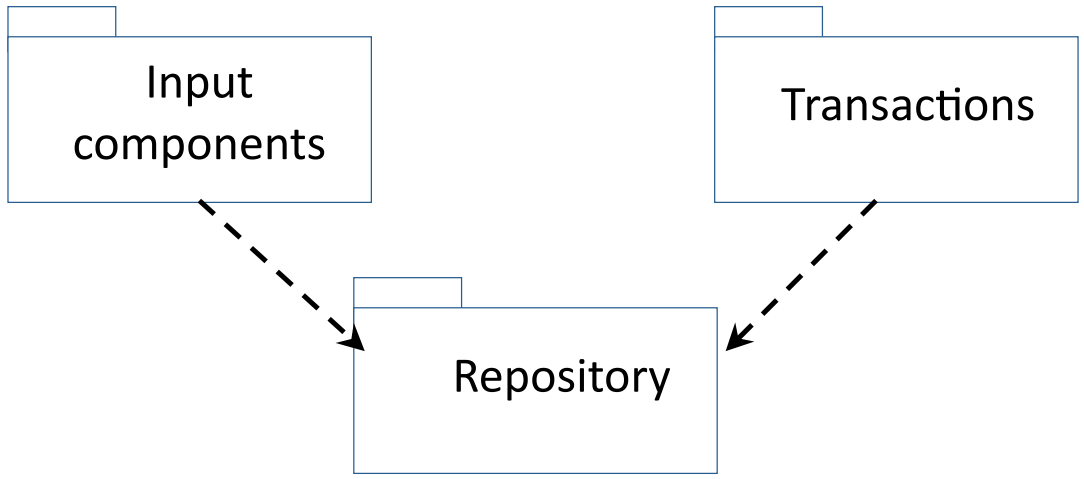
CC-BY *The Architecture of Open Source Applications, Volume II*, Chapter 9: ITK

Example: Oscilloscope

- See Garlan & Shaw, "An Introduction to Software Architecture"

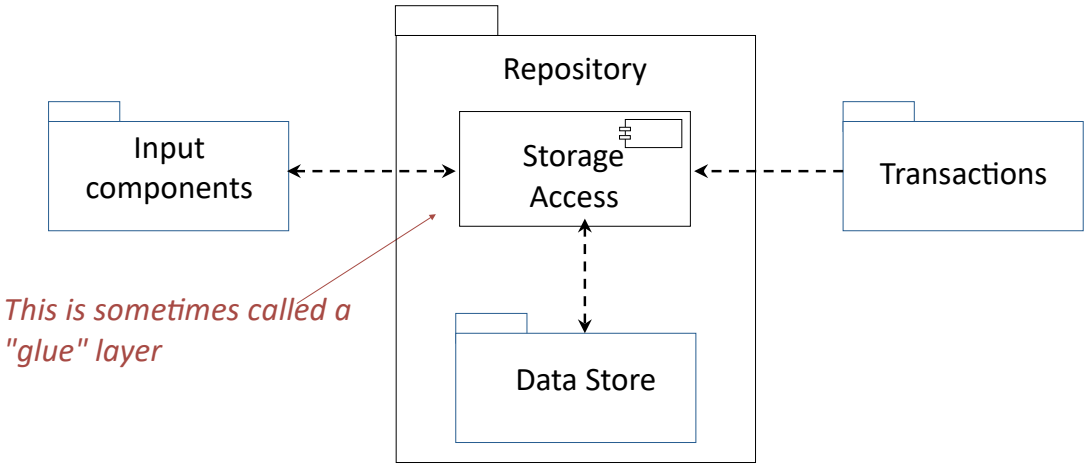
Repository

- Couple subsystems via shared data
  - Repository may need to support atomic transactions
- Advantages:
  - Components are independent (low coupling)
  - Centralized state storage (good for backups)
- Dangers:
  - Bottleneck / single point of failure



Flexibility through indirection

- Repository is highly coupled – difficult to change data store
- By defining higher-level storage access interface, data store is now lightly coupled



Example: Compilers

- See Garlan & Shaw, "An Introduction to Software Architecture"

Credits

- Architectural diagrams adapted from work by William Arms