TCSS 562: SOFTWARE ENGINEERING FOR CLOUD COMPUTING

Cloud Computing Concepts and Models - III

Wes J. Lloyd
School of Engineering and Technology
University of Washington – Tacoma

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OFFICE HOURS – FALL 2025

- **Thursdays:**
  - 6:00 to 7:00 pm - CP 229 & Zoom
- **Friday – *** THIS WEEK *****
  - 11:00 am to 12:00 pm – ONLINE via Zoom
- Or email for appointment

> *Office Hours set based on Student Demographics survey feedback*

> ** - Friday office hours may be adjusted or canceled due meeting conflicts or other obligations. Adjustments will be announced via Canvas.*

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OBJECTIVES – 10/28

- Questions from 10/23
- Tutorials Questions
- Tutorial 5 - Files in S3 and CloudWatch Events
- Activity 2 Review
- From: Cloud Computing Concepts, Technology & Architecture: Chapter 4: Cloud Computing Concepts and Models:
  - Cloud computing delivery models
  - Cloud deployment models
- AWS Overview and demo

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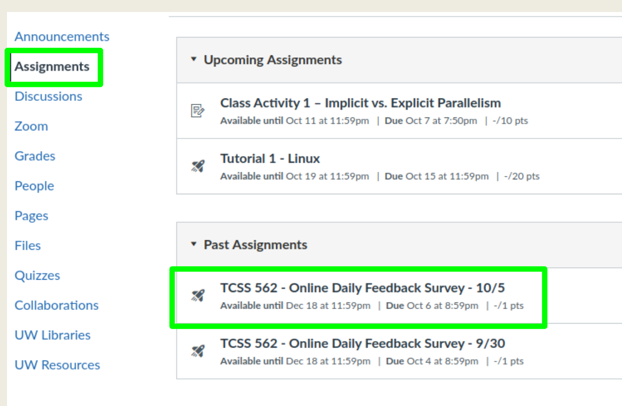
ONLINE DAILY FEEDBACK SURVEY

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



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TCSS 562 - Online Daily Feedback Survey - 10/5

Started: Oct 7 at 1:13am

Quiz Instructions

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

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MATERIAL / PACE

- Please classify your perspective on material covered in today's class (43 respondents, 25 in-person, 18 online):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 7.19 (↓ - *previous 7.32*)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.49 (↑ - previous 5.24)**

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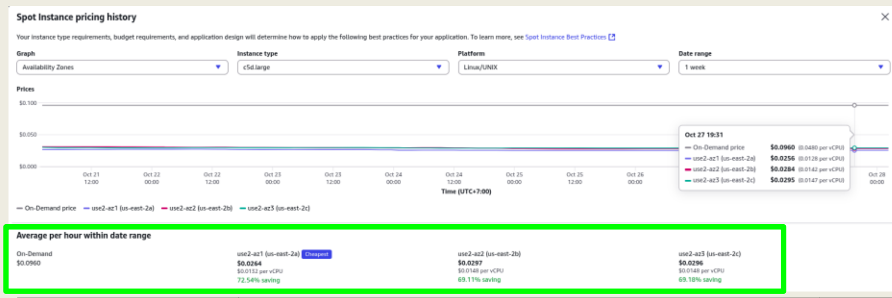
QUESTIONS FROM 10/23

- ***Why does the average $/hour price within a date range change even though the same region is used (Ohio)***
  - The average price shows is shown for each availability zone within the region over the time span of graph (3 hrs, 1 day, 1 week, 1 month, 3 months)



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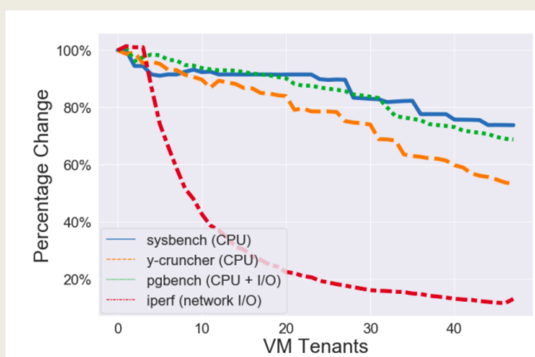
FEEDBACK - 2

- ***Least clear point: With more VMs running, the multi-tenancy drops despite best efforts at isolation***
  - The graph shows increasing multi-tenancy from left to right
    - more VMs running…
  - What drops is the performance of our 4 benchmarking applications: sysbench (prime number gen), y-cruncher, pgbench, and iperf



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FEEDBACK - 3

- ***What is "session state" in a client/server application ?***
  - AWS Lambda functions are considered "**stateless**"
- ***What is "stateless" ?***
  - Each time a client calls an AWS Lambda function, requests are routed to a random function instance (worker) to process the call
  - If a client makes multiple calls, there is no guarantee it will run in the same function instance each time
  - AWS Lambda functions feature static global memory, but if client calls do not return to the same function instance, this memory can't be used to store session state
- ***Key Design Issue With Serverless Applications:***
  - ***How do you persist session state on AWS Lambda ?***

PRACTICE QUESTION 1

- Which of the following can lead to performance problems for application hosting on cloud platforms ?

A. Resource sharing/contention
B. Cloud consumer under-provisioning
C. Heterogeneous hardware
D. Cloud provider over-provisioning
E. All of the above

PRACTICE QUESTION 2

- Which cloud computing delivery model often requires manual configuration to provide resource elasticity?

A. Platform-as-a-Service
B. Infrastructure-as-a-Service
C. Serverless Database
D. Function-as-a-Service
E. All of the above

PRACTICE QUESTION 3

- On Amazon EC2, when using persistent spot requests, what occurs when you intentionally terminate the virtual machine?

A. In addition to the virtual machine being deleted, the persistent spot request is also deleted
B. VM termination is not supported using persistent spot requests
C. Using the AWS management console, the user is prompted to enter a password prior to deletion of the virtual machine
D. After a short delay, a replacement virtual machine is launched to satisfy the persistent spot request
E. The virtual machine is stopped, not terminated, and can be later resumed without loss of data on the disk

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TUTORIAL 3 – OCT 30 (TEAMS OF 2)

- Best Practices for Working with Virtual Machines on Amazon EC2
- https://faculty.washington.edu/wlloyd/courses/tcss562/tutorials/TCSS462_562_f2025_tutorial_3.pdf
- Creating a spot VM
- Creating an image from a running VM
- Persistent spot request
- Stopping (pausing) VMs
- EBS volume types
- Ephemeral disks (local disks)
- Mounting and formatting a disk
- Disk performance testing with Bonnie++
- Cost Saving Best Practices

TUTORIAL 4 – NOV 7

- Introduction to AWS Lambda with the Serverless Application Analytics Framework (SAAF)

  https://faculty.washington.edu/wlloyd/courses/tcss562/tutorials/TCSS462_562_f2025_tutorial_4.pdf

- Set up Java development environment
- Introduction to Maven build files for Java
- Create and Deploy "hello" Java AWS Lambda Function
- Create API Gateway REST endpoint
- Sequential testing of "hello" AWS Lambda Function
  - API Gateway endpoint, AWS Lambda CLI Function invocation, AWS Function URL
- Profiling function performance with SAAF
- Concurrent function testing with faas_runner
- Performance analysis using faas_runner reports
- Two function pipeline development task: Caesar Cipher

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TUTORIAL 5 – TO BE POSTED

- Introduction to Lambda II: Working with Files in S3 and CloudWatch Events
- Customize the Request object (add getters/setters)
  - Why do this instead of HashMap ?
- Import dependencies (jar files) into project for AWS S3
- Create an S3 Bucket
- Give your Lambda function(s) permission to work with S3
- Write to the CloudWatch logs
- Use of CloudTrail to generate S3 events
- Creating CloudWatch rule to capture events from CloudTrail
- Have the CloudWatch rule trigger a target Lambda function with a static JSON input object (hard-coded filename)
- **Optional**: for the S3 PutObject event, dynamically extract the name of the file put to the S3 bucket for processing

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CLOUD COMPUTING: CONCEPTS AND MODELS

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CATCH UP FROM 10/23

- Questions from 10/16
- Tutorials Questions
- Tutorial 4 – Intro to FaaS – AWS Lambda
- Background on AWS Lambda for the Term Project - II
- From: Cloud Computing Concepts, Technology & Architecture: Chapter 4: Cloud Computing Concepts and Models:
  - Roles and boundaries
  - **Cloud characteristics**
  - Cloud delivery models
  - Cloud deployment models
- Team Planning - Breakout Rooms

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CLOUD CHARACTERISTICS

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

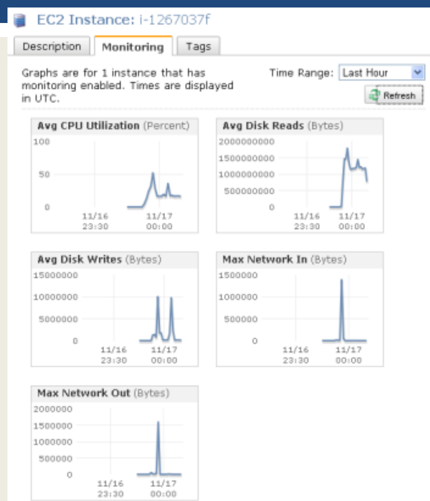
- Assessing these features helps measure the value offered by a given cloud service or platform

MEASURED USAGE

- Cloud platform tracks usage of IT resources
- For billing purposes
- Enables charging only for IT resources actually used
- Can be time-based (millisec, second, minute, hour, day)
  - Granularity is increasing…
- Can be throughput-based (data transfer: MB/sec, GB/sec)
- Can be resource/reservation based (vCPU/hr, GB/hr)

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

EC2 CLOUDWATCH METRICS



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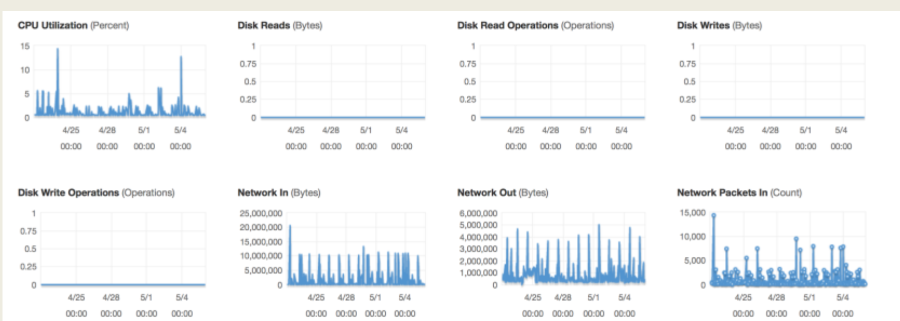
EC2 CLOUDWATCH METRICS



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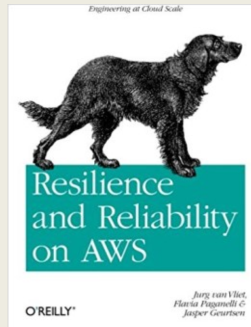
RESILIENCY

- Distributed redundancy across physical locations (regions on AWS)
- 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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Elasticity is often provided using threshold based scaling. When can threshold based scaling (i.e. CPU utilization > 80%) under or over provision resources?

