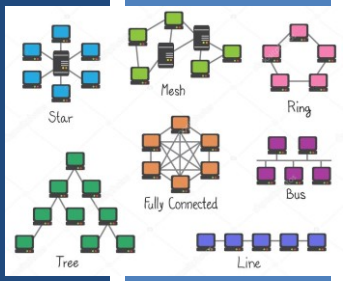
TCSS 558: APPLIED DISTRIBUTED COMPUTING

Middleware Organization and System Architectures



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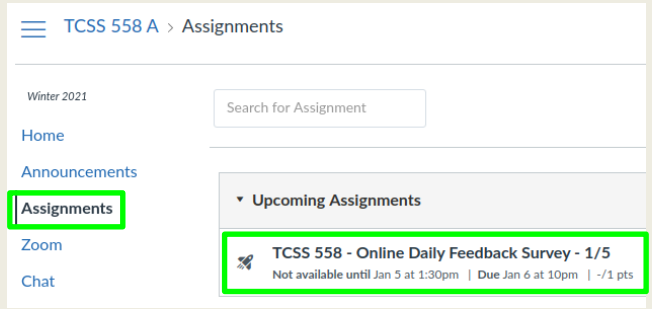
OBJECTIVES – 1/19

- **Questions from 1/17**
- Assignment 0: Cloud Computing Infrastructure Tutorial
- Class Activity: Architectural Styles
- Chapter 2.2: Middleware Organization
  - Wrappers
  - Interceptors
- Chapter 2.3: System Architectures
  - Centralized system architectures
  - Decentralized peer-to-peer architectures
  - Hybrid architectures

2

ONLINE DAILY FEEDBACK SURVEY

- Daily Feedback Quiz in Canvas – Available After Each Class
- Extra credit available for completing surveys ***ON TIME***
- Tuesday surveys: due by ~ Wed @ 10p
- Thursday surveys: due ~ Mon @ 10p



3

TCSS 558 - Online Daily Feedback Survey - 1/5

Due Jan 6 at 10pm **Points** 1 **Questions** 4
Available Jan 5 at 1:30pm - Jan 6 at 11:59pm 1 day **Time Limit** None

Question 1 0.5 pts

On a scale of 1 to 10, please classify your perspective on material covered in today's class:

1	2	3	4	5	6	7	8	9	10
Mostly Review To Me				Equal New and Review					Mostly New to Me

Question 2 0.5 pts

Please rate the pace of today's class:

1	2	3	4	5	6	7	8	9	10
Slow				Just Right					Fast

4

MATERIAL / PACE

- Please classify your perspective on material covered in today's class (29 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 6.16** (↑ - *previous 6.00*)

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.45** (↑ - *previous 5.15*)

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FEEDBACK FROM 1/17

- ***I'm vague about the concept of "stateless"***

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STATELESS VS STATEFUL

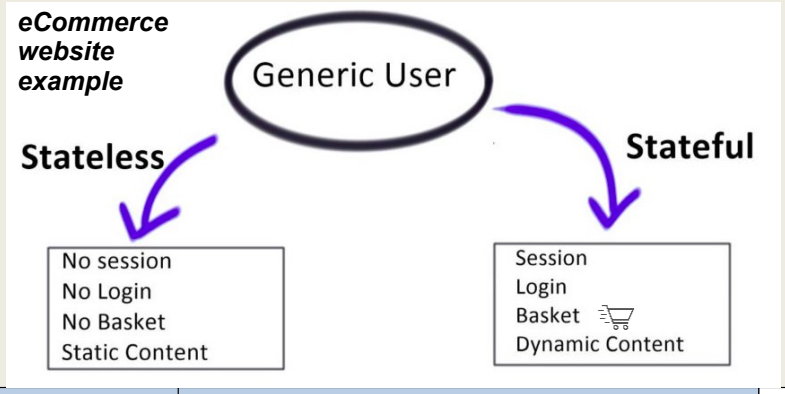
Stateless Server	Stateful Server
Save current state of process	State of process not saved
Anticipates future communication w/ client	Server only responds to client's immediate request
Design is more complex – data must be stored	Design is simplified – no data is stored
Server tracks user session data and information	Server does not track and store user session data
Server and client depend on each other	Server and client do not dependent on each other

STATELESS VS. STATEFUL - 2

Stateless Server	Stateful Server
Implementation of the server design is more difficult	Implementation of the server design is easier
Data can't be recovered when a crash occurs	If server crashes, there's no state data to recover
Requests depend on the server side	Requests are independent of the server side and self-contained
Scaling is more challenging and complex	Scaling is less difficult
Examples: Telnet and FTP (*both application*)	Examples: HTTP, DNS (application), UDP (transport)

STATELESS VS STATEFUL - 3

- ***Can you use diagrams to explain the difference between stateless and stateful?***



