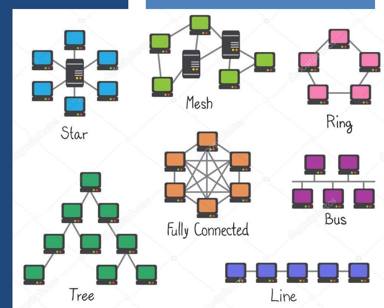
# TCSS 558: APPLIED DISTRIBUTED COMPUTING




## System Architectures

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## OBJECTIVES

- Feedback from 10/12
- Assignment 0 – questions
- Ch. 2 – System architectures
  - Centralized: Single client, multi-tier
  - Decentralized peer-to-peer: structured, unstructured, hierarchical
  - Hybrid
- Ch. 3 – Processes and threads

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# FEEDBACK – 10/12

- **Why is the event-based architecture generally "more scalable", as compared to a layered architecture?**
- Event-based systems are considered "sessionless"
- Creating and destroying TCP sessions incurs overhead
- When a client "subscribes" to a feed, server(s) can simply publish content to the subscriber(s) (*by sending msgs to their IP address*) without establishing a TCP session
- Client(s) monitor a port for messages
- **Clients and servers are referentially decoupled**
- Client(s) are not bound by name (*TCP connection*) to ***any*** particular server



# EVENT-BASED PUBLISH & SUBSCRIBE - 2

- Server pool participating in publishing content to subscribers is inherently scalable because additional nodes can participate without client reconfiguration
- Because the server name is decoupled, in theory…
  ***Every message could originate from a different server !!!***
- **Disadvantage**:
- Message delivery is not guaranteed with connectionless protocols
- Play-it-again Sam…?
  - ***No!***
- Messages are not replayed. Subscribers (clients) must be up-and-running when messages are sent. *(temporal coupling)*

# EVENT-BASED PUBLISH & SUBSCRIBE - 3

- Managing the subscription system may be tedious when there are ***many*** subscriptions
- Agreed
- **Advantage:**
  Due to referential decoupling and distribution transparency, the scale and scope of the implementation used can be entirely abstracted from clients
- While achieving large scale maybe complex and expensive, it is generally reasonable to achieve with access to sufficient resources (e.g. cloud)



# EVENT-BASED PUBLISH & SUBSCRIBE - 4

- **Consider design problem(s):**
- How do we coordinate multiple servers to publish subscription content to clients?
- Do individual nodes provide specific types of content to subscribers? (*content centric*)
  - Enables cache / memory advantages
- Do individual nodes service related clients (*geospatially centric*)?
  - Network latency advantages
- How do we manage and update a shared subscription database?

# FEEDBACK 10/12 - 5

- **What does 'notification only' or 'notification plus data' depend on?**
- For the shared data-space architecture, notification only provides:
  - Referential decoupling
  - Temporal decoupling
- Subscribers receive notifications that new data is available, ***not the data itself***
- Subscribers explicitly fetch data ***if interested*** after notification
- Temporal decoupling defers or eliminates network traffic
- Temporally coupled shared data-space systems send "notification plus data" to clients immediately for "events".



# FEEDBACK 10/12 - 6

- Can Windows OS update messages be related to "Notification only", and when the system ***actually*** updates to "Notification + Data"?
- In a sense, it could be thought of this way, but …
- Imagine if all MS Windows clients elected for notification + data simultaneously.
- What implications would result for the Internet?
- In reality, updates are rolling

# FEEDBACK 10/12 - 7

- Wrappers and interceptors are a bit unclear
- These are similar !
- **Wrapper:**
  A client callable interface which provides functionality
- Functionality may be provided directly by the server code (same program as wrapper), or outsourced to legacy code (engine)
- "Wrappers" decouple client interface from backend implementation
- Backend implementation may change without modifying the client
- Allows specifics of implementation (i.e. business logic) to change
- For example: version upgrades (1.0 to 1.2 …)
- New backend relational database: SQL Server → PostgreSQL
- ***Key: client doesn't need to know***