- When the application is primarily I/O bound, a CPU threshold may never be met, or be met too late to scale up. **A**
- When the current resource utilization does not reflect future system demand. **B**
- When the current resource utilization (e.g. CPU) is temporarily increased as a result of external factors (i.e. resource contention from other tasks) that does not correlate to system demand. **C**
- When an application will soon complete a parallel phase, before executing a largely sequential phase **D**
- All of the above **E**

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When poll is active, respond at **pollev.com/wesleylloyd641**
Text **WESLEYLLOYD641** to **22333** once to join

The scaling threshold of "when CPU utilization > 80% scale up", is:

An application specific threshold

An application agnostic threshold

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

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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

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CLOUD COMPUTING DELIVERY MODELS

- Infrastructure-as-a-Service (IaaS) delivery model

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

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CLOUD COMPUTING DELIVERY MODELS

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

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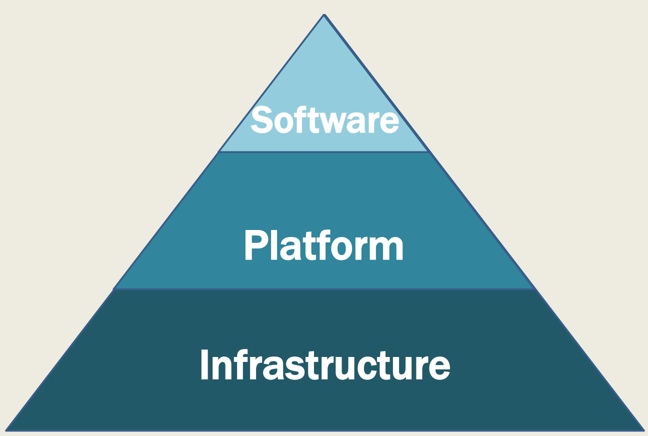
CLASSIC CLOUD COMPUTING DELIVERY MODELS



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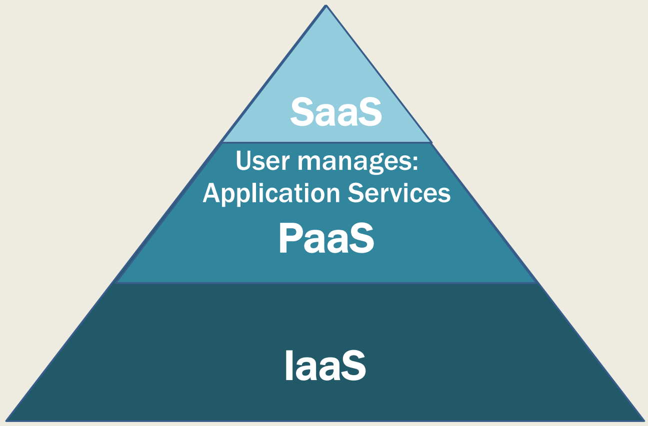
CLASSIC CLOUD COMPUTING DELIVERY MODELS



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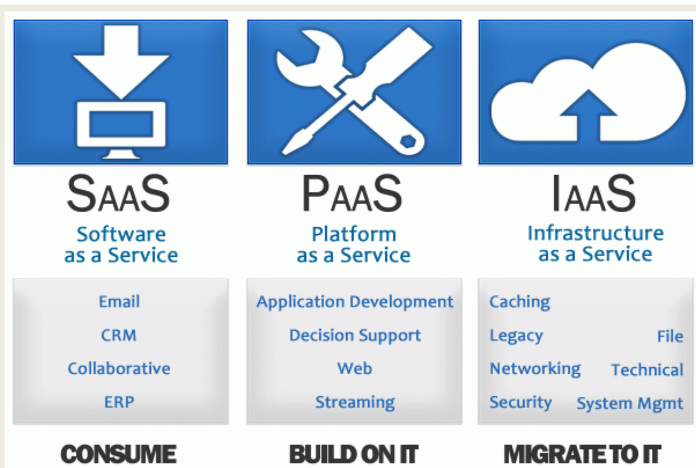
EXAMPLE CLOUD SERVICES



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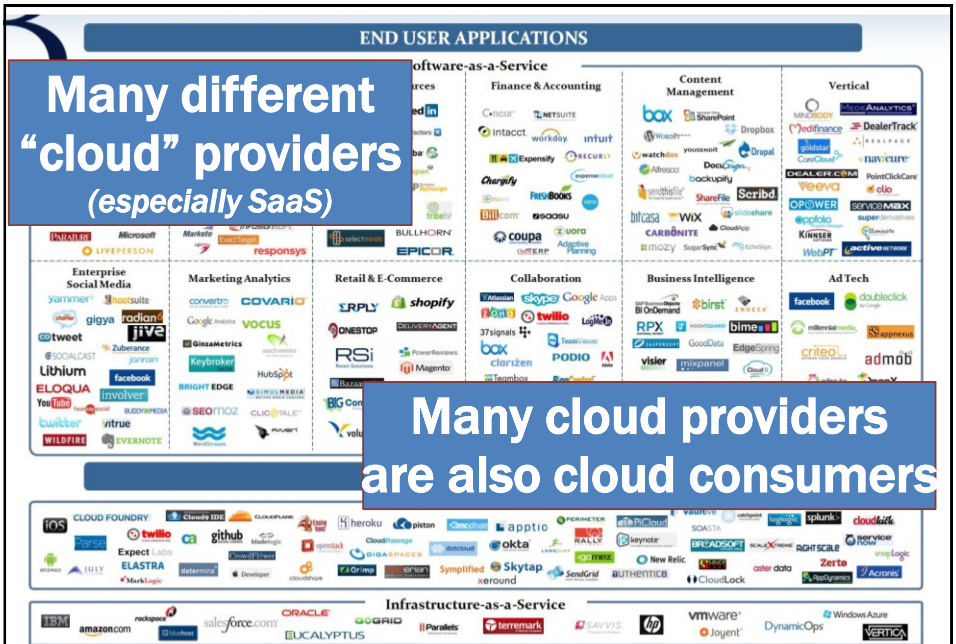

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INFRASTRUCTURE-AS-A-SERVICE

- 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**: Scripts to specify creation of cloud infrastructures using JSON/YAML for app deployment

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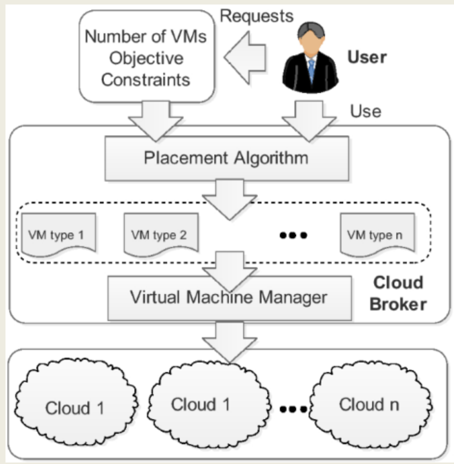
IAAS: VIRTUAL MACHINE PLACEMENT IN THE CLOUD



Controlled by the cloud provider

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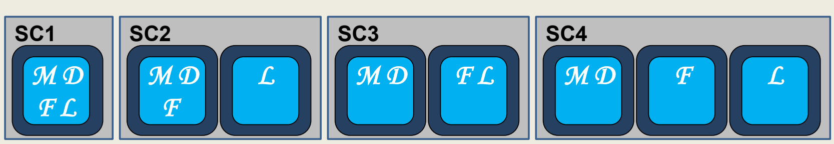
COMPONENT COMPOSITION

- Cloud provider maps VMs to physical servers
- User controls mapping of services to VM images
  - Should components be separated (isolated) ?
  - Should components be combined ?
  - M – modeling web service
  - D – relational database
  - F – file server
  - L – logging server



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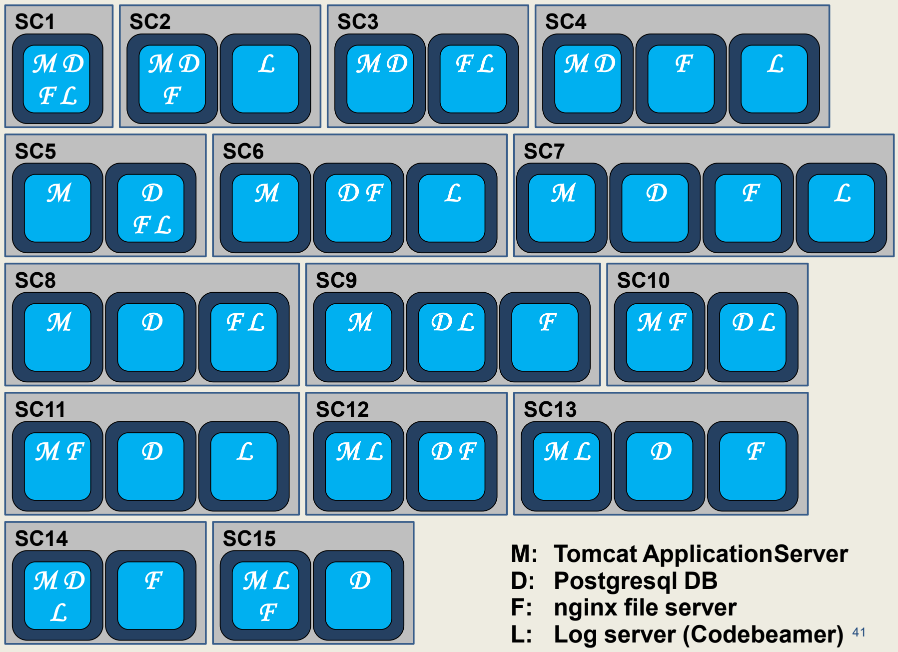

