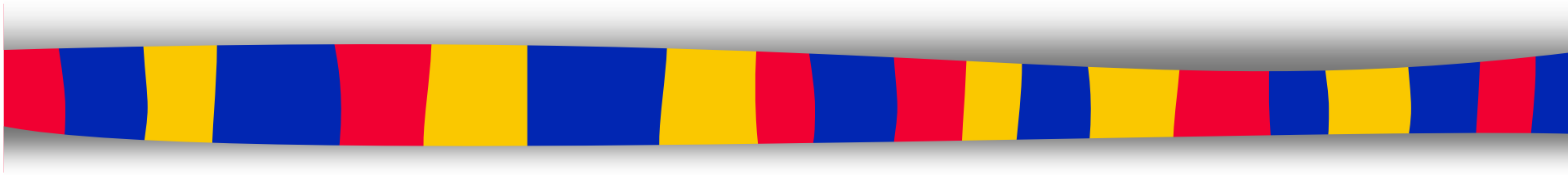
EECS 4314
Advanced Software Engineering



Topic 04:
Software Architecture: Intro and Styles

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Acknowledgement

- Some of the slides are from Richard C. Holt, Spiros Mancoridis, and Emad Shihab

References

- David Garlan and Mary Shaw. An Introduction to Software Architecture, Advances in Software Engineering and Knowledge Engineering, Volume 1, World Scientific Publishing Co., 1993.
- The Architecture of Open Source Applications
  - http://aosabook.org/en/index.html

The Evolution of Programming Abstractions

- The first modern programmable computers (1950s) were largely hardwired. The first software was written in machine language
- Next major breakthrough: assembly languages
  - Symbolic assemblers
  - Macro processors
- 1960s: High-level languages (3GLs)
  - Mostly independent of machine and problem domain
    - Level is “generic problem-solving”
  - FORTRAN, COBOL
  - Algol, Pascal, Modula
  - C, PL/1
  - Simula, Smalltalk; C++, Java

Abstraction from Developers' Perspective

- Typed variables and user-defined types [late 1960s]
- Modules [early 1970s]
  - 1968: "The software crisis", need "software engineering"
  - Create explicit interfaces, enforce information hiding
- ADTs and object-oriented computing [mid 1970s]
  - Programming entities as mathematically precise constructs
  - Abstract commonalities to one place
- Object-oriented design patterns, refactoring [1990s]
  - OO is powerful and complex
    - What constitutes a "good" OO design (small to medium-sized programs)?
    - What re-usable "tricks" can help to solve recurring problems?
  - At the level of data structures, algorithms and a few co-operating classes
- Software architecture [1990s, but really since 1960s]
  - Designing large systems is about understanding broad tasks, defining system-wide structures, interfaces and protocols, understanding how non-functional requirements impact on the system
  - At the level of the handful of "big boxes" that comprise the major components of your system, plus their interdependencies

Software Architecture

- As the size and complexity of software systems increases, the design problem goes beyond algorithms and data structures.
- Designing and specifying the overall system structure (**Software Architecture**) emerges as a new kind of problem.
- Reference Architecture
  - General architecture for an application domain. E.g., common structure for compilers or for operating systems
- Product Line Architecture (PLA)
  - Architecture for a line of similar software products. E.g., software structure for a family of computer games

Software Architecture Issues

- Organization and global control structure,
- Protocols of communication, synchronization, and data access,
- Assignment of functionality to design elements,
- Physical distribution,
- Selection among design alternatives.

State of Practice

- Currently there is no well-defined terminology or notation to characterize architectural structures.
- However, good software engineers make common use of architectural principles when designing complex software.
- These principles represent rules of thumb or idiomatic patterns that have emerged informally over time. Others are more carefully documented as industry standards.

Descriptions of Software Architectures - Example # 1

- *"Camelot is based on the **client-server model** and uses remote procedure calls both locally and remotely to provide communication among applications and servers."*
- *"We have chosen a **distributed**, **object-oriented** approach to managing information."*

Descriptions of Software Architectures – Example # 2

- *"**Abstraction layering** and system decomposition provide the appearance of system uniformity to clients, yet allow Helix to accommodate a diversity of autonomous devices. The architecture encourages a **client-server model** for the structuring of applications."*

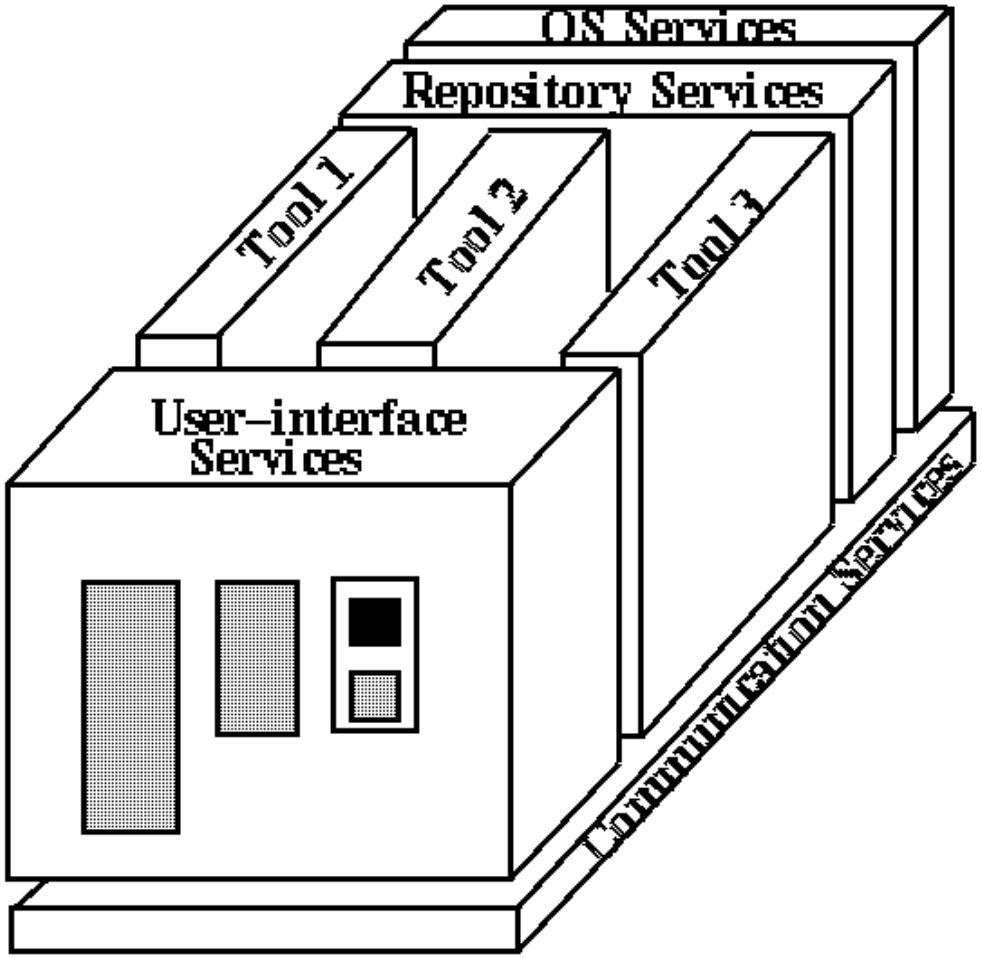
Descriptions of Software Architectures – Example # 3

- *"The easiest way to make a canonical sequential compiler into a concurrent compiler is to **pipeline** the execution of the compiler phases over a number of processors. A more effective way is to split the source code into many segments, which are concurrently processed through the various phases of compilation (by multiple compiler processes) before a final, merging pass recombines the object code into a single program."*

Some Standard Software Architectures

- **ISO/OSI Reference Model** is a layered network architecture.
- **X Window System** is a distributed windowed user interface architecture based on event triggering and callbacks.
- **NIST/ECMA Reference Model** is a generic software engineering environment architecture based on layered communication substrates.