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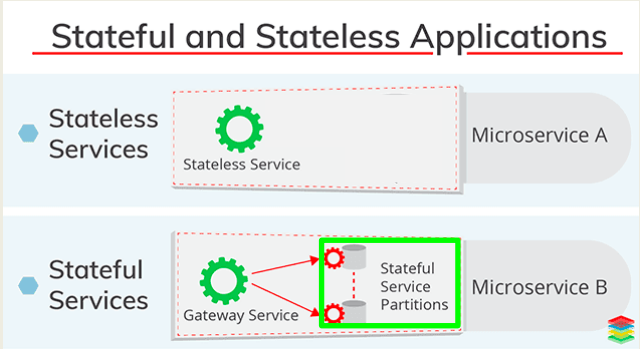
STATELESS VS STATEFUL - 4

- Stateful webservices often have requirement to store user session information local to the server processing the request
- Gateway/load balancer needs to be aware of this



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FEEDBACK - 2

- ***There is a sentence on page 65 of the book:***
  The simplicity of RESTful architectures can easily prohibit easy solutions to intricate communication schemes.
  What does it mean?
- An intricate communicate scheme is a more complex one
- RESTful architectures are restricted to the simple HTTP interface
- This prohibits design a more detailed interface that may better suit an intricate (more complex) communication scheme

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FEEDBACK - 3

- ***There is a sentence on page 65 of the book:***
  The simplicity of RESTful architectures can easily prohibit easy solutions to intricate communication schemes.
  What does it mean?
- Alternatively, SOAP allows a custom API to be defined
- Not sure GET, POST, PUT, DELETE
- With RESTful services we create more services with specific names and functions vs. define uniquely named actions within a service
- RESTful services therefore don't map directly to OO schemes

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FEEDBACK - 4

- ***How are service-oriented systems different from REST?***
- Service oriented applications do not mandate RESTful services
- Services could be SOAP-based or other protocols
- GraphQL – is a data query and manipulation service protocol alternative to REST developed by Facebook
- GraphQL is specifically for querying specific fields of objects

```
{
  hero {
    name
  }
}
```

query

```
{
  "data": {
    "hero": {
      "name": "R2-D2"
    }
  }
}
```

result

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GRAPH QL

```
query HeroNameAndFriends {
  hero {
    name
    friends {
      name
    }
  }
}
```

query

```
{
  "data": {
    "hero": {
      "name": "R2-D2",
      "friends": [
        {
          "name": "Luke Skywalker"
        },
        {
          "name": "Han Solo"
```

result

```
query HeroNameAndFriends($episode: Episode) {
  hero(episode: $episode) {
    name
    friends {
      name
    }
  }
}
```

query

Variable in query

```
{
  "episode": "JEDI"
}
```

client passes a variable

```
{
  "data": {
    "hero": {
      "name": "R2-D2",
      "friends": [
        {
          "name": "Luke Skywalker"
        },
        {
          "name": "Han Solo"
        },
        {
          "name": "Leia Organa"
        }
```

result

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FEEDBACK - 5

- ***What is meant by "Messages to/from a service are fully described" (slide L5.23 about REST services)? How are they described?***
- ***"Fully described" implies that REST supports Self-Describing Messages***
  Services interact by exchanging request and response messages, which contain both the data (or the representations of resources) and the corresponding meta-data. Representations can vary according to the client context, interests, and abilities.
- **Self-describing** means there is no need for a definition file (WSDL) or any other messages to support the web service transaction
- Everything is complete and contained in the single client-to-server request (everything is self contained)
- Nothing else is required
- The structureless next of JSON objects help enable this

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EXAMPLE: SELF DESCRIBING REST ARCHITECTURE

- Mobile client can retrieve a low-bandwidth representation of a resource (ASCII text)
- Web browser can request a representation of a Web page in a particular language based on user preferences (HTML5)
- Flexibility of the response output format (text vs html) greatly enhances interoperability of REST architectures
- Client can dynamically negotiate the most appropriate data response format (also called media type) with the service
- All clients are not forced to use the same format
- Request and response messages contain explicit meta-data describing the data representation so services do not need to assume or try to interpret the data format

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SOAP & FIREWALLS

- ***What is it about other protocols, like SOAP, that are unsafe, such that they may be blocked by firewalls, whereas REST often is not?***
- Because many organizations host webservers which communicate using TCP port 80, port 80 is open allowing traffic to flow
  - Common practice then is to map your protocol over port 80
- Connection-oriented (TCP) application protocols often communicate on distinct ports, for example:
  SSH 22, SMTP 25, TCP 25, VNC 5900, TELNET 23
  - SOAP in fact is most often implemented on top of HTTP
  - I had wrongly assumed SOAP defined its own communication protocol
  - SOAP just defines a messaging scheme (i.e. with XML, WSDL, etc.) that is carried over HTTP

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BONUS

- ***What is the TCP port for HTTPS ?***
- A TCP port number is specified in a URI/URL by using a colon and a number after the resource name
- Example:
- Server hosting climate API exposes service on port 8083:
- http://csip.engr.colostate.edu:8083/csip-erosion/d/rusle2/climate/
- (Assignment 0)
  Default web service port in Apache Tomcat is 8080

