TCSS 562: SOFTWARE ENGINEERING FOR CLOUD COMPUTING

Cloud Computing: Concepts and Models

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School of Engineering and Technology
University of Washington – Tacoma

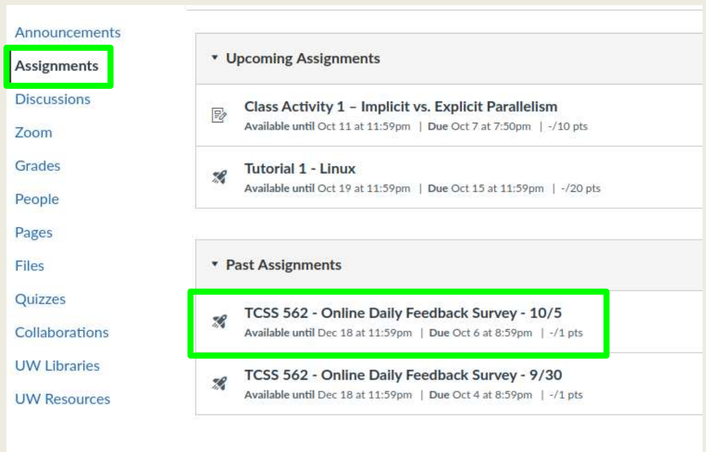
MW 5:50-7:50 PM

OBJECTIVES – 10/19

- Questions from 10/14
- From: Cloud Computing Concepts, Technology & Architecture: Cloud Computing Concepts and Models:
  - Roles and boundaries
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models
- 2nd hour:
- Introduce Tutorial #3 – Best Practices for Working with Virtual Machines on Amazon EC2
- Term project case studies
- Team planning

ONLINE DAILY FEEDBACK SURVEY

- Daily Feedback Quiz in Canvas – Take After Each Class
- Extra Credit for completing



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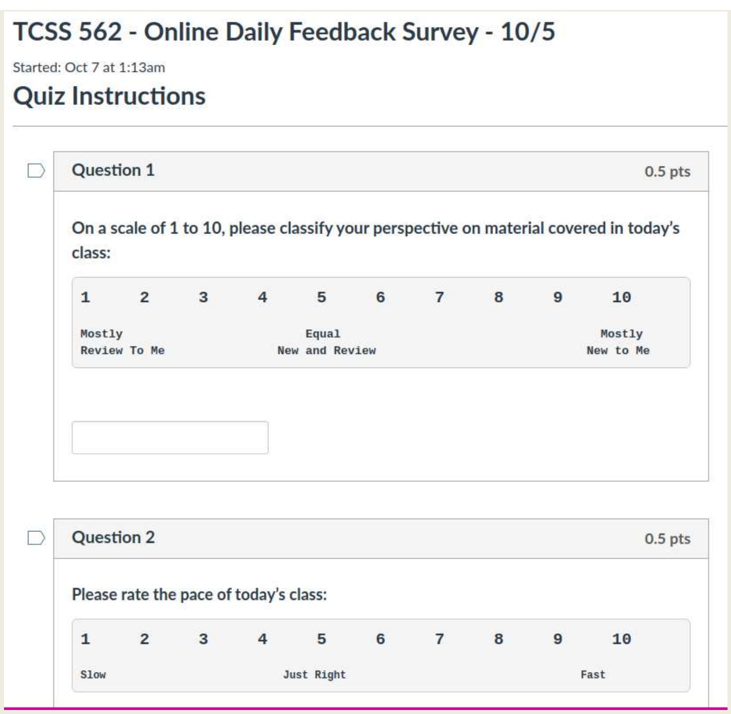

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MATERIAL / PACE

- Please classify your perspective on material covered in today's class (16 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 6.43 (↑ - *previous 6.31*)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.48 (↑ - previous 5.38)**

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FEEDBACK FROM 10/14

- No survey questions

- But there was some good discussion during office hours

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PROJECT PROPOSAL

- ***If unsure of the case study topic:***
- Groups can propose a primary and backup case study topic
- Groups can propose a topic, and change once the project proposal is approved by notifying the instructor
- ***Reasons for change:***
- Discover that original topic may not work, or may require too much effort…
- Once learning more and doing initial investigations, groups may acquire a sudden passion for a particular topic
- **How to change topics:**
- Provide instructor with revised proposal as soon as possible
- Instructor will review proposal to approve/deny within ~1 day

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AMDAHL'S LAW

- Portion of computation which cannot be parallelized determines the overall speedup
- For an embarrassingly parallel job of fixed size
- Assun[…]nd a perfe[…]

  α: fra[…] parall[…] (e.g. must run sequentially)

- Max[…](N):

In the last class, we were having difficulty moving between Amdahl's Law and Gustafson's because as it turns out, this formula was OVERSIMPLIFIED from the text

LESSON LEARNED !!!
DO NOT TRY TO MOVE BETWEEN THE FORMULAS WHEN USING THE SIMPLIFIED FORM OF AMDAHL'S LAW

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AMDAHL'S LAW

- Portion of computation which cannot be parallelized determines the overall speedup
- For an embarrassingly parallel job of fixed size
- Assuming no overhead for distributing the work, and a perfectly even work distribution

  α: fraction of program run time which can't be parallelized (e.g. must run sequentially)

- Maximum speedup with a large number of processors (N):

$$S = 1/\alpha$$

Where $\alpha = \sigma / (\pi + \sigma)$

Where σ= sequential time, π =parallel time

Where $T(1) = \sigma + \pi$

And $T(N) = \sigma + \pi / N$, where N = parallel computations performed

AMDAHL'S LAW

- Alternate form (may see this form more often):

$$S = \frac{1}{(1-f) + \frac{f}{N}}$$

- f= fraction that is parallel
- N= number of processors

GUSTAFSON'S LAW

- Calculates the ***scaled speed-up*** using "N" processors

$$S(N) = N + (1 - N)\,\alpha$$

N: Number o

α: fraction o … parallelized
(e.g. must

- *Can be use … tion of program*

Here Gustafson's was also simplified, we need to substitute for α…

GUSTAFSON'S LAW

- Calculates the ***scaled speed-up*** using "N" processors

$$S(N) = N + (1 - N)\,\alpha$$

N: Number of processors

α: fraction of program run time which can't be parallelized
(e.g. must run sequentially)

- *Can be used to estimate runtime of parallel portion of program*
- Where $\alpha = \sigma / (\pi + \sigma)$
- Where σ= sequential time, π =parallel time
- → NEXT TIME will work to provide examples…

CLOUD COMPUTING: CONCEPTS AND MODELS

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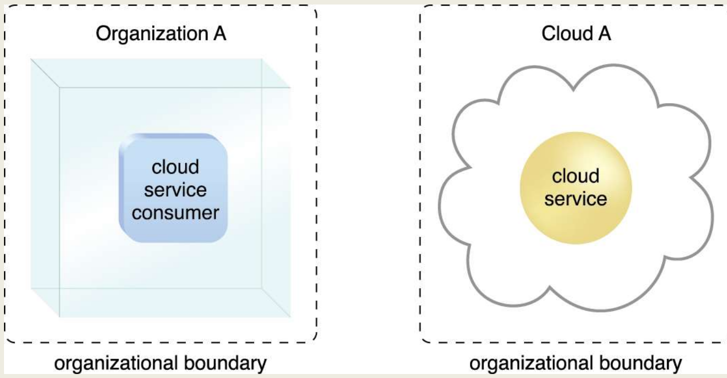
ROLES

- Cloud provider
  - Organization that provides cloud-based resources
  - Responsible for fulfilling SLAs for cloud services
  - Some cloud providers "resell" IT resources from other cloud providers
    - Example: Heroku sells PaaS services running atop of Amazon EC2
- Cloud consumers
  - Cloud users that consume cloud services
- Cloud service owner
  - Both cloud providers and cloud consumers can own cloud services
  - A cloud service owner may use a cloud provider to provide a cloud service (e.g. Heroku)

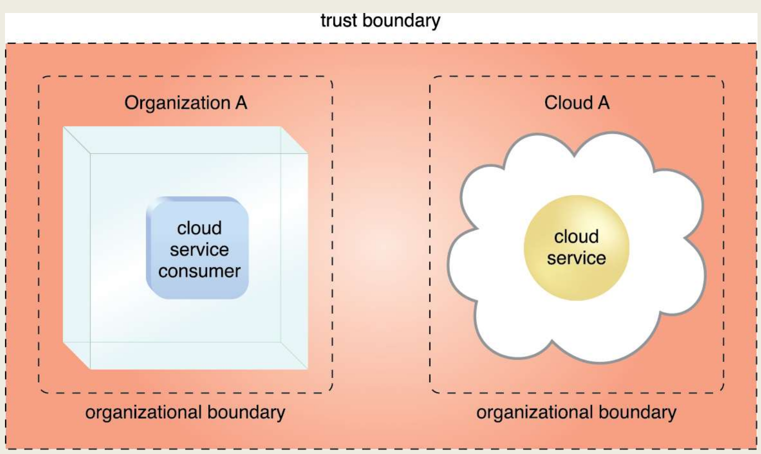
ROLES - 2

- Cloud resource administrator
  - Administrators provide and maintain cloud services
  - Both cloud providers and cloud consumers have administrators
- Cloud auditor
  - Third-party which conducts independent assessments of cloud environments to ensure security, privacy, and performance.
  - Provides unbiased assessments
- Cloud brokers
  - An intermediary between cloud consumers and cloud providers
  - Provides service aggregation
- Cloud carriers
  - Network and telecommunication providers which provide network connectivity between cloud consumers and providers

ORGANIZATION BOUNDARY



TRUST BOUNDARY



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CLOUD CHARACTERISTICS

- On-demand usage
- Ubiquitous access
- Multitenancy (resource pooling)
- Elasticity
- Measured usage
- Resiliency

- Assessing these features helps measure the value offered by a given cloud service or platform

ON-DEMAND USAGE

- The freedom to self-provision IT resources
- Generally with automated support
- Automated support requires no human involvement
- Automation through software services interface