The “Toaster” Model



Intuition About Architecture

- It is interesting that we have so few *named* software architectures. This is not because there are so few architectures, but so many.
- We next look at several architectural disciplines in order to develop an intuition about software architecture. Specifically, we look at:
  - Hardware Architecture
  - Network Architecture
  - Building Architecture

Hardware Architecture

- **RISC** machines emphasize the instruction set as an important feature.
- **Pipelined** and **multi-processor** machines emphasize the configuration of architectural pieces of the hardware.

Differences & Similarities Between SW & HW Architectures

- **Differences:**
  - relatively (to software) small number of design elements.
  - scale is achieved by replication of design elements.
- **Similarities:**
  - we often configure software architectures in ways analogous to hardware architectures. (*e.g.,* we create multi-process software and use pipelined processing).

Network Architecture

- Networked architectures are achieved by abstracting the design elements of a network into nodes and connections.
- Topology is the most emphasized aspect:
  - Star networks
  - Ring networks
  - Manhattan Street networks
- Unlike software architectures, in network architectures only few topologies are of interest.

Building Architecture

- **Multiple Views:** skeleton frames, detailed views of electrical wiring, etc.
- **Architectural Styles:** Classical, Romanesque, and so on.
- **Materials:** One does not build a skyscraper using wooden posts and beams.

What are Architectural Styles

- An **Architectural Style** defines a family of systems in terms of a pattern of structural organization. It determines:
  - the **vocabulary** of components and connectors that can be used in instances of that style
  - a set of **constraints** on how they can be combined.

Why Architectural Styles

- Makes for an easy way to communicate among stakeholders
- Documentation of early design decisions
- Allow for the reuse and transfer of qualities to similar systems

Roy T. Fielding
@fielding

Follow

Architectural styles are named so we can easily discuss & contrast them, not so they can be carried on banners or elevated to purity.

RETWEETS 110 LIKES 128

5:31 pm - 23 Oct 2016

110 128

Roy T. Fielding @fielding · 13h
Event Based Integration vs REST is a great discussion. So is EBI + REST and EBI  REST, especially on mobile platforms with built-in EBI.

1 7

Roy T. Fielding @fielding · 13h
Just don't assume EBI will work on platforms that don't have it built-in; it requires careful balance of social, economic, and tech factors.

1 4

Greg L. Turnquist @gregturn · 14h
@fielding its vocabulary, not dogma.

2

Matthew Cannon @matt_p_cannon · 1h
@fielding @keithb_b Exactly this! Even the old GoF patterns had expressive metaphorical names like Bridge and Visitor. There was a reason.

Determining an Architectural Style

- We can understand what a style is by answering the following questions:
  - What is the **structural pattern**? (*i.e.,* components, connectors, constraints)
  - What is the underlying **computational model**?
  - What are the essential **invariants** of the style?
  - What are some common **examples** of its use?
  - What are the **advantages** and **disadvantages** of using that style?
  - What are some of the common **specializations** of that style?

Describing an Architectural Style

- The architecture of a specific system is a collection of:
  - computational components
  - description of the interactions between these components (connectors)
- Software architectures are represented as graphs where **nodes** represent components:
  - procedures
  - modules
  - processes
  - tools
  - databases
- and **edges** represent connectors:
  - procedure calls
  - event broadcasts
  - database queries
  - pipes

Architecture Styles Covered

- Pipe and filter
- Repository
- Implicit invocation
- Layered
- Client-server
- Process-control

Pipe and Filter Style

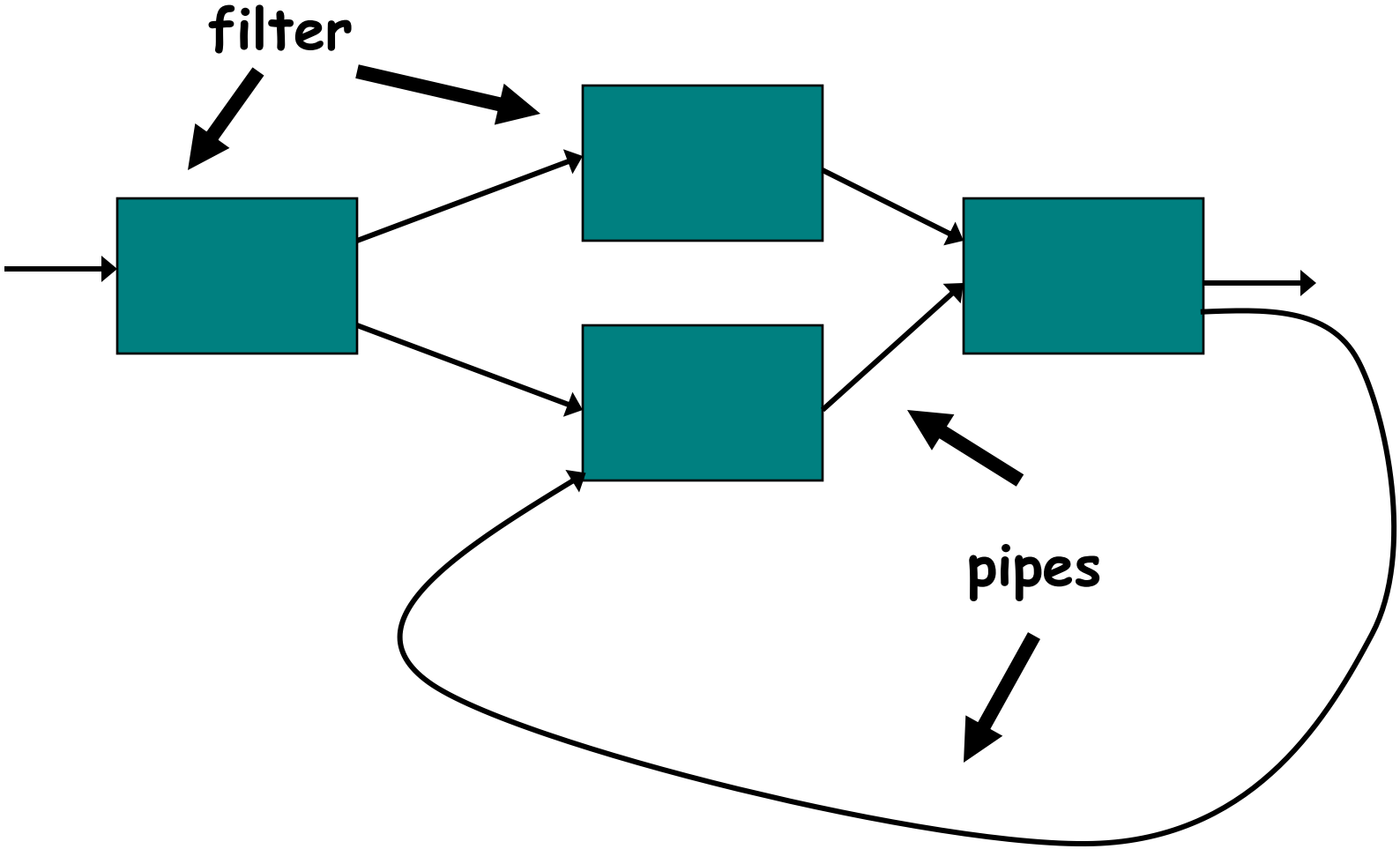
Pipe and Filter Architectural Style

- Suitable for applications that require a defined series of independent computations to be performed on ordered data.
- A component reads streams of data on its inputs and produces streams of data on its outputs.