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ASSIGNMENT 0

- ***Preparing for Assignment 0:***
  - Establish AWS Account
    - Standard account
      - Complete AWS Cloud Credits Survey and provide AWS account ID
      - Credits will be automatically loaded by Amazon into accounts
- Tasks:
  - Task 1 - Establish local Linux/Ubuntu environment
  - Task 2 –AWS account setup, obtain user credentials
  - Task 3 – Intro to: Amazon EC2 & Docker: create Dockerfile for Apache Tomcat
  - Task 4 – Create Dockerfile for haproxy
  - Task 5 – Working with Docker-Machine
  - Task 6 - Config 3 multiple server configs to load balance requests for RESTful Fibonacci web service
  - Task 7 – Test configs and submit results

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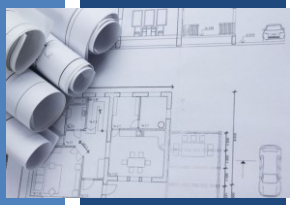

IN-CLASS ACTIVITY: ARCHITECTURAL STYLES

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CLASS ACTIVITY 2

- We will form groups of ~2-3
  - On Zoom breakout rooms will be created
- Each group will complete a MS Doc worksheet
- Add names to MS Doc as they appear in Canvas
- Once completed, **one person** submits a PDF of the MS Doc to Canvas
- Instructor will score all group members based on the uploaded PDF file
- To get started:
  - Log into your *** **UW Google Account** ***
  - Link to shared Google Drive
  - Follow link:

    https://canvas.uw.edu/courses/1621385/files/100858747

DISTRIBUTED SYSTEM GOALS TO CONSIDER

- **Consider how the architectural change may impact:**
- Availability
- Accessibility
- Responsiveness
- Scalability
- Openness
- Distribution transparency
- Supporting resource sharing
- Other factors…

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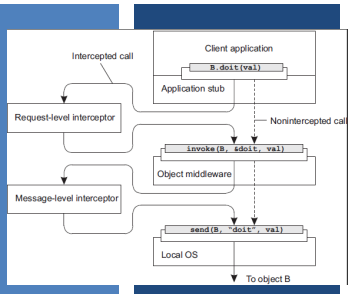

CH 2.2: MIDDLEWARE ORGANIZATION

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MIDDLEWARE ORGANIZATION

- Relies on two important design patterns:
  - Wrappers
  - Interceptors
- Both help achieve the goal of openness

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MIDDLEWARE: WRAPPERS

- **Wrappers (also called adapters)**
  - **WHY?:** Interfaces available from legacy software may not be sufficient for all new applications to use
  - **WHAT:** Special "frontend" components that provide interfaces for clients
  - Interface wrappers transform client requests to "implementation" (i.e. legacy software) at the component-level
  - Can then provide modern service interfaces for legacy code/systems
  - Components encapsulate (i.e. abstract) dependencies to meet all preconditions to operate and host legacy code
  - Interfaces parameterize legacy functions, abstract environment configuration (i.e. make into black box)
- Contributes towards system **OPENNESS**
- **Example: Amazon S3:** S3 HTTP REST interface
- GET/PUT/DELETE/POST: requests handed off for fulfillment

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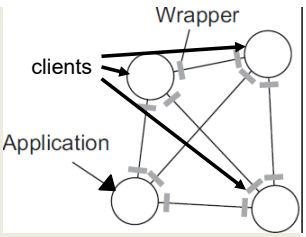
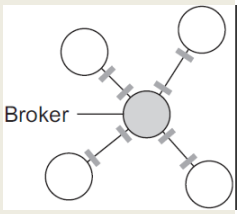
MIDDLEWARE: WRAPPERS - 2

- Inter-application communication
  - Applications may provide unique interface for every client application
- Scalability suffers
  - N applications → $O(N^2)$ wrappers
- **ALTERNATE: Use a Broker**
  - Provide a common intermediary
  - Broker knows how to communicate with every application
  - Applications only know how to communicate with the broker





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MIDDLEWARE: INTERCEPTORS

- ***Interceptor***
- Software construct, breaks flow of control, allows other application code to be executed
- Interceptors send calls to other servers, or to ALL servers that replicate an object while abstracting the ***distribution*** and/or ***replication***
  - Used to enable remote procedure calls (RPC), remote method invocation (RMI)
- Object A calls method belonging to object B
  - Interceptors route calls to object B regardless of location

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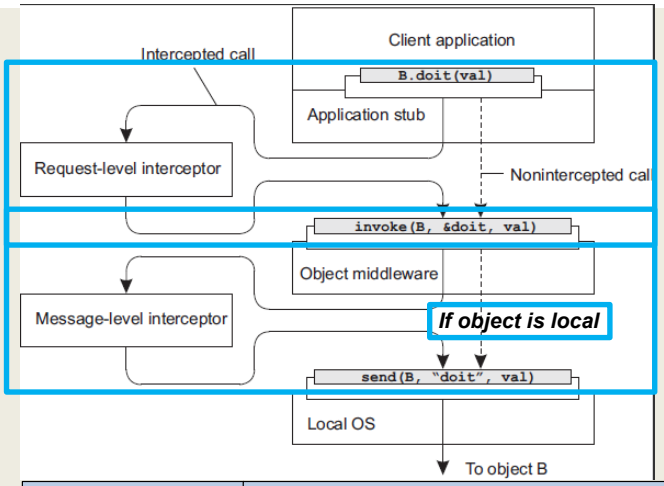
MIDDLEWARE: INTERCEPTORS - 2