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# FEEDBACK 10/12 - 8

- **Interceptor:**
  An interface which **"routes"** client requests somewhere else
- For example, interface stub(s) route calls to remote objects
- Conceptually similar to wrappers, as the implementation is decoupled
- Enables geospatial decoupling
  - Location of the implementation may change
  - Through routing (to different providers) the details of the implementation may change…

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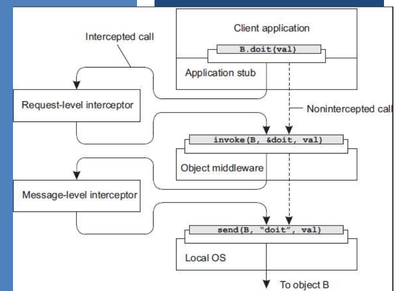


# SYSTEM ARCHITECTURES

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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 a **system architecture**
- System architectures represent designs used in practice

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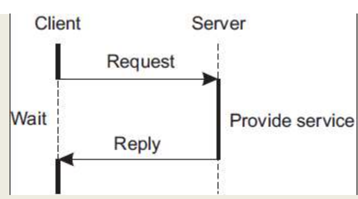
# SYSTEM ARCHITECTURES - 2

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



# 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?***

## 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*

- Example: Distributed databases
- Nodes must service client requests and initiate them to other database 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 |