Pipe and Filter Architectural Style (Cont'd)

- **Components:** called **filters**, apply local transformations to their input streams and often do their computing incrementally so that output begins before all input is consumed.
- **Connectors:** called **pipes**, serve as conduits for the streams, transmitting outputs of one filter to inputs of another.

Pipe and Filter Architectural Style



Pipe and Filter Invariants

- Filters **do not share state** with other filters.
- Filters **do not know the identity** of their upstream or downstream filters.
- The **correctness** of the output of a pipe and filter network should not depend on the order in which their filters perform their incremental processing.

Pipe and Filter Specializations

- **Pipelines:** Restricts topologies to linear sequences of filters.
- **Batch Sequential:** A degenerate case of a pipeline architecture where each filter processes all of its input data before producing any output.

Pipe and Filter Examples

- **Unix Shell Scripts:** Provides a notation for connecting Unix processes via pipes.
  - *cat file | grep Eroll | wc -l*
- **Traditional Compilers:** Compilation phases are pipelined, though the phases are not always incremental. The phases in the pipeline include:
  - *lexical analysis + parsing + semantic analysis + code generation*

Pipe and Filter Style Advantages & Disadvantage

- Advantages
  - **Easy to understand** the overall input/output behavior of a system as a simple composition of the behaviors of the individual filters.
  - They **support reuse**, since any two filters can be hooked together, provided they agree on the data that is being transmitted between them.
  - Systems can be **easily maintained and enhanced**, since new filters can be added to existing systems and old filters can be replaced by improved ones.
  - They permit certain kinds of **specialized analysis**, such as throughput and deadlock analysis.
  - The naturally **support concurrent execution**.
- Disadvantages
  - Not good for handling **interactive systems**, because of their transformational character.
  - Excessive parsing and unparsing leads to **loss of performance** and **increased complexity** in writing the filters themselves.

Summary of Pipe-and-Filter Style

- Independent components connected by pipes that route data streams between filters

- Advantages
  - Easy to understand
  - Easy to maintain and enhance

- Disadvantages
  - Poor performance
  - Increased complexity

Repository Style

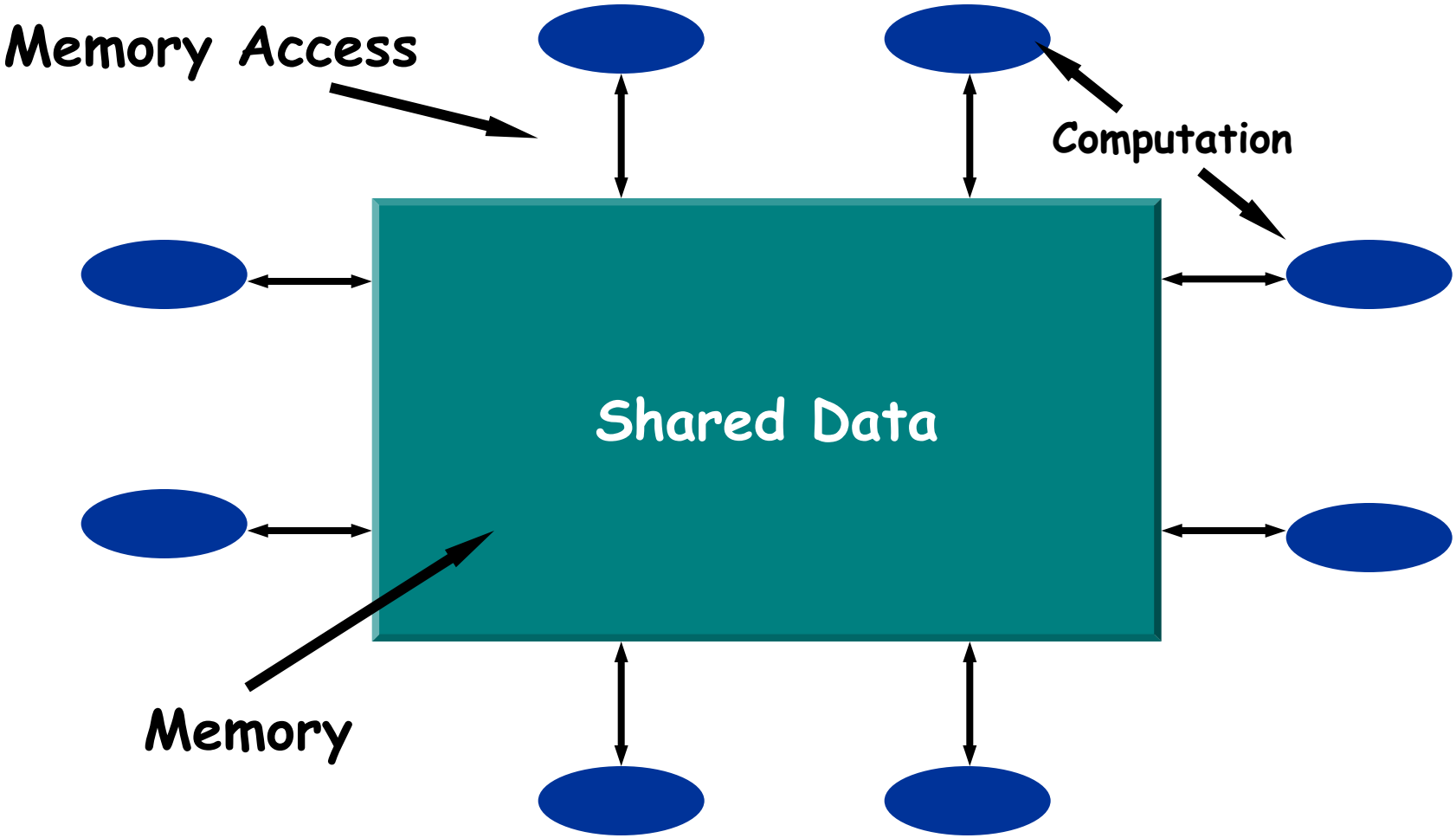
Repository Style

- Suitable for applications in which the central issue is establishing, augmenting, and maintaining a complex central body of information.
- Typically the information must be manipulated in a variety of ways. Often long-term persistence is required.

Repository Style (Cont'd)

- **Components:**
  - A central data structure representing the current state of the system.
  - A collection of independent components that operate on the central data structure.
- **Connectors:**
  - Typically procedure calls or direct memory accesses.

Repository Style (Cont'd)



Repository Style Specializations

- Changes to the data structure trigger computations.
- Data structure in memory (persistent option).
- Data structure on disk.
- Concurrent computations and data accesses.

Repository Style Examples

- Information Systems
- Central Code Repository Systems
- Programming Environments
- Graphical Editors
- Database Management Systems
- Games (World of Warcraft)

Repository Style Advantages

- **Efficient** way to store large amounts of data.
- **Sharing** model is published as the repository schema.
- Centralized **management**:
  - backup
  - security
  - concurrency control

Repository Style Disadvantages

- Must **agree on a data model** a priori.
- Difficult to **distribute data**.
- Data **evolution is expensive**.