Request-level interceptor transforms:
`B.doit(val)`
into generic call:
`invoke(B,&doit,val)`

Message-level interceptor in middleware sends message through OS (TCP/IP socket) to transfer data:
`send(B,"doit",val)`

Non-intercepted:

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MIDDLEWARE INTERCEPTION - METHOD

- **MIDDLEWARE**: Provides local interface matching Object B to Object A
- Object A calls Object B's method provided by local interface
- A's call is transformed into a "*generic object invocation*" by **request-level interceptor**
- "*Generic object invocation*" is transformed into a **message** by **message-level interceptor** and sent over Object A's network to Object B
- Interception automatically routes calls to all object replicas

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MODIFIABLE MIDDLEWARE

- **GOAL:** It should be possible to modify middleware without loss of availability
  - *Software components can be replaced at runtime*
- Component-based design
  - Modifiability through composition
  - Systems may have static or dynamic configuration of components
  - Dynamic configuration requires ***late binding***
  - Components can be changed at runtime
- Component based software supports modifiability at runtime by enabling components to be swapped out.
- **Does a microservices architecture (e.g. AWS Lambda) support modifiability at runtime ?**

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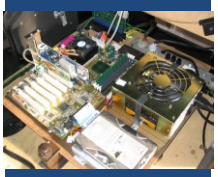
WE WILL RETURN AT 2:36PM



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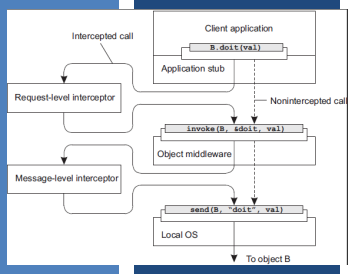

CH 2.3: SYSTEM ARCHITECTURES

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SYSTEM ARCHITECTURES

- Architectural styles (or patterns)
- General, reusable solutions to commonly occurring system design problems
- Expressed as a logical organization of ***components*** and ***connectors***
- Deciding on the system components, their interactions, and placement is a "realization" of an **architectural style**
- System architectures represent designs used in practice

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TYPES OF SYSTEM ARCHITECTURES

- Centralized system architectures
  - Client-server
  - Multitiered
- Decentralized peer-to-peer architectures
  - Structured
  - Unstructured
  - Hierarchically organized
- Hybrid architectures

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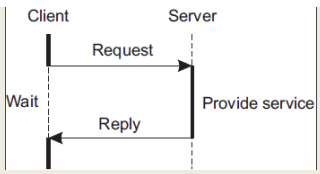
CENTRALIZED: SIMPLE CLIENT-SERVER ARCHITECTURE

- **Clients** request services
- **Servers** provide services
- Request-reply behavior



- **Connectionless protocols (UDP)**
- Assume stable network communication with no failures
- Best effort communication: No guarantee of message arrival without errors, duplication, delays, or in sequence. No acknowledgment of arrival or retransmission
- Problem: How to detect whether the client request message is lost, or the server reply transmission has failed
- Clients can resend the request when no reply is received
- ***But what is the server doing?***

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CLIENT-SERVER PROTOCOLS

- **Connectionless cont'd**
- Is resending the client request a good idea?
- Examples:
  Client message: "transfer $10,000 from my bank account"
  Client message: "tell me how much money I have left"
- **Idempotent** – repeating requests is safe

- **Connection-oriented (TCP)**
- Client/server communication over wide-area networks (WANs)
- When communication is inherently reliable
- Leverage "reliable" TCP/IP connections

CLIENT-SERVER PROTOCOLS - 2

- **Connection-oriented cont'd**
- Set up and tear down of connections is relatively expensive
- Overhead can be amortized with longer lived connections
  - Example: database connections often retained

- Ongoing debate:
- How do you differentiate between a client and server?
- Roles are ***blurred***

- **Blurred Roles Example:** Distributed databases
- DB nodes both **service** client requests, *and* ***submit*** new requests to other DB nodes for replication, synchronization, *etc.*

TCP/UDP

TCP	UDP
Reliable	Unreliable
Connection-oriented	Connectionless
Segment retransmission and flow control through windowing	No windowing or retransmission
Segment sequencing	No sequencing
Acknowledge segments	No acknowledgement

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CONNECTIONLESS VS CONNECTION ORIENTED

	Connectionless (UDP) *stateless*	Connection-oriented (TCP) *stateful*
Advantages		
Disadvantages		

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CONNECTIONLESS VS CONNECTION ORIENTED

	Connectionless (UDP) *stateless*	Connection-oriented (TCP) *stateful*
Advantages	• Fast to communicate (no connection overhead) • Broadcast to an audience • Network bandwidth savings	• Message delivery confirmation • Idempotence not required • Messages automatically resent - if client (or network) is temporarily unavailable • Message sequences guaranteed
Disadvantages	• Cannot tell difference of request vs. response failure • Requires idempotence • Clients must be online and ready to receive messages	• Connection setup is time-consuming • More bandwidth is required (protocol, retries, multinode-communication)

