Cornell University
Computing and Information Science

CS 5150 Software Engineering

System Architecture: Introduction

William Y. Arms

Design

The **requirements** describe the function of a system as seen by the client.

Given a set of requirements, the software development team must **design** a system that will meet those requirements.

In this course, we look at the following aspects of design:

- system architecture
- program design
- usability
- security
- performance

In practice these aspects are interrelated and many aspects of the design emerge during the requirements phase of a project. This is a particular strength of the iterative and incremental methods of software development.

Creativity and Design

Software development

Software development is a **craft**. Software developers have a variety of **tools** that can be applied in different situations.

Part of the art of software development is to select the appropriate tool for a given implementation.

Creativity and design

System and program design are a particularly creative part of software development, as are user interfaces. You hope that people will describe your designs as “elegant”, “easy to implement, test, and maintain.”

Above all strive for **simplicity**. The aim is find simple ways to implement complex requirements.

System Architecture

System architecture is the overall design of a system

- Computers and networks (e.g., monolithic, distributed)
- Interfaces and protocols (e.g., http, ODBC)
- Databases (e.g., relational, distributed)
- Security (e.g., smart card authentication)
- Operations (e.g., backup, archiving, audit trails)

At this stage of the development process, you should also be selecting:

- Software environments (e.g., languages, database systems, class frameworks)
- Testing frameworks

Models for System Architecture

Our models for systems architecture are based on UML

The slides provide diagrams that give an outline of the systems, without the supporting specifications.

For every system, there is a choice of models

Choose the models that best model the system and are clearest to everybody.

When developing a system, every diagram must have supporting specification

The diagrams shows the relationships among parts of the system, but much, much more detail is needed to specify a system explicitly.

For example, to specify a web plug-in, at the very least, the specification should include the version of the protocols to be supported at the interfaces, options (if any), and implementation restrictions.

Subsystems

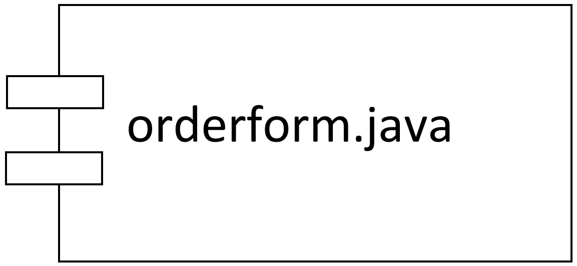
Subsystem

A subsystem is a grouping of elements that form part of a system.

- **Coupling** is a measure of the dependencies between two subsystems. If two subsystems are strongly coupled, it is hard to modify one without modifying the other.
- **Cohesion** is a measure of dependencies within a subsystem. If a subsystem contains many closely related functions its cohesion is high.

An ideal division of a complex system into subsystems has low coupling between subsystems and high cohesion within subsystems.

Component



A **component** is a replaceable part of a system that conforms to and provides the realization of a set of interfaces.

A component can be thought of as an implementation of a subsystem.

UML definition of a component

"A distributable piece of implementation of a system, including software code (source, binary, or executable), but also including business documents, etc., in a human system."

Components as Replaceable Elements

Components allow system to be assembled from **binary replaceable elements**

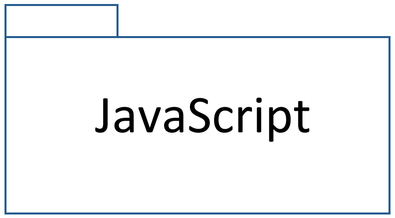
- A component is bits not concepts
- A component can be replaced by any other component(s) that conforms to the interfaces
- A component is part of a system
- A component provides the realization of a set of interfaces

Components and Classes

Classes represent logical abstractions. They have attributes (data) and operations (methods).

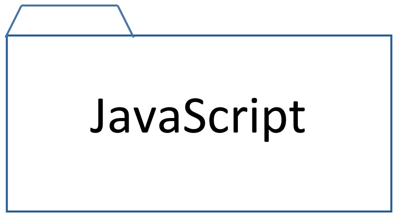
Components have operations that are reachable only through interfaces.

Package

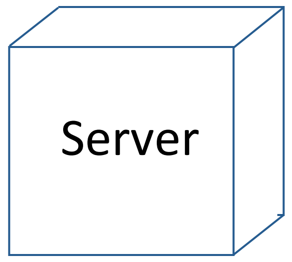


A **package** is a general-purpose mechanism for organizing elements into groups.

Note: Some authors draw packages with a different shaped box:



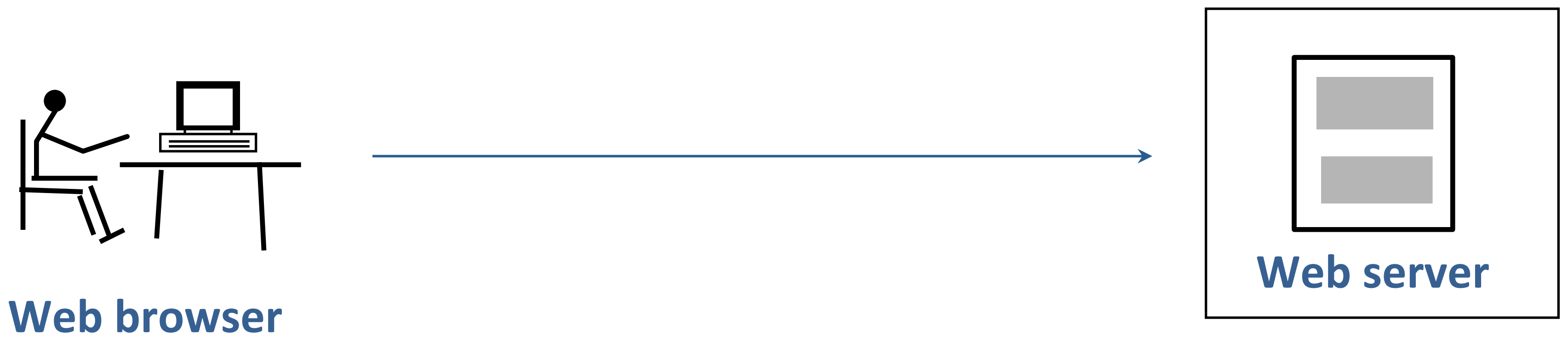
Node



A **node** is a physical element that exists at run time and provides a computational resource, e.g., a computer, a smartphone, a router.

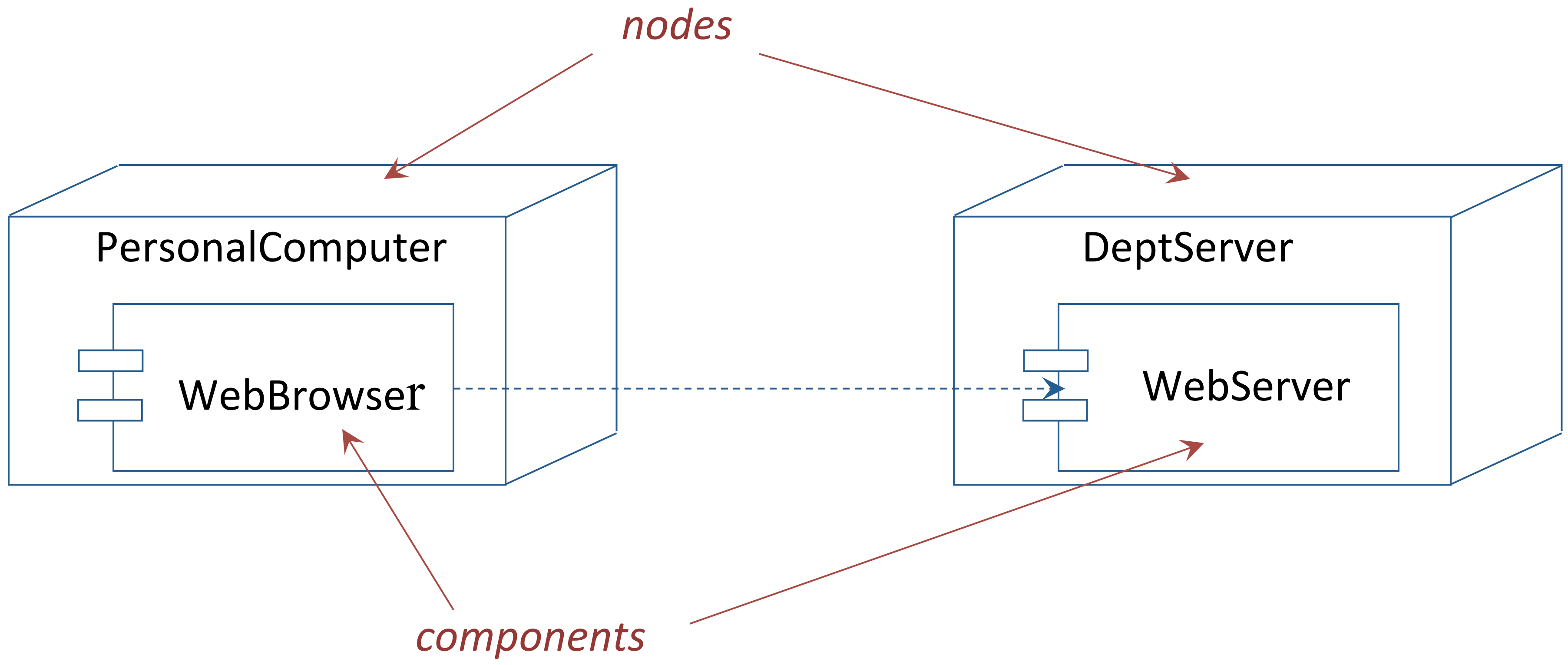
Components may live on **nodes**.

Example: Simple Web System

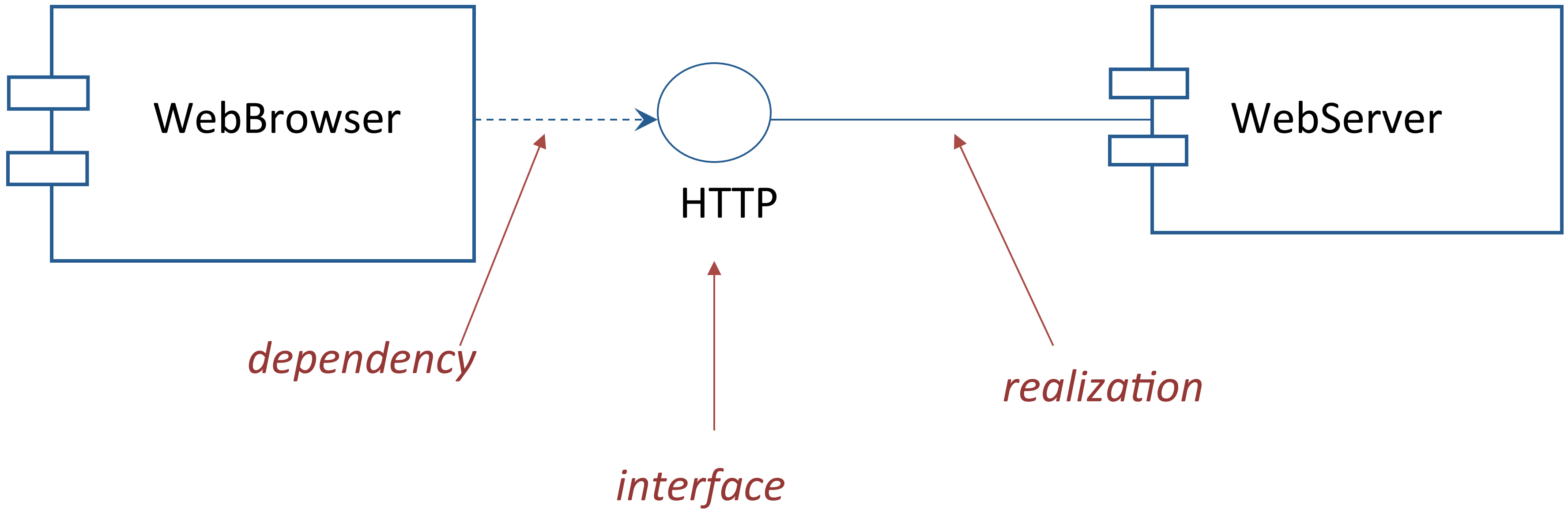


- Static pages from server
- All interaction requires communication with server

Deployment Diagram

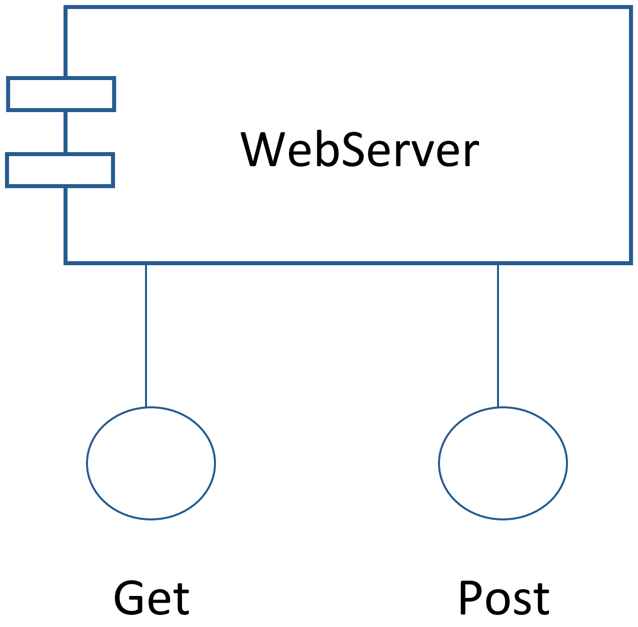


Component Diagram: Interfaces



Application Programming Interface (API)

An **API** is an interface that is realized by one or more components.