M: Tomcat ApplicationServer
D: Postgresql DB
F: nginx file server
L: Log server (Codebeamer) 41

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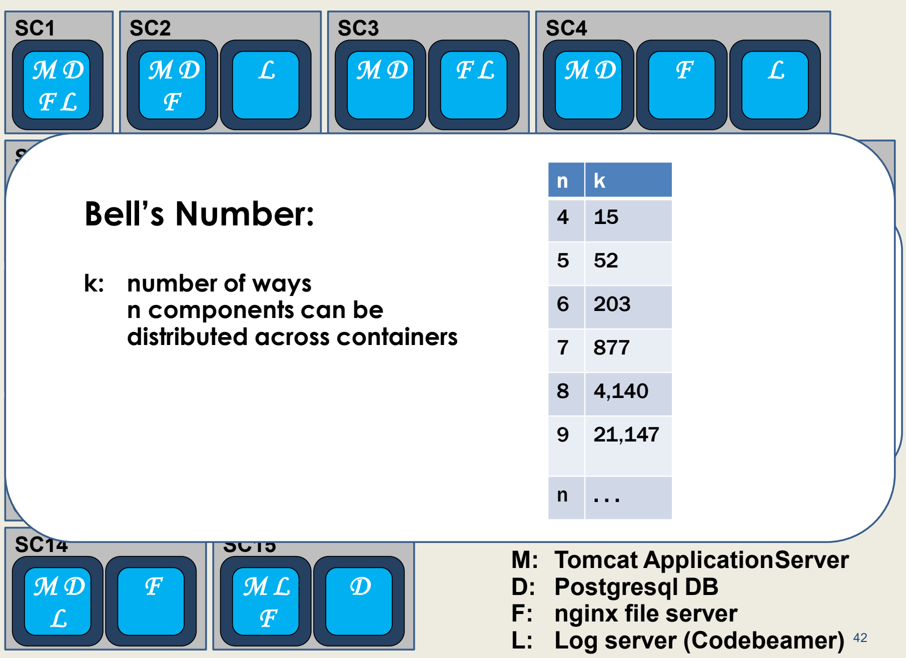

Bell's Number:

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 ApplicationServer
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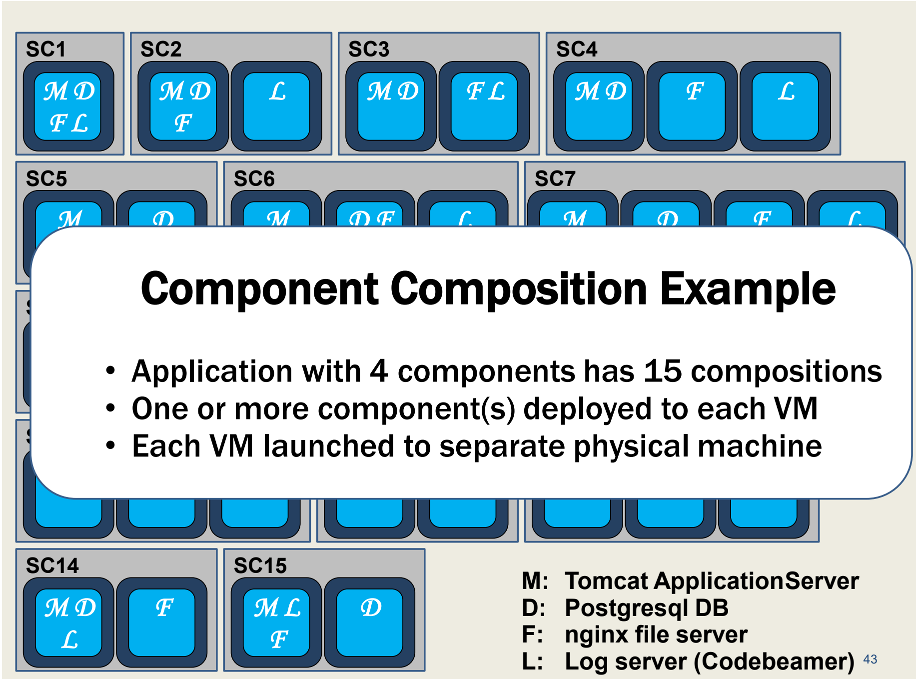

Component Composition Example

- Application with 4 components has 15 compositions
- One or more component(s) deployed to each VM
- Each VM launched to separate physical machine

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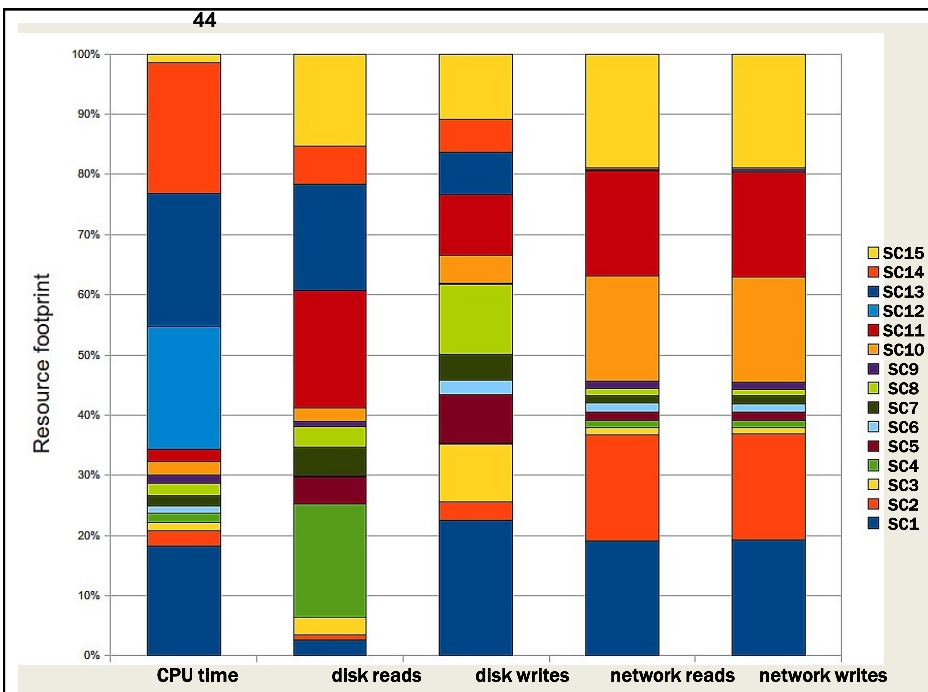

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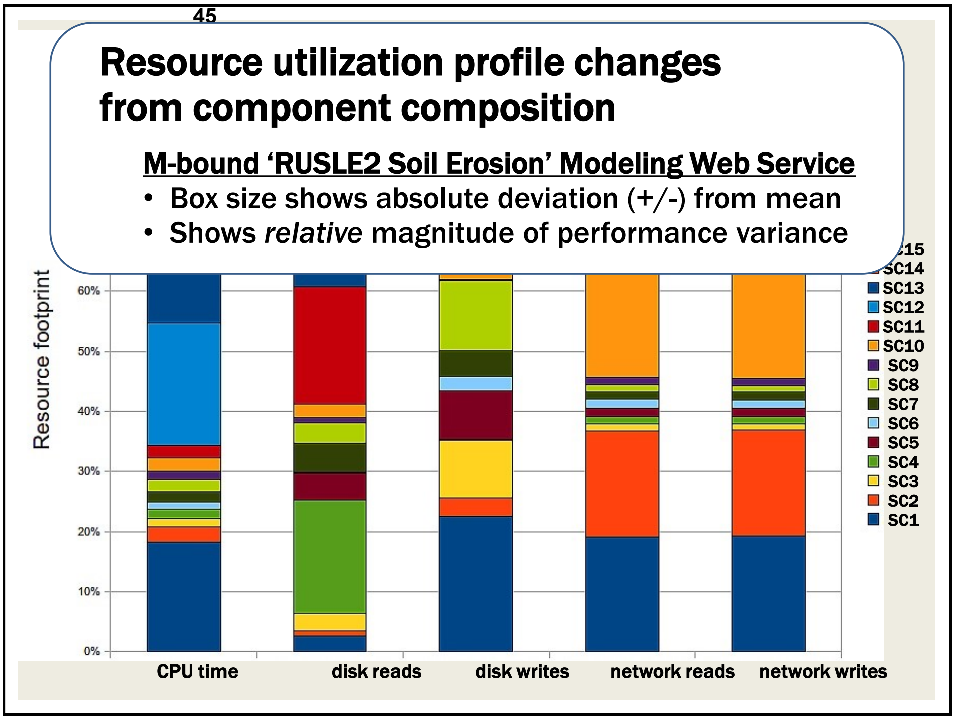
Resource utilization profile changes from component composition