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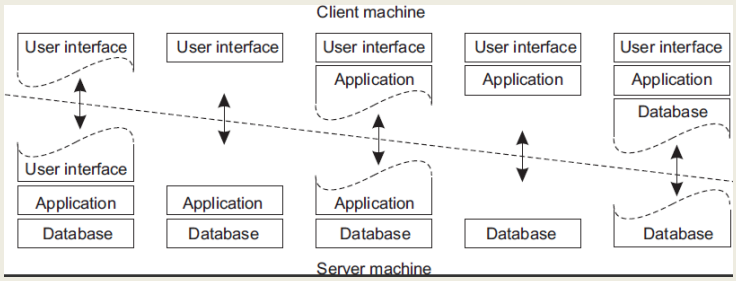
MULTITIERED ARCHITECTURES

- Where should functionality be distributed?
  - At the client?
  - At the server?



- Why should we consider component composition?

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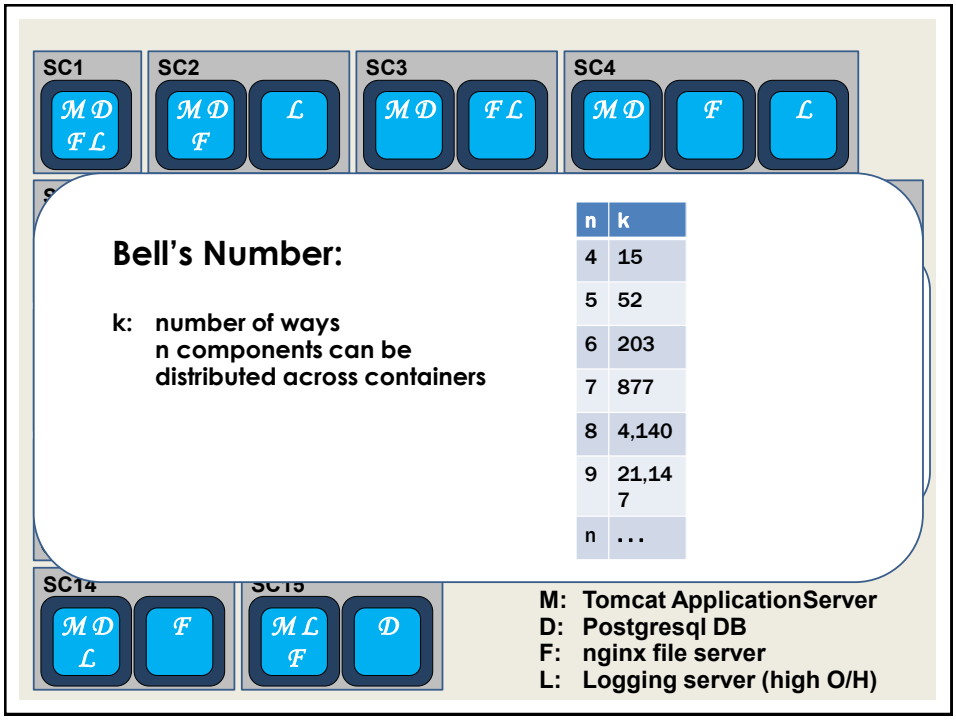
SC1
SC2
SC3
SC4
SC14
SC15
Bell's Number:
k: number of ways
n components can be
distributed across containers
n k
4 15
5 52
6 203
7 877
8 4,140
9 21,147
n ...
M: Tomcat ApplicationServer
D: Postgresql DB
F: nginx file server
L: Logging server (high O/H)

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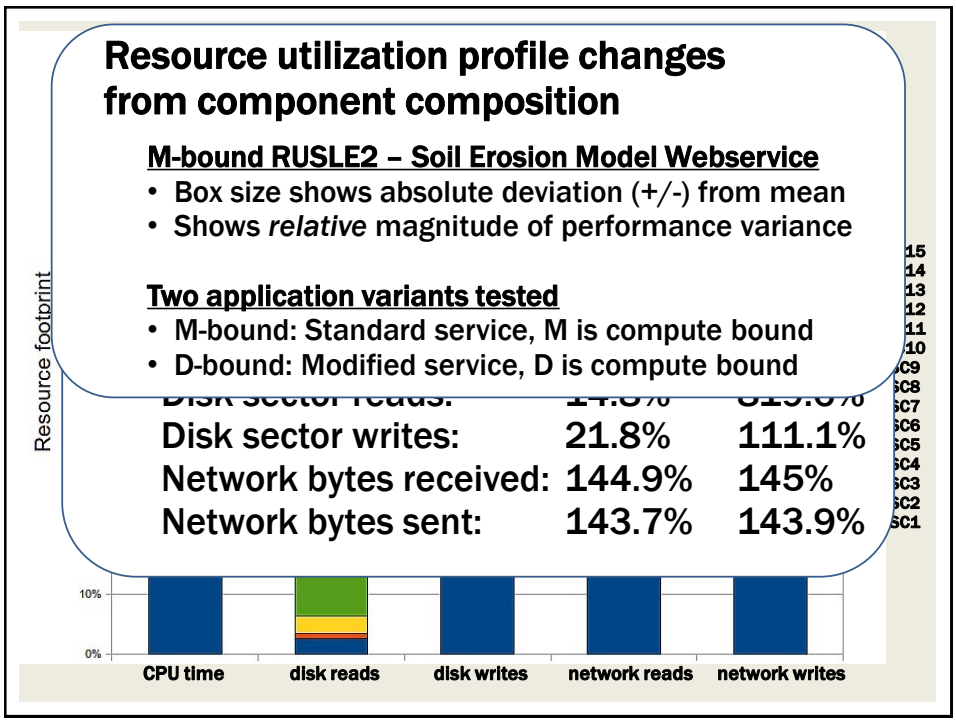
Resource utilization profile changes from component composition
M-bound RUSLE2 – Soil Erosion Model Webservice
• Box size shows absolute deviation (+/-) from mean
• Shows relative magnitude of performance variance
Two application variants tested
• M-bound: Standard service, M is compute bound
• D-bound: Modified service, D is compute bound
Disk sector writes: 21.8% 111.1%
Network bytes received: 144.9% 145%
Network bytes sent: 143.7% 143.9%
Resource footprint
10%
0%
CPU time
disk reads
disk writes
network reads
network writes