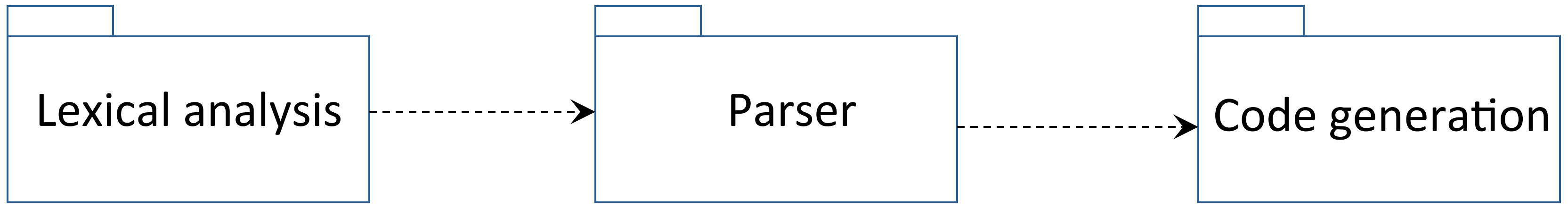
Architectural Styles

An **architectural style** is system architecture that recurs in many different applications.

See: Mary Shaw and David Garlan, *Software architecture: perspectives on an emerging discipline*. Prentice Hall, 1996

Architectural Style: Pipe

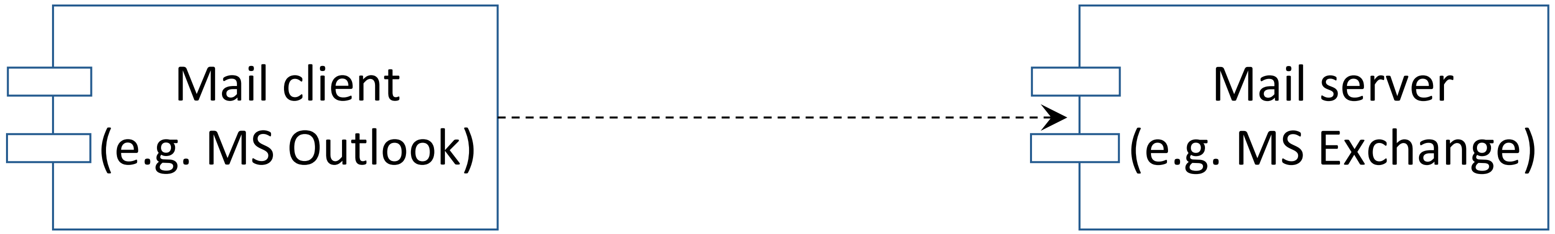
Example: A three-pass compiler



Output from one subsystem is the input to the next.

Architectural Style: Client/Server

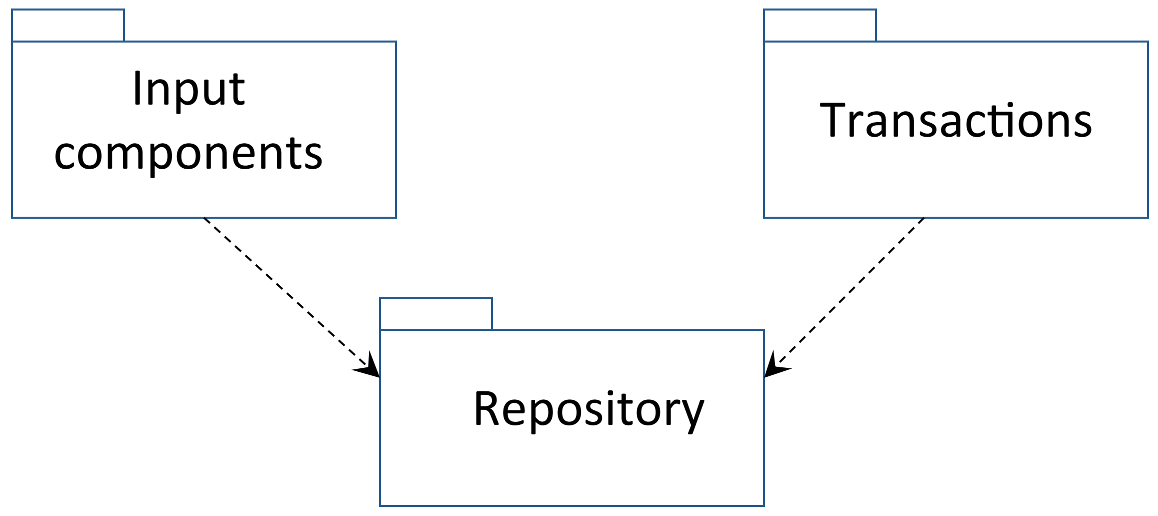
Example: A mail system



The control flows in the client and the server are independent. Communication between client and server follows a protocol.

In a peer-to-peer architecture, the same component acts as both a client and a server.

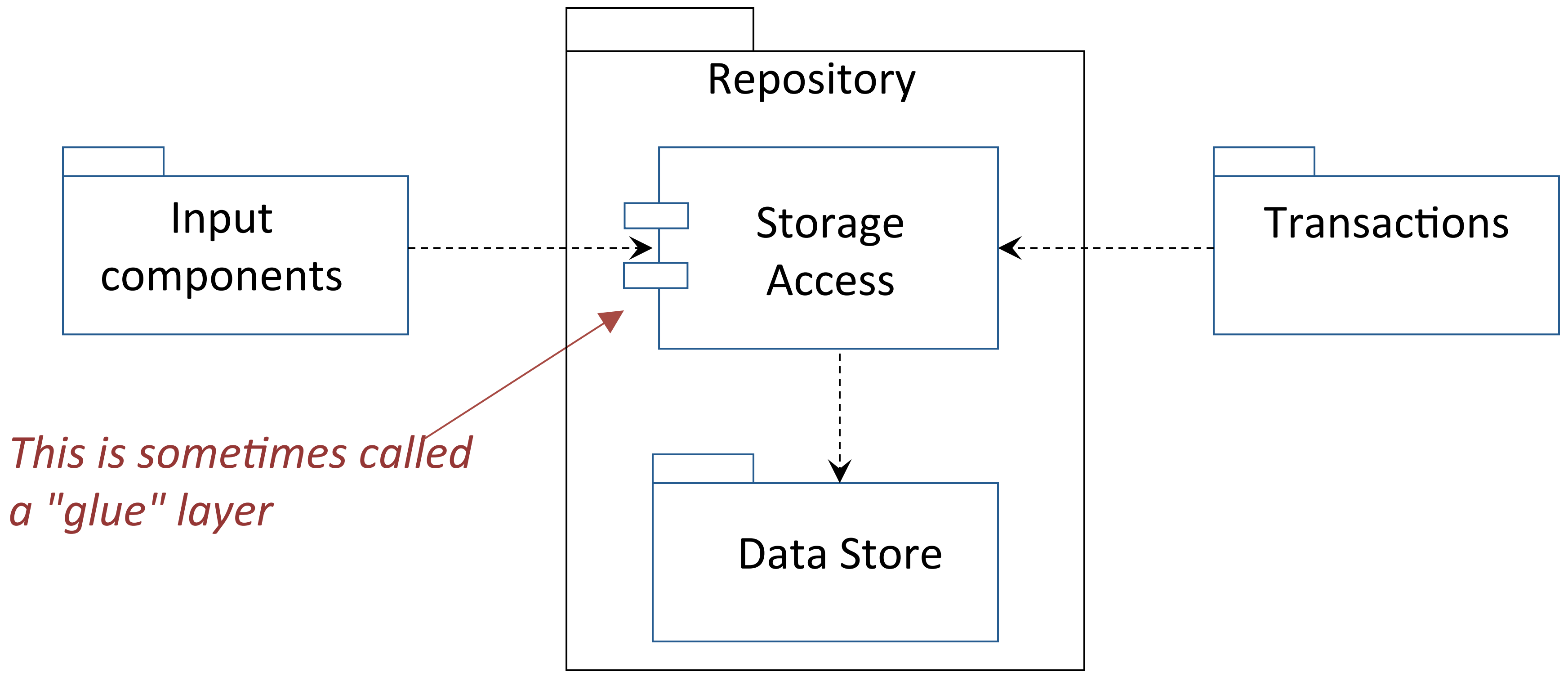
Architectural Style: Repository



Advantages: Flexible architecture for data-intensive systems.

Disadvantages: Difficult to modify repository since all other components are coupled to it.

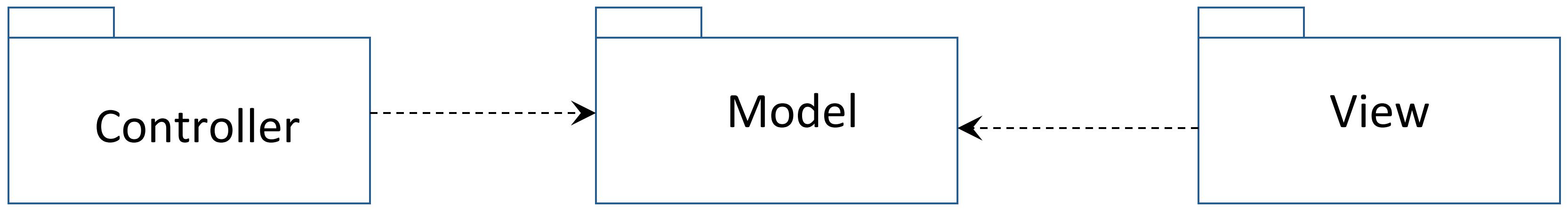
Architectural Style: Repository with Storage Access Layer



Advantages: Data Store subsystem can be changed without modifying any component except the Storage Access.