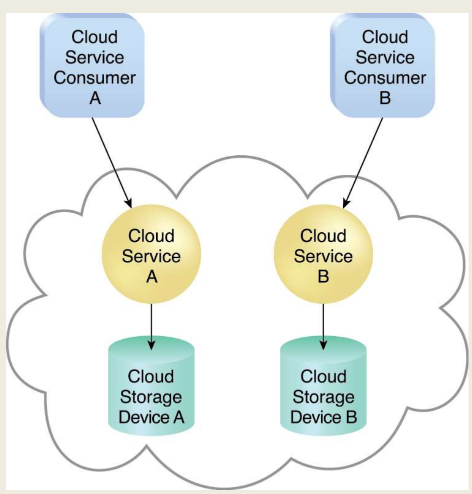
UBIQUITOUS ACCESS

- Cloud services are widely accessible
- Public cloud: internet accessible
- Private cloud: throughout segments of a company's intranet
- 24/7 availability

MULTITENANCY

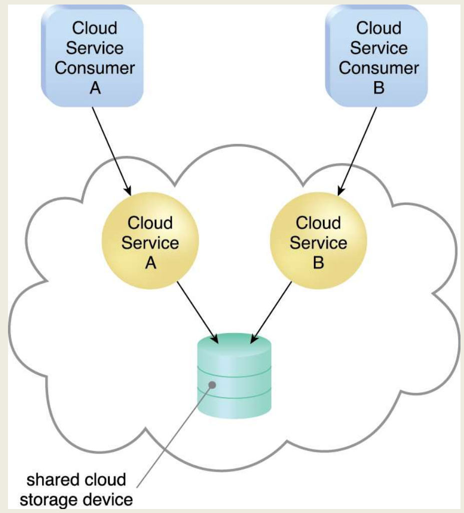
- Cloud providers pool resources together to share them with many users
- Serve multiple cloud service consumers
- IT resources can be dynamically assigned, reassigned based on demand
- Multitenancy can lead to performance variation

SINGLE TENANT MODEL

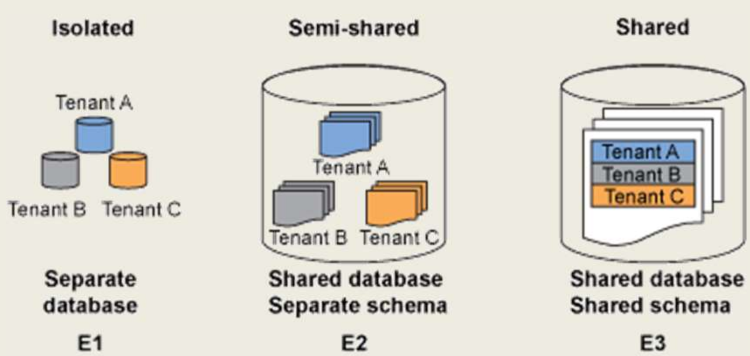


MULTITENANT MODEL

- Resource is "multiplexed" and share amongst multiple users
- Goal is to increase utilization
- Often server resources are underutilized
- There are many "sunk costs" whether usage is 0% or 100%
- Cloud computing tries to maximize "sunk cost" investments

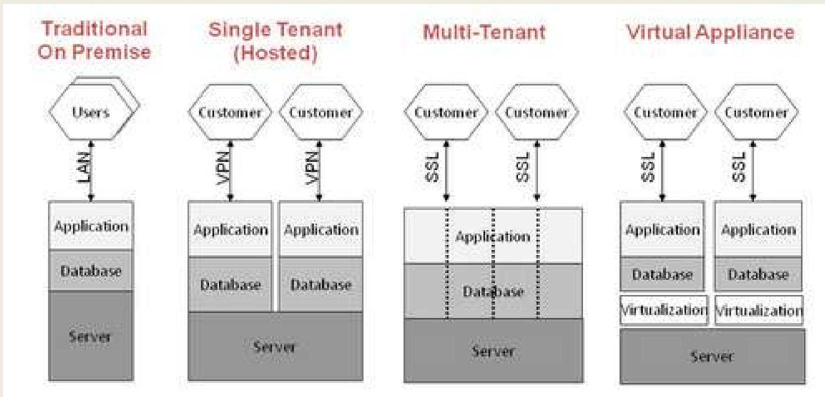


MULTITENANT DATABASE



MULTITENANCY OF RESOURCES

- Where is the multitenancy?

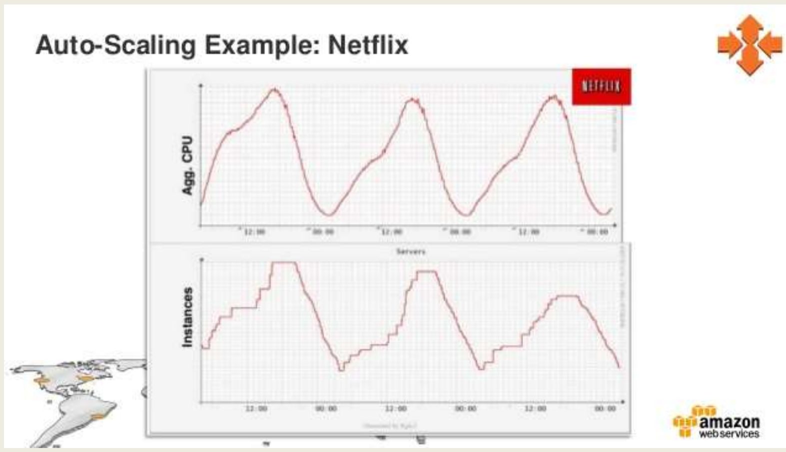


ELASTICITY

- Automated ability of cloud to transparently scale resources
- Scaling based on runtime conditions or pre-determined by cloud consumer or cloud provider
- Threshold based scaling
  - `CPU-utilization > threshold_A, Response_time > 100ms`
  - Application agnostic vs. application specific thresholds
  - Why might an application agnostic threshold be non-ideal?
- Load prediction
  - Historical models
  - Real-time trends

PREDICTABLE DEMAND

- Example:

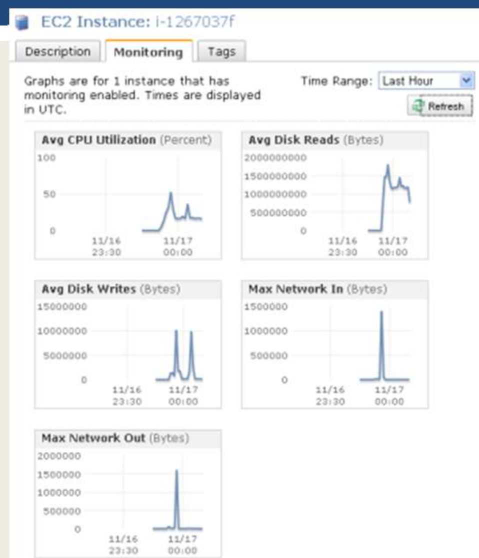


MEASURED USAGE

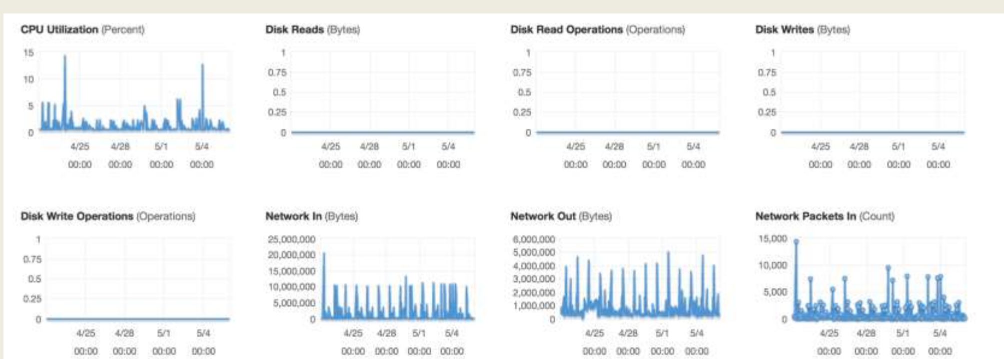
- Cloud platform tracks usage of IT resources
- For billing purposes
- Enables charging only for IT resources actually used
- Can be time-based (minute, hour, day)
- Can be throughput-based (MB, GB)

- Not all measurements are for billing
- Some measurements can support auto-scaling
- For example CPU utilization

EC2 CLOUDWATCH METRICS

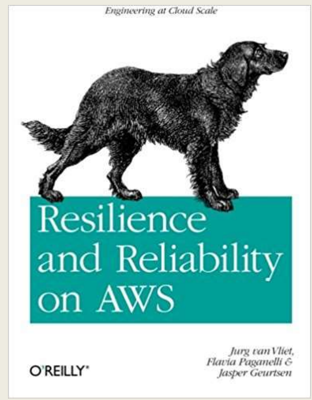


EC2 CLOUDWATCH METRICS



RESILIENCY

- Distributed redundancy across physical locations
- Used to improve reliability and availability of cloud-hosted applications
- Very much an engineering problem
- No "resiliency-as-a-service" for user deployed apps
- Unique characteristics of user applications make a one-size fits all service solution challenging



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CLOUD COMPUTING DELIVERY MODELS

- Infrastructure-as-a-Service (IaaS)
- Platform-as-a-Service (PaaS)
- Software-as-a-Service (SaaS)

Serverless Computing:

- Function-as-a-Service (FaaS)
- Container-as-a-Service (CaaS)
- Other Delivery Models

CLOUD COMPUTING DELIVERY MODELS

- Infrastructure-as-a-Service (IaaS) delivery model
- Virtualization is a key-enabling technology of IaaS cloud
- Uses virtual machines to deliver cloud resources to end users

CLOUD COMPUTING DELIVERY MODELS

Virtualization is key to sharing powerful servers among users by running _many_ isolated private virtual computers known as virtual machines (VMs)

…VMs are the basis of cloud v1.0

CLOUD COMPUTING DELIVERY MODELS

Virtual Machines are the building blocks for "Cloud Service Delivery Models"