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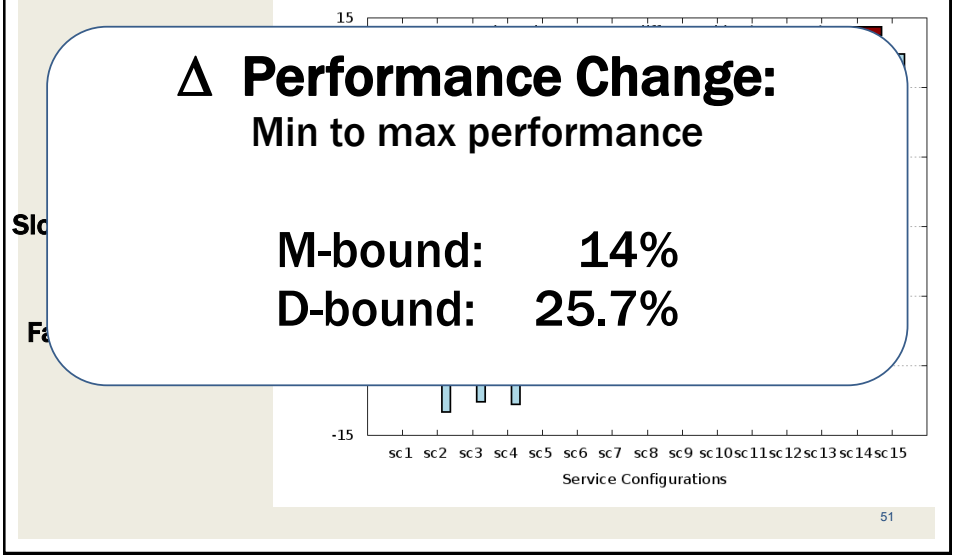
PERFORMANCE IMPLICATIONS OF COMPONENT DEPLOYMENTS



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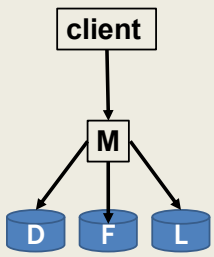
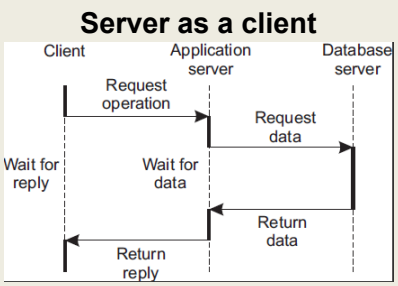
MULTITIERED ARCHITECTURES - 2

- **M D F L** architecture
- **M** – is the application server
- **M** – is also a client to the database (**D**), fileserver (**F**), and logging server (**L**)





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MULTITIERED RESOURCE SCALING

- **Vertical distribution**
- The distribution of "M D F L"
- Application is scaled by placing "tiers" on separate servers
  - M – The application server
  - D – The database server
- Vertical distribution impacts "network footprint" of application
- Service isolation: each component is isolated on its own HW

- **Horizontal distribution**
- Scaling an individual tier
- Add multiple machines and distribute load
- Load balancing

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MULTITIERED RESOURCE SCALING - 2

- **Horizontal distribution cont'd**
  - Sharding: portions of a database map" to a specific server
  - Distributed hash table
  - Or replica servers

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  - Hybrid architectures

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TYPES OF SYSTEM ARCHITECTURES

- Centralized system architectures
  - Client-server
  - Multitiered
- Decentralized peer-to-peer architectures
  - Structured
  - Unstructured
  - Hierarchically organized
- Hybrid architectures

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DECENTRALIZED PEER-TO-PEER ARCHITECTURES

- Client/server:
  - Nodes have specific roles
- Peer-to-peer:
  - Nodes are seen as ***all equal…***
- **How should nodes be organized for communication?**