Architectural Style: Model/View/Controller

Example: Control of a unmanned model aircraft

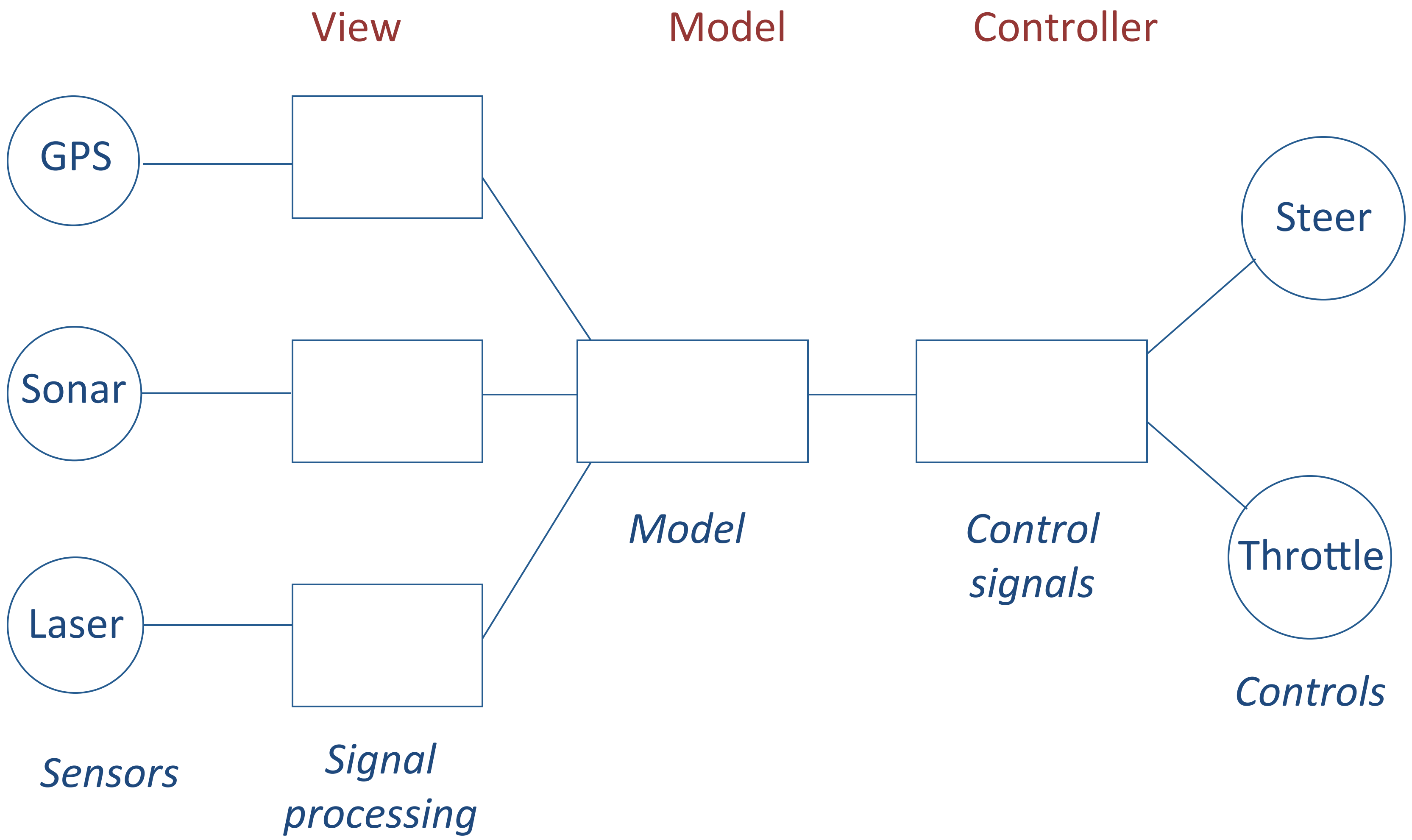


Controller: Receives instrument readings from the aircraft and sends controls signals to the aircraft.

Model: Translates data received from and sent to the aircraft, and instructions from the user into a model of flight performance. Uses domain knowledge about the aircraft and flight.

View: Displays information about the aircraft to the user on the ground and transmits instructions to the model.

Model/View/Controller: Autonomous Land Vehicle



Model/View/Controller for Web Applications

1 User interacts with the user interface (e.g., presses a mouse button).

2 Controller handles input event from the user interface, (e.g., via a registered handler or callback) and converts the event into appropriate user action.

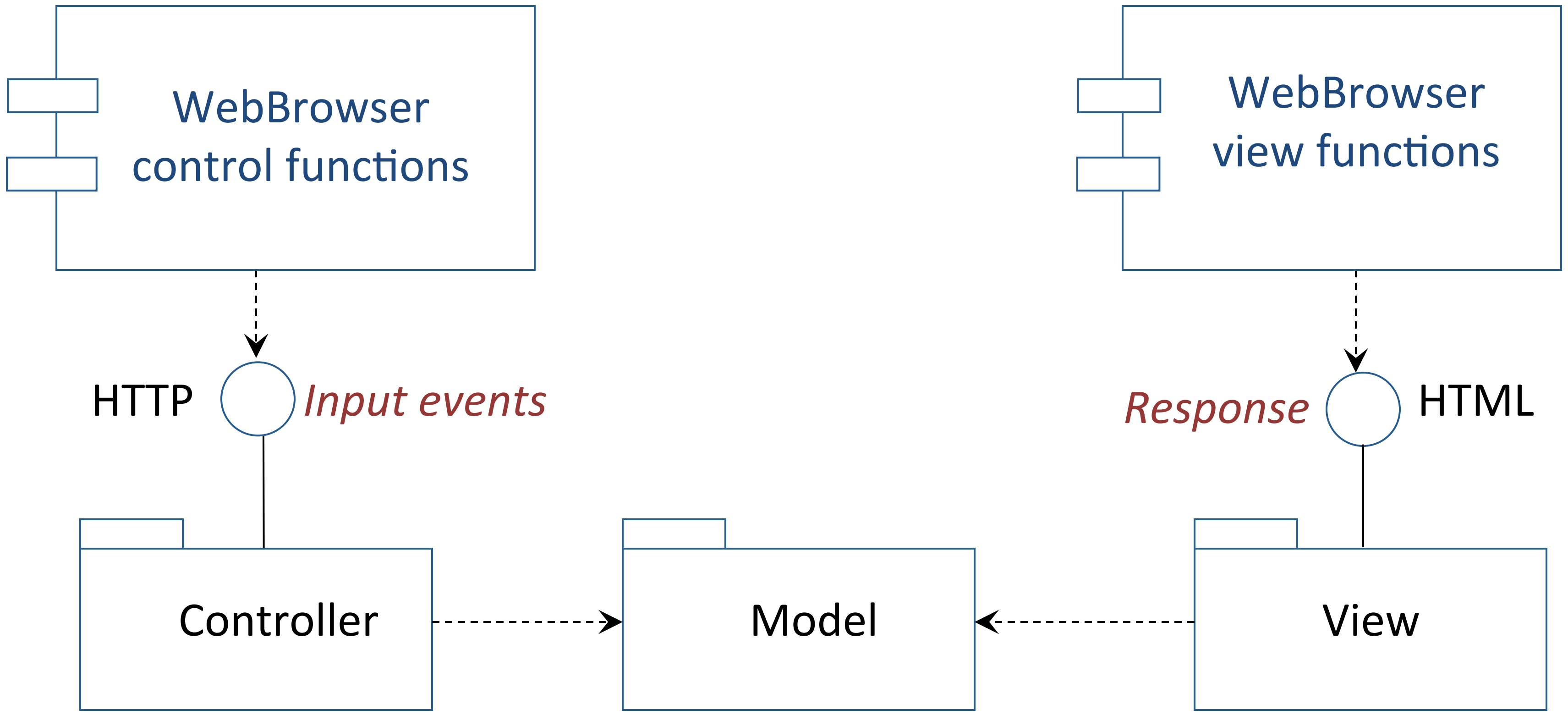
3 Controller notifies the model of user action, possibly resulting in a change in the model's state (e.g., update shopping cart).

4 View interacts with the model to generate an appropriate user interface response (e.g., list shopping cart's contents).

5 User interface waits for further user interactions.

from Wikipedia 10/18/2009

Model/View/Controller for Web Applications



Time-Critical Systems

A **time-critical** (real time) system is a software system whose correct functioning depends upon the results produced and the time at which they are produced.

- A hard real time system fails if the results are not produced within required time constraints

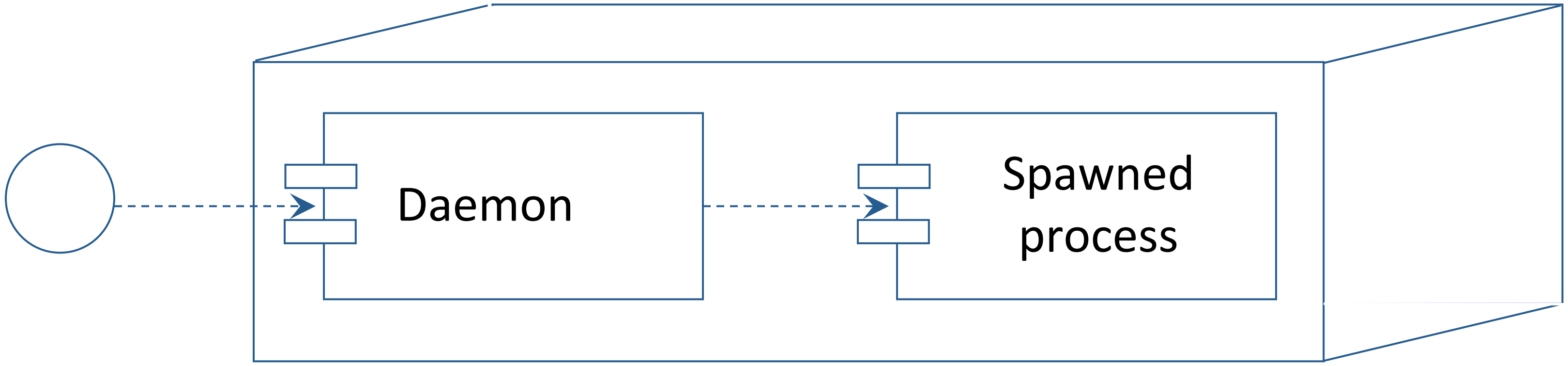
  e.g., a fly-by-wire control system for an airplane must respond within specified time limits

- A soft real time system is degraded if the results are not produced within required time constraints

  e.g., a network router is permitted to time out or lose a packet

Time Critical System: Architectural Style - Daemon

A **daemon** is used when messages might arrive at closer intervals than the the time to process them.



Example: Web server

The daemon listens at port 80

When a message arrives it:

spawns a processes to handle the message

returns to listening at port 80

Architectural Styles for Distributed Data

Replication:

Several copies of the data are held in different locations.

Mirror: Complete data set is replicated

Cache: Dynamic set of data is replicated (e.g., most recently used)

With replicated data, the biggest problems are concurrency and consistency.

Example: The Domain Name System

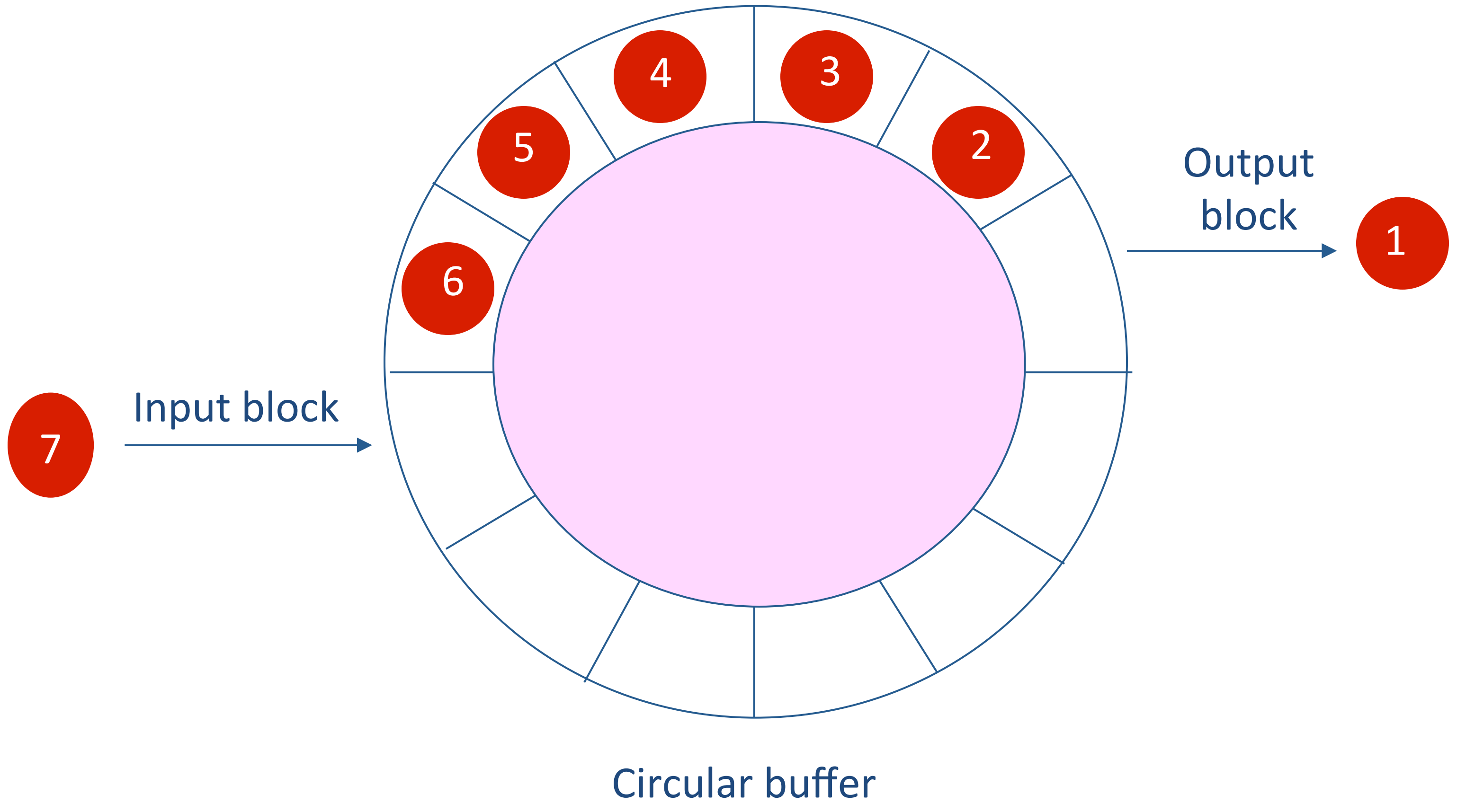
For details of the protocol read:

Paul Mockapetris, "Domain Names - Implementation and Specification". IETF Network Working Group, *Request for Comments*: 1035, November 1987.

http://www.ietf.org/rfc/rfc1035.txt?number=1035

Architectural Style: Buffering

When an application wants a continuous stream of data from a source that delivers data in bursts (e.g., over a network or from a disk), the software reads the bursts of data into a buffer and the application draws data from the buffer.