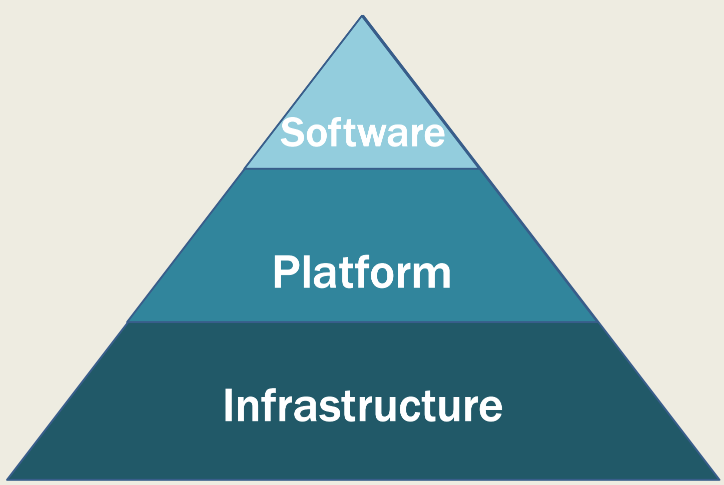
They are the "vehicles" used to deliver compute resources to end users…

cloud 1.0

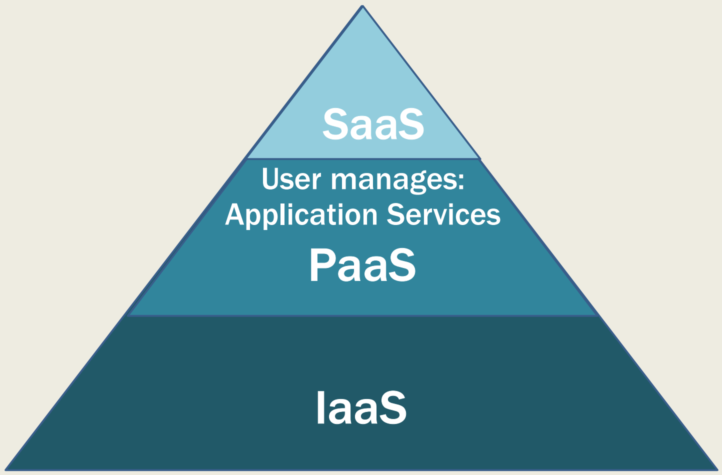
CLOUD DELIVERY MODELS

- What is the appropriate level of <u>**abstraction**</u>?
- How should applications be deployed?
  - IaaS, PaaS, SaaS, DbaaS, FaaS
- How do we ensure Quality-of-Service?
  - Performance, Availability, Responsiveness, Fault Tolerance
- How is <u>***scalability***</u> provided?
- As users, how do we minimize hosting costs?
  - How do we estimate hosting costs?

CLASSIC CLOUD DELIVERY MODELS



CLASSIC CLOUD DELIVERY MODELS



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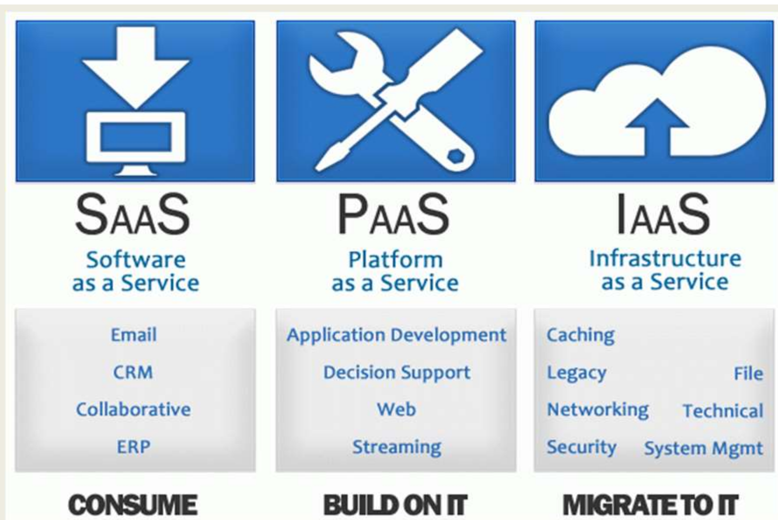
EXAMPLE CLOUD SERVICES



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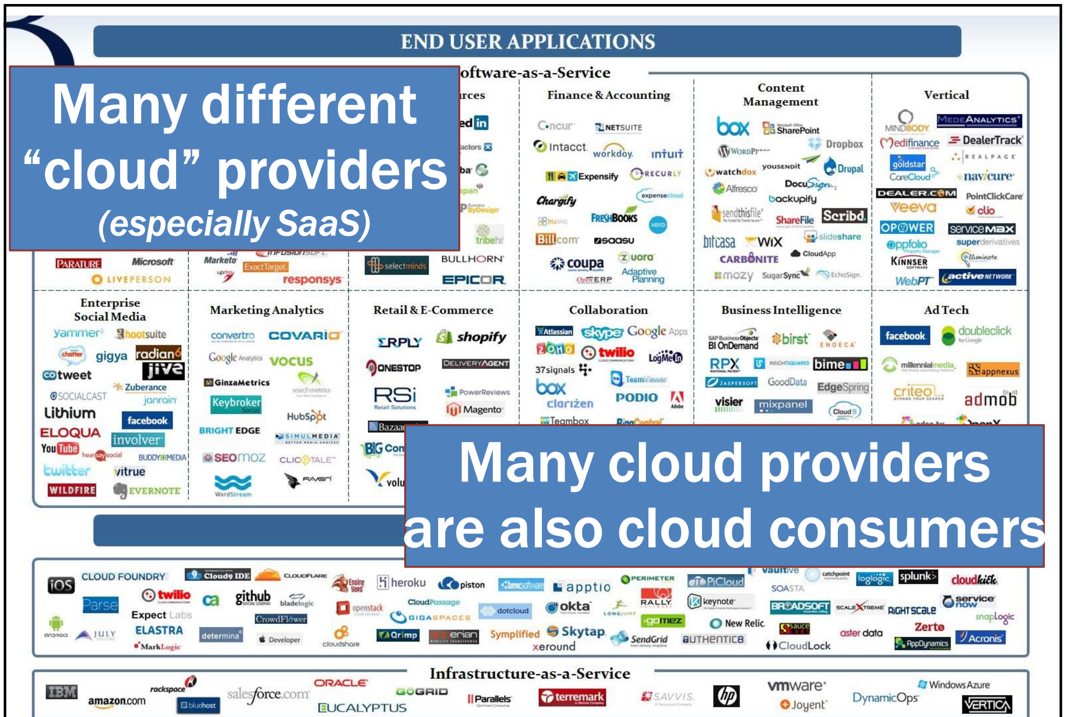

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INFRASTRUCTURE-AS-A-SERVICE

- Compute resources, on demand, as-a-service
  - Generally raw “IT” resources
  - Hardware, network, containers, operating systems
- Typically provided through virtualization
- Generally not-preconfigured
- Administrative burden is owned by cloud consumer
- Best when high-level control over environment is needed
- Scaling is generally **not** automatic…
- Resources can be managed in bundles
- AWS CloudFormation: Allows specification in JSON/YAML of cloud infrastructures