Summary of Repository Style

- Independent components (programs) access and communicate exclusively through global repository

- Advantages
  - Efficient storage of data
  - Easily manageable
  - Can solve complex problems

- Disadvantages
  - Evolving data is expensive
  - Cannot handle high volume or complex logic

Case Study
- The Architecture of a Compiler

Case Study: Architecture of a Compiler

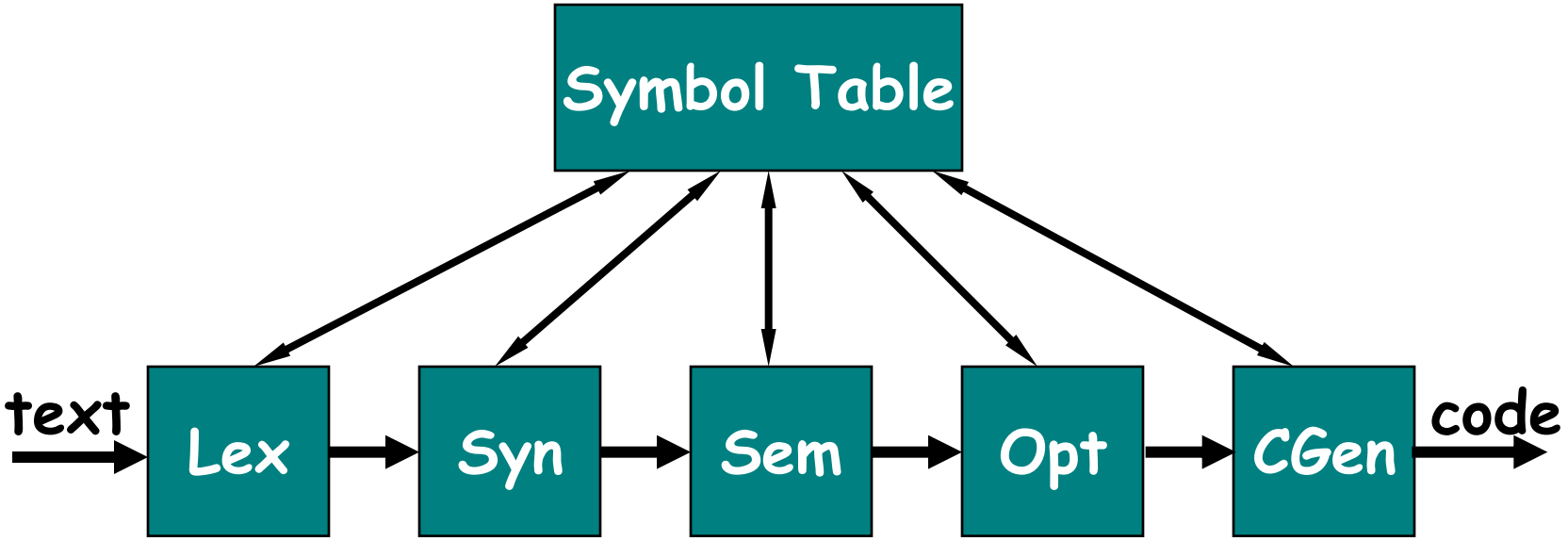
- The architecture of a system can change in response to improvements in technology.
- This can be seen in the way we think about compilers.

Early Compiler Architectures

- In the 1970s, compilation was regarded as a sequential (batch sequential or pipeline) process:

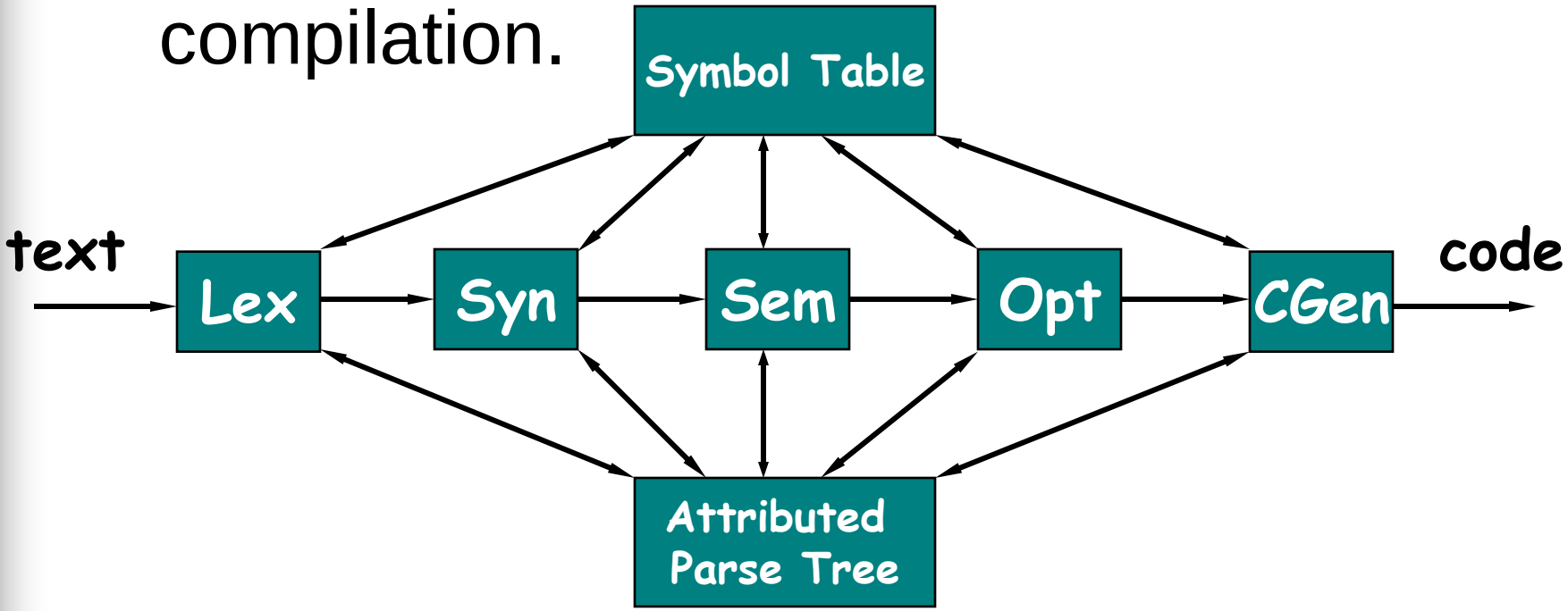
Early Compiler Architectures

- Most compilers create a separate symbol table during lexical analysis and used or updated it during subsequent passes.