An Old Exam Question

*A company that makes sports equipment decides to create a system for selling sports equipment online. The company already has a **product database** with description, marketing information, and prices of the equipment that it manufactures.*

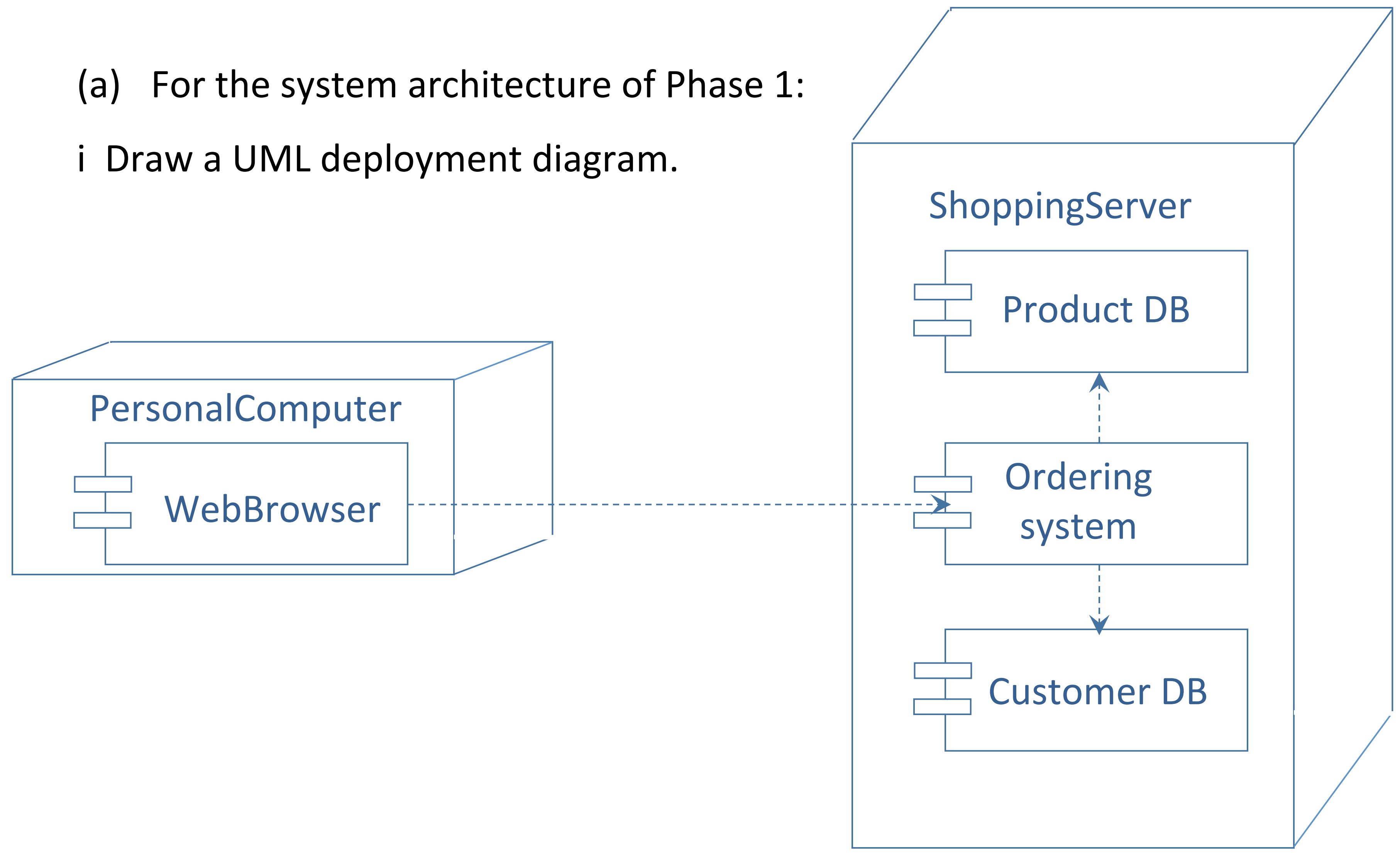
*To sell equipment online the company will need to create: a **customer database**, and an **ordering system** for online customers.*

The plan is to develop the system in two phases. During Phase 1, simple versions of the customer database and ordering system will be brought into production. In Phase 2, major enhancements will be made to these components.

An Old Exam Question

(a) For the system architecture of Phase 1:

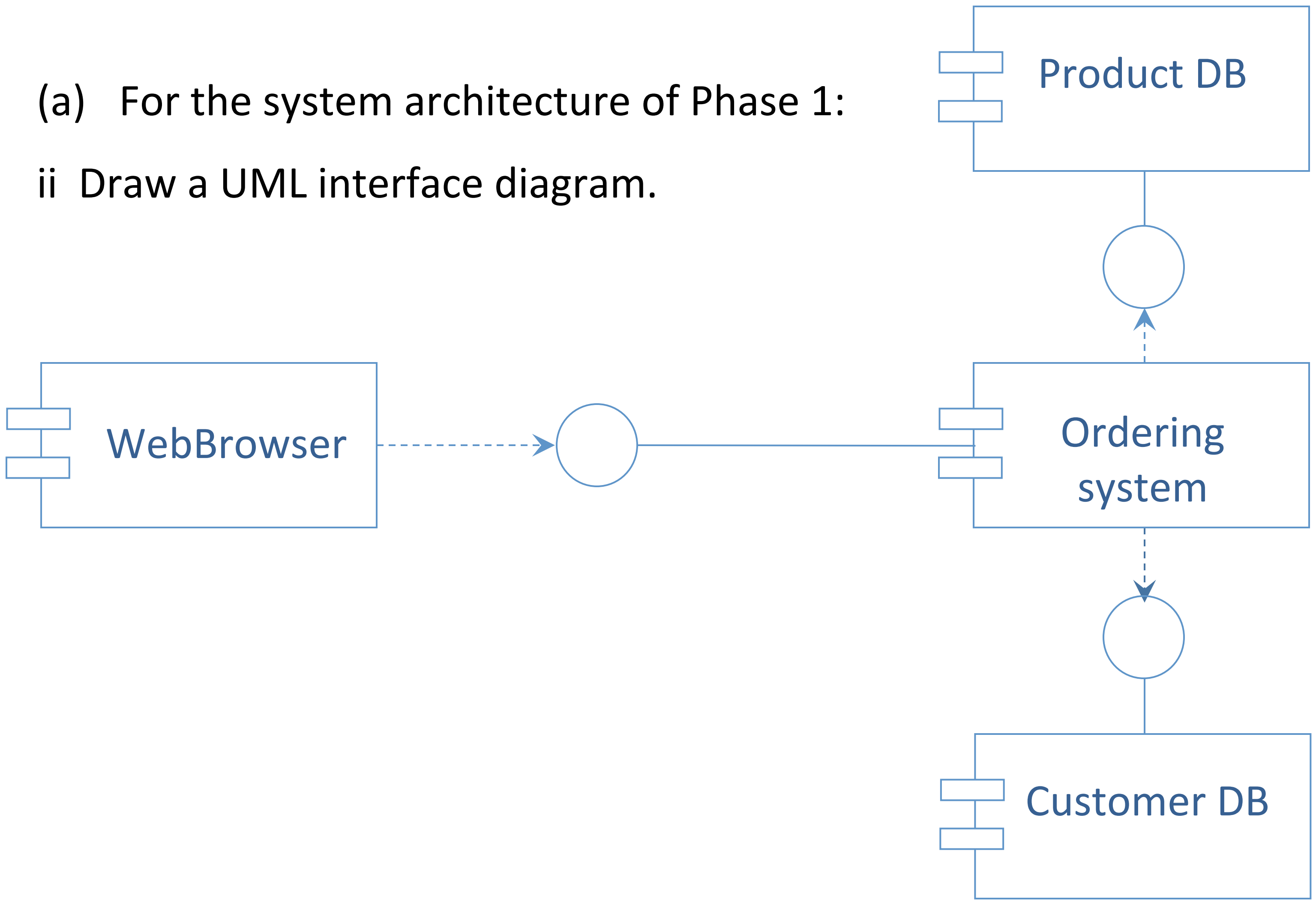
i Draw a UML deployment diagram.



An Old Exam Question

(a) For the system architecture of Phase 1:

ii Draw a UML interface diagram.



An Old Exam Question

(b) For Phase 1:

i What architectural style would you use for the customer database?

Repository with Storage Access Layer

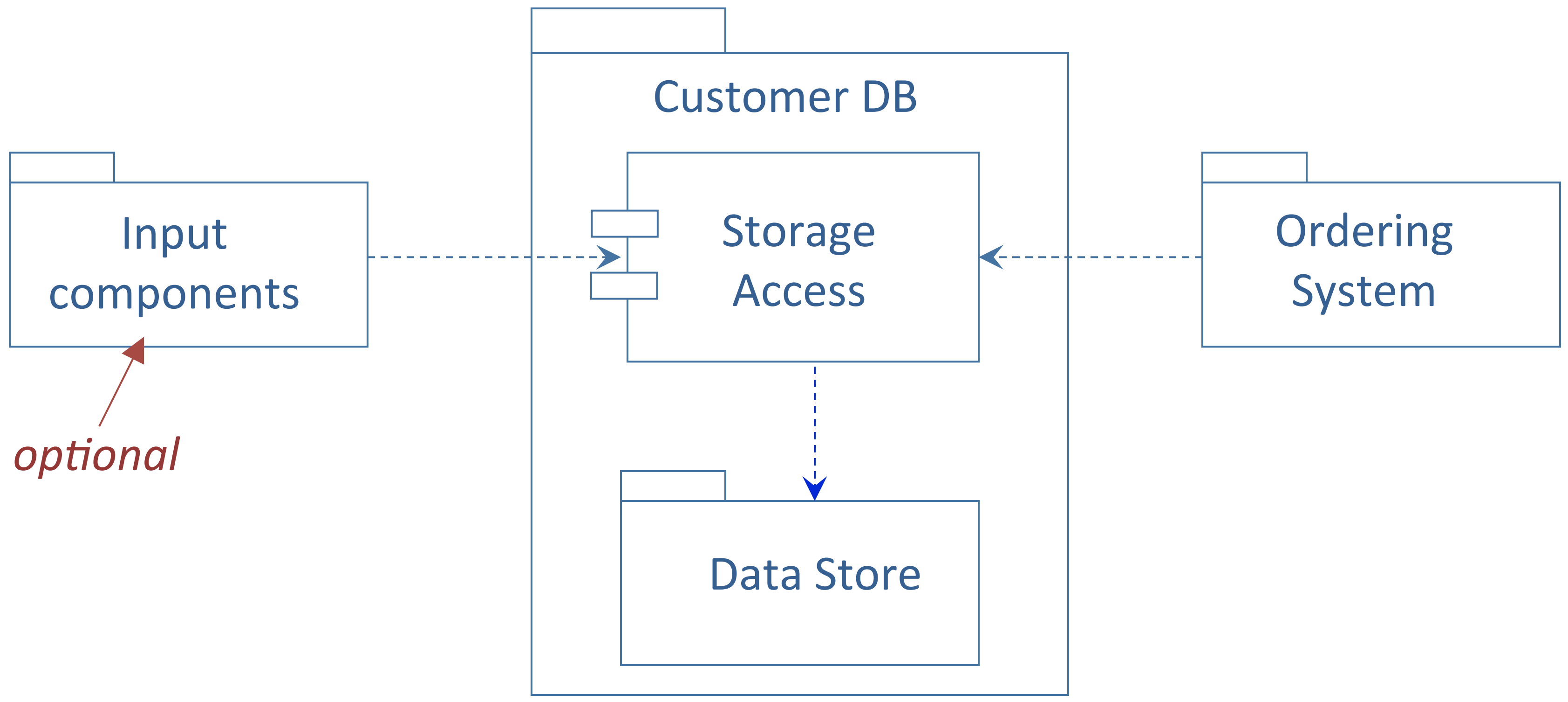
ii Why would you choose this style?