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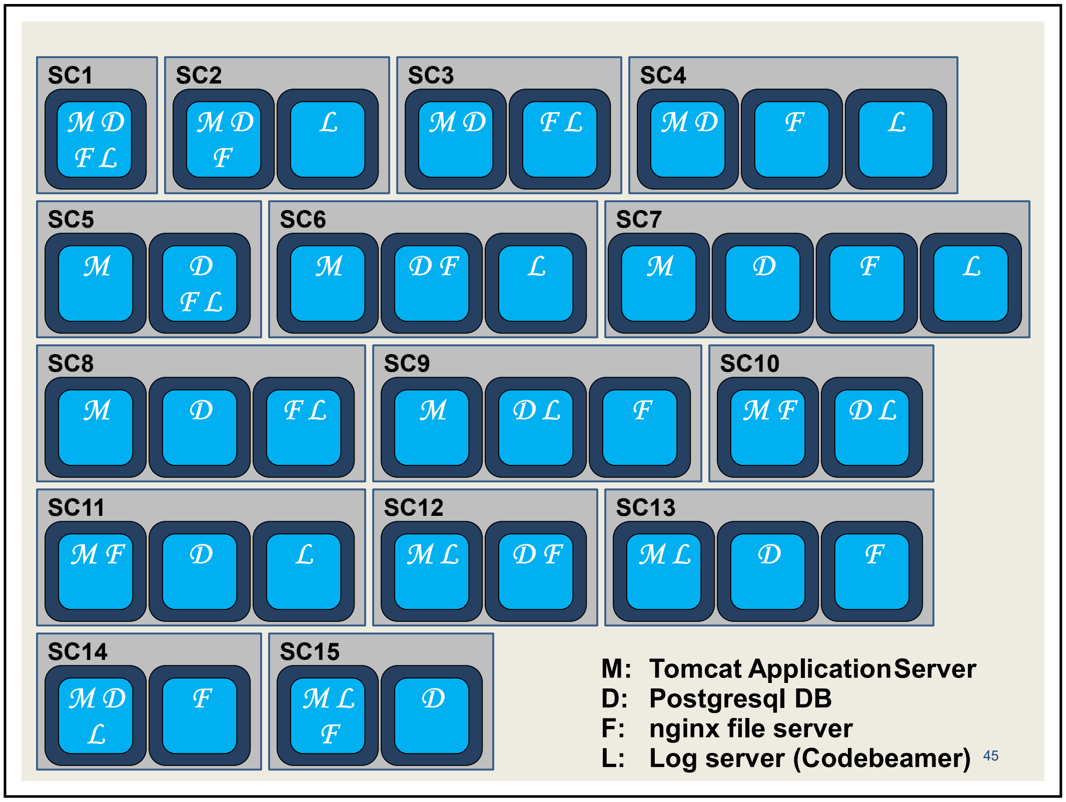
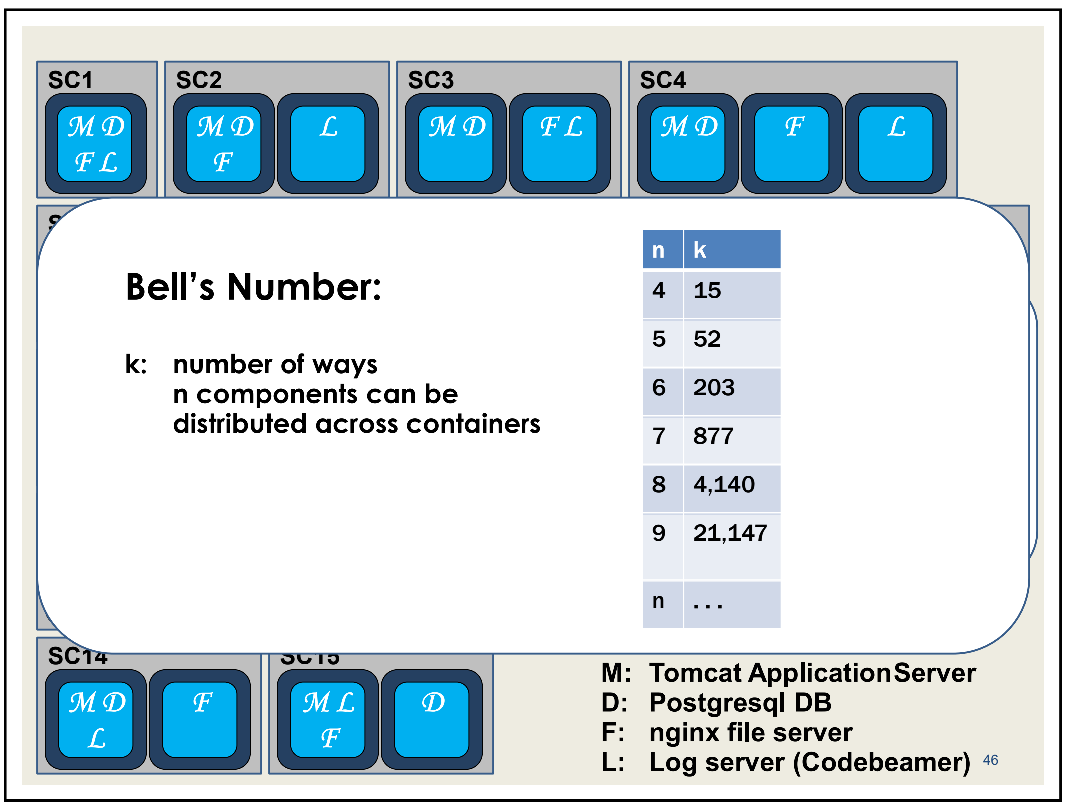
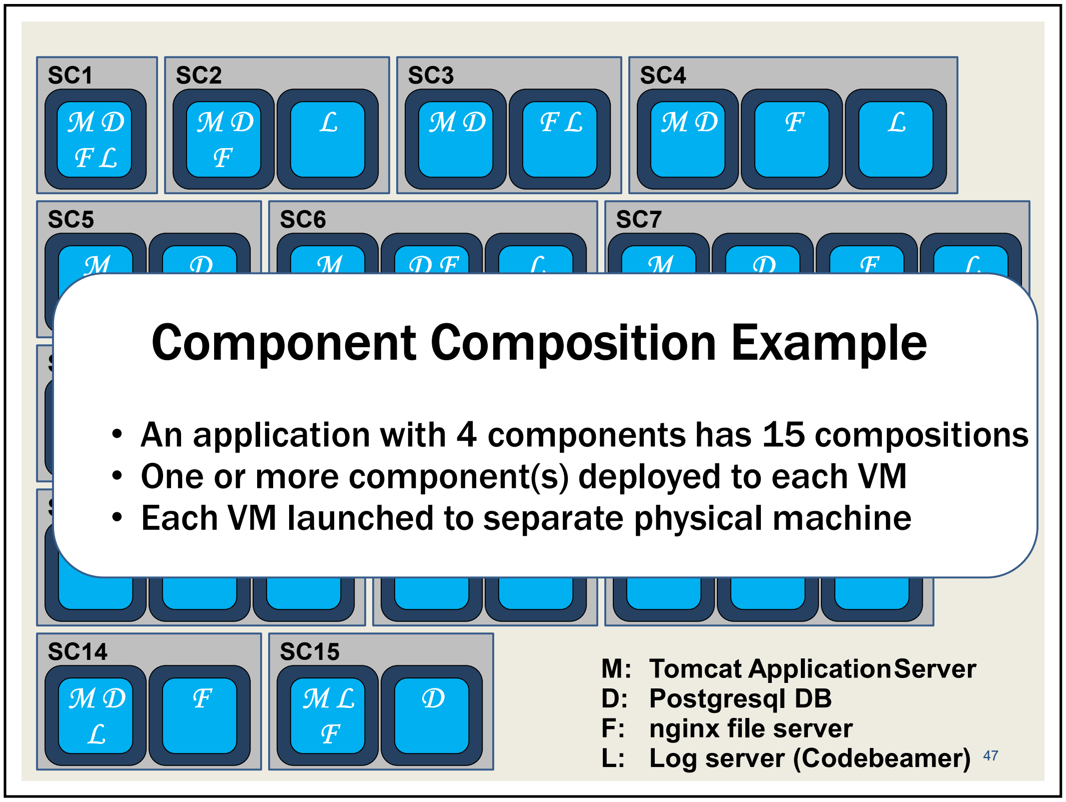


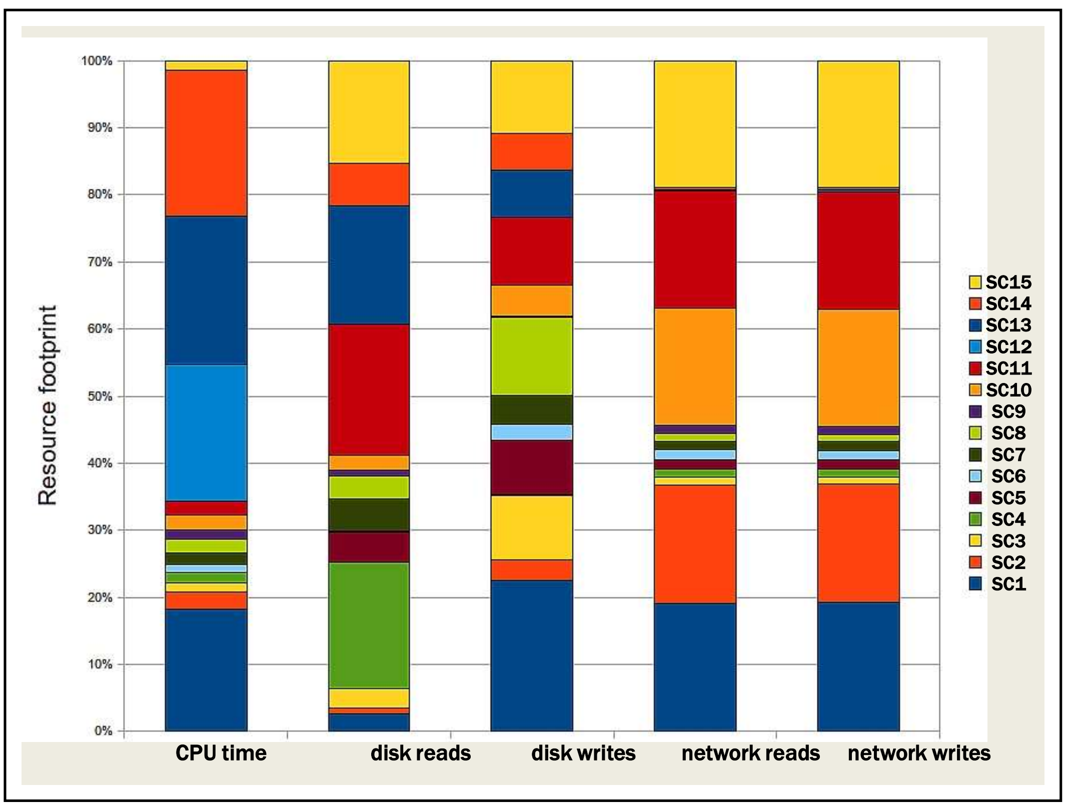


Bell's Number:

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	. . .

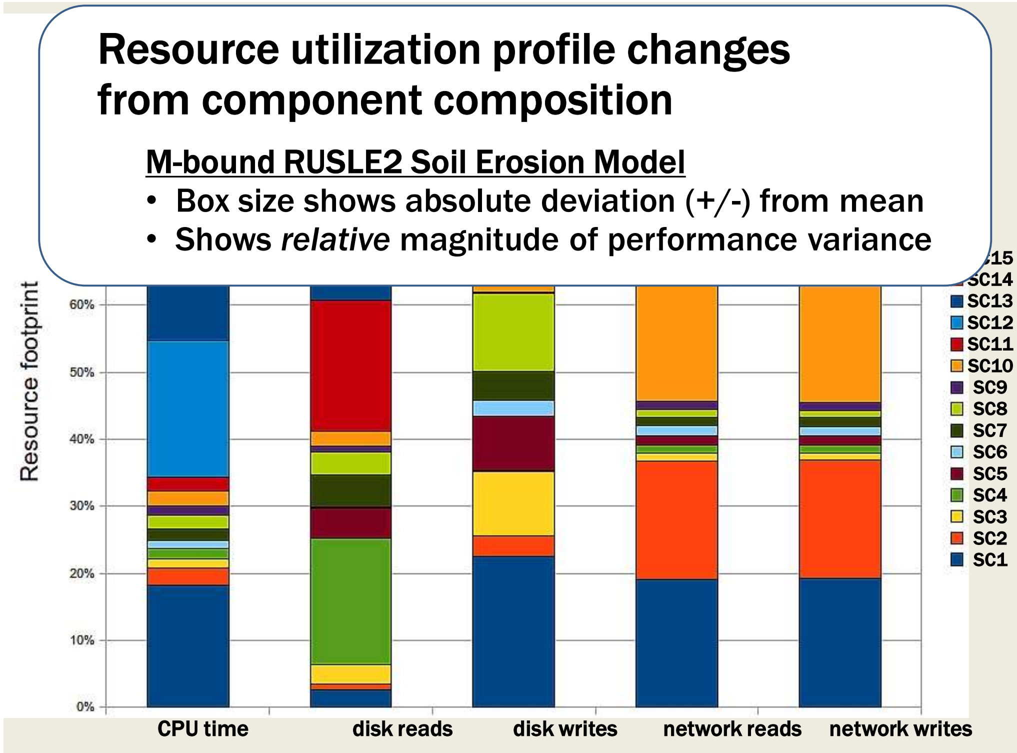

SC1
SC2
SC3
SC4
SC5
SC6
SC7
SC14
SC15
Component Composition Example
• An application with 4 components has 15 compositions
• One or more component(s) deployed to each VM
• Each VM launched to separate physical machine
M: Tomcat Application Server
D: Postgresql DB
F: nginx file server
L: Log server (Codebeamer)
47


Resource footprint
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
CPU time
disk reads
disk writes
network reads
network writes
SC15
SC14
SC13
SC12
SC11
SC10
SC9
SC8
SC7
SC6
SC5
SC4
SC3
SC2
SC1

