TCSS 558: APPLIED DISTRIBUTED COMPUTING

Distributed Systems: Types and Architectures

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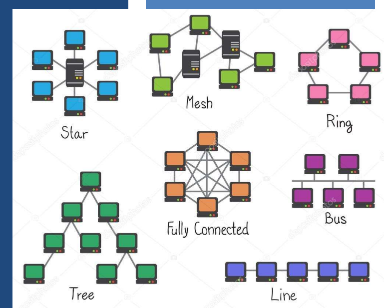

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OBJECTIVES

- Class Activity 2 – Rearchitecting Distributed Systems
- Homework 0 – networking review
- Feedback from 1/21
- Chapter 2.2: Middleware organization
- Research directions overview
- Chapter 2.3: System architectures

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IN-CLASS ACTIVITY: ARCHITECTURAL STYLES

L6.3

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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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MATERIAL / PACE

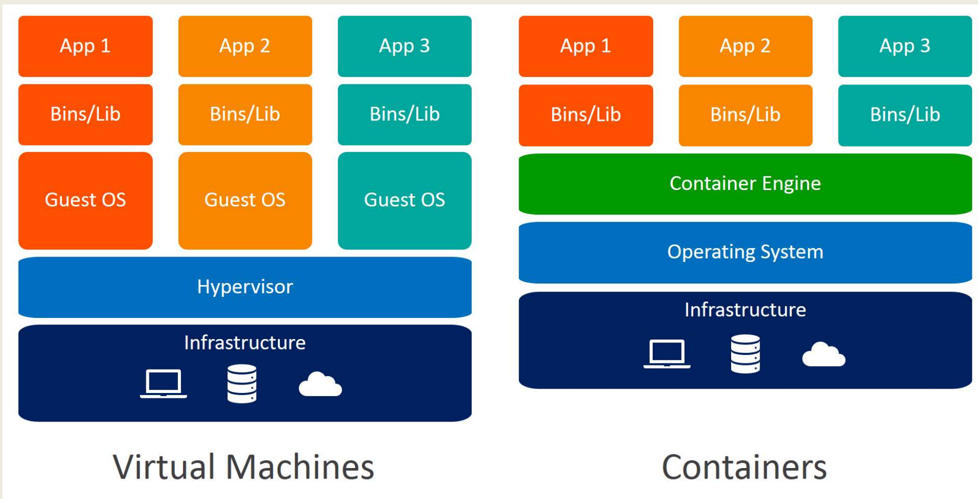
- Please classify your perspective on material covered in today's class (9 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- Average – 7.55

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- Average – 6.44

FEEDBACK FROM 1/21

- What are the differences between Docker (containers) and virtual machines?

VM VS. CONTAINER (BARE METAL)



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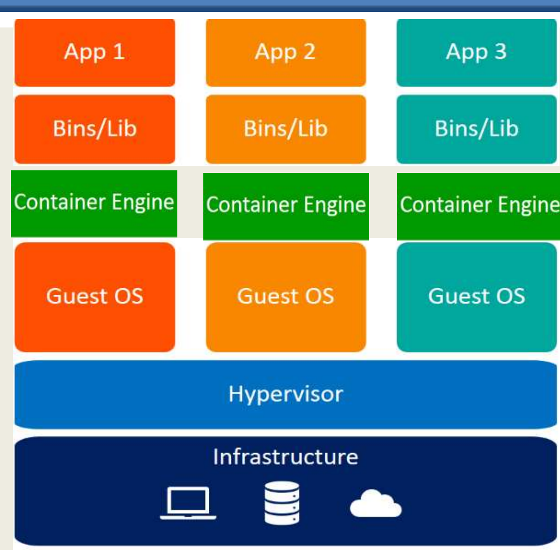
What architecture does this look like?



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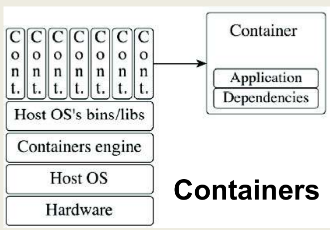
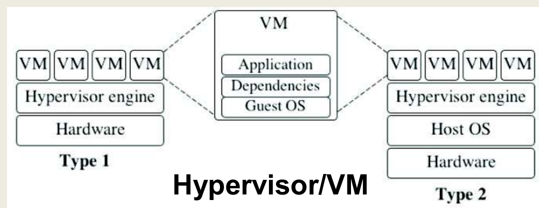
MOTIVATION FOR CONTAINERIZATION