It allows the database to be replaced without changing the applications that use the database.

An Old Exam Question

(b) For Phase 1:

iii Draw an UML diagram for this architectural style showing its use in this application.



System Design Study 1
Extending the Architecture of the Web

The basic client/server architecture of the web has:

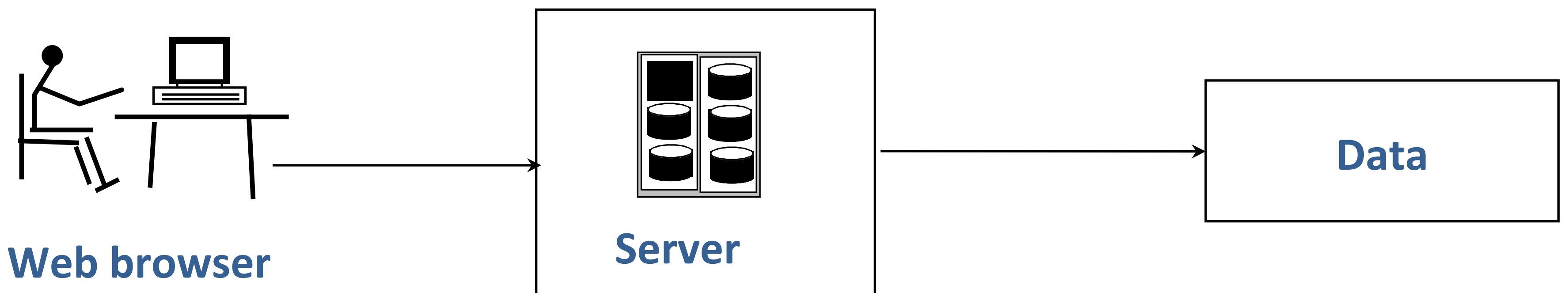
- a server that delivers static pages in HTML format
- a client (known as a browser) that renders HTML pages

Both server and client implement the HTTP interface.

Problem

Extend the architecture of the server so that it can configure HTML pages dynamically.

Web Server with Data Store



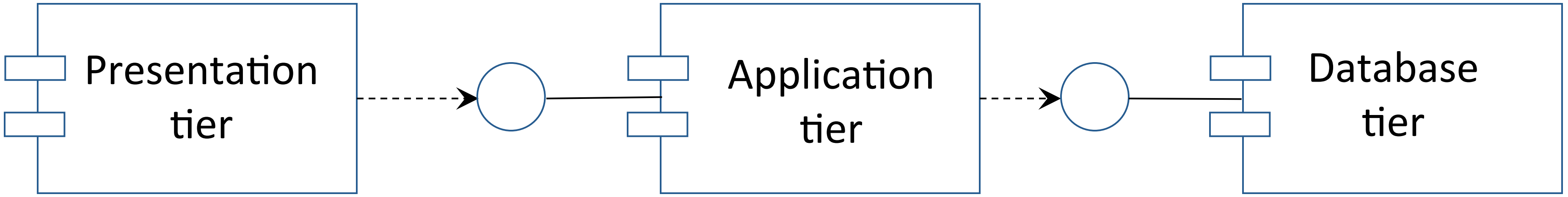
Advantage:

Server-side code can configure pages, access data, validate information, etc.

Disadvantage:

All interaction requires communication with server

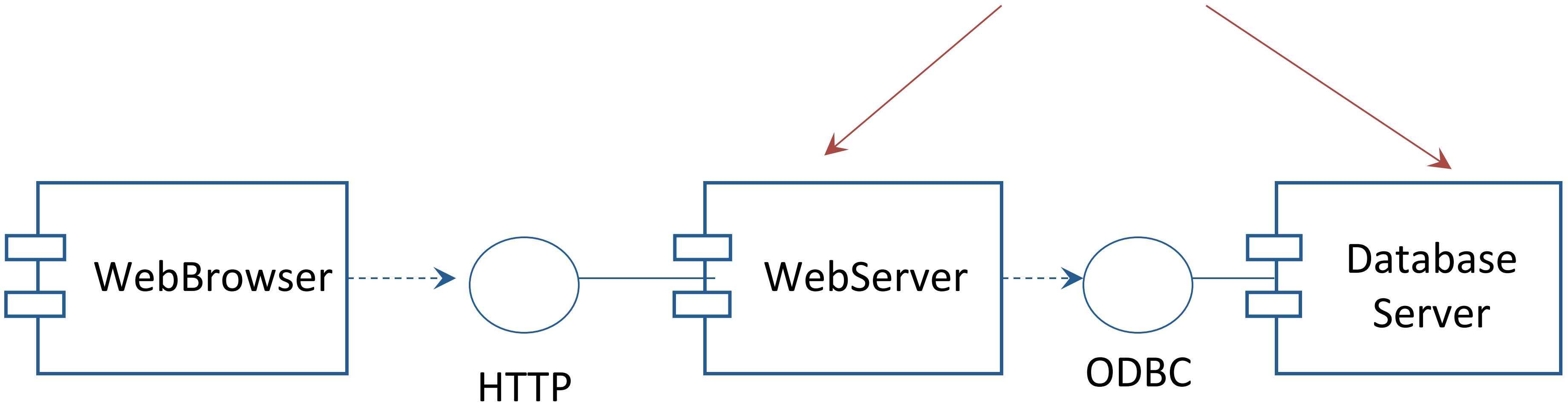
Architectural Style: Three Tier Architecture



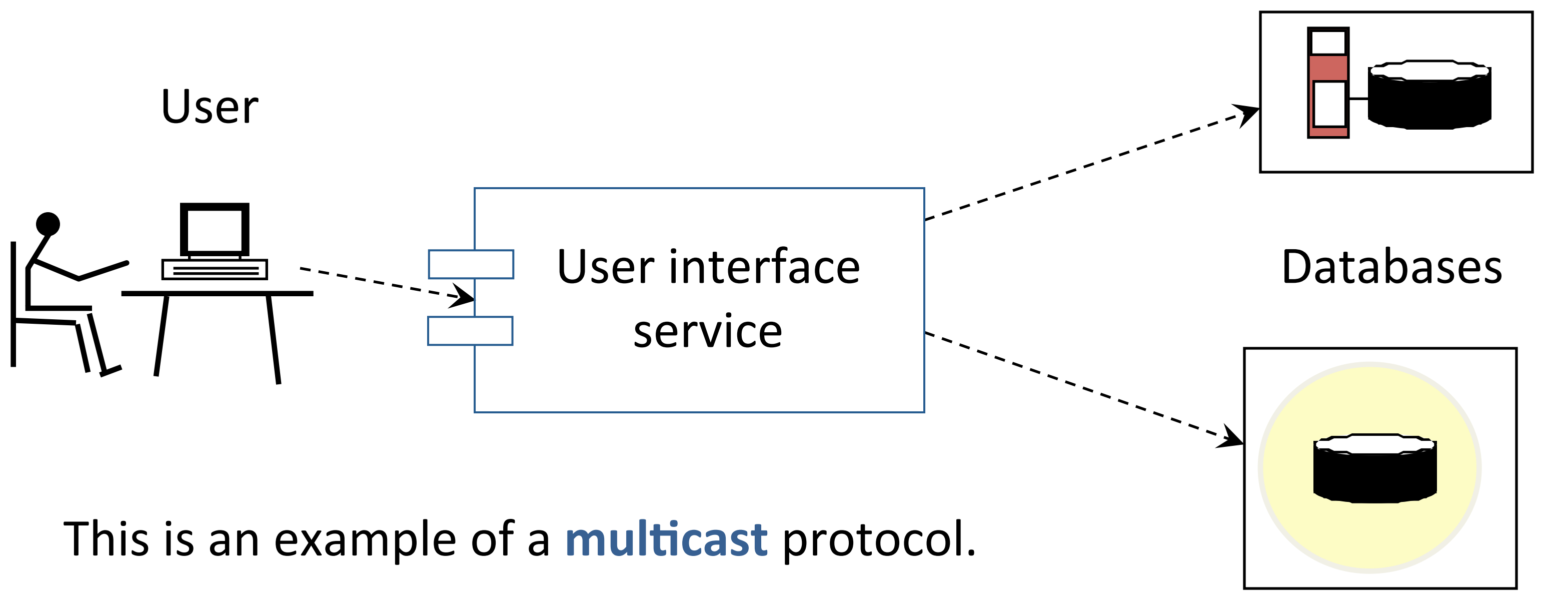
Each of the tiers can be replaced by other components that implement the same interfaces

Component Diagram

These components might be located on a single node



Three Tier Architecture: Broadcast Searching



This is an example of a **multicast** protocol.

The primary difficulty is to avoid troubles at one site degrading the entire system (e.g., every transaction cannot wait for a system to time out).

System Design Study 1 (continued)
Extending the Architecture of the Web

Using a three tier architecture, the web has:

- a server that delivers dynamic pages in HTML format
- a client (known as a browser) that renders HTML pages

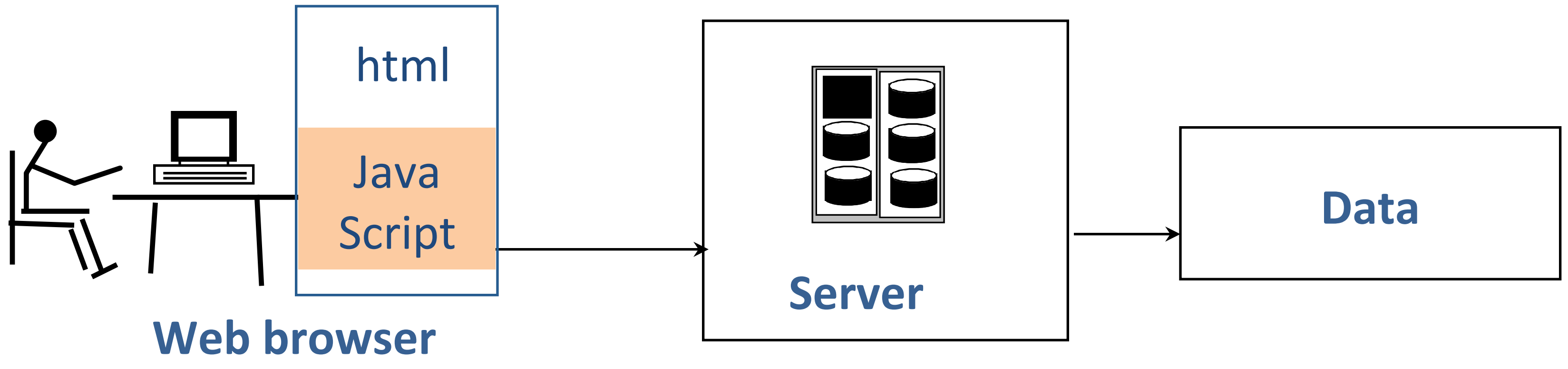
Both server and client implement the HTTP interface.

Problem 2

Every interaction with the user requires communication between the client and the server.

Extend the architecture so that simple user interactions do not need messages to be passed between the client and the server.