Modern Compiler Architectures

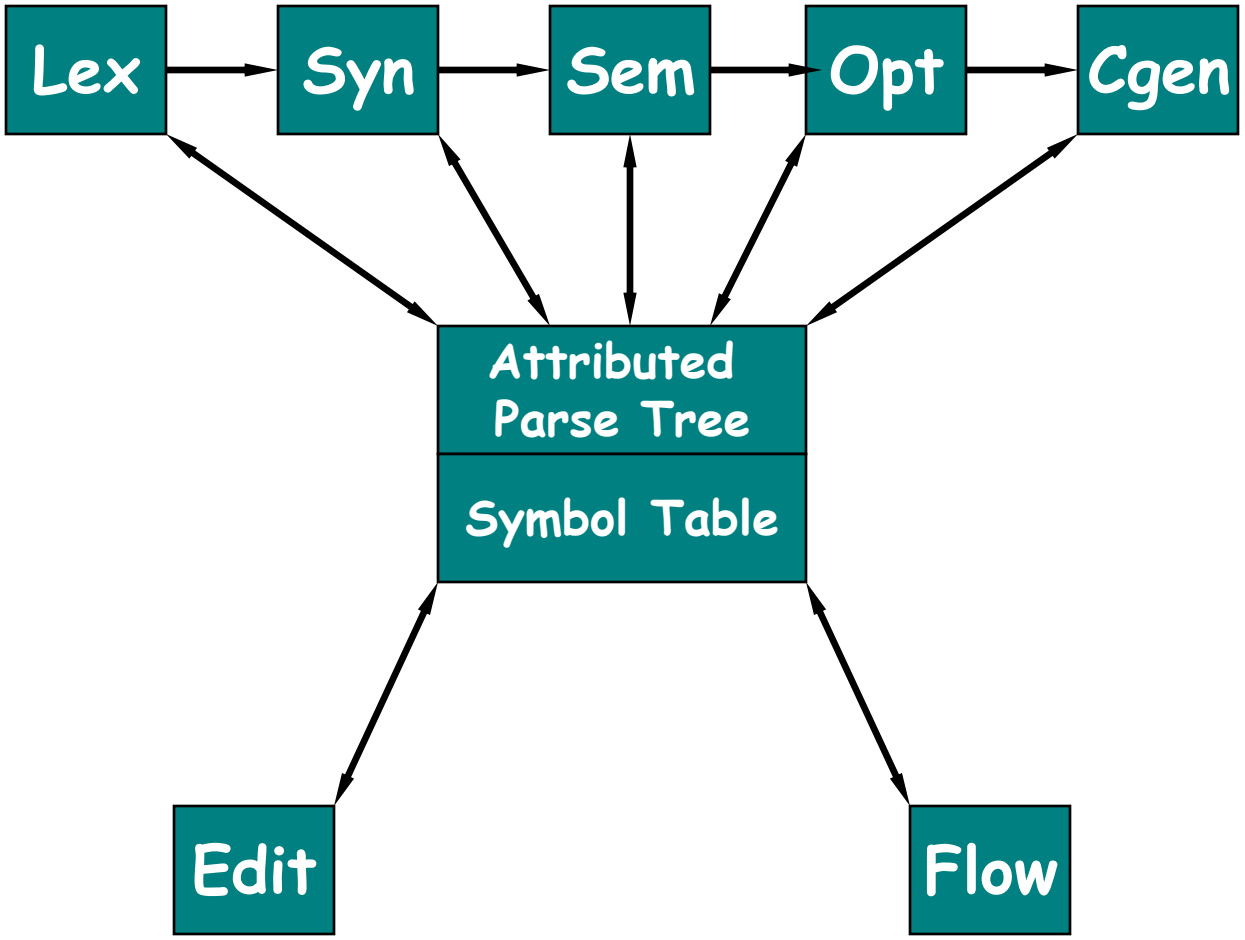
- Later, in the mid 1980s, increasing attention turned to the intermediate representation of the program during compilation.



Hybrid Compiler Architectures

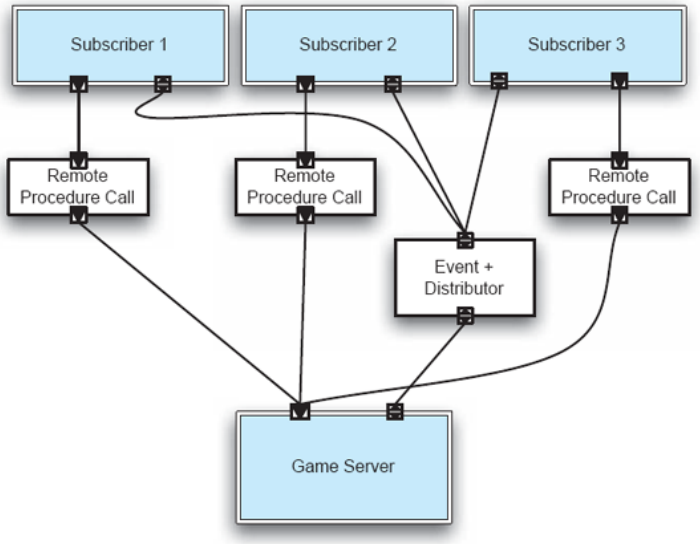
- The new view accommodates various tools (*e.g.,* syntax-directed editors) that operate on the internal representation rather than the textual form of a program.
- Architectural shift to a **repository** style, with elements of the **pipeline** style, since the order of execution of the processes is still predetermined.

Hybrid Compiler Architectures

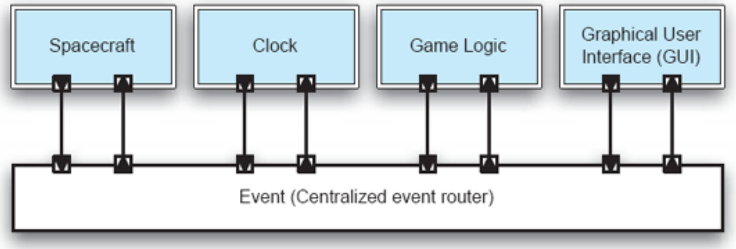


Implicit Invocation Style

Implicit Invocation Style



Publish-Subscribe



Event Based

Taylor et al. 2010

Implicit Invocation Variants

- **Publish-Subscribe**
  - Subscribers register to receive specific messages
  - Publishers maintain a subscription list and broadcast messages to subscribers
- **Event-Based**
  - ICs asynchronously emit and receive “events” communicated over event bus

Implicit Invocation Style

- **Components**
  - Publishers, subscribers
  - Event generators and consumers
- **Connectors**
  - (PS) Procedure calls
  - Event bus

Implicit Invocation Style Topology

- Subscribers connect to publishers directly (or through network)
- Components communicate with the event bus, **not directly to each other**

Implicit Invocation Advantages

- (PS) Efficient dissemination of one-way information
- Provides strong support for **reuse**
  - Any component can be added, by registering/subscribing for events
- **Eases system evolution**
  - components may be replaced without affecting other components in the system

Implicit Invocation Disadvantages

- (PS) Need special protocols when number of subscribers is very large

- When a component announces an event:
  - it has no idea what other components will respond to it,
  - it cannot rely on the order in which the responses are invoked
  - it cannot know when responses are finished

Implicit Invocation Examples

- Used in **programming environments** to integrate tools:
  - Debugger stops at a breakpoint and makes that announcement
  - Editor scrolls to the appropriate source line and highlights it
- Twitter, Google+

QA evaluation for Implicit Invocation

- **Performance**
  - (PS) Can deliver 1000s of msgs
  - Event bus: how does it compare to Repository?
- **Availability**
  - Publisher needs to be replicated
- **Scalability**
  - Can support 1000s of users, growth in data size
- **Modifiability**
  - Easily add more subscribers, change in message format affects many subscribers

Layered Style

Layered Style

- Architecture is separated into ordered layers
  - A program in one layer may obtain services from a layer below it