# CONNECTIONLESS VS CONNECTION ORIENTED

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

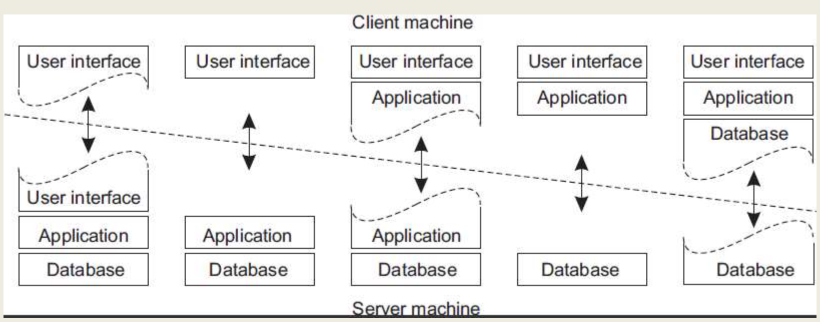
# CONNECTIONLESS VS CONNECTION ORIENTED

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

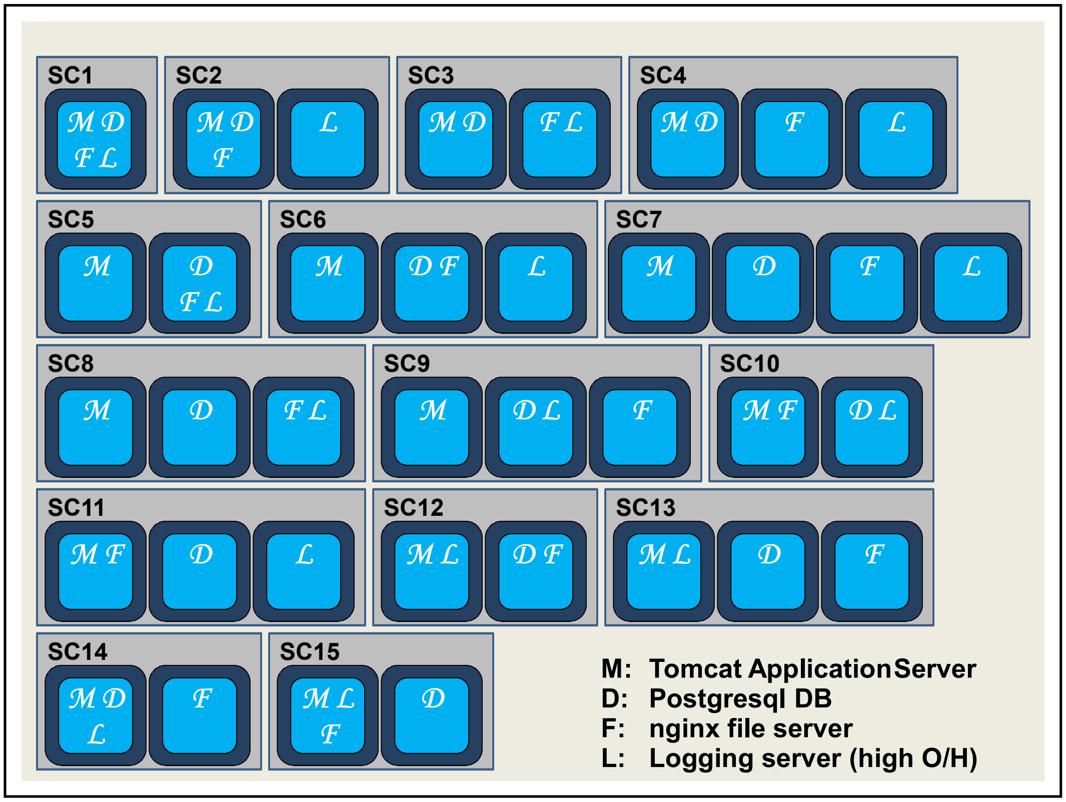


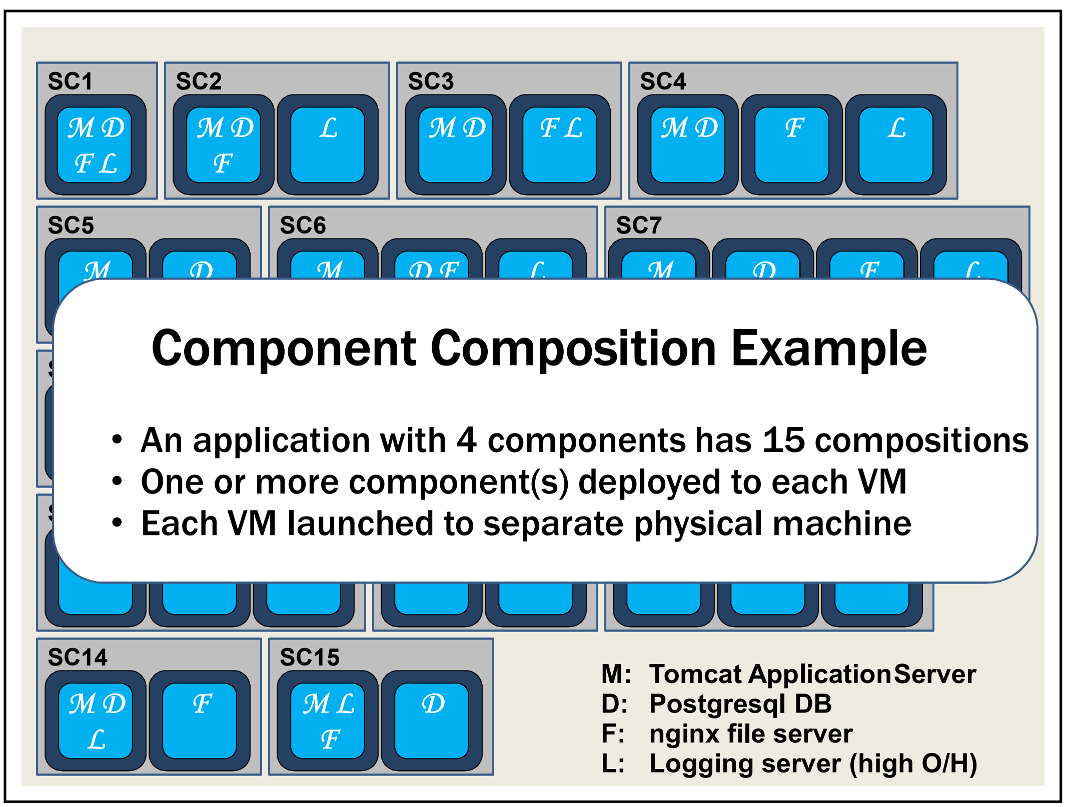
# MULTITIERED ARCHITECTURES

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




- Why should we consider component composition?