M-bound 'RUSLE2 Soil Erosion' Modeling Web Service

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



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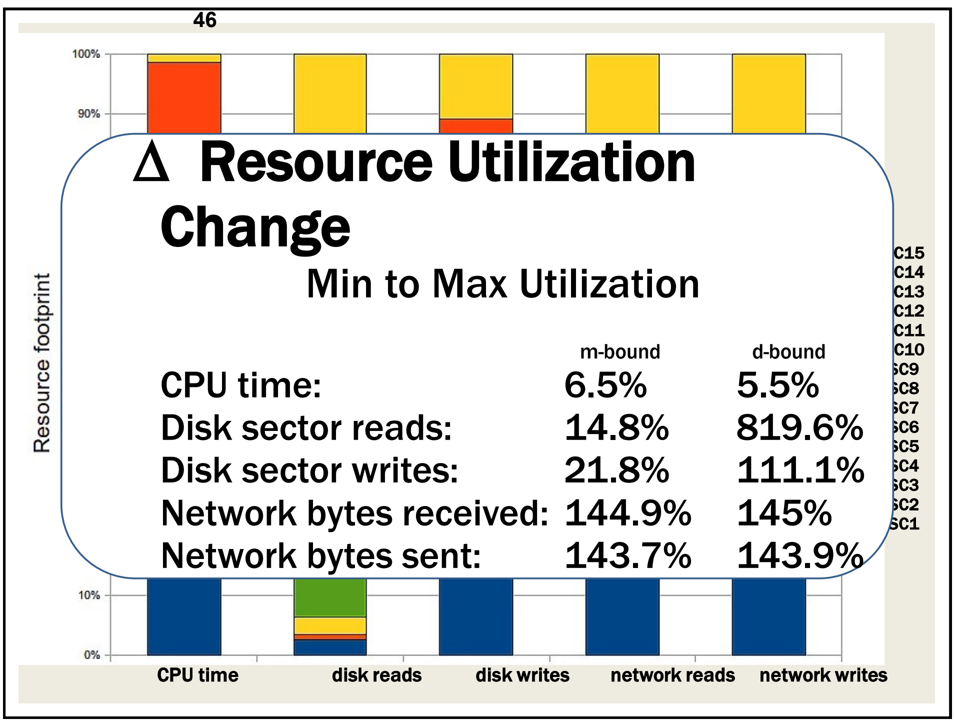
Δ Resource Utilization Change

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%



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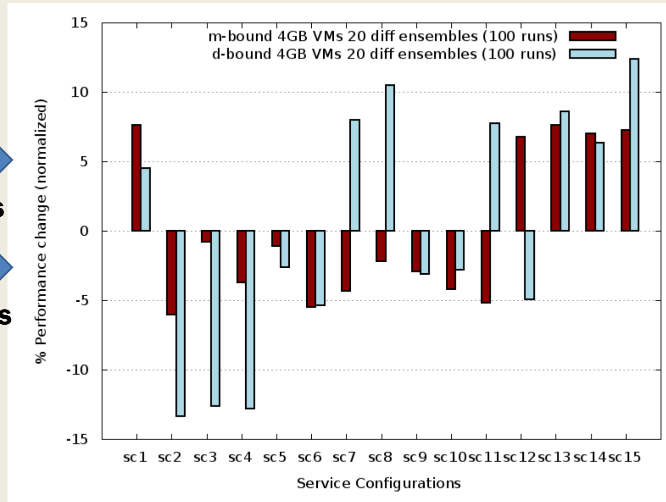
PERFORMANCE IMPLICATIONS OF APPLICATION DEPLOYMENTS

Slower deployments

Faster deployments



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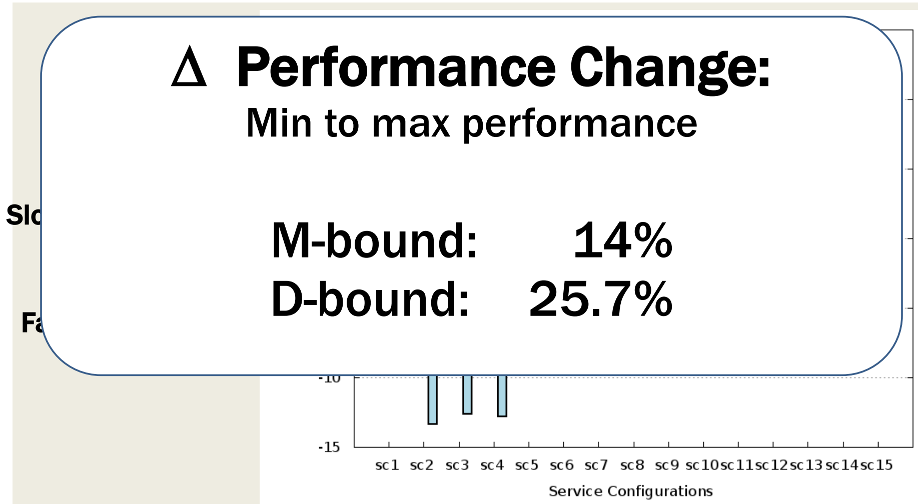
PERFORMANCE IMPLICATIONS OF APPLICATION DEPLOYMENTS



Δ Performance Change:

Min to max performance

M-bound: 14%

D-bound: 25.7%

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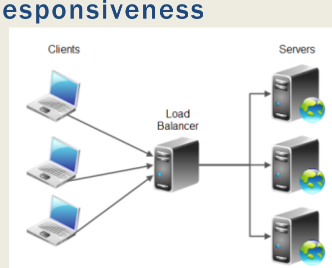
PLATFORM-AS-A-SERVICE

- 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)



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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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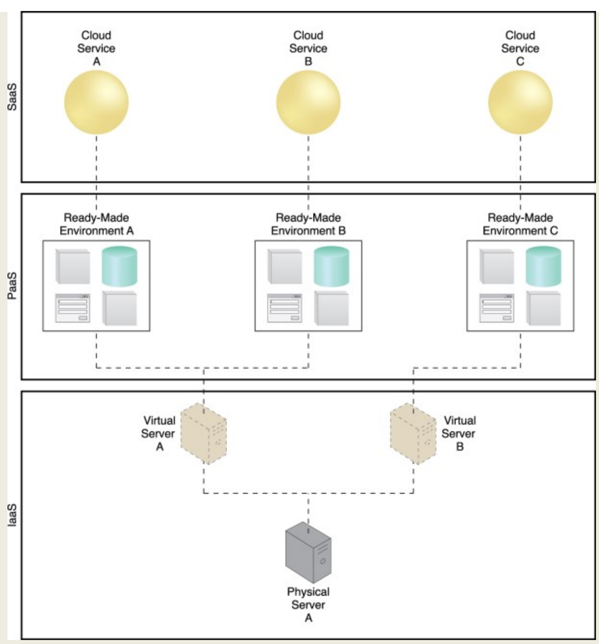
SOFTWARE-AS-A-SERVICE

- 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/

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SERVERLESS COMPUTING

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SERVERLESS COMPUTING

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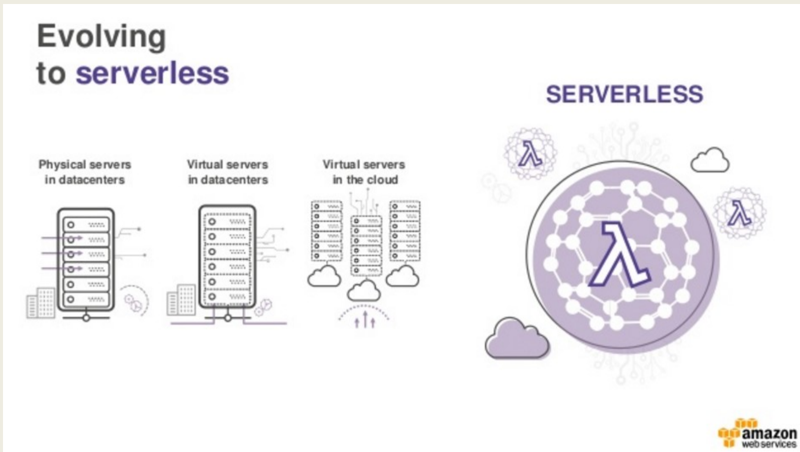
SERVERLESS COMPUTING - 2



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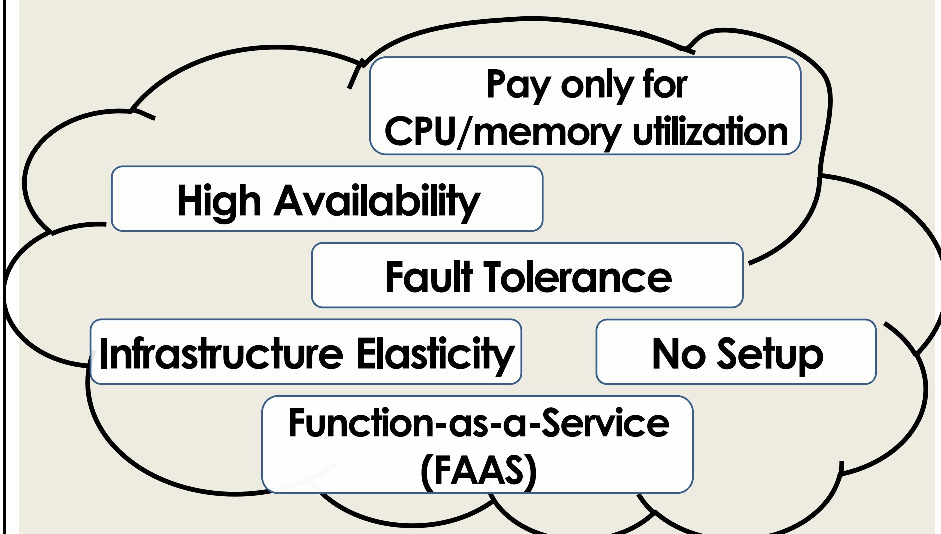
SERVERLESS COMPUTING



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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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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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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…