Resource utilization profile changes from component composition

M-bound RUSLE2 Soil Erosion Model

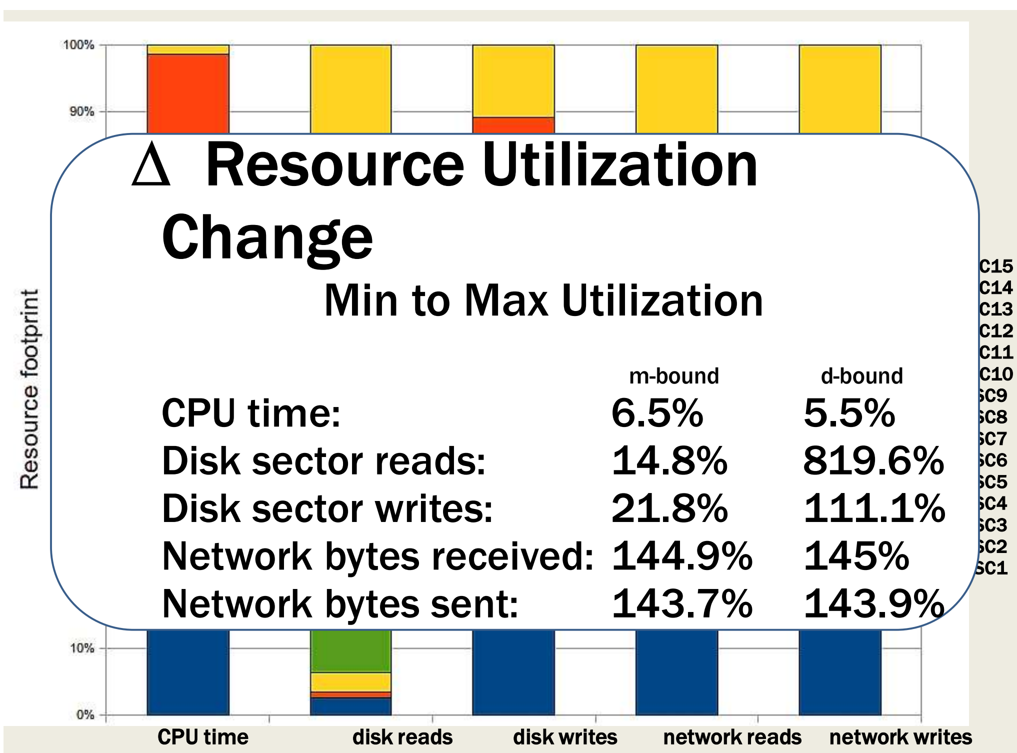
- Box size shows absolute deviation (+/-) from mean
- Shows *relative* magnitude of performance variance



Δ Resource Utilization Change

Min to Max Utilization

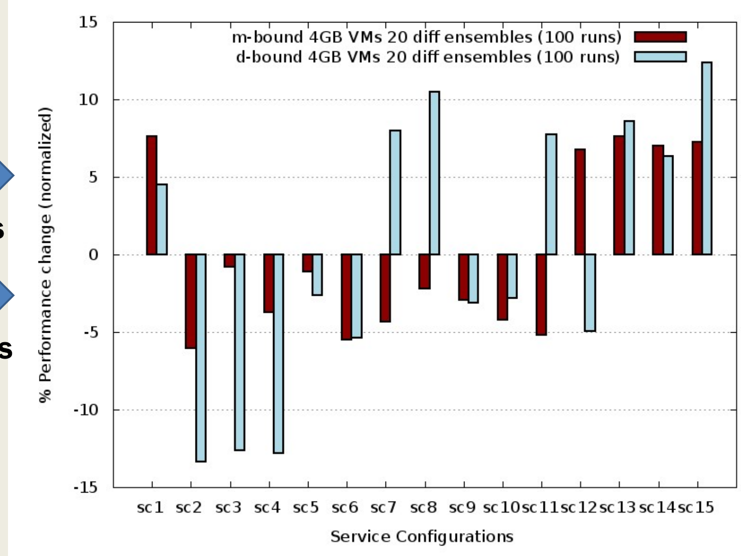
	m-bound	d-bound
CPU time:	6.5%	5.5%
Disk sector reads:	14.8%	819.6%
Disk sector writes:	21.8%	111.1%
Network bytes received:	144.9%	145%
Network bytes sent:	143.7%	143.9%



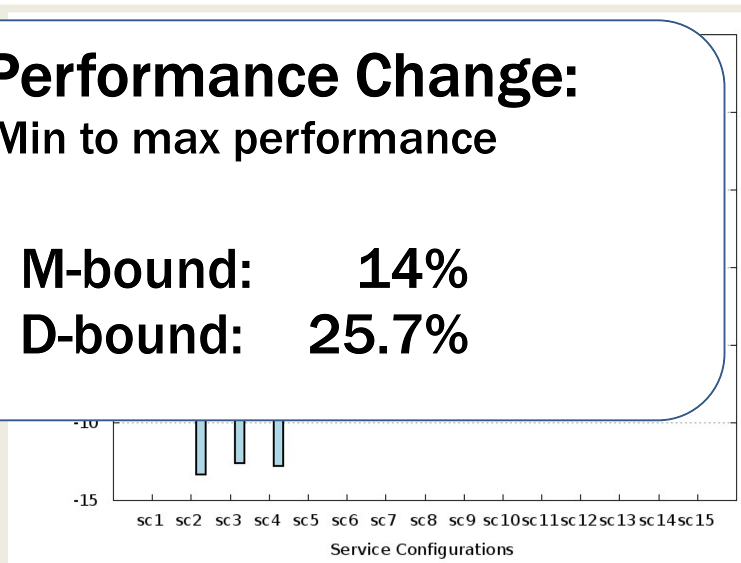
PERFORMANCE IMPLICATIONS OF APPLICATION DEPLOYMENTS

Slower deployments

Faster deployments



PERFORMANCE IMPLICATIONS OF APPLICATION DEPLOYMENTS



∆ Performance Change:

Min to max performance

M-bound: 14%

D-bound: 25.7%

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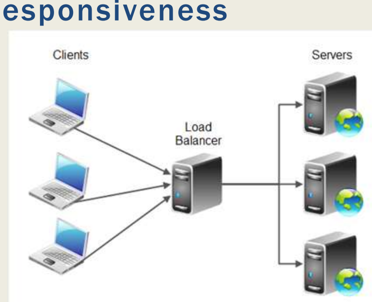
- Other Delivery Models

PLATFORM-AS-A-SERVICE

- Predefined, ready-to-use, hosting environment
- Infrastructure is further obscured from end user
- Scaling and load balancing may be automatically provided and automatic
- Variable to no ability to influence responsiveness

- Examples:
- Google App Engine
- Heroku
- AWS Elastic Beanstalk
- AWS Lambda (FaaS)



USES FOR PAAS

- Cloud consumer
  - Wants to extend on-premise environments into the cloud for “web app” hosting
  - Wants to entirely substitute an on-premise hosting environment
  - Cloud consumer wants to become a cloud provider and deploy its own cloud services to external users
- PaaS spares IT administrative burden compared to IaaS

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SOFTWARE-AS-A-SERVICE

- Software applications as shared cloud service
- Nearly all server infrastructure management is abstracted away from the user
- Software is generally configurable
- SaaS can be a complete GUI/UI based environment
- Or UI-free (database-as-a-service)

- SaaS offerings
  - Google Docs
  - Office 365
  - Cloud9 Integrated Development Environment
  - Salesforce

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SERVERLESS COMPUTING

Introducing Cloud 2.0

Image from: https://mobisoftinfotech.com/resources/blog/serverless-computing-deploy-applications-without-fiddling-with-servers/

SERVERLESS COMPUTING

How should my app withstand a server **failing**?

How can I tell if a server has been **compromised**?

How can I increase **utilization** of my servers?

Which **OS** should my servers run?

How much remaining **capacity** do my servers have?

How should I implement dynamic **configuration changes** on my servers

When should I decide to **scale up** my servers?

What size servers are right for my budget?

How will I keep my server OS **patched**?

How can I control **access from** my servers?

Which packages should be baked into my **server images**?

Servers

(AAHHHHHHHHH!!)

How will new code be **deployed** to my servers?

How will the application handle server **hardware failure**?

How many users create **too much load** for my servers?

What size server is right for my **performance**?

Which users should have **access to** my servers?

Should I **tune OS settings** to optimize my application?

When should I decide to **scale out** my servers?

How many servers should I budget for?

SERVERLESS COMPUTING

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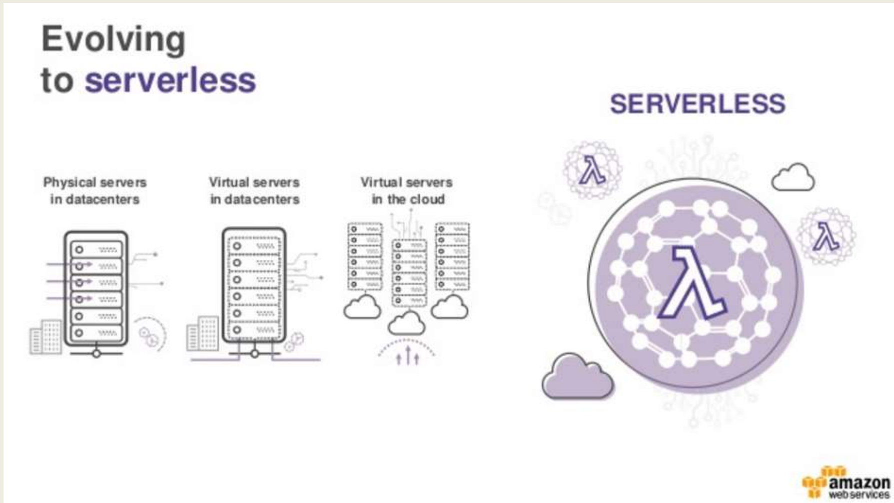
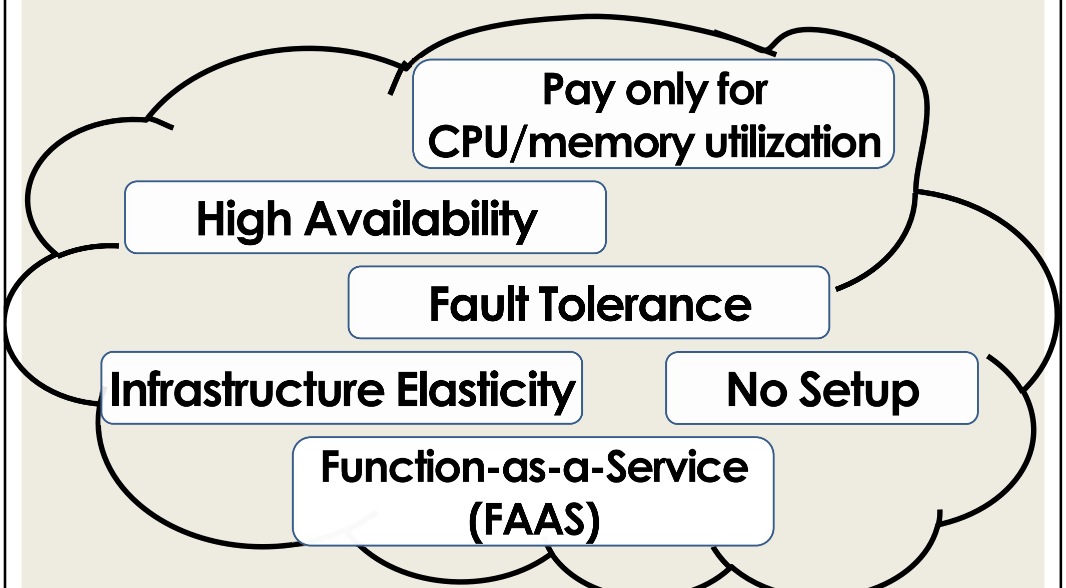
SERVERLESS COMPUTING - 2



SERVERLESS COMPUTING



SERVERLESS COMPUTING

Why Serverless Computing?