SC1
M D F L
SC2
M D F
L
SC3
M D
F L
SC4
M D
F
L
SC5
M
D F L
SC6
M
D F
L
SC7
M
D
F
L
SC8
M
D
F L
SC9
M
D L
F
SC10
M F
D L
SC11
M F
D
L
SC12
M L
D F
SC13
M L
D
F
SC14
M D L
F
SC15
M L F
D
M: Tomcat Application Server
D: Postgresql DB
F: nginx file server
L: Logging server (high O/H)


Component Composition Example
An application with 4 components has 15 compositions
One or more component(s) deployed to each VM
Each VM launched to separate physical machine
SC1
M D F L
SC2
M D F
L
SC3
M D
F L
SC4
M D
F
L
SC5
SC6
SC7
SC14
M D L
F
SC15
M L F
D
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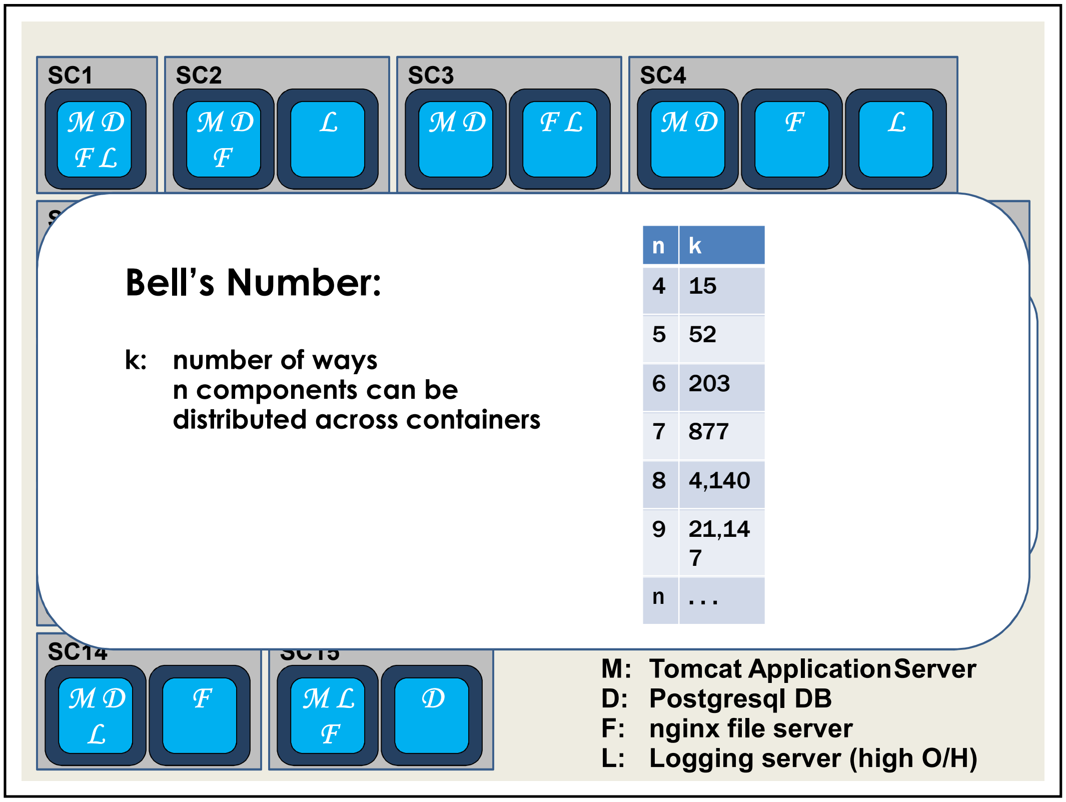
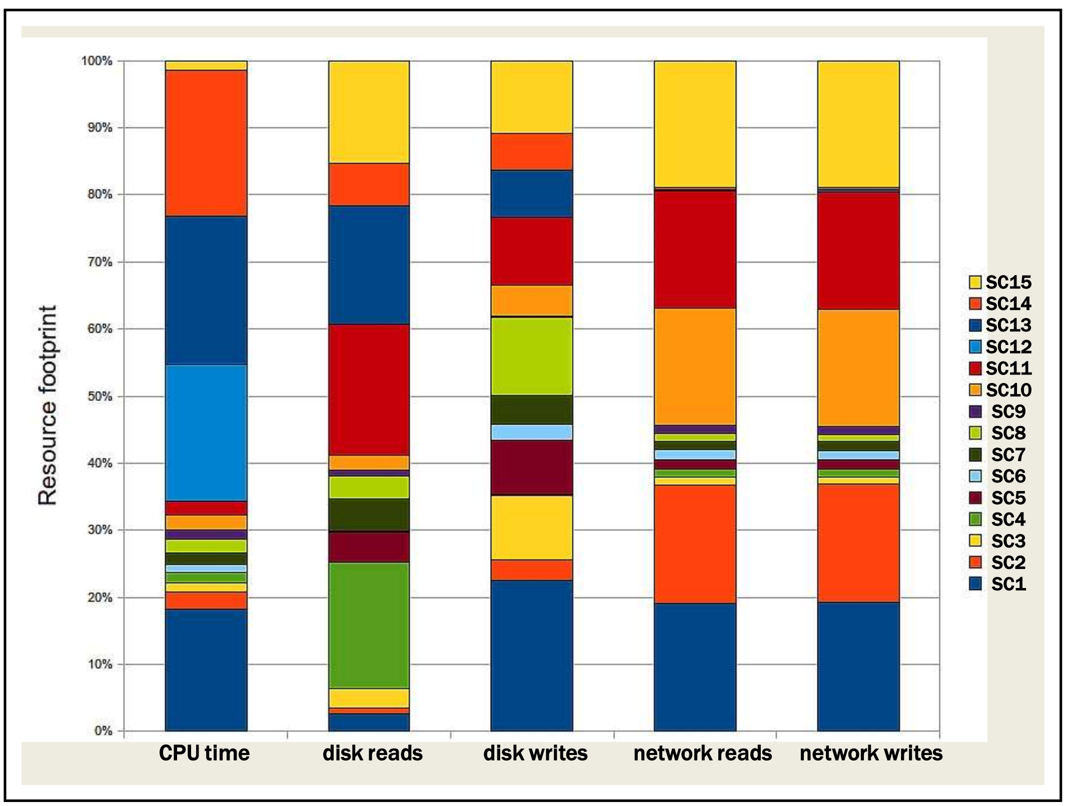
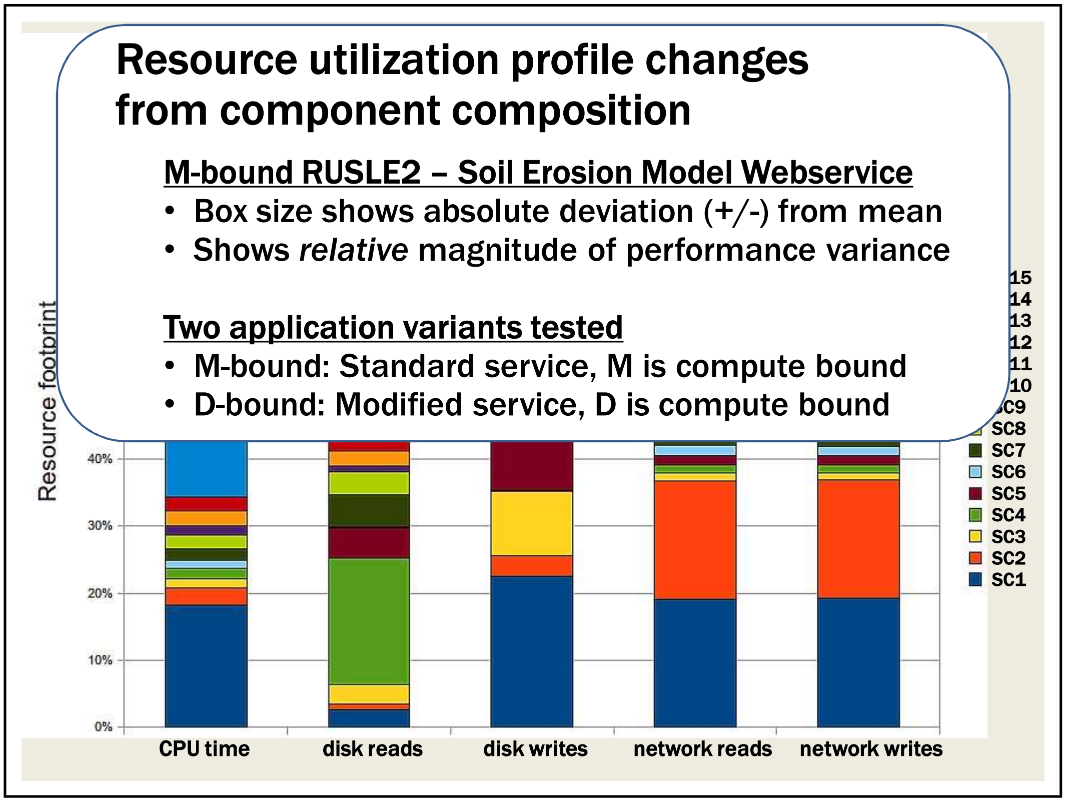