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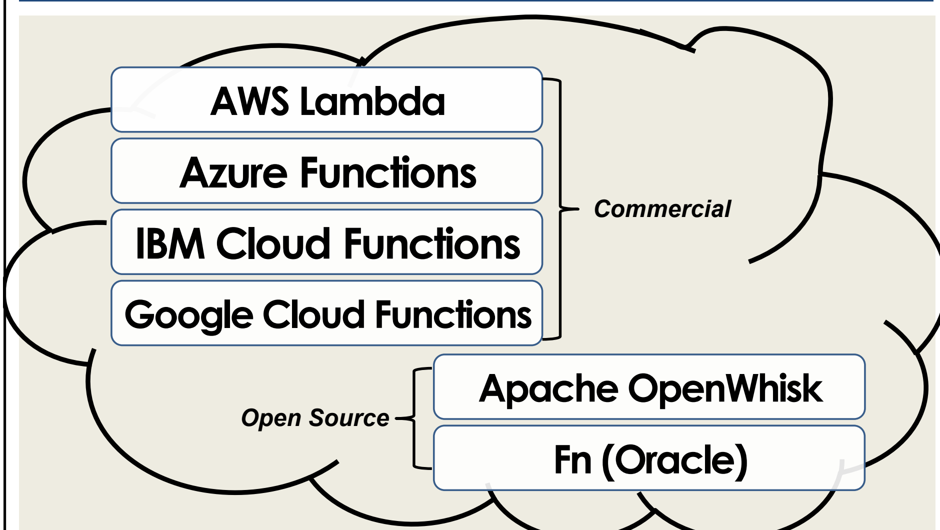
FAAS PLATFORMS



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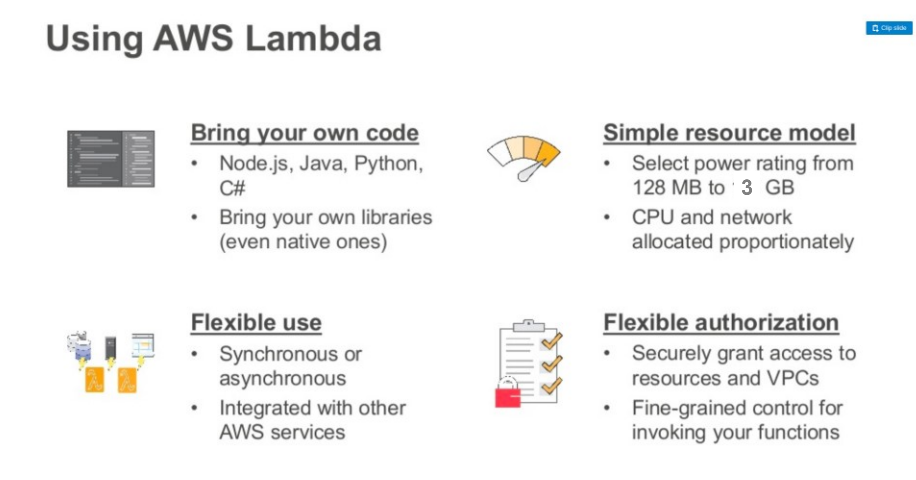
AWS LAMBDA



Images credit: aws.amazon.com

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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

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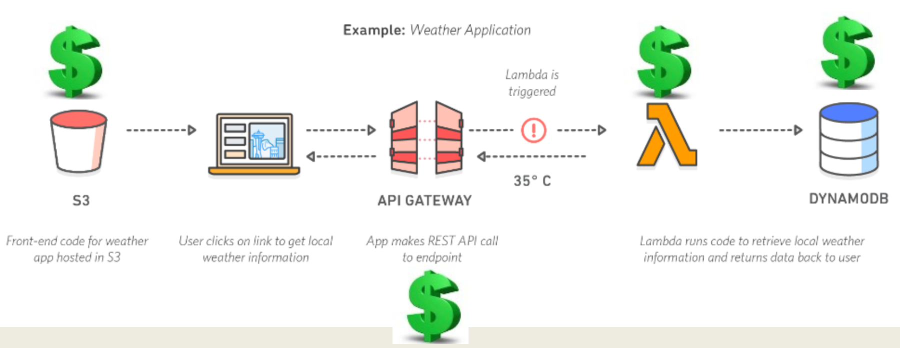
FAAS PLATFORMS - 3

- 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

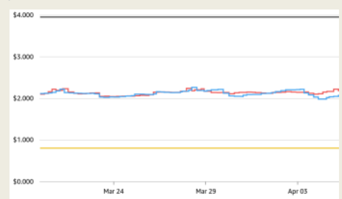


IAAS BILLING MODELS

- 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 →



PRICING OBFUSCATION

- **VM pricing:** hourly rental pricing, billed to nearest second is intuitive…
- **FaaS pricing:** non-intuitive pricing policies
- **FREE TIER:**
  first 1,000,000 function calls/month → FREE
  first 400,000 GB-sec/month → FREE
- Afterwards: *obfuscated pricing (AWS Lambda):*
  $0.0000002 per request
  $0.000000208 to rent 128MB / 100-ms
  $0.00001667 GB /second

CLOUD COMPUTING DELIVERY MODELS

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

Serverless Computing:

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- Other Delivery Models

WEBSERVICE HOSTING EXAMPLE

- ON AWS Lambda
- Each service call: 100% of 2 CPU-cores
  100% of 4GB of memory
- Workload: uses 2 continuous threads
- Duration: 1 month (30.41667 days)

- ON AWS EC2: Amazon EC2 c5.large 2-vCPU VM x 4GB
- c5.large: 8.5¢/hour, 24 hrs/day x 30.41667 days
- Hosting cost: $62.05/month

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

PRICING OBFUSCATION

Assume 1 month = 30.41667 days (365d / 12)

Worst-case FaaS scenario = ~2.72x !

AWS EC2: **$62.05**
AWS Lambda: **$168.91**

Break Even: **3,702,459 GB-sec**
@4GB **~10.71 days**

- **BREAK-EVEN POINT: $62.05 - $0.33 (calls) = $61.72**
  - **$61.72/.00001667 GB-sec = ~3,702,459 GB-sec-mon/4GB/call= ~925,614 sec or ~10.71 days**

Point at which using FaaS costs the same as IaaS

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FAAS PRICING

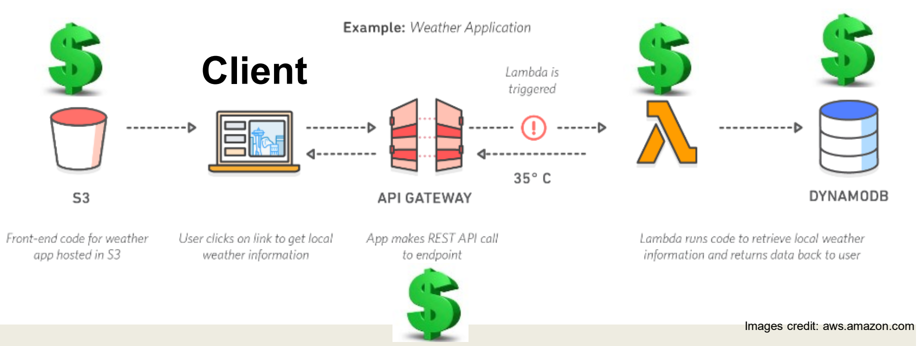
- Break-even point is the point where renting VMs or deploying to a serverless platform (e.g. Lambda) is exactly the same.
- Our example is for one month
- Could also consider one day, one hour, one minute
- **What factors influence the break-even point for an application running on AWS Lambda?**

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?
- Performance – what will it be?

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
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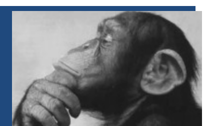
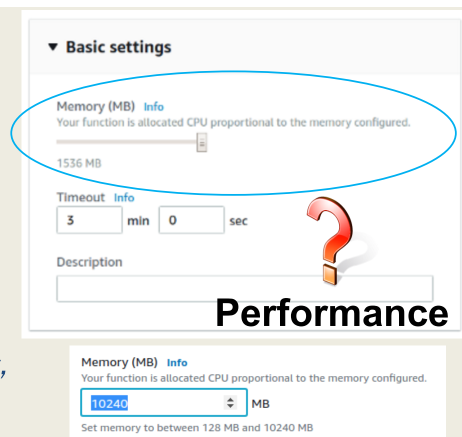
MEMORY RESERVATION QUESTION…



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



- **But how much memory do FaaS functions require?**

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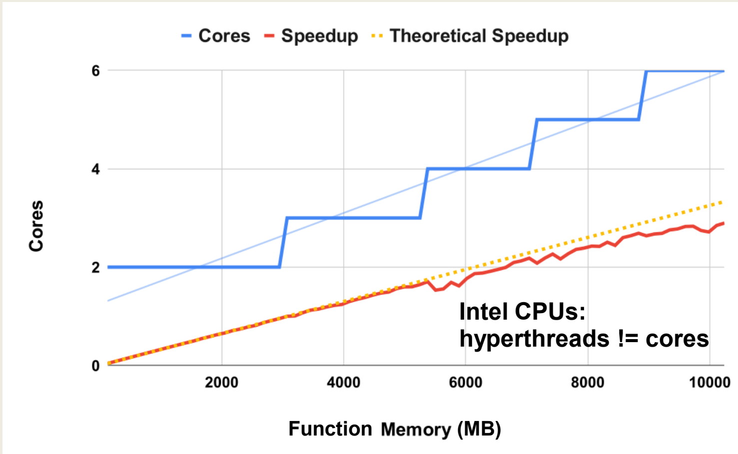
AWS LAMBDA COUPLES FUNCTION MEMORY TO CPU CORES & TIME SHARE



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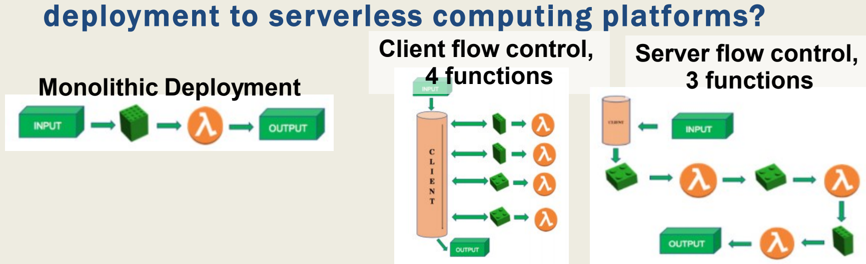
SERVICE COMPOSITION