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STRUCTURED PEER-TO-PEER

- Nodes organized using specific ***topology*** (e.g. ring, binary-tree, grid, etc.)
  - Organization assists in data lookups
- Data indexed using "semantic-free" indexing
  - Key / value storage systems
  - Key used to look-up data
- Nodes store data associated with a subset of keys

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DISTRIBUTED HASH TABLE (DHT)

- Distributed hash table (DHT) *(ch. 5)*
- Hash function

```
key(data item) = hash(data item's value)
```

- Hash function "generates" a unique key based on the data
- No two data elements will have the same key (hash)
- System supports data lookup via key
- ***Any*** node can receive and resolve the request
- Lookup function determines which node stores the key

```
existing node = lookup(key)
```

- Node forwards request to node with the data

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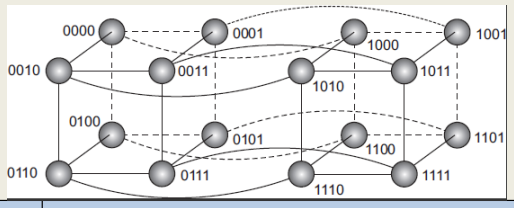
FIXED HYPERCUBE EXAMPLE

- Example where topology helps ***route*** data lookup request
- Statically sized 4-D hypercube, every node has 4 connectors
- 2 x 3-D cubes, 8 vertices, 12 edges
- Node IDs represented as 4-bit code (0000 to 1111)
- Hash data items to 4-bit key (1 of 16 slots)
- Distance (number of hops) determined by identifying number of varying bits between neighboring nodes and destination



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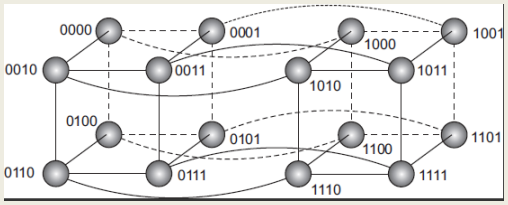
FIXED HYPERCUBE EXAMPLE - 2

- **Example:** *fixed hypercube*
  node 0111 (7) retrieves data from node 1110 (14)
- Node 1110 is not a neighbor to 0111
- **Which connector leads to the shortest path?**



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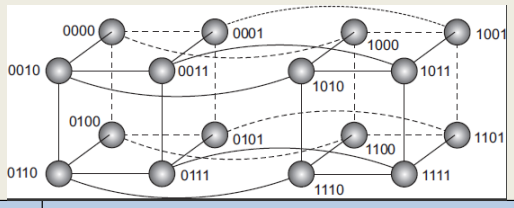
WHICH CONNECTOR LEADS TO THE SHORTEST PATH?

- **Example:** node 0111 (7) retrieves data from node 1110 (14)
- Node 1110 is not a neighbor to 0111

[0111] Neighbors:

1111 (1 bit different than 1110) 0011 (3 bits different– bad path)
0110 (1 bit different than 1110) 0101 (3 bits different– bad path)

- **Does it matter which node is selected for the first hop?**



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DYNAMIC TOPOLOGY

- Fixed hypercube requires static topology
  - Nodes cannot join or leave
- Relies on symmetry of number of nodes
- Can force the DHT to a certain size
- Chord system – DHT (again in ch.5)
  - Dynamic topology
  - Nodes organized in ring
  - Every node has unique ID
  - Each node connected with other nodes (shortcuts)
  - Shortest path between any pair of nodes is ~ order O(log N)
  - N is the total number of nodes

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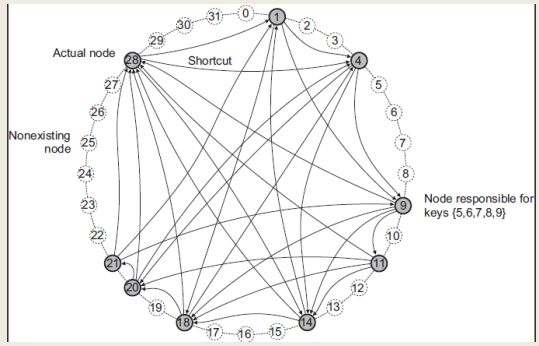
CHORD SYSTEM

- Data items have m-bit key
- Data item is stored at closest "successor" node with ID ≥ key k
- Each node maintains finger table of successor nodes
- Client sends key/value lookup to ***any*** node
- Node forwards client request to node with m-bit ID closest to, but not greater than key k
- Nodes must continually refresh finger tables by communicating with adjacent nodes to incorporate node joins/departures



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UNSTRUCTURED PEER-TO-PEER

- **No topology:** ***How do nodes find out about each other?***
- Each node maintains adhoc list of neighbors
- Facilitates nodes frequently joining, leaving, adhoc systems
- **Neighbor:** node reachable from another via a network path
- Neighbor lists constantly refreshed
  - Nodes query each other, remove unresponsive neighbors
- Forms a "random graph"
- Predetermining network routes not possible
  - How would you calculate the route algorithmically?
- Routes must be discovered