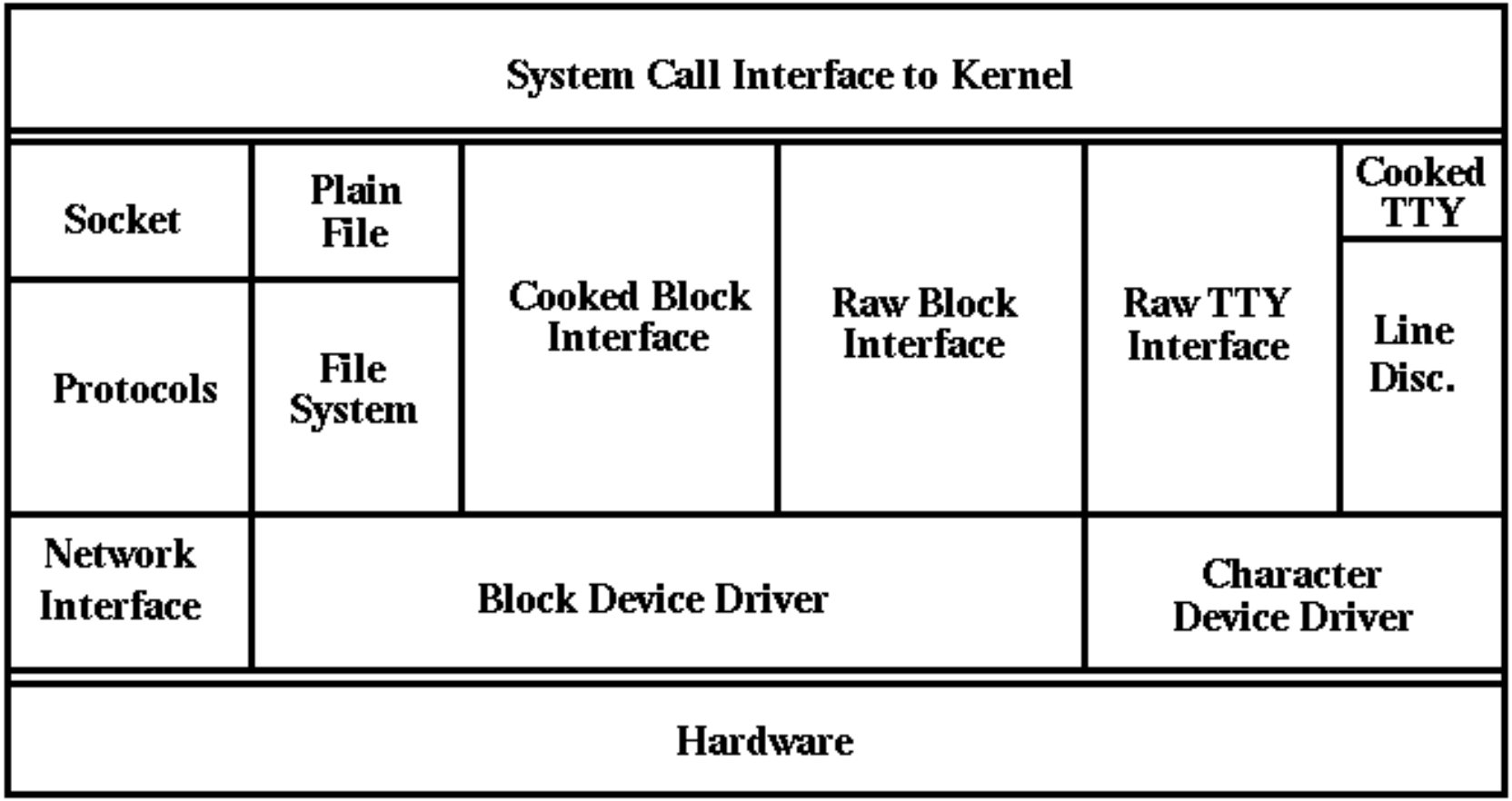
Layered Style Specializations

- Often exceptions are be made to **permit non-adjacent layers to communicate directly**.
  - This is usually done for efficiency reasons.

Layered Style Examples

- **Layered Communication Protocols:**
  - Each layer provides a substrate for communication at some level of abstraction.
  - Lower levels define lower levels of interaction, the lowest level being hardware connections (physical layer).
- **Operating Systems**
  - Unix

Unix Layered Architecture



Layered Style Advantages

- **Design:** based on increasing levels of abstraction.
- **Enhancement:** since changes to the function of one layer affects at most two other layers.
- **Reuse:** since different implementations (with identical interfaces) of the same layer can be used interchangeably.

Layered Style Disadvantages

- Not all systems are easily structured in a layered fashion.
- Performance requirements may force the coupling of high-level functions to their lower-level implementations.

Client-Server Style

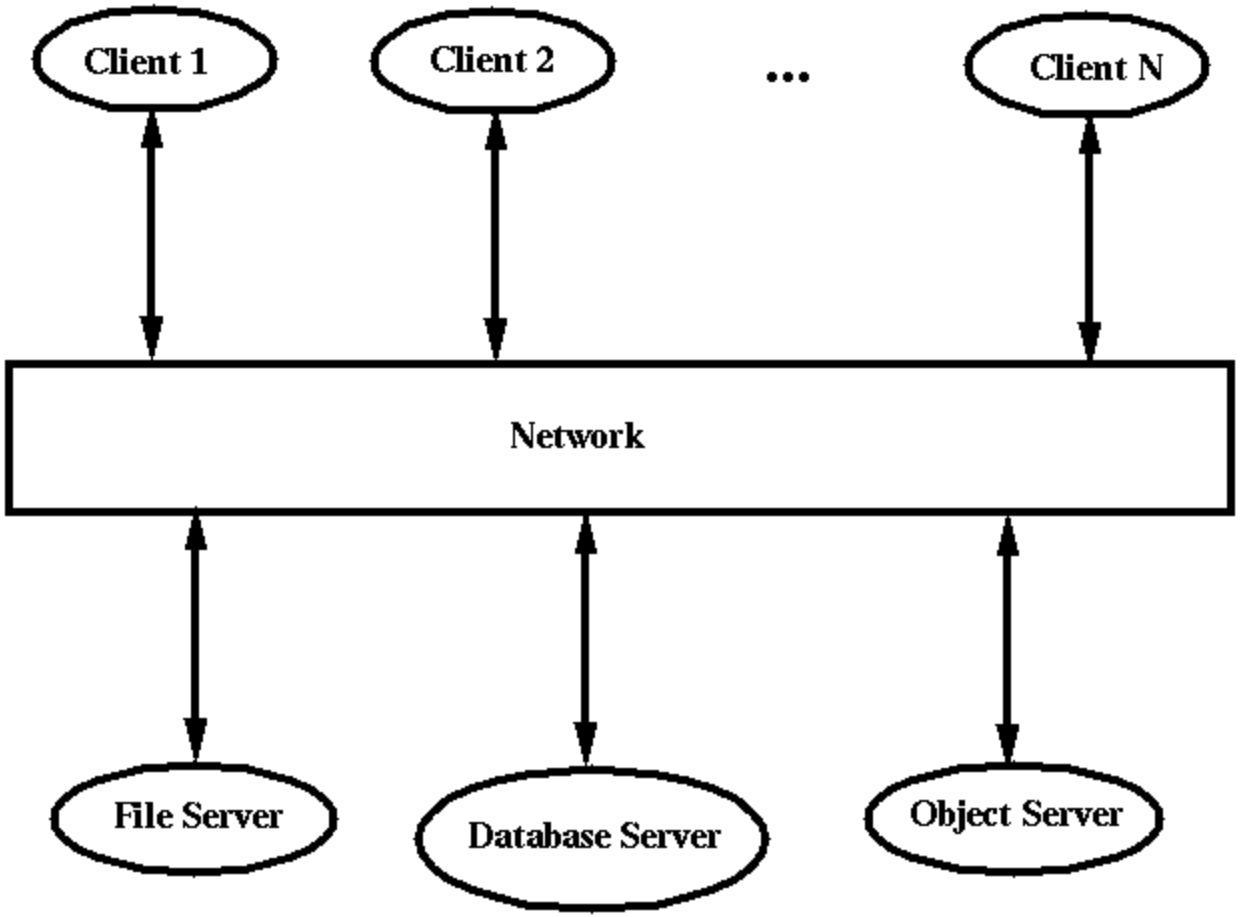
Client-Server Style

- Suitable for applications that involve distributed data and processing across a range of components.

Client-Server Style

- **Components:**
  - **Servers:** Stand-alone components that provide specific services such as printing, data management, etc.
  - **Clients:** Components that call on the services provided by servers.
- **Connector:** The network, which allows clients to access remote servers.