Extending the Web with Executable Code that can be Downloaded



Executable code in a scripting language such as JavaScript can be downloaded from the server

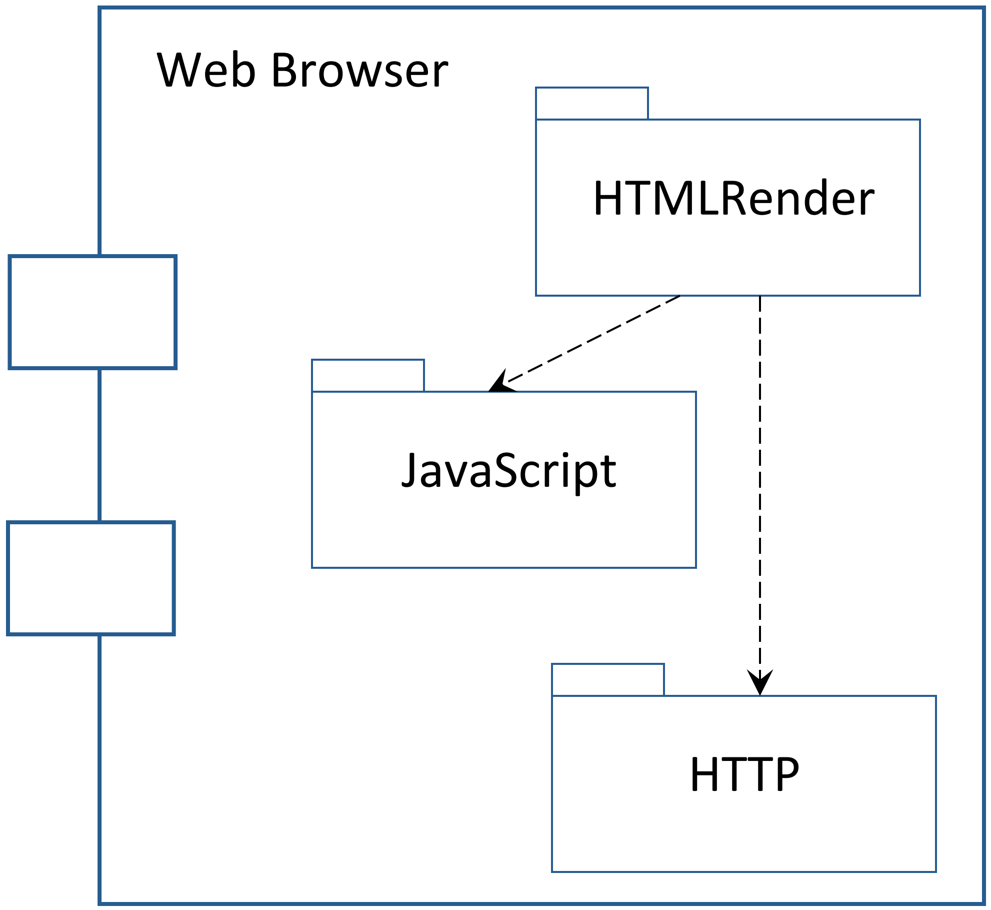
Advantage:

Scripts can interact with user and process information locally

Disadvantage:

All interactions are constrained by web protocols

Web Browser with JavaScript



In this example, each package represents a related set of classes.

System Design Study 1 (continued)
Extending the Architecture of the Web

Using a three tier architecture with downloadable scripts, the web has:

- a server that delivers dynamic pages in HTML format
- a client (known as a browser) that renders HTML pages and executes scripts

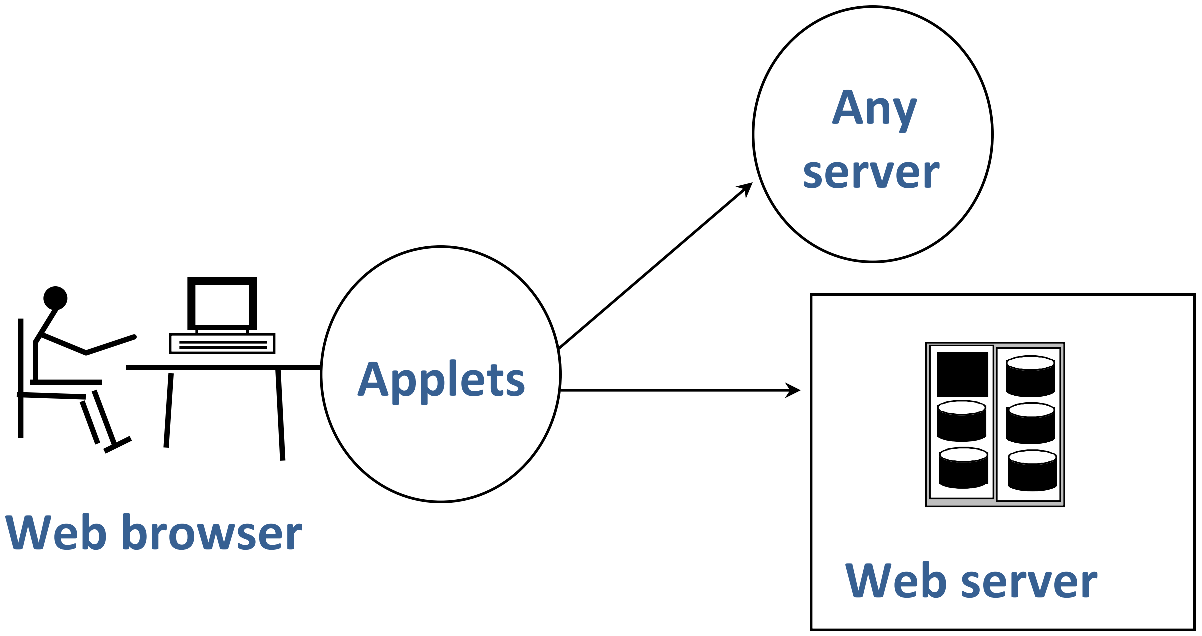
Both server and client implement the HTTP interface.

Problem 3

Every interaction between the client and a server uses the HTTP protocol.

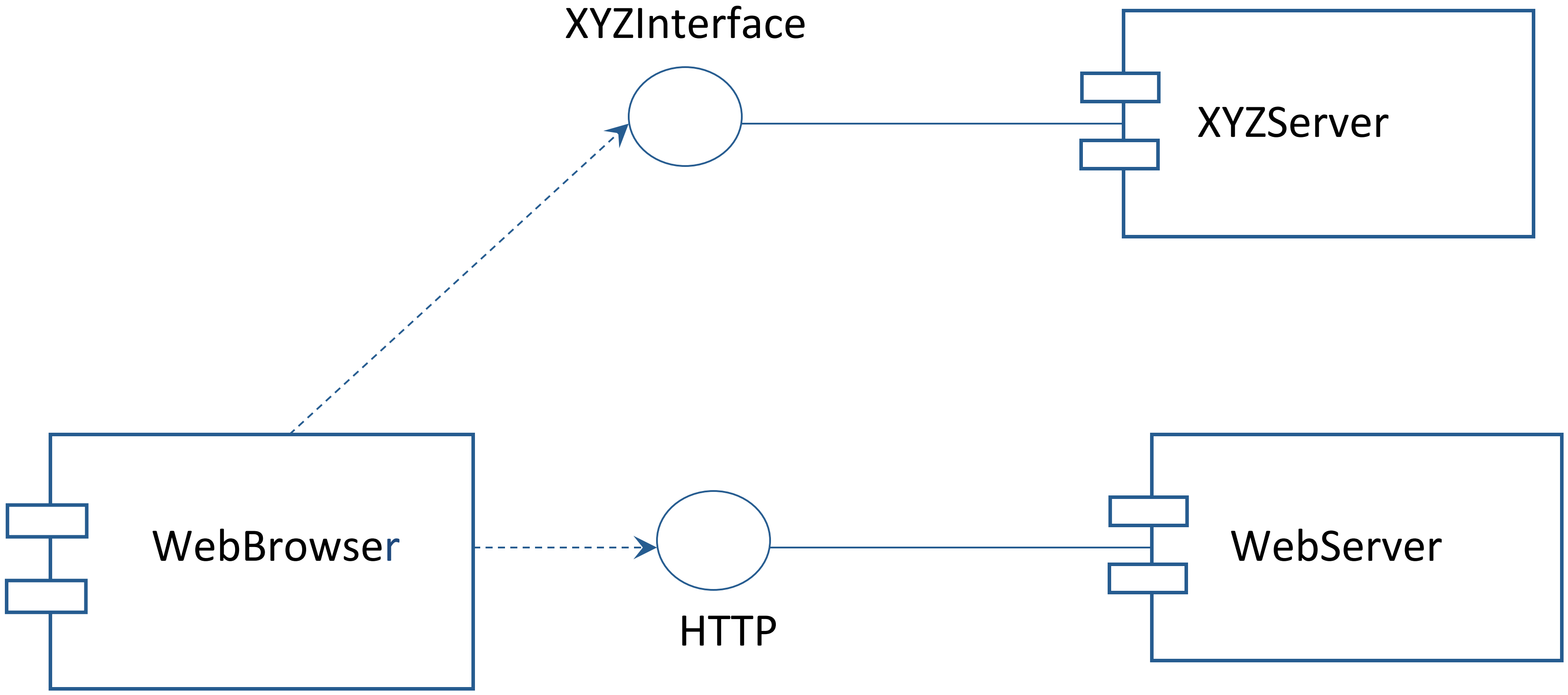
Extend the architecture so that other protocols can be used.

Web User Interface: Applet



- Any executable code can run on client
- Client can connect to any server
- Functions are constrained by capabilities of browser

Applet Interfaces



System Design Study 1 (continued) Extending the Architecture of the Web

These examples (three tier architecture, downloadable scripts, and applets) are just some of the ways in which the basic architecture has been extended. Here are some more:

Protocols:

HTTP, FTP, etc., proxies

Data types:

helper applications, plug-ins, etc.

Executable code:

Server-side code, e.g., servlets, CGI

Style sheets:

CSS, etc.

System Design Study 2
Data Intensive Systems

Examples

- Electricity utility customer billing (e.g., NYSEG)
- Telephone call recording and billing (e.g., Verizon)
- Car rental reservations (e.g., Hertz)
- Stock market brokerage (e.g., Charles Schwab)
- E-commerce (e.g., Amazon.com)
- University grade registration (e.g., Cornell)

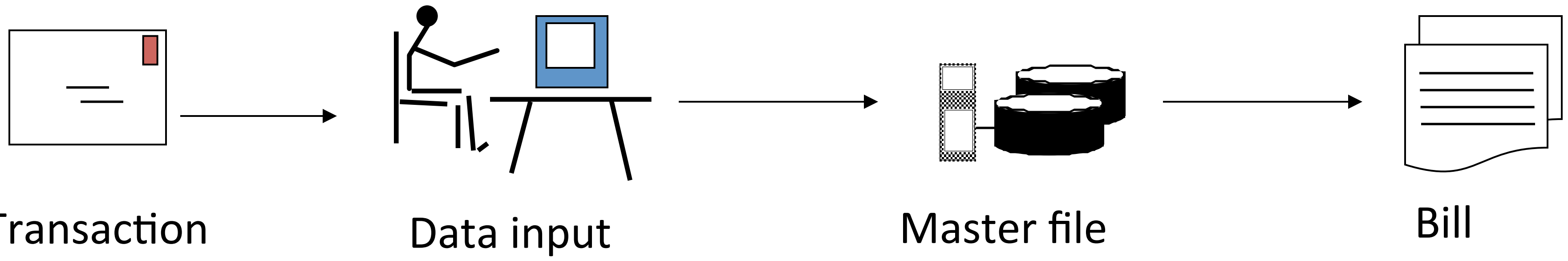
Data Intensive Systems

Example: Electricity Utility Billing

Requirements analysis identifies several transaction types:

- Create account / close account
- Meter reading
- Payment received
- Other credits / debits
- Check cleared / check bounced
- Account query
- Correction of error
- etc., etc., etc.,

System Design Study 2 (continued)
First Attempt



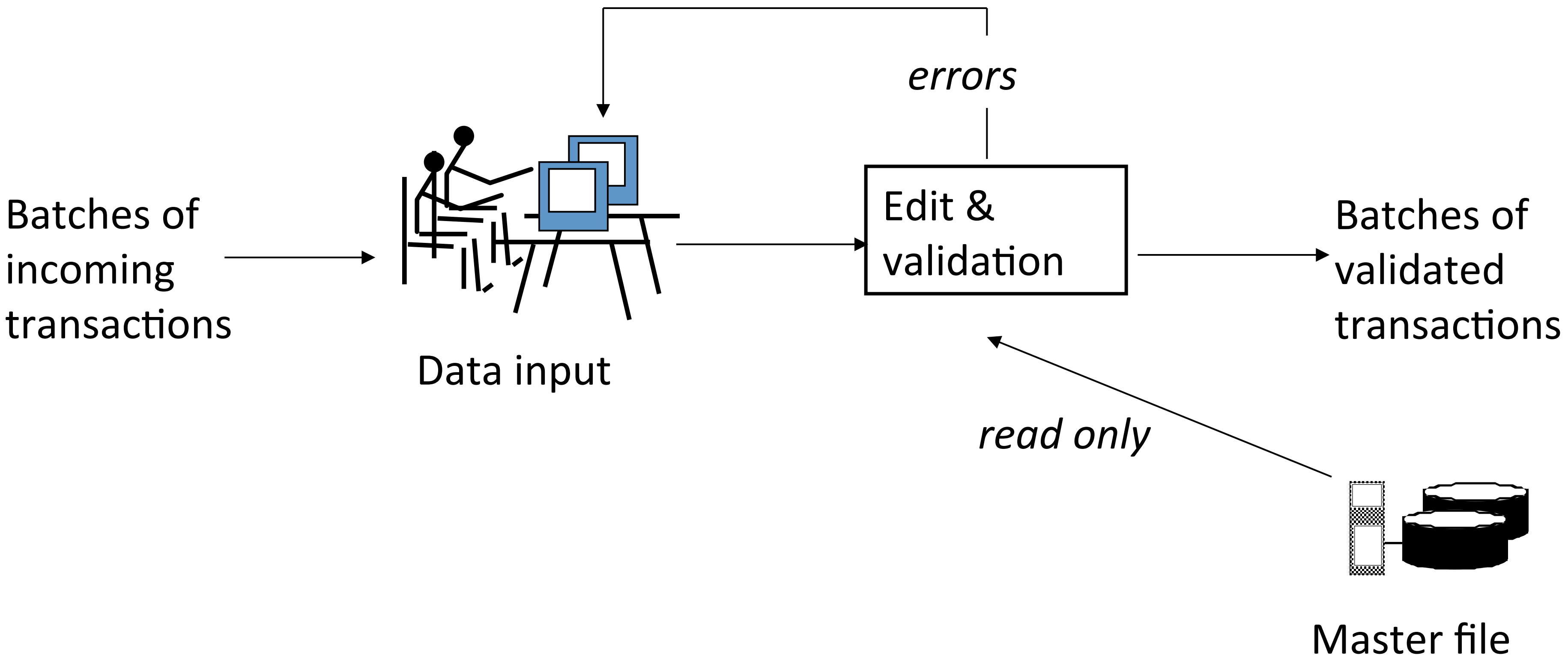
Each transaction is handled as it arrives.