**Bell's Number:**

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 | . . . |





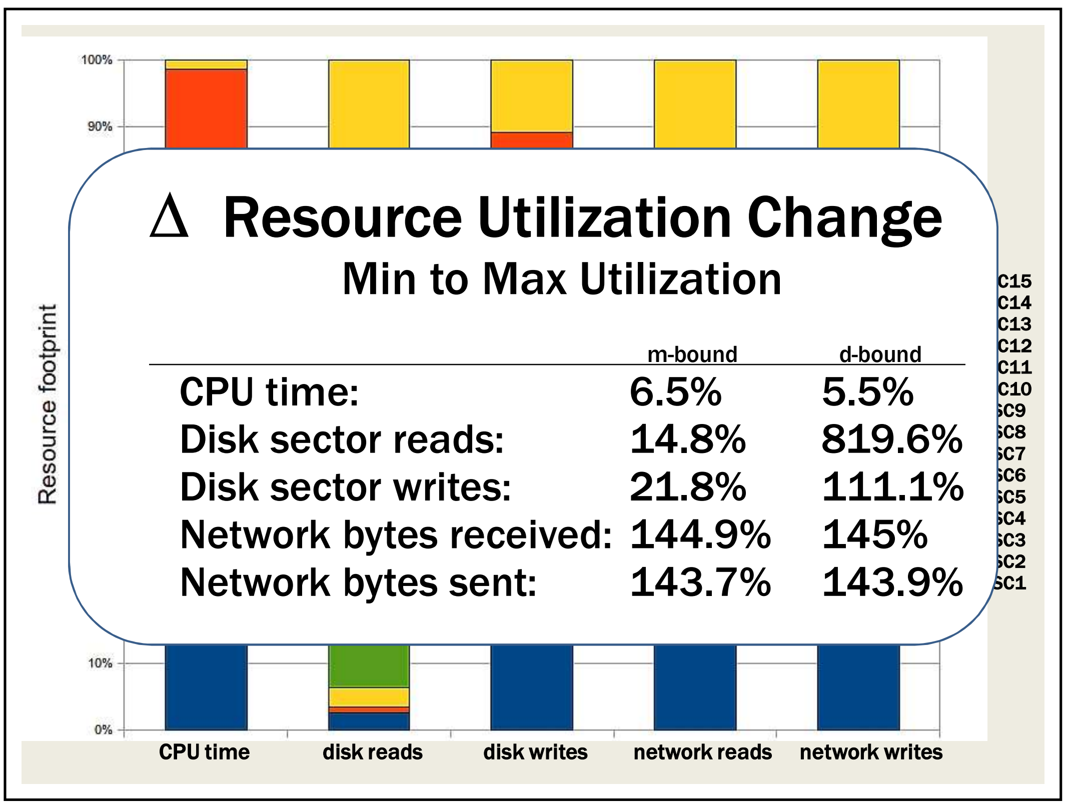

## Resource utilization profile changes from component composition

**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




## Δ Resource Utilization Change

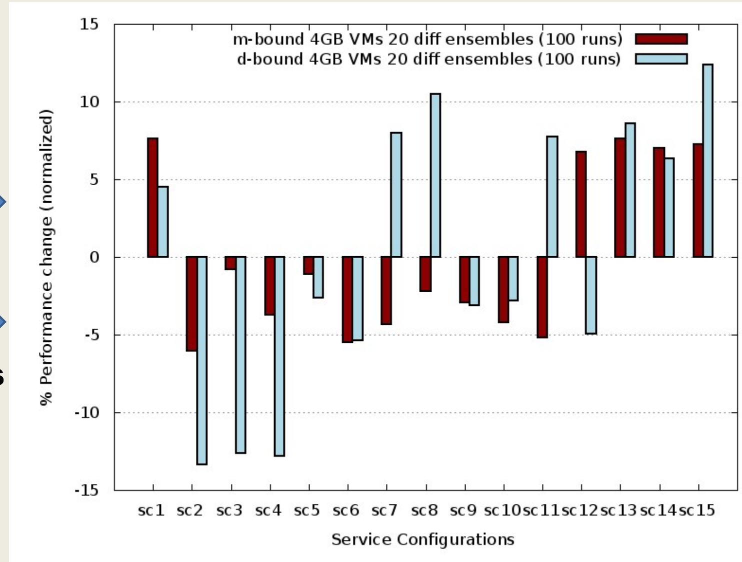
### Min to Max Utilization

| | m-bound | d-bound |
|---|---|---|
| CPU time: | 6.5% | 5.5% |
| Disk sector reads: | 14.8% | 819.6% |
| Disk sector writes: | 21.8% | 111.1% |
| Network bytes received: | 144.9% | 145% |
| Network bytes sent: | 143.7% | 143.9% |

# PERFORMANCE IMPLICATIONS OF COMPONENT DEPLOYMENTS

Slower deployments

Faster deployments

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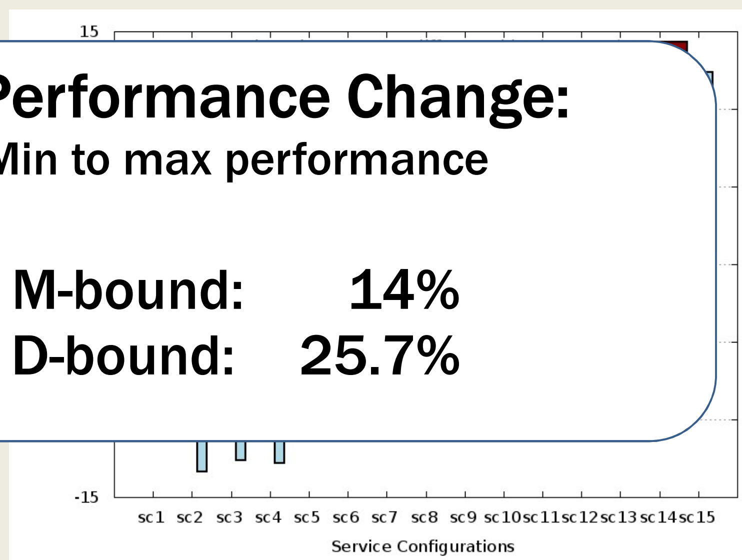
# PERFORMANCE IMPLICATIONS OF COMPONENT DEPLOYMENTS