- Containers provide "light-weight" alternative to full OS virtualization provided by a hypervisor
- Containers do not provide a full "machine"
- Instead use operating system constructs to provide "sand boxes" for execution
  - Linux cgroups, namespaces, etc.
- Containers can run on bare metal, or atop of VMs





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FEEDBACK - 2

- **Assignment 0: For haproxy, using VM private IPs, why doesn't network traffic need to go out to the internet?**
  - Every VM has a default VPC, and subnet
  - VMs that share the same (private) subnet can directly communicate
  - VMs that are on two different subnets within a VPC with a router can communicate via the router

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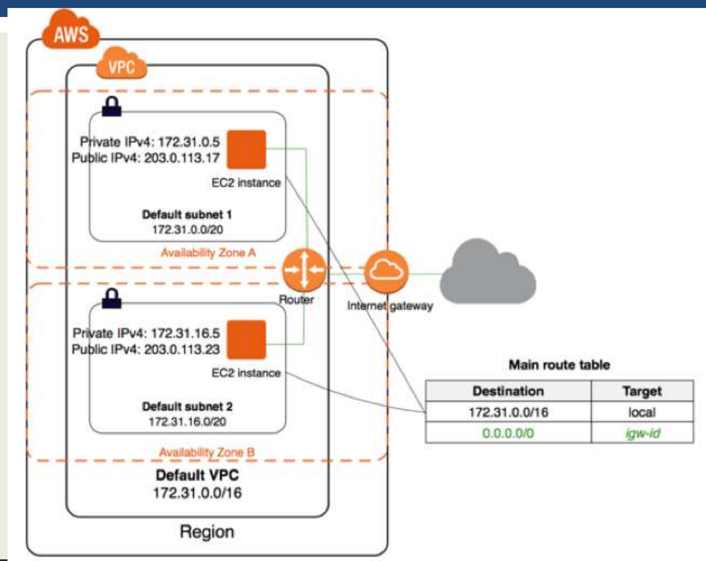
DEFAULT VPC



FEEDBACK - 3

- I'm not understanding the haproxy diagram (whiteboard).
- Why multiple ports?

FEEDBACK - 4

- What is coupled?
  - Source code coupling
  - Referential coupling
  - Temporal coupling
- What is decoupled?

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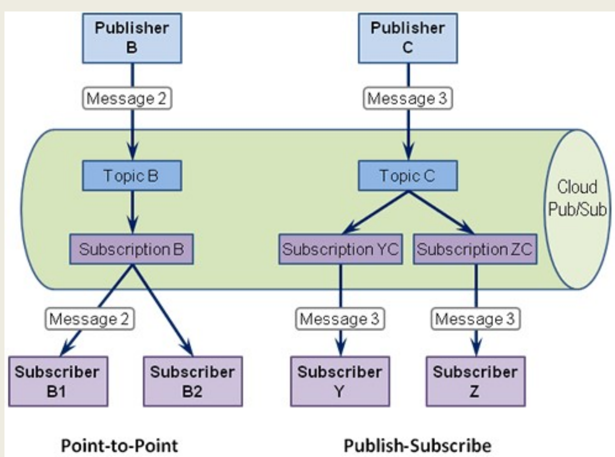
FEEDBACK - 5

- Could you explain more about the publish-subscribe architecture?
- How does a subscription model support decoupling?



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FEEDBACK - 6

- Could we please open zoom section for every class?
- Can we have zoom online classes from now on?
  - *Due to new novel cornavirus*

- UW faculty only have basic zoom license
- Limited to 40-minute sessions

- SET allows faculty to schedule full-length zoom sessions during inclement weather or campus quarantine *(by special request)*
  - Insufficient resources for daily use

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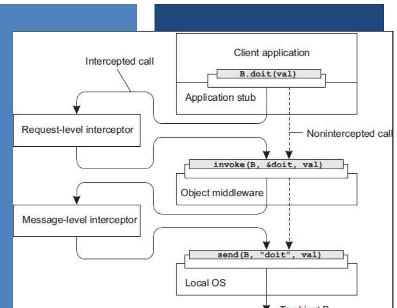