Criticisms of First Attempt

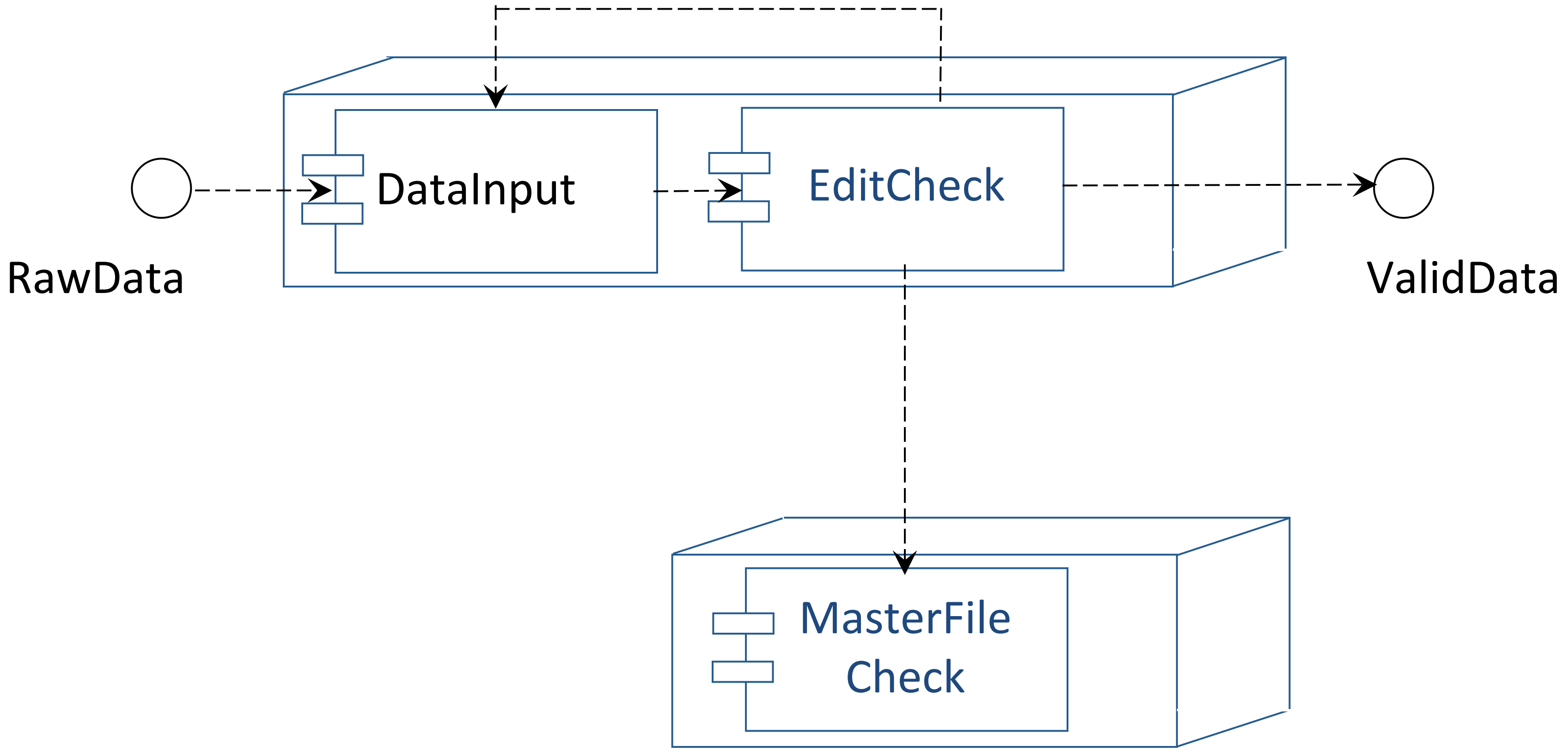
Where is this first attempt weak?

- All activities are triggered by a transaction
- A bill is sent out for each transaction, even if there are several per day
- Bills are not sent out on a monthly cycle
- Awkward to answer **customer queries**
- No process for **error checking** and **correction**
- Inefficient in staff time

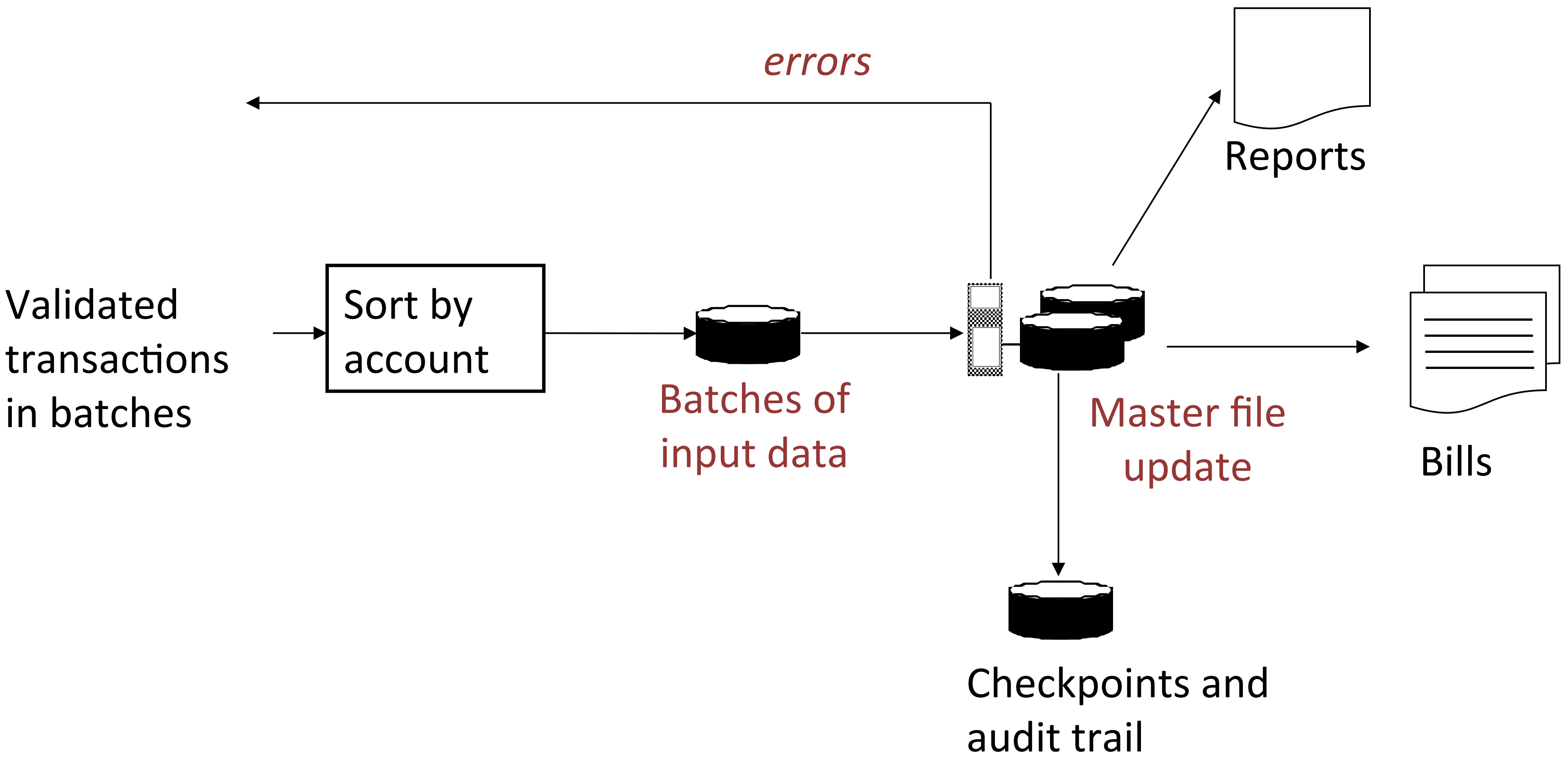
System Design Study 2 (continued)
Batch Processing: Edit and Validation


errors
Batches of incoming transactions
Data input
Edit & validation
Batches of validated transactions
read only
Master file

Deployment Diagram: Validation



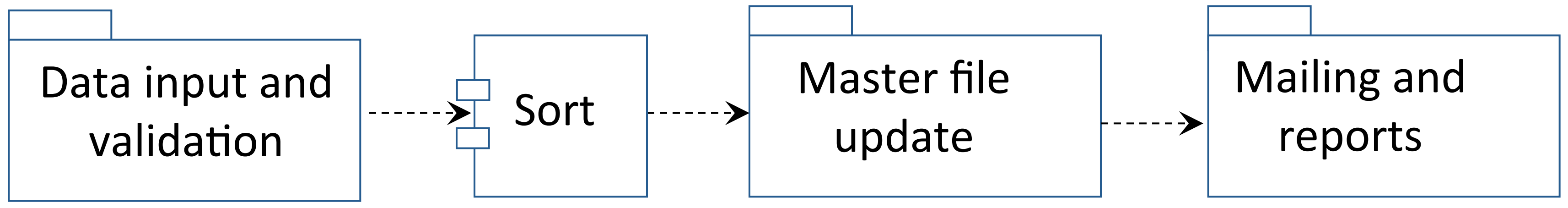
System Design Study 2 (continued)
Batch Processing: Master File Update



System Design Study 2 (continued)
Benefits of Batch Processing with Master File Update

- All transactions for an account are processed together at appropriate intervals, e.g., monthly
- Backup and recovery have fixed checkpoints
- Better management control of operations
- Efficient use of staff and hardware
- Error detection and correction is simplified

Architectural Style: Master File Update (basic)



Advantages:

Efficient way to process batches of transactions.