Many features of distributed systems, that are challenging to deliver, are provided automatically

…they are built into the platform

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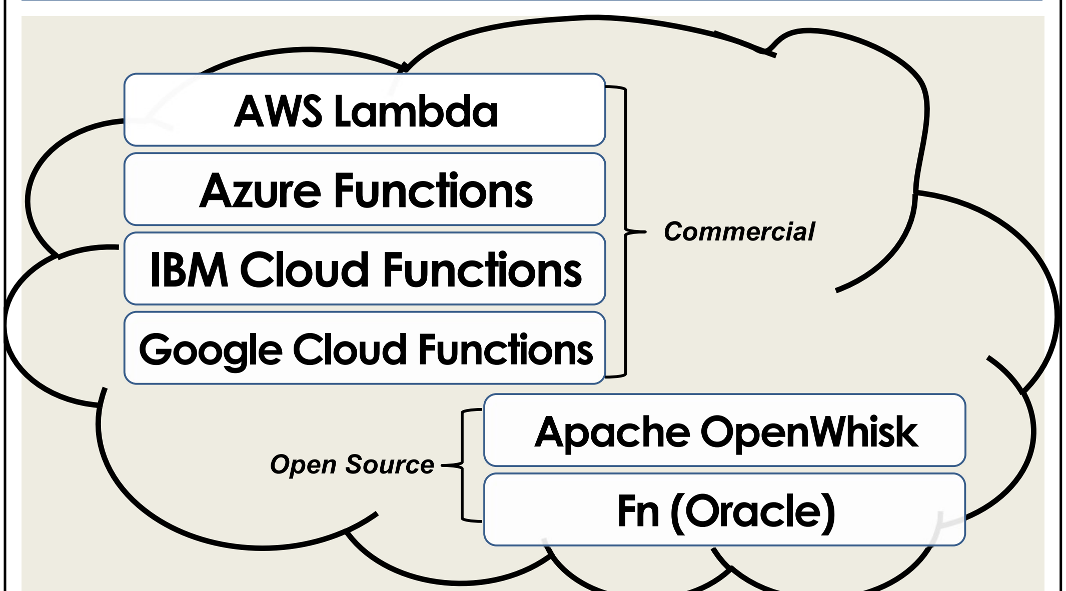
SERVERLESS VS. FAAS

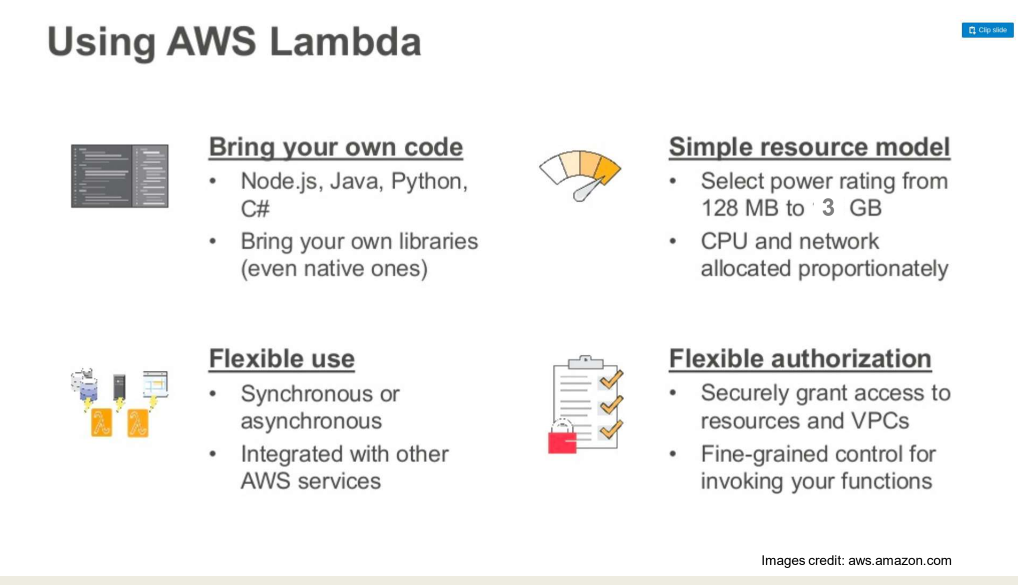
- Serverless Computing
- Refers to the avoidance of managing servers
- Can pertain to a number of "as-a-service" cloud offerings
- Function-as-a-Service (FaaS)
  - Developers write small code snippets (microservices) which are deployed separately
- Database-as-a-Service (DBaaS)
- Container-as-a-Service (CaaS)
- Others…

- Serverless is a buzzword
- This space is evolving…

FAAS PLATFORMS



AWS LAMBDA



FAAS PLATFORMS - 2

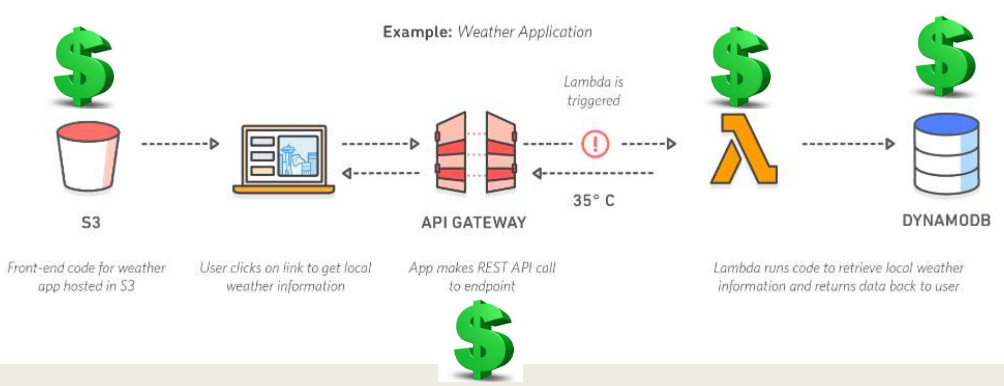
- New cloud platform for hosting application code
- Every cloud vendor provides their own:
  - AWS Lambda, Azure Functions, Google Cloud Functions, IBM OpenWhisk
- Similar to platform-as-a-service
- Replace opensource web container (e.g. Apache Tomcat) with abstracted vendor-provided black-box environment

FAAS PLATFORMS - 3

- Many challenging features of distributed systems are provided automatically
- ***Built into the platform:***
- Highly availability (24/7)
- Scalability
- Fault tolerance

CLOUD NATIVE SOFTWARE ARCHITECTURE

- Every service with a different pricing model



IAAS BILLING MODELS

- Virtual machines as-a-service at ¢ per hour
- No premium to scale:

```
        1000 computers   @     1 hour
=          1 computer    @  1000 hours
```

- Illusion of infinite scalability to cloud user
- As many computers as you can afford
- Billing models are becoming increasingly granular
  - By the minute, second, 1/10th sec
- Auction-based instances: Spot instances →

FAAS COMPUTING BILLING MODELS

- AWS Lambda Pricing
- FREE TIER:
  first 1,000,000 function calls/month → FREE
  first 400 GB-sec/month → FREE
- Afterwards: *obfuscated pricing (AWS Lambda):*
  $0.0000002 per request
  $0.000000208 to rent 128MB / 100-ms

WEBSERVICE HOSTING EXAMPLE

- **ON AWS Lambda**
- Each service call: 100% of 1 CPU-core
  100% of 4GB of memory
- Workload: 2 continuous client threads
- Duration: 1 month (30 days)

- **ON AWS EC2:**
- Amazon EC2 c4.large 2-vCPU VM
- Hosting cost: $72/month
  c4.large: 10¢/hour, 24 hrs/day x 30 days

- **How much would hosting this workload cost on AWS Lambda?**

PRICING OBFUSCATION

- Workload: 20,736,000 GB-sec
- FREE: - 400 GB-sec
- Ch ... ec
- M ... 04
- In
- FF
- Charge:
- Calls: $.84
- **Total: $345.88**
- **BREAK-EVEN POINT = ~4,326,927 GB-sec-month**

Worst-case scenario = ~4.8x !

AWS EC2: $72.00

AWS Lambda: $345.88

FAAS PRICING

- Break-even point is the point where renting VMs or deploying to a serverless platform (e.g. Lambda) is exactly the same.
- Our example is for one month
- Could also consider one day, one hour, one minute
- What factors influence the break-even point for an application running on AWS Lambda?