- **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

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INFRASTRUCTURE FREEZE/THAW CYCLE

- Unused infrastructure is deprecated
  - *But after how long? (varies by platform)*
- Infrastructure: microVMs (on AWS Lambda), containers on some platforms

Performance

- **COLD**
  - Code image - built/transferred to physical host & cached
- **WARM**
  - Host has local code cache – create function instance (microVM) on host
- **HOT**
  - Function instance ready to use

Image from: Denver7 – The Denver Channel News

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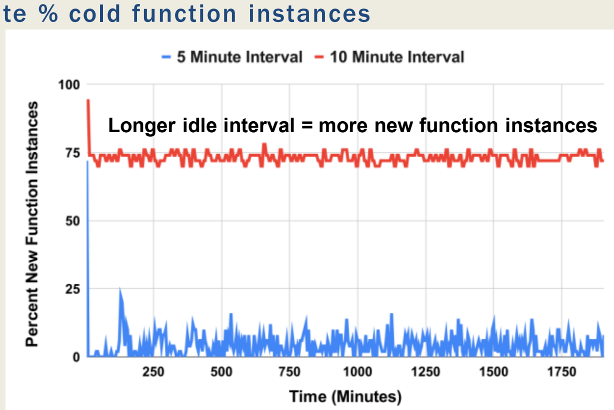
AWS LAMBDA – FREEZE/THAW

- Experiment: 50 concurrent calls, 5 or 10-min calling interval
- Evaluate % cold function instances



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FACTORS IMPACTING PERFORMANCE OF FAAS COMPUTING PLATFORMS

- Infrastructure scaling/elasticity
- Resource contention (CPU, network, memory caches)
- Hardware heterogeneity (CPU types, hyperthread, etc)
- Load balancing / provisioning variation
- Infrastructure retention: COLD vs. WARM
  - Infrastructure freeze/thaw cycle
- Function memory reservation size
- Application service composition

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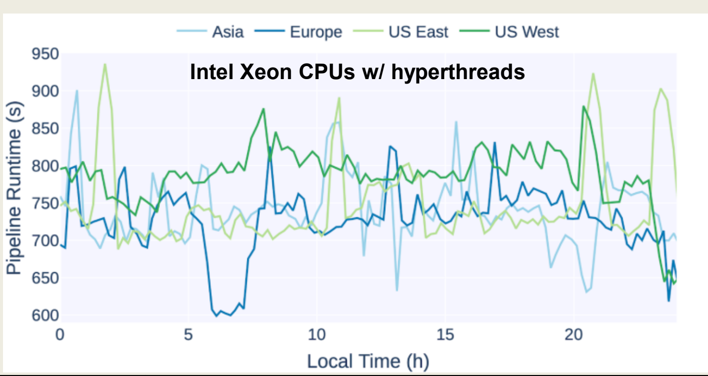
AWS LAMBDA PERFORMANCE VARIATION

- NLP processing pipeline use case
- Performance variance from: diurnal changes in load (e.g. resource contention), Intel hyperthreading



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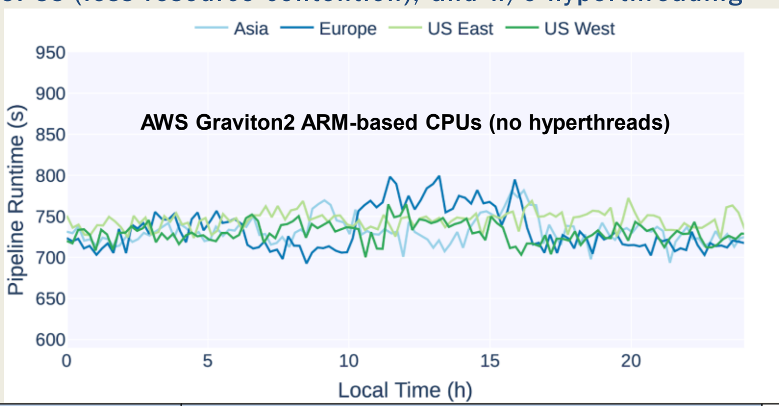
AWS LAMBDA PERFORMANCE VARIATION - 2

- NLP use case: Less performance variance using ARM-based CPUs (less resource contention), and w/o hyperthreading



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FUNCTION-AS-A-SERVICE

AWS Lambda Demo

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CLOUD COMPUTING DELIVERY MODELS

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- Other Delivery Models

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CONTAINER-AS-A-SERVICE

- Cloud service model for deploying application containers (e.g. Docker containers) to the cloud
- Deploy containers without worrying about managing infrastructure:
  - Servers (virtual machines)
  - 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
  - Google Cloud Run
  - Azure Container Instances

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CLOUD COMPUTING DELIVERY MODELS

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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

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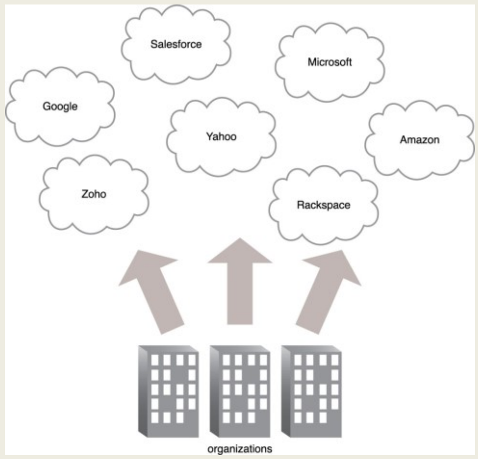
OBJECTIVES – 10/28

- Questions from 10/23
- Tutorials Questions
- Tutorial 5 - Files in S3 and CloudWatch Events
- Activity 2 Review
- From: Cloud Computing Concepts, Technology & Architecture: Chapter 4: Cloud Computing Concepts and Models:
  - Cloud computing delivery models
  - **Cloud deployment models**
- AWS Overview and demo

CLOUD DEPLOYMENT MODELS

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

PUBLIC CLOUDS



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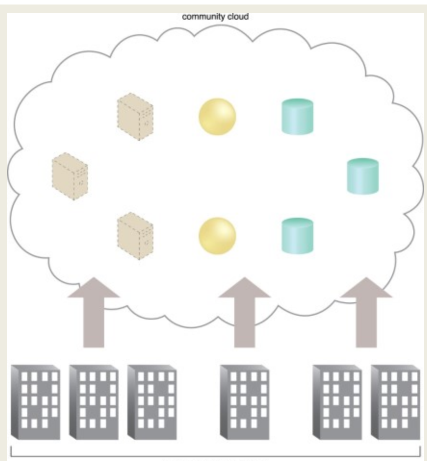
COMMUNITY CLOUD

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



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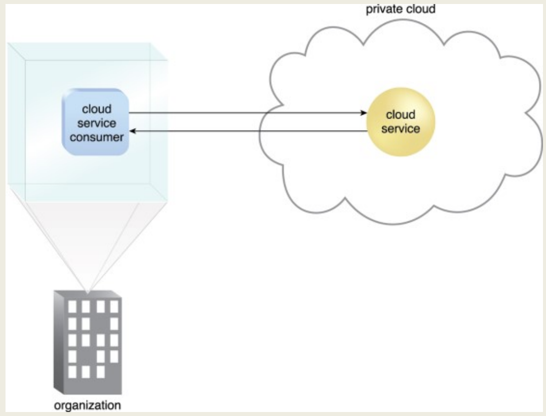
PRIVATE CLOUD

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



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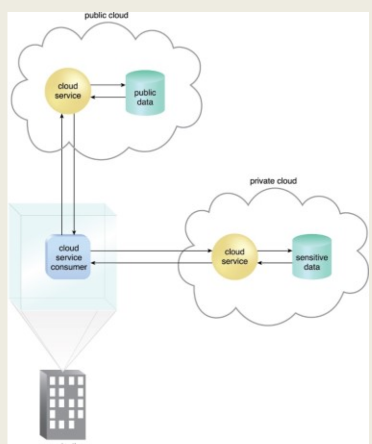
HYBRID CLOUD

- 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



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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

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WE WILL RETURN AT 4:50 PM

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OBJECTIVES – 10/28

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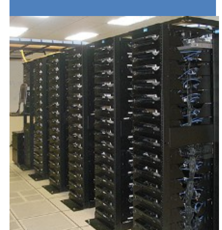
AWS OVERVIEW AND DEMO



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ONLINE CLOUD TUTORIALS

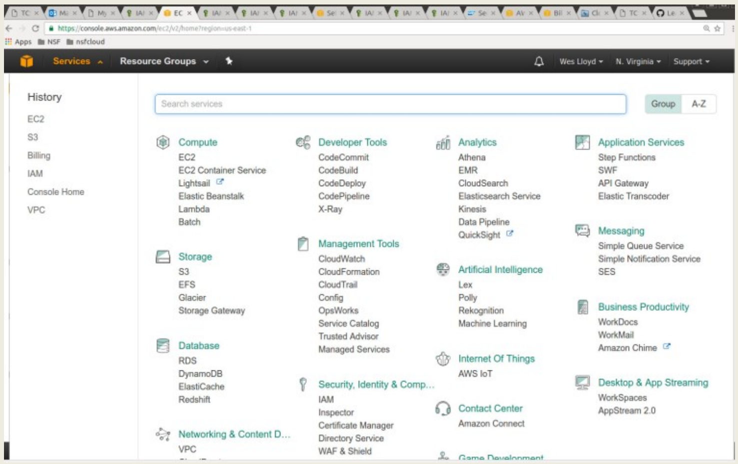
- From the eScience Institute @ UW Seattle: https://escience.washington.edu/
- Online cloud workshops
- Introduction to AWS, Azure, and Google Cloud
- Task: Deploying a Python DJANGO web application
- Self-guided workshop materials available online:
- https://cloudmaven.github.io/documentation/

- AWS Educate provides access to many online tutorials / learning resources:
- https://aws.amazon.com/education/awseducate/

LIST OF TOPICS

- AWS Management Console
- Elastic Compute Cloud (EC2)
- Instance Storage: Virtual Disks on VMs
- Elastic Block Store: Virtual Disks on VMs
- Elastic File System (EFS)
- Amazon Machine Images (AMIs)
- EC2 Paravirtualization
- EC2 Full Virtualization (hvm)
- EC2 Virtualization Evolution
- (VM) Instance Actions
- EC2 Networking
- EC2 Instance Metadata Service
- Simple Storage Service (S3)
- AWS Command Line Interface (CLI)
- Legacy / Service Specific CLIs
- AMI Tools
- Signing Certificates
- Backing up live disks
- Cost Savings Measures

AWS MANAGEMENT CONSOLE



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AWS EC2

- **E**lastic **C**ompute **C**loud
- Instance types: https://ec2instances.info
  - **On demand instance** – full price
  - **Reserved instance** – contract based where customer guarantees VM rental for a fixed period of time (e.g. 1 year, 3 years, etc.) Deeper discounts with longer term commitments
  - **Spot instance** – portion of cloud capacity reserved for low cost instances, when demand exceeds supply instances are randomly terminated with 2 minute warning
    - Users can make diverse VM requests using different types, zones, regions, etc. to minimize instance terminations
    - Developers can design for failure because often only 1 or 2 VMs in a cluster fail at any given time. They then need to be replaced.
  - **Dedicated host** – reserved private HW (server)
  - **Instance families** - General, compute-optimized, memory-optimized, GPU, etc.