CH 2.2: MIDDLEWARE ORGANIZATION

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MIDDLEWARE ORGANIZATION

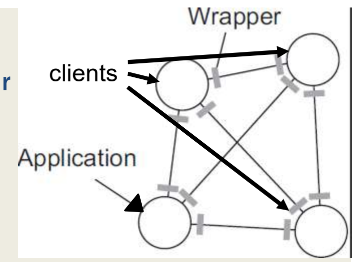
- Relies on two important design patterns:
  - Wrappers
  - Interceptors
- Both help achieve the goal of openness

MIDDLEWARE: WRAPPERS

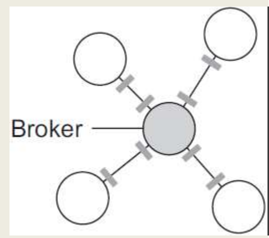
- **Wrappers (also called adapters)**
  - **WHY?:** Interfaces available from legacy software may not be sufficient for all new applications to use
  - **WHAT:** Special "frontend" components that provide interfaces for clients
  - Interface wrappers transform client requests to "implementation" (i.e. 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

MIDDLEWARE: WRAPPERS - 2

- Inter-application communication
  - Applications may provide unique interface for every client application
- Scalability suffers
  - N applications → O(N^2) wrappers



- <u>ALTERNATE: Use a Broker</u>
  - 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

- <u>Interceptor</u>
- 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 <u>***distribution***</u> and/or <u>***replication***</u>
  - 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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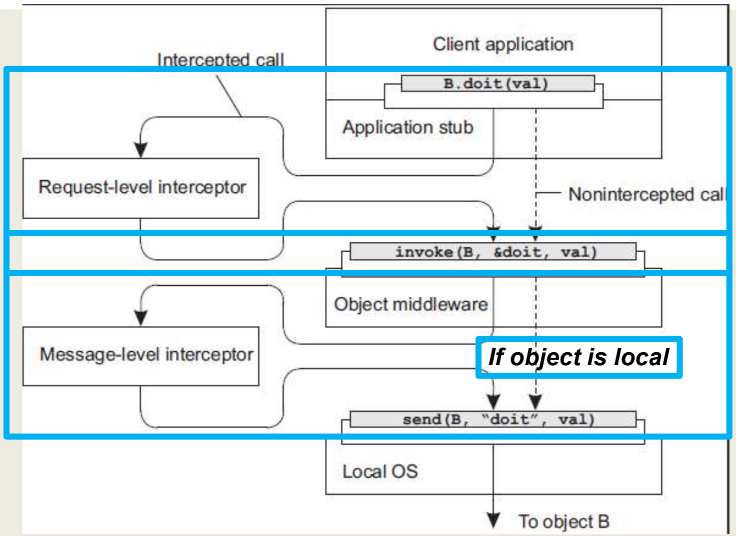
MIDDLEWARE: INTERCEPTORS - 2



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

- 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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RESEARCH DIRECTIONS

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CLOUD AND DISTRIBUTED SYSTEMS RESEARCH GROUP

- Meetings on Wednesdays from 12 (12:30) to 1:30pm
- MDS 202
- *MDS is just south of Cherry Parkes*

The CDS group collaborates on research projects spanning Serverless computing (FaaS), Containerization, Infrastructure-as-a-Service (IaaS) cloud, virtualization, infrastructure management, and performance and cost modeling of application deployments. Our research aims to demystify the myriad of options to guide software developers, engineers, scientists, and practitioners to intelligently harness cloud computing to improve performance and scalability of their applications, while reducing hosting costs.

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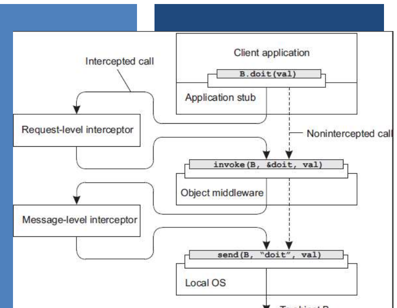

CH 2.3: SYSTEM ARCHITECTURES

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SYSTEM ARCHITECTURES

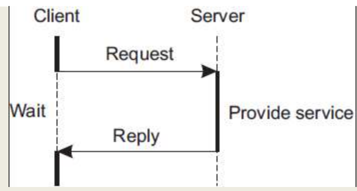
- Architectural styles (or patterns)
- General, reusable solutions to commonly occurring system design problems
- Expressed as a logical organization of ***components*** and ***connectors***
- Deciding on the system components, their interactions, and placement is a "realization" of an **architectural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

TYPES OF SYSTEM ARCHITECTURES

- 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?***

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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

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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.*