FACTORS IMPACTING PERFORMANCE OF FAAS COMPUTING PLATFORMS

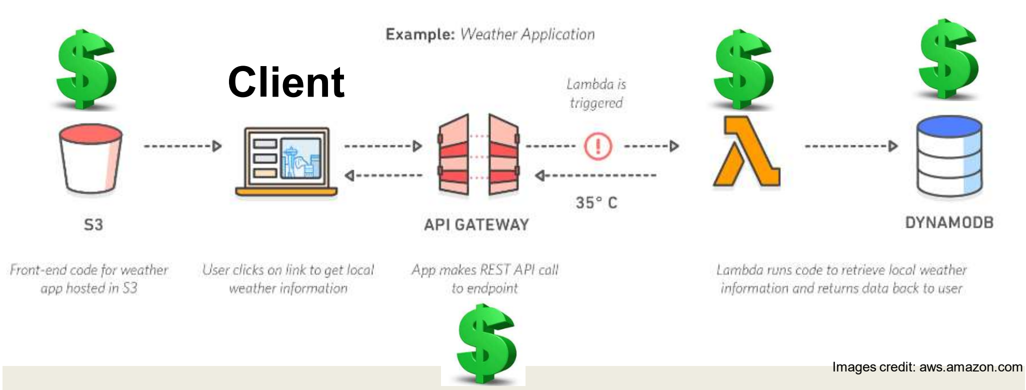
- Infrastructure elasticity
- Load balancing
- Provisioning variation
- Infrastructure retention: COLD vs. WARM
  - Infrastructure freeze/thaw cycle
- Memory reservation
- Service composition

FAAS CHALLENGES

- Vendor architectural lock-in – how to migrate?
- Pricing obfuscation – is it cost effective?
- Memory reservation – how much to reserve?
- Service composition – how to compose software?
- Infrastructure freeze/thaw cycle – how to avoid?

VENDOR ARCHITECTURAL LOCK-IN

- Cloud native (FaaS) software architecture requires external services/components



Images credit: aws.amazon.com

- Increased dependencies → increased hosting costs

PRICING OBFUSCATION

- **VM pricing:** hourly rental pricing, billed to nearest second is intuitive…
- **FaaS pricing:**

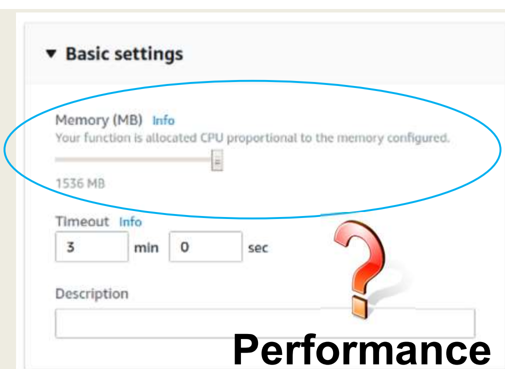
AWS Lambda Pricing

FREE TIER: first 1,000,000 function calls/month → FREE
first 400 GB-sec/month → FREE

- Afterwards: $0.0000002 per request
  $0.000000208 to rent 128MB / 100-ms

MEMORY RESERVATION QUESTION…

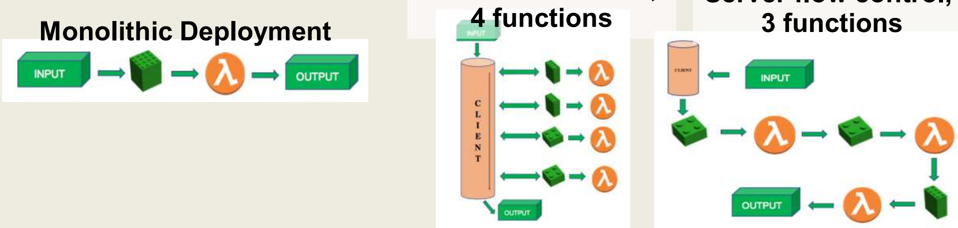
- Lambda memory reserved for functions
- UI provides "slider bar" to set function's memory allocation
- Resource capacity (CPU, disk, network) coupled to slider bar:
  "every doubling of memory, doubles CPU…"



- **But how much memory do model services require?**

SERVICE COMPOSITION

- How should application code be composed for deployment to serverless computing platforms?



- Recommended practice: Decompose into many microservices
- Platform limits: code + libraries ~250MB
- How does composition impact the number of function invocations, and memory utilization?

Performance

INFRASTRUCTURE FREEZE/THAW CYCLE

- Unused infrastructure is deprecated
  - *But after how long?*
- Infrastructure: VMs, "containers"
- <u>Provider-COLD / VM-COLD</u>
  - "Container" images - built/transferred to VMs
- <u>Container-COLD</u>
  - Image cached on VM
- <u>Container-WARM</u>
  - "Container" running on VM

Performance

Image from: Denver7 – The Denver Channel News

FUNCTION-AS-A-SERVICE

AWS
Lambda
Demo

85

CLOUD COMPUTING DELIVERY MODELS

- Infrastructure-as-a-Service (IaaS)
- Platform-as-a-Service (PaaS)
- Software-as-a-Service (SaaS)

Serverless Computing:

- Function-as-a-Service (FaaS)
- Container-as-a-Service (CaaS)
- Other Delivery Models

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CONTAINER-AS-A-SERVICE

- Cloud service model for deploying application containers (e.g. Docker) to the cloud
- Deploy containers without worrying about managing infrastructure:
  - Servers
  - Or container orchestration platforms
  - Container platform examples: Kubernetes, Docker swarm, Apache Mesos/Marathon, Amazon Elastic Container Service
  - Container platforms support creation of container clusters on the using cloud hosted VMs
- CaaS Examples:
  - AWS Fargate
  - Azure Container Instances
  - Google KNative

CLOUD COMPUTING DELIVERY MODELS

- Infrastructure-as-a-Service (IaaS)
- Platform-as-a-Service (PaaS)
- Software-as-a-Service (SaaS)

Serverless Computing:

- Function-as-a-Service (FaaS)
- Container-as-a-Service (CaaS)
- Other Delivery Models

OTHER CLOUD SERVICE MODELS

- IaaS
  - Storage-as-a-Service
- PaaS
  - Integration-as-a-Service
- SaaS
  - Database-as-a-Service
  - Testing-as-a-Service
  - Model-as-a-Service
- ?
  - Security-as-a-Service
  - Integration-as-a-Service

OBJECTIVES – 10/19

- Questions from 10/14
- From: Cloud Computing Concepts, Technology & Architecture: Cloud Computing Concepts and Models:
  - Roles and boundaries
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models
- 2nd hour:
- Introduce Tutorial #3 – Best Practices for Working with Virtual Machines on Amazon EC2
- Term project case studies
- Team planning

CLOUD DEPLOYMENT MODELS

- Distinguished by ownership, size, access
- Four common models
  - Public cloud
  - Community cloud
  - Hybrid cloud
  - Private cloud

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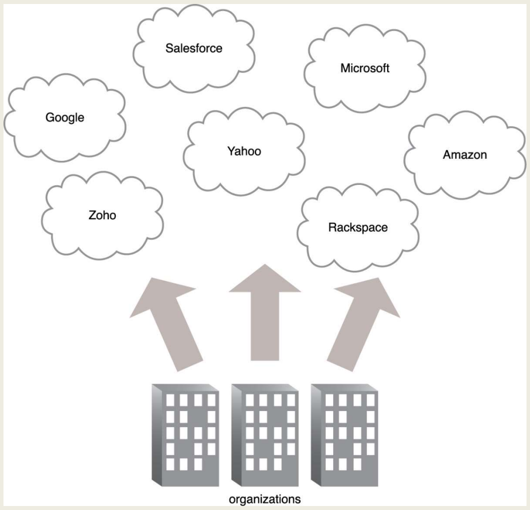
PUBLIC CLOUDS



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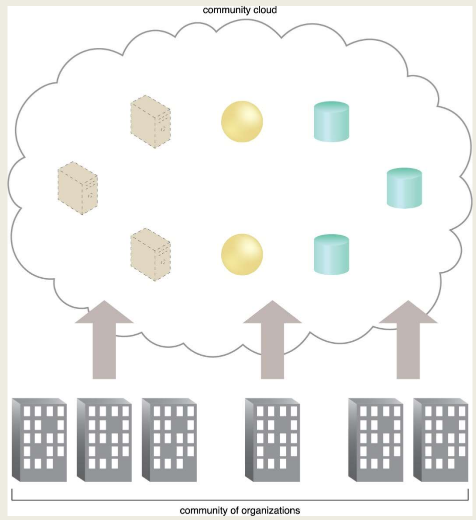
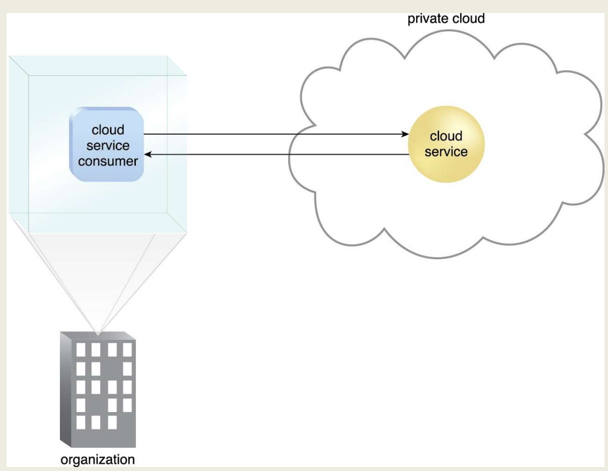
COMMUNITY CLOUD

- Specialized cloud built and shared by a particular community
- Leverage economies of scale within a community
- Research oriented clouds
- Examples:
  - Bionimbus - bioinformatics
  - Chameleon
  - CloudLab



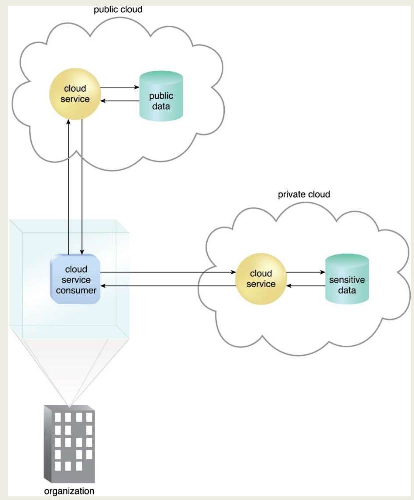
PRIVATE CLOUD

- Compute clusters configured as IaaS cloud
- Open source software
- Eucalyptus
- Openstack
- Apache Cloudstack
- Nimbus
- Virtualization: XEN, KVM, …



HYBRID CLOUD

- Extend private cloud typically with public or community cloud resources
- Cloud bursting:
  Scale beyond one cloud when resource requirements exceed local limitations
- Some resources can remain local for security reasons



OTHER CLOUDS

- Federated cloud
  - Simply means to aggregate two or more clouds together
  - Hybrid is typically private-public
  - Federated can be public-public, private-private, etc.
  - Also called inter-cloud
- Virtual private cloud
  - Google and Microsoft simply call these virtual networks
  - Ability to interconnect multiple independent subnets of cloud resources together
  - Resources allocated private IPs from individual network subnets can communicate with each other (10.0.1.0/24) and (10.0.2.0/24)
  - Subnets can span multiple availability zones within an AWS region