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AWS EC2 - 2

- Storage types
  - Instance storage - ephemeral storage
    - Temporary disk volumes stored on disks local to the VM
    - Evolution: physical hard disk drives (HDDs)
    - Solid state drives (SSDs)
    - Non-volatile memory express (NVMe) drives (closer to DRAM speed)
  - EBS - Elastic block store
    - Remotely hosted disk volumes
  - EFS - Elastic file system
    - Shared file system based on network file system
    - VMs, Lambdas, Containers mount/interact with shared file system
    - Somewhat expensive

INSTANCE STORAGE

- Also called ephemeral storage
- Persisted using images saved to S3 (simple storage service)
  - ~2.3₵ per GB/month on S3
  - 5GB of free tier storage space on S3
- Requires "burning" an image
- Multi-step process:
  - Create image files
  - Upload chunks to S3
  - Register image
- Launching a VM
  - Requires downloading image components from S3, reassembling them… is potentially slow
- VMs with instance store backed root volumes not pause-able
- Historically root volume limited to 10-GB max– ***faster imaging…***

ELASTIC BLOCK STORE

- EBS provides 1 drive to 1 virtual machine **(1 : 1)** **(not shared)**
- EBS cost model is different than instance storage (uses S3)
  - ~10₵ per GB/month for General Purpose Storage (GP2)
  - ~8₵ per GB/month for General Purpose Storage (GP3)
  - 30GB of free tier storage space
- EBS provides "live" mountable volumes
  - Listed under volumes
  - **Data volumes**: can be mounted/unmounted to any VM, dynamically at any time
  - **Root volumes**: hosts OS files and acts as a boot device for VM
  - In Linux drives are linked to a mount point "directory"
- Snapshots back up EBS volume data to S3
  - Enables replication (required for horizontal scaling)
  - EBS volumes not actively used should be snapshotted, and deleted to save EBS costs…

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EBS VOLUME TYPES - 2

- Metric: I/O Operations per Second (IOPS)
- **General Purpose 2 (GP2)**
  - 3 IOPS per GB, min 100 IOPS (<34GB), max of 16,000 IOPS
  - 250MB/sec throughput per volume
- **General Purpose 3** (GP3 – new Dec 2020)
  - Max 16,000 IOPS, Default 3,000 IOPS
  - GP2 requires creating a 1TB volume to obtain 3,000 IOPS
  - GP3 all volumes start at 3000 IOPS and 125 MB/s throughput
  - 1000 additional IOPS beyond 3000 is $5/month up to 16000 IOPS
  - 125 MB/s additional throughput is $5/month up to 1000 MB/s throughput

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EBS VOLUME TYPES - 3

- **Provisioned IOPS (IO1)**
  - Legacy, associated with GP2
  - Allows user to create custom disk volumes where they pay for a specified IOPS and throughput
  - 32,000 IOPS, and 500 MB/sec throughput per volume MAX
- **Throughput Optimized HDD (ST1)**
  - Up to 500 MB/sec throughput
  - 4.5 ₵ per GB/month
- **Cold HDD (SC1)**
  - Up to 250 MB/sec throughput
  - 2.5 ₵ per GB/month
- **Magnetic**
  - Up to 90 MB/sec throughput per volume
  - 5 ₵ per GB/month

ELASTIC FILE SYSTEM (EFS)

- EFS provides 1 volume to many client **(1 : n) shared storage**
- Network file system (based on NFSv4 protocol)
- Shared file system for EC2, Fargate/ECS, Lambda
- Enables mounting (sharing) the same disk “volume” for R/W access across multiple instances at the same time
- Different performance and limitations vs. EBS/Instance store
- Implementation uses abstracted EC2 instances
- ~ 30 ₵ per GB/month storage – ***default burstable throughput***
- **Throughput modes:**
- Can modify modes only once every 24 hours
- Burstable Throughput Model:
  - Baseline – 50kb/sec per GB
  - Burst – 100MB/sec pet GB (for volumes sized 10GB to 1024 GB)
  - Credits - .72 minutes/day per GB

ELASTIC FILE SYSTEM (EFS) - 2

Information subject to revision

- Burstable Throughput Rates
  - Throughput rates: baseline vs burst
  - Credit model for bursting: maximum burst per day

File System Size (GiB)	Baseline Aggregate Throughput (MiB/s)	Burst Aggregate Throughput (MiB/s)	Maximum Burst Duration (Min/Day)	% of Time File System Can Burst (Per Day)
10	0.5	100	7.2	0.5%
256	12.5	100	180	12.5%
512	25.0	100	360	25.0%
1024	50.0	100	720	50.0%
1536	75.0	150	720	50.0%
2048	100.0	200	720	50.0%
3072	150.0	300	720	50.0%
4096	200.0	400	720	50.0%

ELASTIC FILE SYSTEM (EFS) - 3

Information subject to revision

- **Throughput Models**
- Provisioned Throughput Model
- For applications with:
  high performance requirements, but low storage requirements
- Get high levels of performance w/o overprovisioning capacity
- $6 MB/s-Month (Virginia Region)
  - Default is 50kb/sec for 1 GB, .05 MB/s = 30 ₵ per GB/month
- If file system metered size has higher baseline rate based on size, file system follows default Amazon EFS Bursting Throughput model
  - No charges for Provisioned Throughput below file system's entitlement in Bursting Throughput mode
  - Throughput entitlement = 50kb/sec per GB

ELASTIC FILE SYSTEM (EFS) - 4

Information subject to revision

Performance Comparison, Amazon EFS and Amazon EBS

	Amazon EFS	Amazon EBS Provisioned IOPS
Per-operation latency	Low, consistent latency.	Lowest, consistent latency.
Throughput scale	10+ GB per second.	Up to 2 GB per second.

Storage Characteristics Comparison, Amazon EFS and Amazon EBS

	Amazon EFS	Amazon EBS Provisioned IOPS
Availability and durability	Data is stored redundantly across multiple AZs.	Data is stored redundantly in a single AZ.
Access	Up to thousands of Amazon EC2 instances, from multiple AZs, can connect concurrently to a file system.	A single Amazon EC2 instance in a single AZ can connect to a file system.
Use cases	Big data and analytics, media processing workflows, content management, web serving, and home directories.	Boot volumes, transactional and NoSQL databases, data warehousing, and ETL.

AMAZON MACHINE IMAGES

- AMIs
- Unique for the operating system (root device image)
- Two types
  - Instance store
  - Elastic block store (EBS)
- Deleting requires multiple steps
  - Deregister AMI
  - Delete associated data - (*files in S3*)
- Forgetting both steps leads to costly “orphaned” data
  - No way to instantiate a VM from deregistered AMIs
  - Data still in S3 resulting in charges

EC2 VIRTUALIZATION - PARAVIRTUAL

- **1st, 2nd, 3rd, 4th generation → XEN-based**
- **5th generation instances → AWS Nitro virtualization**

- XEN - two virtualization modes
- XEN Paravirtualization "paravirtual"
  - 10GB Amazon Machine Image – base image size limit
  - Addressed poor performance of old XEN HVM mode
  - I/O performed using special XEN kernel with XEN paravirtual mode optimizations for better performance
  - Requires OS to have an available paravirtual kernel
  - PV VMs: will use common AKI files on AWS – ***Amazon kernel image(s)***
    - *Look for common identifiers*

EC2 VIRTUALIZATION - HVM

- XEN HVM mode
  - Full virtualization – no special OS kernel required
  - Computer entirely simulated
  - MS Windows runs in "hvm" mode
  - Allows work around: 10GB instance store root volume limit
  - Kernel is on the root volume (under /boot)
  - No AKIs (kernel images)
  - Commonly used today (*EBS-backed instances*)

EC2 VIRTUALIZATION - NITRO

- Nitro based on Kernel-based-virtual-machines
  - Stripped down version of Linux KVM hypervisor
  - Uses KVM core kernel module
  - I/O access has a direct path to the device
- Goal: provide indistinguishable performance from bare metal

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EVOLUTION OF AWS VIRTUALIZATION

- From: http://www.brendangregg.com/blog/2017-11-29/aws-ec2-virtualization-2017.html

AWS EC2 Virtualization Types

Bare-metal performance
Near-metal performance
Optimized performance
Poor performance

Importance: Most → Least

#	Tech	Type	With	CPU, Memory	Network I/O	Local Storage I/O	Remote Storage I/O	Interrupts, Timers	Motherboard, Boot
1	VM	Fully Emulated		VS	VS	VS	VS	VS	VS
2	VM	Xen PV 3.0	PV drivers	P	P	P	P	VS	VS
3	VM	Xen HVM 3.0	PV drivers	VH	P	P	P	VS	VS
4	VM	Xen HVM 4.0.1	PVHVM drivers	VH	P	P	P	P	VS
5	VM	Xen AWS 2013	PVHVM + SR-IOV(net)	VH	VH	P	P	P	VS
6	VM	Xen AWS 2017	PVHVM + SR-IOV(net, stor.)	VH	VH	VH	P	P	VS
7	VM	AWS Nitro 2017		VH	VH	VH	VH	VH	VS
8	HW	AWS Bare Metal 2017		H	H	H	H	H	H
		Bare Metal		H	H	H	H	H	H

Old → New

VM: Virtual Machine. HW: Hardware.
VS: Virt. in software. VH: Virt. in hardware. P: Paravirt. Not all combinations shown.
SR-IOV(net): ixgbe/ena driver. SR-IOV(storage): nvme driver.