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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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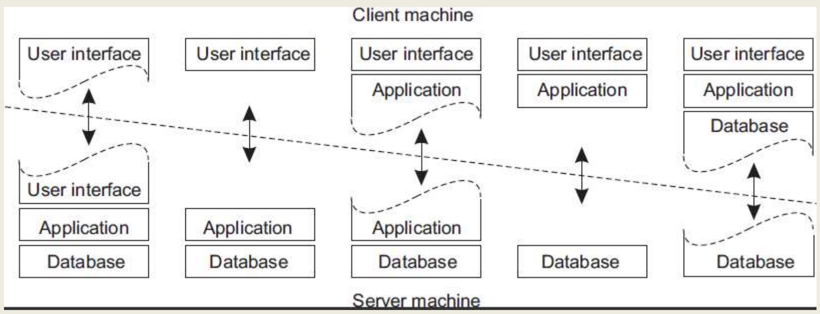
MULTITIERED ARCHITECTURES

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



- Why should we consider component composition?

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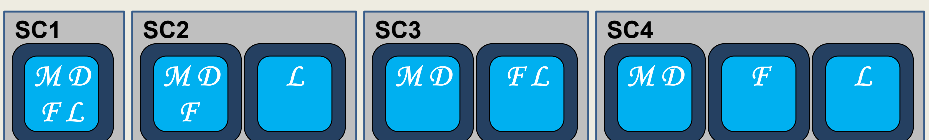
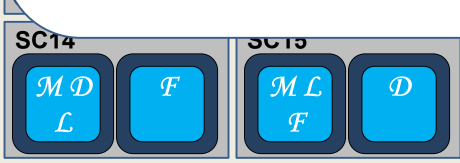


Bell's Number:

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 Application Server
D: Postgresql DB
F: nginx file server
L: Logging server (high O/H)

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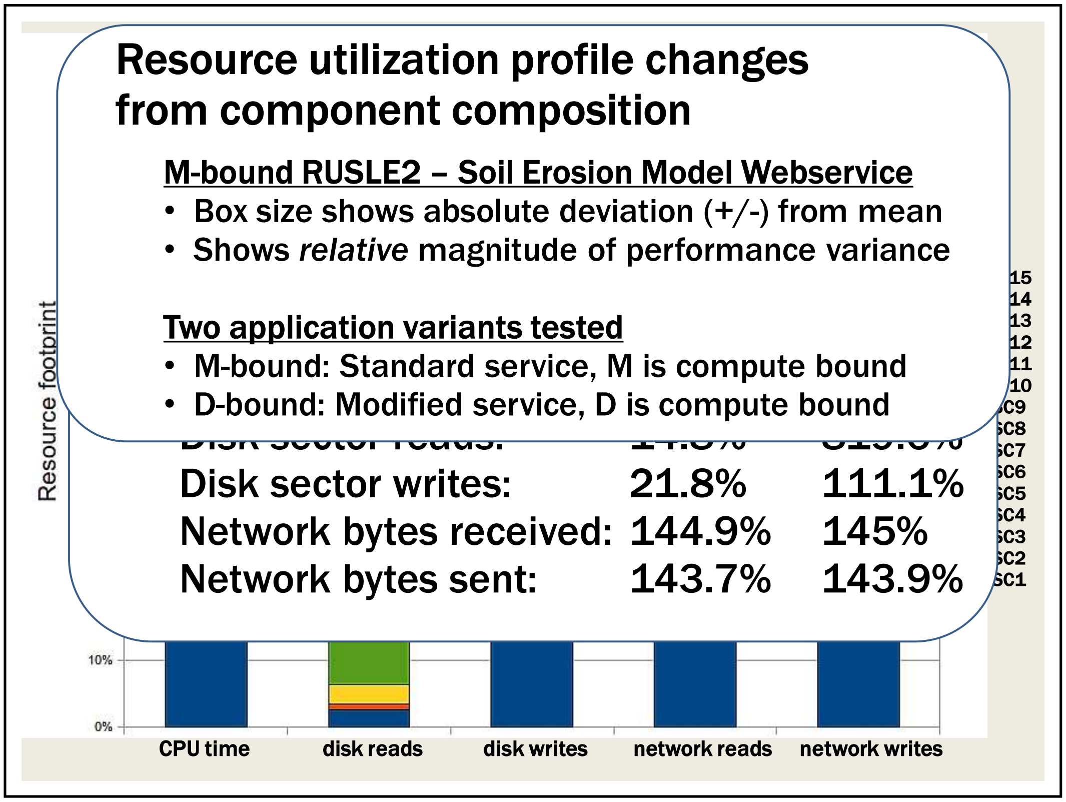
Resource utilization profile changes from component composition
M-bound RUSLE2 – Soil Erosion Model Webservice
• Box size shows absolute deviation (+/-) from mean
• Shows *relative* magnitude of performance variance
Two application variants tested
• M-bound: Standard service, M is compute bound
• D-bound: 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
SC15
SC14
SC13
SC12
SC11
SC10
SC9
SC8
SC7
SC6
SC5
SC4
SC3
SC2
SC1
10%
0%
CPU time
disk reads
disk writes
network reads
network writes