## $\Delta$ Performance Change:

**Min to max performance**

**M-bound: 14%**

**D-bound: 25.7%**

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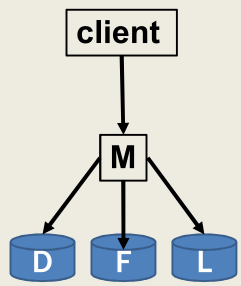
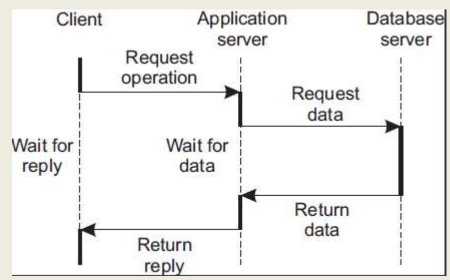
# MULTITIERED ARCHITECTURES - 2

- **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)




**Server as a client**






# MULTITIERED RESOURCE SCALING

- <u>Vertical distribution</u>
- 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

- <u>Horizontal distribution</u>
- Scaling an individual tier
- Add multiple machines and distribute load
- Load balancing

# MULTITIERED RESOURCE SCALING - 2

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



# 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?**

# 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



# DISTRIBUTED HASH TABLE (DHT)

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

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

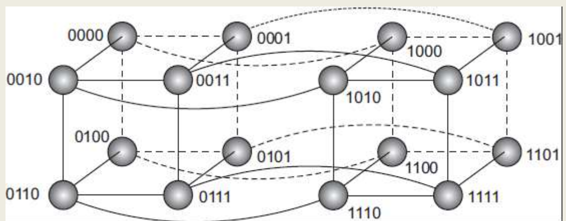
- Hash function "generates" a unique key based on the data
- No two data elements will have the same key (hash)
- System supports data lookup via key
- ***Any*** node can receive and resolve the request
- Lookup function determines which node stores the key

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

- Node forwards request to node with the data

# FIXED HYPERCUBE EXAMPLE

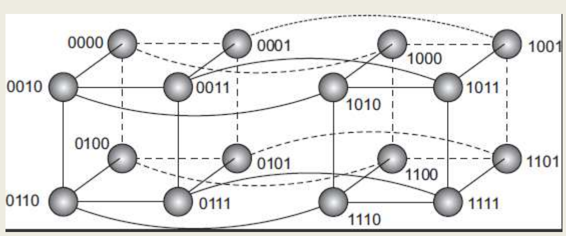
- Example where topology helps ***route*** data lookup request
- Statically sized 4-D hypercube, every node has 4 connectors
- 2 x 3-D cubes, 8 vertices, 12 edges
- Node IDs are 4-bit code (0000 to 1111)
- Hash data items to 4-bit key (1 of 16 slots)
- Distance (number of hops) determined by identifying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






# 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?**



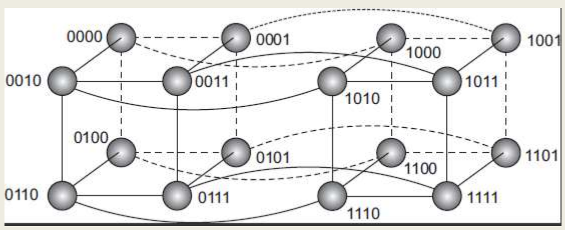
# WHICH CONNECTOR LEADS TO THE SHORTEST PATH?

- **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)

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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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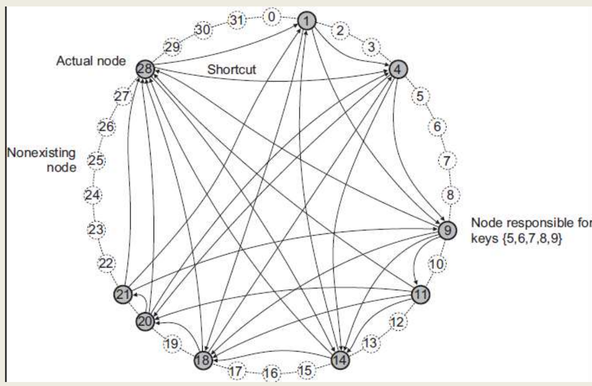
# CHORD SYSTEM

- 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






# 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

# 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 via saturated 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



# 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 perform parallel random walks to reduce search time
  - As few as 16..64 random walks effective to reduce search time
  - 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

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## QUESTIONS

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# EXTRA SLIDES

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