Client-Server Style



Client-Server Style Examples

- **File Servers:**
  - Primitive form of data service.
  - Useful for sharing files across a network.
  - The client passes request for files over the network to the file server.

Client-Server Style Examples (Cont'd)

- **Database Servers:**
  - More efficient use of distributing power than file servers.
  - Client passes SQL requests as messages to the DB server; results are returned over the network to the client.
  - Query processing done by the server.
  - No need for large data transfers.
  - Transaction DB servers also available.

Client-Server Style Advantages

- Distribution of data is straightforward,
- Transparency of location,
- Mix and match heterogeneous platforms,
- Easy to add new servers or upgrade existing servers.

Client-Server Style Disadvantages

- No central register of names and services -- it may be hard to find out what services are available

Process-Control Style

Process-Control Style

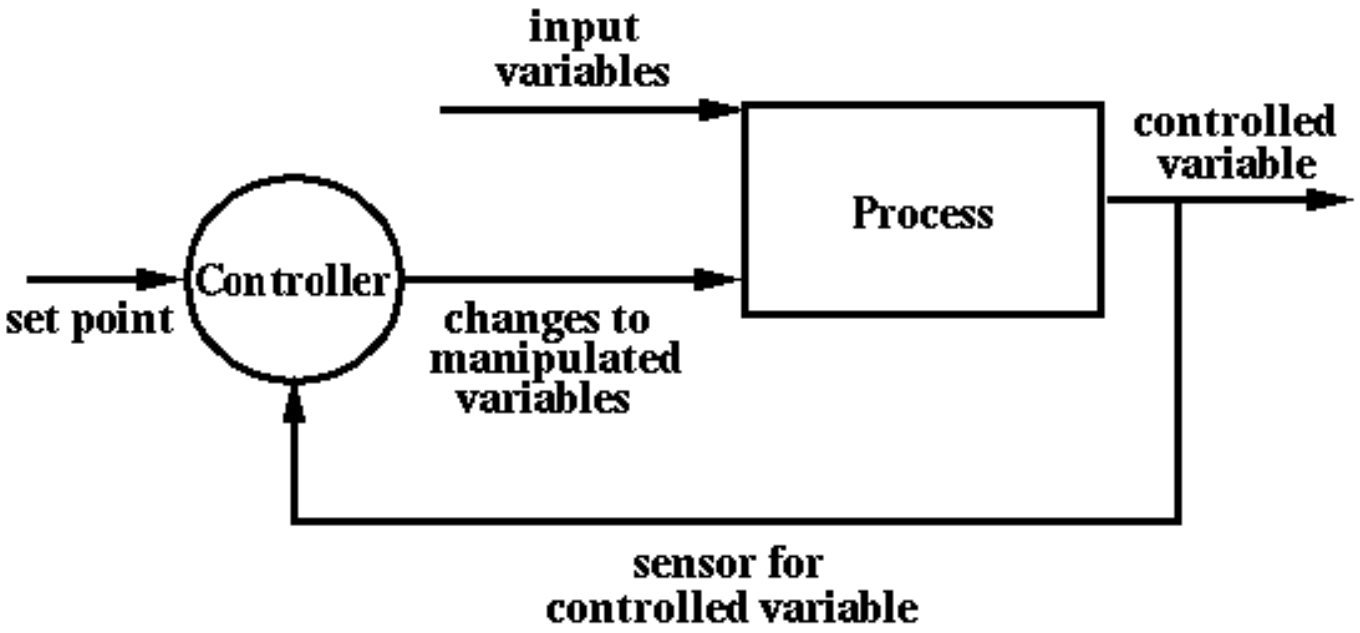
- Suitable for applications whose purpose is to maintain specified properties of the outputs of the process at (sufficiently near) given reference values.

Process-Control Style

- **Components:**
  - **Process Definition** includes mechanisms for manipulating some process variables.
  - **Control Algorithm** for deciding how to manipulate process variables.
- **Connectors:** are the data flow relations for:
  - **Process Variables:**
    - *Controlled variable* whose value the system is intended to control.
    - *Input variable* that measures an input to the process.
    - *Manipulated variable* whose value can be changed by the controller.
  - **Set Point** is the desired value for a controlled variable.
  - **Sensors** to obtain values of process variables pertinent to control.

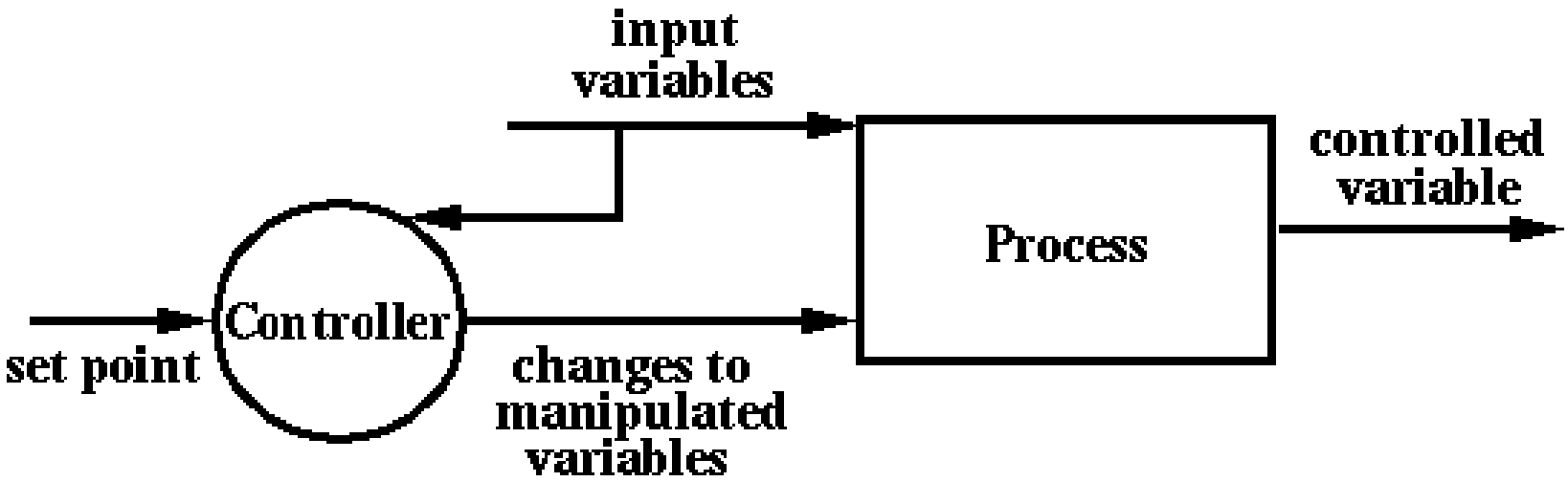
Feed-Back Control System

- The controlled variable is measured and the result is used to manipulate one or more of the process variables.