WE WILL RETURN AT ~7:12PM

TCSS 562 TERM PROJECT

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TCSS 562 TERM PROJECT

- Build a serverless cloud native application
- Application provides case study to investigate architecture/design trade-offs
  - Application provides a vehicle to compare and contrast one or more trade-offs

DESIGN TRADE-OFFS

- Service composition
  - Switchboard architecture:
    - compose services in single package
    - Address COLD Starts
    - Infrastructure Freeze/Thaw cycle of AWS Lambda (FaaS)
  - Full service isolation (each service is deployed separately)
- Application flow control
  - client-side, step functions, server-side controller, asynchronous hand-off
- Programming Languages
- Alternate FaaS Platforms

DESIGN TRADE-OFFS - 2

- Alternate Cloud Services (e.g. databases, queues, etc.)
  - Compare alternate data backends for data processing pipeline
- Performance variability (by hour, day, week, and host location)
  - Deployments (to different zones, regions)
- Service abstraction
  - Abstract one or more services with cloud abstraction middleware: Apache libcloud, apache jcloud; make code cross-cloud; measure overhead

OTHER PROJECT IDEAS

- Elastic File System (EFS)
  Performance & Scalability Evaluation
- Resource contention study using CpuSteal metric
- & others…

SERVERLESS APPLICATIONS

- Extract Transform Load Data Processing Pipeline
  - * >>>This is the STANDARD project<<< *
  - Batch-oriented data
  - Stream-oriented data
- Image Processing Pipeline
  - Apply series of filters to images
- Stream Processing Pipeline
  - Data conversion, filtering, aggregation, archival storage
    Can use AWS Kinesis Data Streams and DB backend:
  - https://aws.amazon.com/getting-started/hands-on/build-serverless-real-time-data-processing-app-lambda-kinesis-s3-dynamodb-cognito-athena/
  - Kinesis data streams claim multiple GB/sec throughput
  - What throughput can Lambda ingest directly?
  - What is the cost difference?

EXTRACT TRANSFORM LOAD DATA PIPELINE

- Service 1: TRANSFORM
- Read CSV file, perform some transformations
- Write out new CSV file
- Service 2: LOAD
- Read CSV file, load data into relational database
- Cloud DB (AWS Aurora), or local DB (Derby/SQLite)
  - Derby DB and/or SQLite code examples to be provided in Java

EXTRACT TRANSFORM LOAD DATA PIPELINE - 2

- Service 3: QUERY
- Using relational database, apply filter(s) and/or functions to aggregate data to produce sums, totals, averages
- Output aggregations as JSON

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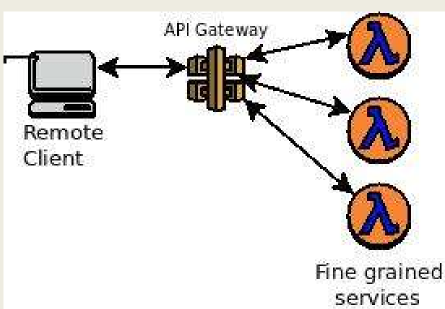
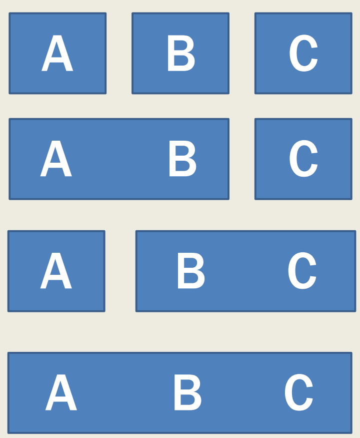
SERVICE COMPOSITION





3 services **Full Service Isolation**

2 services

2 services

1 service **Full Service Aggregation**

Other possible compositions: group by library, functional cohesion, etc.

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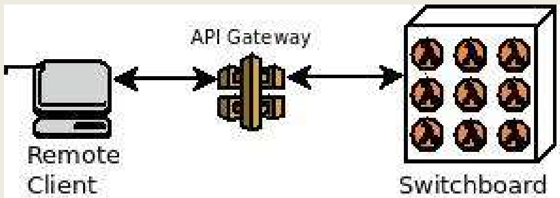
SWITCH-BOARD ARCHITECTURE



1 service

Single deployment package with consolidated codebase (Java: one JAR file)

Entry method contains "switchboard" logic
Case statement that route calls to proper service

Routing is based on data payload
Check if specific parameters exist, route call accordingly

Goal: reduce # of COLD starts to improve performance

APPLICATION FLOW CONTROL

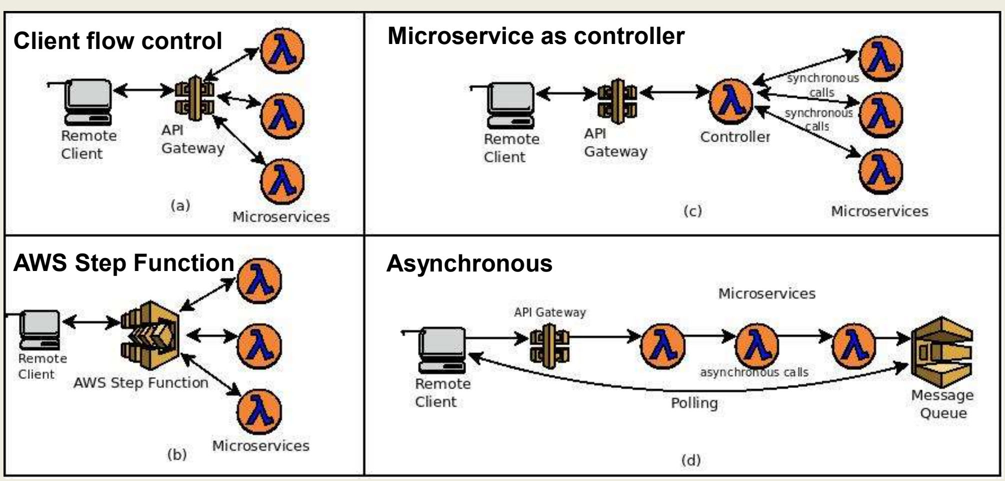
- Serverless Computing:
- AWS Lambda (FAAS: Function-as-a-Service)
- Provides HTTP/REST like web services
- Client/Server paradigm

- Synchronous web service:
- Client calls service
- Client blocks (freezes) and waits for server to complete call
- Connection is maintained in the "OPEN" state
- Problematic if service runtime is long!
  - Connections are notoriously dropped
  - System timeouts reached
- Client can't do anything while waiting unless using threads

APPLICATION FLOW CONTROL - 2

- Asynchronous web service
- Client calls service
- Server responds to client with OK message
- Client closes connection
- Server performs the work associated with the service
- Server posts service result in an external data store
  - AWS: S3, SQS (queueing service), SNS (notification service)

APPLICATION FLOW CONTROL - 3



PROGRAMMING LANGUAGE COMPARISON

- FaaS platforms support hosting code in multiple languages
- AWS Lambda- common: Java, Node.js, Python
  - Plus others: Go, PowerShell, C#, and Ruby
- Also Runtime API (“BASH”) which allows deployment of binary executables from any programming language
- August 2020 – Our group’s paper:
- https://tinyurl.com/y46eq6np
- If wanting to perform a language study either:
  - Implement in C#, Ruby, or multiple versions of Java, Node.js, Python
  - OR implement different app than TLQ (ETL) data processing pipeline

FAAS PLATFORMS

- Many commercial and open source FaaS platforms exist
- TCSS562 projects can choose to compare performance and cost implications of alternate platforms.
- Supported by SAAF:
- AWS Lambda
- Google Cloud Functions
- Azure Functions
- IBM Cloud Functions

DATA PROVISIONING

- Consider performance and cost implications of the data-tier design for the serverless application
- Use different tools as the relational datastore to support service #2 (LOAD) and service #3 (EXTRACT)

- **SQL / Relational:**
- Amazon Aurora (serverless cloud DB), Amazon RDS (cloud DB), DB on a VM (MySQL), DB inside Lambda function (SQLite, Derby)

- **NO SQL / Key/Value Store:**
- Dynamo DB, MongoDB, S3

PERFORMANCE VARIABILITY

- Cloud platforms exhibit performance variability which varies over time
- Goal of this case study is to measure performance variability (i.e. extent) for AWS Lambda services by hour, day, week to look for common patterns
- Can also examine performance variability by availability zone and region
  - Do some regions provide more stable performance?
  - Can services be switched to different regions during different times to leverage better performance?
- Remember that performance = cost
- If we make it faster, we make it cheaper…

ELASTIC FILE SYSTEM (AWS EFS)

- Traditionally AWS Lambda functions have been limited to 500MB of storage space
- Recently the Elastic File System (EFS) has been extended to support AWS Lambda
- The Elastic File System supports the creation of a shared volume like a shared disk (or folder)
  - EFS is similar to NFS (network file share)
  - Multiple AWS Lambda functions and/or EC2 VMs can mount and share the same EFS volume
  - Provides a shared R/W disk
  - Breaks the 500MB capacity barrier on AWS Lambda
- ***Downside: EFS is expensive: ~30 ¢/GB/month***
- **Project**: EFS performance & scalability evaluation on Lambda

CPUSTEAL

- *CpuSteal*: Metric that measures when a CPU core is ready to execute but the physical CPU core is busy and unavailable
- Symptom of over provisioning physical servers in the cloud
- Factors which cause *CpuSteal*:
  1. Physical CPU is shared by too many busy VMs
  2. Hypervisor kernel is using the CPU
     - On AWS Lambda this would be the Firecracker MicroVM which is derived from the KVM hypervisor
  3. VM's CPU time share <100% for 1 or more cores, and 100% is needed for a CPU intensive workload.
- Man procfs – press "/" – type "proc/stat"
  - CpuSteal is the 8th column returned
  - Metric can be read using SAAF in tutorial #4

CPUSTEAL CASE STUDY

- On AWS Lambda (or other FaaS platforms), when we run functions, how much CpuSteal do we observe?
- How does CpuSteal vary for different workloads? (e.g. functions that have different resource requirements)
- How does CpuSteal vary over time hour, day, week, location?
- How does CpuSteal relate to function performance?

QUESTIONS

QUESTIONS

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OFFICE HOURS

PLEASE SAY HELLO

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