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SEARCHING FOR DATA: UNSTRUCTURED PEER-TO-PEER SYSTEMS

- **Flooding**
- `[Node u]` sends request for data item to all neighbors
- `[Node v]`
  - Searches locally, responds to u (or forwarder) if having data
  - Forwards request to **ALL** neighbors
  - Ignores repeated requests
- Features
  - High network traffic
  - Fast search results by saturating the network with requests
  - Variable # of hops
  - Max number of hops or time-to-live (TTL) often specified
  - Requests can "retry" by gradually increasing TTL/max hops until data is found

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SEARCHING FOR DATA - 2

- **Random walks**
- [Node u] asks a randomly chosen neighbor [node v]
- If [node v] does not have data, forwards request to a random neighbor
- Features
  - Low network traffic
  - Akin to sequential search
  - Longer search time
  - [node u] can start "n" random walks simultaneously to reduce search time
  - As few as n=16..64 random walks sufficient to reduce search time (LV et al. 2002)
  - Timeout required - need to coordinate stopping network-wide walk when data is found…

SEARCHING FOR DATA - 3

- **Policy-based search methods**
- Incorporate history and knowledge about the adhoc network ***at the node-level*** to enhance effectiveness of queries
- Nodes maintain lists of preferred neighbors which often succeed at resolving queries
- Favor neighbors having highest number of neighbors
  - Can help minimize hops

HIERARCHICAL PEER-TO-PEER NETWORKS

- **Problem:**
  Adhoc system search performance does not scale well as system grows
- Allow nodes to assume **ROLES** to improve search
- Content delivery networks (CDNs) *(video streaming)*
  - Store (cache) data at nodes local to the requester (client)
  - Broker node – tracks resource usage and node availability
    - Track where data is needed
    - Track which nodes have capacity (disk/CPU resources) to host data
- Node roles
  - Super peer –Broker node, routes client requests to storage nodes
  - Weak peer – Store data

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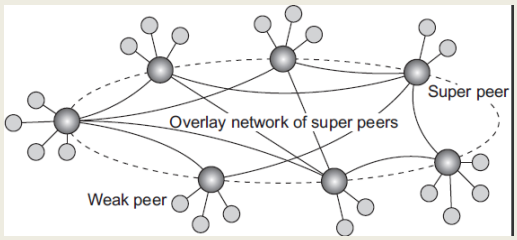
HIERARCHICAL PEER-TO-PEER NETWORKS - 2

- Super peers
  - Head node of local centralized network
  - Interconnected via overlay network with other super peers
  - May have replicas for fault tolerance
- Weak peers
  - Rely on super peers to find data
- Leader-election problem:
  - Who can become a super peer?
  - What requirements must be met to become a super peer?



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OBJECTIVES – 1/19

- Questions from 1/17
- Assignment 0: Cloud Computing Infrastructure Tutorial
- Class Activity: Architectural Styles
- Chapter 2.2: Middleware Organization
  - Wrappers
  - Interceptors
- Chapter 2.3: System Architectures
  - Centralized system architectures
  - Decentralized peer-to-peer architectures
  - **Hybrid architectures**

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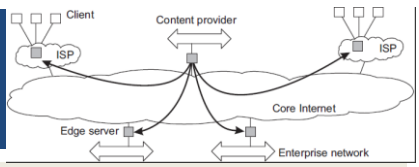
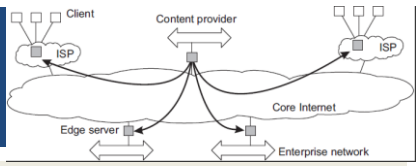
HYBRID ARCHITECTURES



- Combine centralized server concepts with decentralized peer-to-peer models
- **Edge-server systems:**
- Adhoc peer-to-peer devices connect to the internet through an edge server (origin server)
- Edge servers (provided by an ISP) can optimize content and application distribution by storing assets near the edge
- **Example:**
- AWS Lambda@Edge: Enables Node.js Lambda Functions to execute "at the edge" harnessing existing CloudFront Content Delivery Network (CDN) servers
- **https://www.infoq.com/news/2017/07/aws-lambda-at-edge**

HYBRID ARCHITECTURES - 2



- **Fog computing:**
- Extend the scope of managed resources beyond the cloud to leverage compute and storage capacity of end-user devices
- End-user devices become part of the overall system
- Middleware extended to incorporate managing edge devices as participants in the distributed system
- Cloud → in the sky
  - *compute/resource capacity is huge, but far away…*
- Fog → (devices) on the ground
  - *compute/resource capacity is constrained and local…*

COLLABORATIVE DISTRIBUTED SYSTEM EXAMPLE

- **BitTorrent Example:**
  File sharing system – users must contribute as a file host to be eligible to download file resources
- Original implementation features hybrid architecture
- Leverages idle client network capacity in the background
- User joins the system by interacting with a central server
- Client accesses global directory from a ***tracker*** server at well known address to access torrent file
- Torrent file tracks nodes having chunks of requested file
- Client begins downloading file chunks and immediately then participates to reserve downloaded content **or network bandwidth is reduced!!**
- Chunks can be downloaded in parallel from distributed nodes

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QUESTIONS

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