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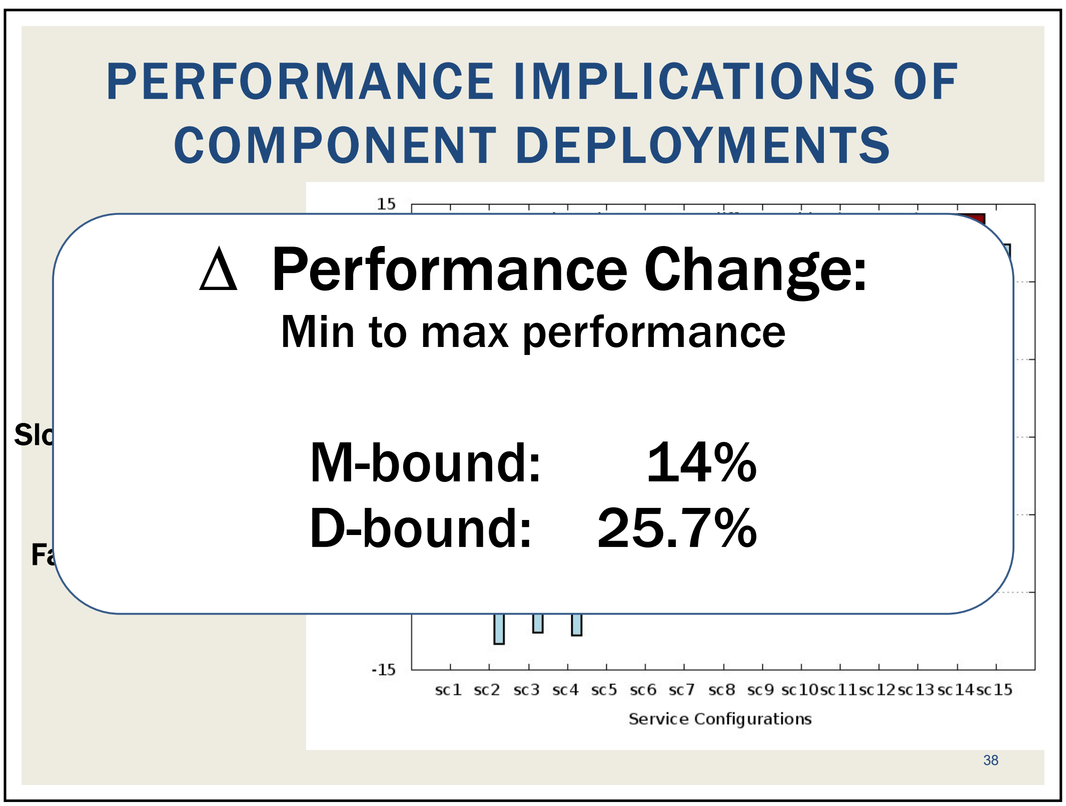
PERFORMANCE IMPLICATIONS OF COMPONENT DEPLOYMENTS
∆ Performance Change:
Min to max performance
M-bound: 14%
D-bound: 25.7%
15
-15
sc1 sc2 sc3 sc4 sc5 sc6 sc7 sc8 sc9 sc10 sc11 sc12 sc13 sc14 sc15
Service Configurations
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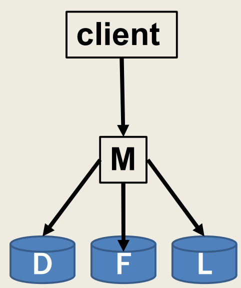
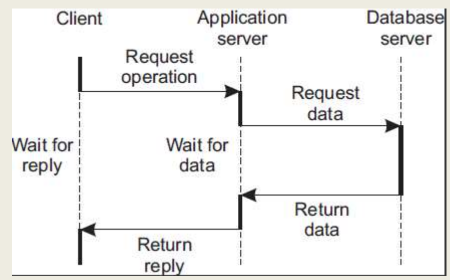
MULTITIERED ARCHITECTURES - 2