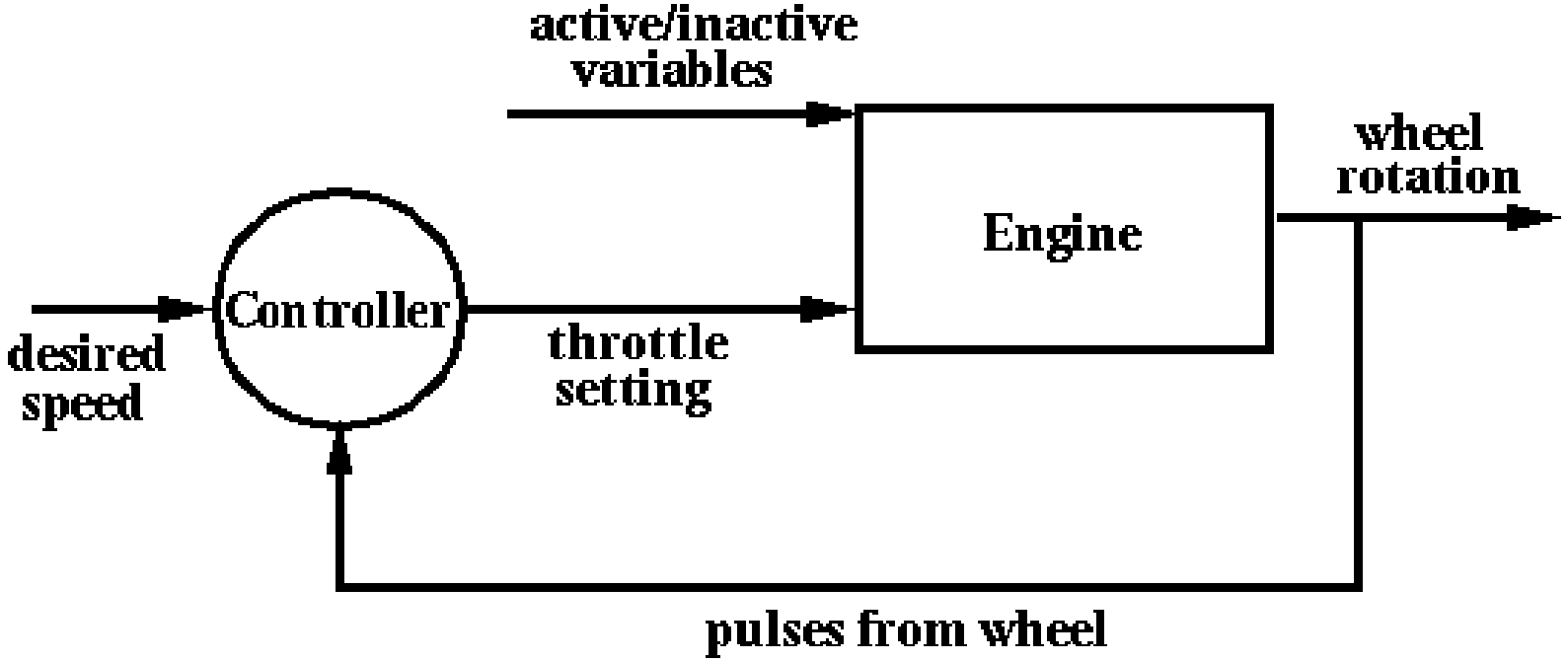
Open-Loop Control System

- Information about process variables is not used to adjust the system.

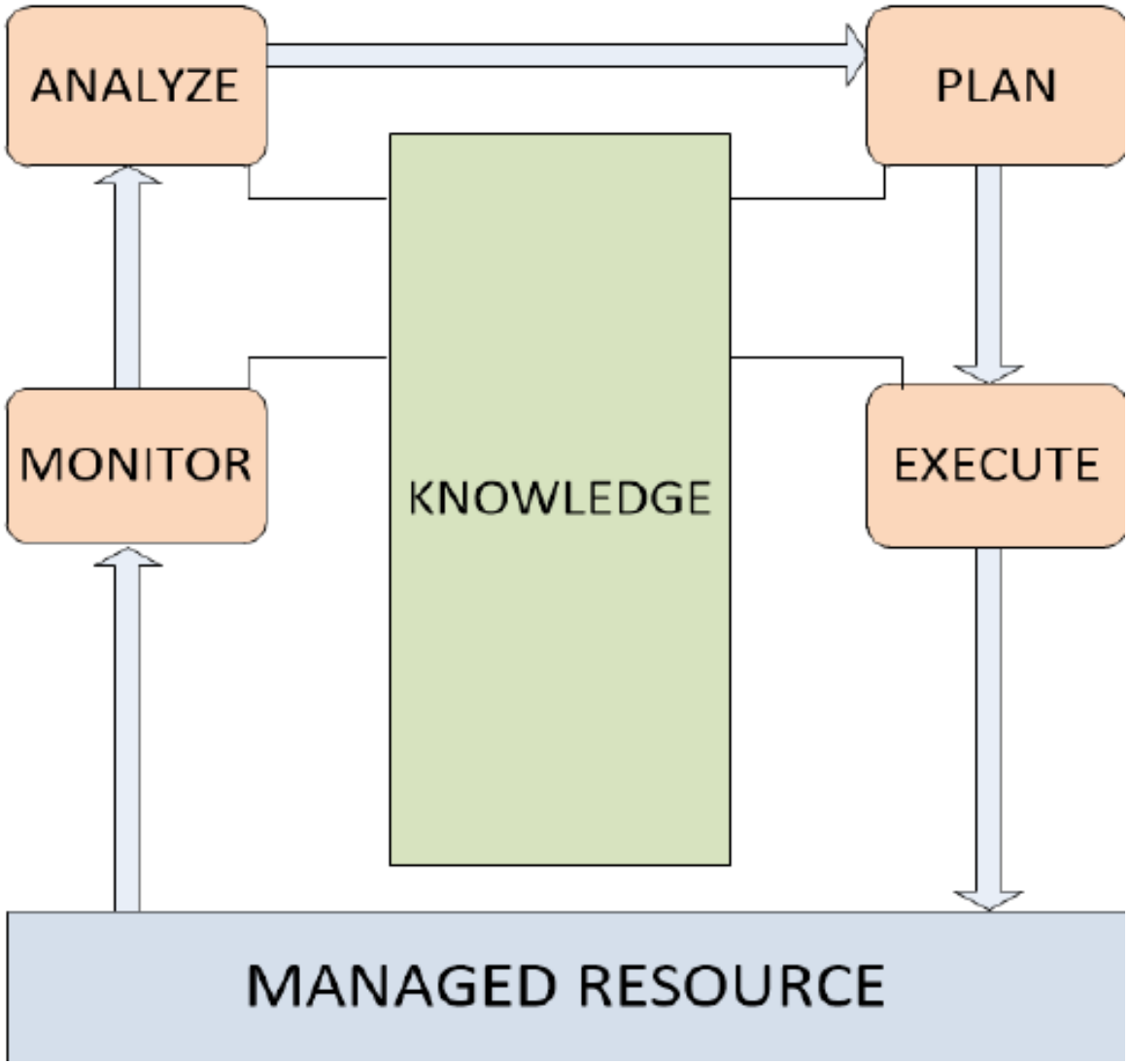


Process Control Examples

- Real-Time System Software to Control:
  - Automobile Anti-Lock Brakes
  - Nuclear Power Plants
  - Automobile Cruise-Control



MAPE-K loop



Exercise

Automated Stock Trading System

- A customer approaches YOURSTRULYTradingSolutions with the need for an architecture design for an automated stock trading system. The system needs to take in a list of stocks, related to specific sectors and buy/sell these stocks based on some predefined algorithms.
- The system needs to perform well (place many orders) and scale to support many investors.
- Your task is to propose an architecture for the system, accompanied by an informal evaluation of the advantages and disadvantages of the proposed architecture.

Automated Stock Trading System

- Input
  - List of sectors/stocks to trade
  - List of investors and their daily budget
- Output
  - Notification to buyers/sellers
    - List of stocks bought/sold
    - Cost, if bought; Gain/Loss, if sold
  - Withdraw/deposit money based on orders

Automated Stock Trading System Assumptions

- Historical data of all stocks will be provided (very large)
  - To perform historical analysis on the stocks/sectors
- Buy/Sell algorithms will be provided by financial engineers
  - To know which stocks to buy/sell
- Investor personal data will be provided
  - To withdraw and deposit money