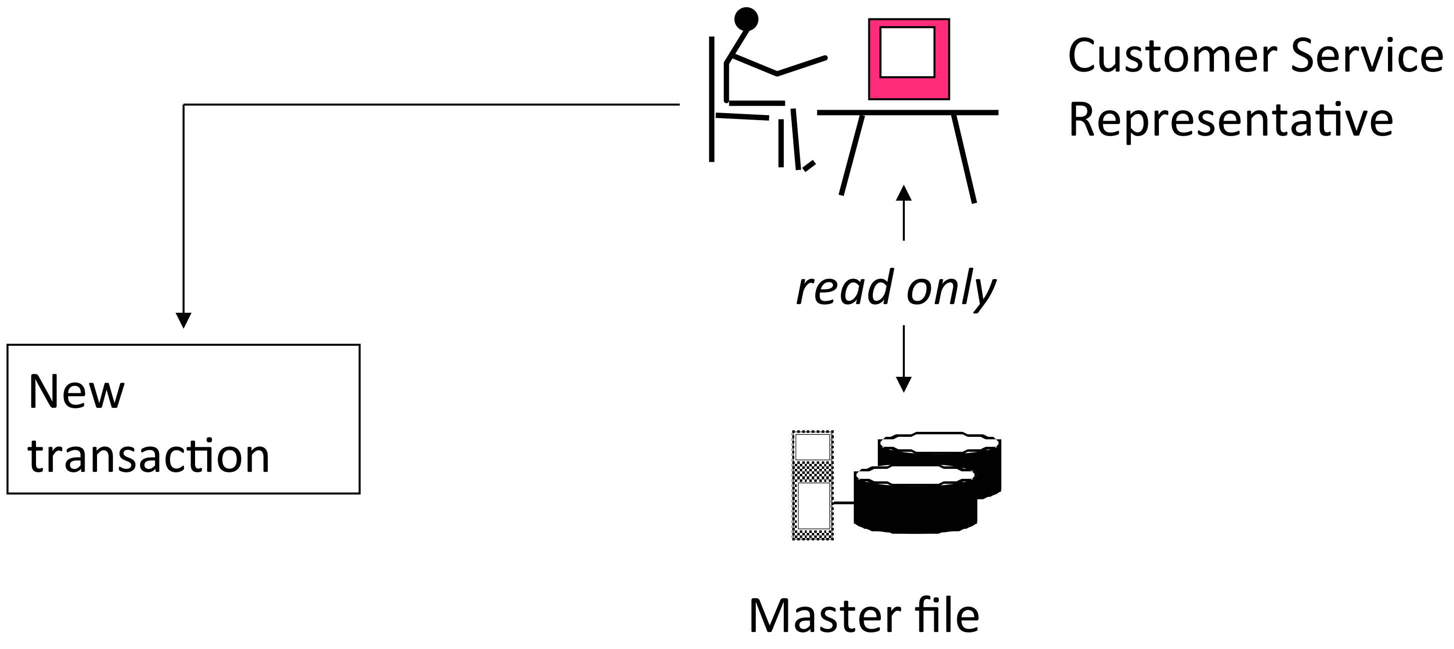
Disadvantages:

Information in master file is not updated immediately. No good way to answer customer inquiries.

Example: billing system for electric utility

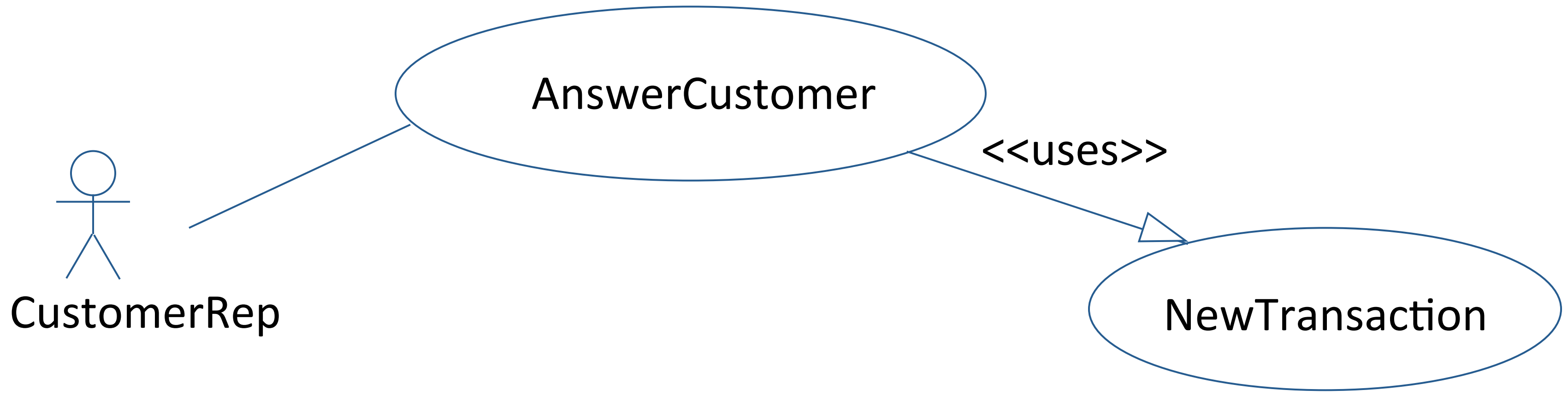
System Design Study 2 (continued) Online Inquiry

A customer calls the utility and speaks to a customer service representative.



Customer service department can read the master file, make annotations, and create transactions, but cannot change the master file.

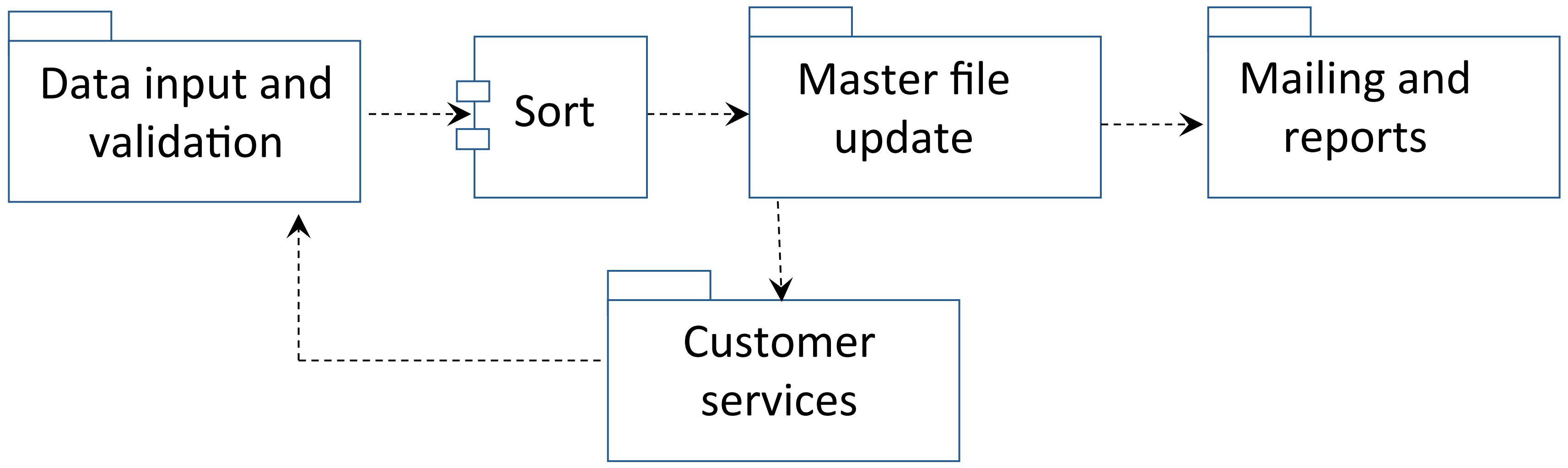
Online Inquiry: Use Case



The representative can read the master file, but not make changes to it.

If the representative wishes to change information in the master file, a new transaction is created as input to the master file update system.

Architectural Style: Master File Update (full)



Advantage:

Efficient way to answer customer inquiries.

Disadvantage:

Information in master file is not updated immediately.

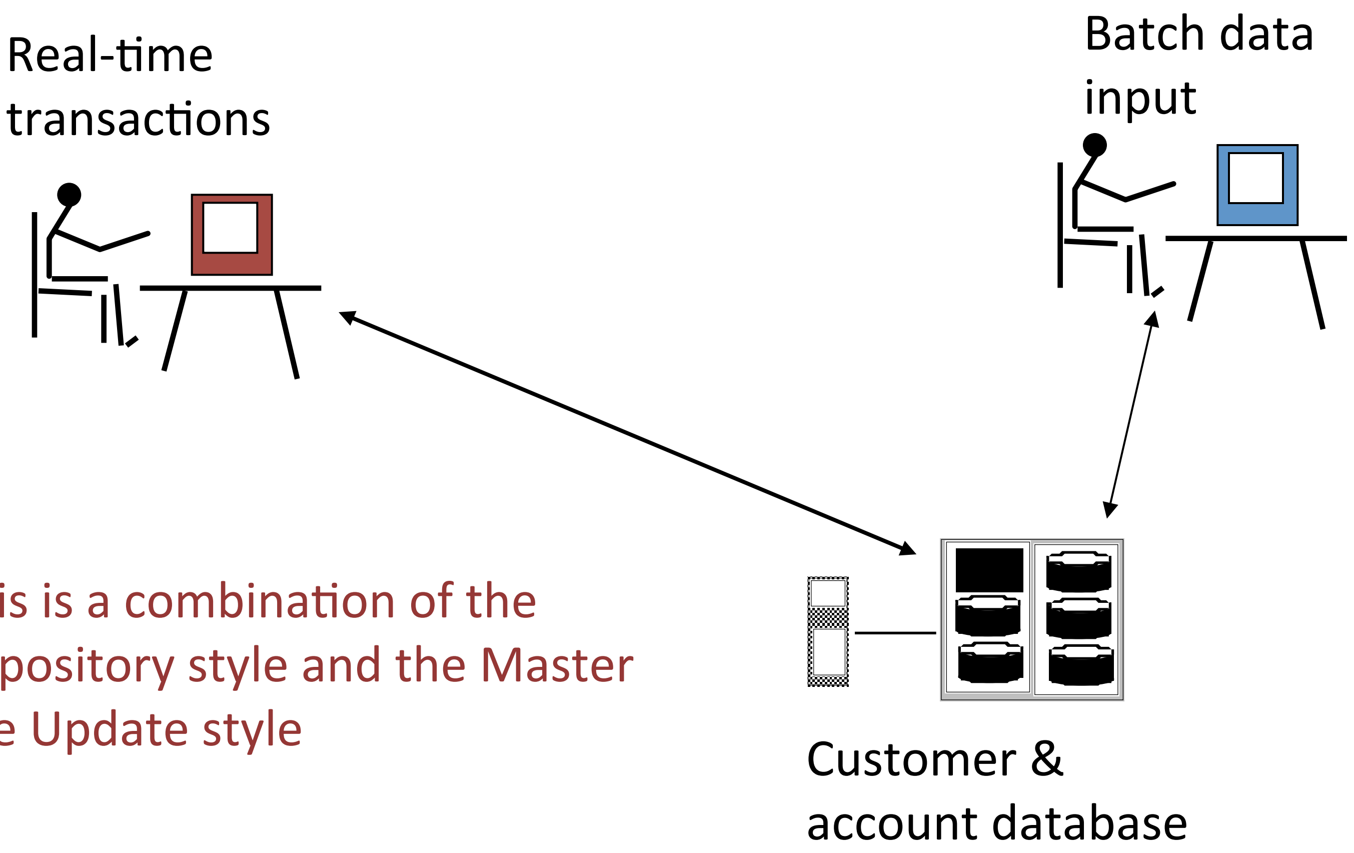
Example: billing system for electric utility

System Design Study 2 (continued)
Real Time Transactions

Example: A small bank

- Transactions are received by customer in person, over the Internet, by mail or by telephone.
- Some transactions must be processed immediately (e.g., cash withdrawal), others are suitable for overnight processing (e.g., check clearing).
- Complex customer inquiries.
- Highly competitive market.

Real-time Transactions & Batch Processing



This is a combination of the Repository style and the Master File Update style

System Design Study 2 (continued)
Practical Consideration

- Can real-time service during scheduled hours be combined with batch processing overnight?
- How will the system guarantee database consistency after any type of failure?

  reload from checkpoint + log

  detailed audit trail
- How will **transaction errors** be avoided and identified?
- How will **transaction errors** be **corrected**?
- How will **staff dishonesty** be controlled?

These practical considerations may be major factors in the choice of architecture.

System Design Study 2 (continued)
Data Intensive Systems

Many data intensive systems, e.g., those used by banks, universities, etc. are legacy systems. They may have been developed forty years ago as batch processing master file update systems and been continually modified.

- Recent modifications might include customer interfaces for the web, smartphones, etc.
- The systems will have migrated from computer to computer, across operating systems, to different database systems, etc.
- The organizations may have changed through mergers, etc.

Maintaining a coherent system architecture for such legacy systems is an enormous challenge, yet the complexity of building new systems is so great that it is rarely attempted.

System Design: Non-Functional Requirements

In some types of system architecture, non-functional requirements of the system may dictate the software design and development process.

Continuous Operation

Many systems must operate continuously

- Software update while operating
- Hardware monitoring and repair
- Alternative power supplies, networks, etc.
- Remote operation

These functions must be designed into the fundamental architecture.

Testing

Example: Testing multi-threaded and parallel systems

Several similar threads operating concurrently:

- Re-entrant code -- separation of pure code from data for each thread
- May be real-time (e.g., telephone switch) or non-time critical

The difficult of testing real-time, multi-threaded systems may determine the entire software architecture.

- Division into components, each with its own acceptance test.

Time-Critical Systems

Developers of advanced time-critical software spend much of their effort developing the software environment:

- Monitoring and testing -- debuggers
- Crash restart -- component and system-wide
- Downloading and updating
- Hardware troubleshooting and reconfiguration

etc., etc., etc.