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INSTANCE ACTIONS

- Stop
  - Costs of "pausing" an instance
- Terminate
- Reboot

- Image management
- Creating an image
  - EBS (snapshot)
- Bundle image
  - Instance-store

EC2 INSTANCE: NETWORK ACCESS

- Public IP address
- Elastic IPs
  - Costs: in-use FREE, not in-use ~12 ₵/day
  - Not in-use (e.g. "paused" EBS-backed instances)

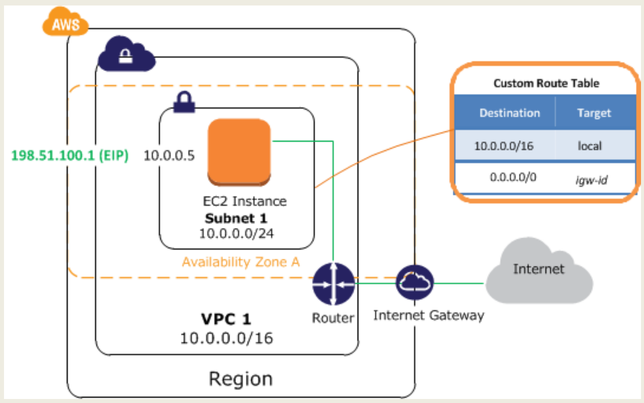
- Security groups
  - E.g. firewall

- Identity access management (IAM)
  - AWS accounts, groups

- VPC / Subnet / Internet Gateway / Router
- NAT-Gateway

SIMPLE VPC

- Recommended when using Amazon EC2



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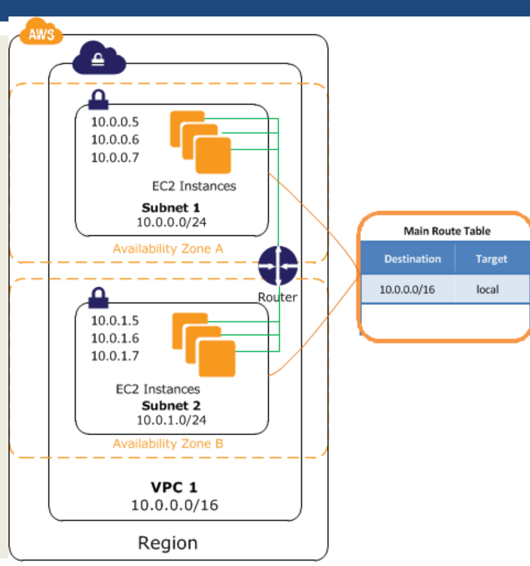
VPC SPANNING AVAILABILITY ZONES



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INSPECTING INSTANCE INFORMATION

- EC2 VMs run a local metadata service
- Can query instance metadata to self discover cloud configuration attributes

- Find your instance ID:

```
curl http://169.254.169.254/
curl http://169.254.169.254/latest/
curl http://169.254.169.254/latest/meta-data/
curl http://169.254.169.254/latest/meta-data/instance-id
; echo
```

- `ec2-get-info` command
- Python API that provides easy/formatted access to metadata

SIMPLE STORAGE SERVICE (S3)

- Key-value blob storage
- What is the difference vs. key-value stores (NoSQL DB)?
- Can mount an S3 bucket as a volume in Linux
  - Supports common file-system operations
- Provides eventual consistency
- Can store Lambda function state for life of container.

AWS CLI

- Launch Ubuntu 16.04 VM
  - Instances | Launch Instance
- Install the general AWS CLI
  - sudo apt install awscli
- Create config file

```
[default]
aws_access_key_id = <access key id>
aws_secret_access_key = <secret access key>
region = us-east-1
```

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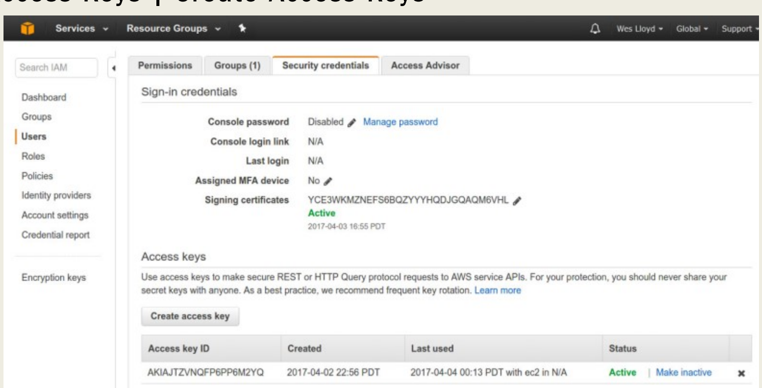
AWS CLI - 2

- Creating access keys: IAM | Users | Security Credentials | Access Keys | Create Access Keys



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AWS CLI - 3

- Export the config file
  - Add to /home/ubuntu/.bashrc

```
export AWS_CONFIG_FILE=$HOME/.aws/config
```

- Try some commands:
  - `aws help`
  - `aws command help`
  - `aws ec2 help`
  - `aws ec2 describes-instances --output text`
  - `aws ec2 describe-instances --output json`
  - `aws s3 ls`
  - `aws s3 ls vmscaleruw`

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LEGACY / SERVICE SPECIFIC CLI(S)

- `sudo apt install ec2-api-tools`
- Provides more concise output
- Additional functionality

- Define variables in .bashrc or another sourced script:
- `export AWS_ACCESS_KEY={your access key}`
- `export AWS_SECRET_KEY={your secret key}`

- `ec2-describe-instances`
- `ec2-run-instances`
- `ec2-request-spot-instances`

- EC2 management from Java:
- http://docs.aws.amazon.com/AWSJavaSDK/latest/javadoc/index.html

- Some AWS services have separate CLI installable by package

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AMI TOOLS

- Amazon Machine Images tools
- For working with disk volumes
- Can create live copies of any disk volume
  - Your local laptop, ec2 root volume (EBS), ec2 ephemeral disk
- Installation: https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/ami-tools-commands.html
- AMI tools reference:
- https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/ami-tools-commands.html
- Some functions may require private key & certificate files

PRIVATE KEY AND CERTIFICATE FILE

- Install openssl package on VM

```
# generate private key file
$openssl genrsa 2048 > mykey.pk

# generate signing certificate file
$openssl req -new -x509 -nodes -sha256 -days 36500 -key
mykey.pk -outform PEM -out signing.cert
```

- Add signing.cert to IAM | Users | Security Credentials | - - *new signing certificate* - -
- From: http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/set-up-ami-tools.html?icmpid=docs_iam_console#ami-tools-create-certificate

PRIVATE KEY, CERTIFICATE FILE

- These files, combined with your AWS_ACCESS_KEY and AWS_SECRET_KEY and AWS_ACCOUNT_ID enable you to publish new images from the CLI

- Objective:

1. Configure VM with software stack
2. Burn new image for VM replication (**horizontal scaling**)

- An alternative to bundling volumes and storing in S3 is to use a containerization tool such as Docker. . .

- Create image script . . .

SCRIPT: CREATE A NEW INSTANCE STORE IMAGE FROM LIVE DISK VOLUME

```
image=$1
echo "Burn image $image"
echo "$image" > image.id
mkdir /mnt/tmp
AWS_KEY_DIR=/home/ubuntu/.aws
export EC2_URL=http://ec2.amazonaws.com
export S3_URL=https://s3.amazonaws.com
export EC2_PRIVATE_KEY=${AWS_KEY_DIR}/mykey.pk
export EC2_CERT=${AWS_KEY_DIR}/signing.cert
export AWS_USER_ID={your account id}
export AWS_ACCESS_KEY={your aws access key}
export AWS_SECRET_KEY={your aws secret key}
ec2-bundle-vol -s 5000 -u ${AWS_USER_ID} -c ${EC2_CERT} -k ${EC2_PRIVATE_KEY}
--ec2cert /etc/ec2/amitools/cert-ec2.pem --no-inherit -r x86_64 -p $image -i
/etc/ec2/amitools/cert-ec2.pem
cd /tmp
ec2-upload-bundle -b tcss562 -m $image.manifest.xml -a ${AWS_ACCESS_KEY} -s
${AWS_SECRET_KEY}  --url http://s3.amazonaws.com --location US
ec2-register tcss562/$image.manifest.xml --region us-east-1 --kernel aki-
88aa75e1
```

COST SAVINGS MEASURES

- ***From Tutorial 3:***
- #1: ALWAYS USE SPOT INSTANCES FOR COURSE/RESEARCH RELATED PROJECTS
- #2: NEVER LEAVE AN EBS VOLUME IN YOUR ACCOUNT THAT IS NOT ATTACHED TO A RUNNING VM
- #3: BE CAREFUL USING PERSISTENT REQUESTS FOR SPOT INSTANCES
- #4: TO SAVE/PERSIST DATA, USE EBS SNAPSHOTS AND THEN
- #5: DELETE EBS VOLUMES FOR TERMINATED EC2 INSTANCES.
- #6: UNUSED SNAPSHOTS AND UNUSED EBS VOLUMES SHOULD BE PROMPTLY DELETED !!
- #7: USE PERSISTENT SPOT REQUESTS AND THE “STOP” FEATURE TO PAUSE VMS DURING SHORT BREAKS

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QUESTIONS

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