- 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



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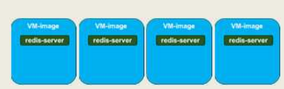
MULTITIERED RESOURCE SCALING

- <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

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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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TYPES OF SYSTEM 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?**

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

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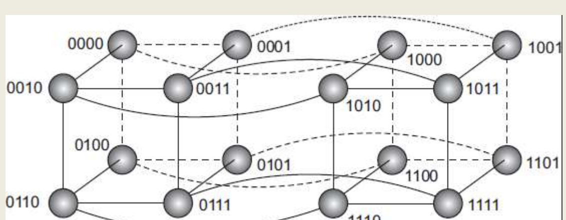
FIXED HYPERCUBE EXAMPLE

- 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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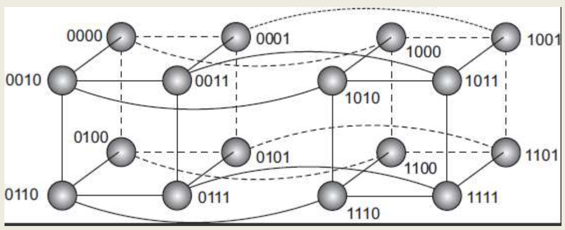
FIXED HYPERCUBE EXAMPLE - 2

- **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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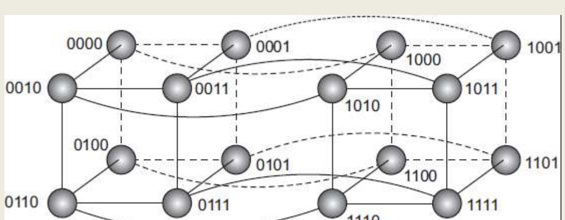
WHICH CONNECTOR LEADS TO THE SHORTEST PATH?

- **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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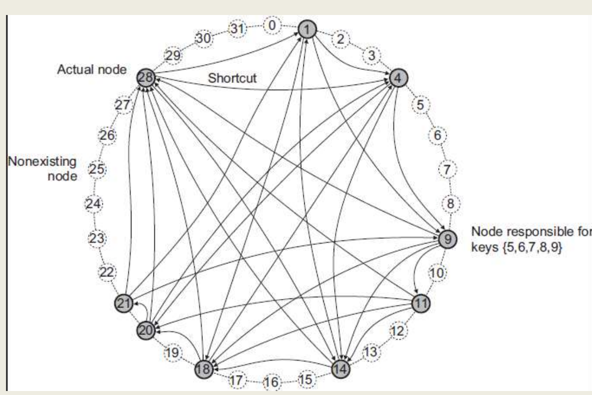
DYNAMIC TOPOLOGY

- 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

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 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

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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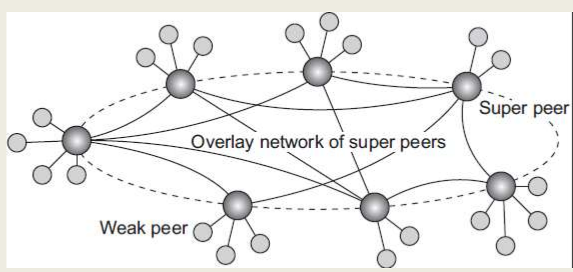
HIERARCHICAL PEER-TO-PEER NETWORKS - 2

- 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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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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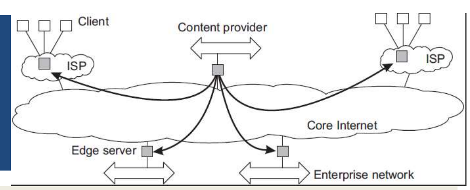
HYBRID ARCHITECTURES



- Combine centralized server concepts with decentralized peer-to-peer models
- <u>Edge-server systems:</u>
- 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
- <u>Example:</u>
- 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

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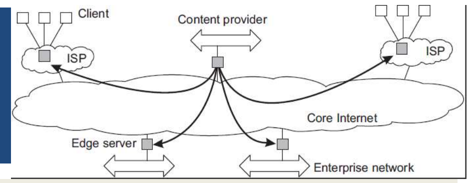
HYBRID ARCHITECTURES - 2



- **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

QUESTIONS

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EXTRA SLIDES

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