# TCSS 562: SOFTWARE ENGINEERING FOR CLOUD COMPUTING

## Cloud Computing Concepts and Models

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

TR 5:00-7:00 PM

1

## OFFICE HOURS – FALL 2021

- **Tuesdays:**
  - 4:00 to 4:30 pm - CP 229
  - 7:15 to 7:45+ pm – ONLINE via Zoom
- **Thursdays**
  - 4:15 to 4:45 pm – ONLINE via Zoom
  - 7:15 to 7:45+ pm – ONLINE via Zoom
- Or email for appointment
- Zoom Link sent as Canvas Announcement

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

| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.2 |
|---|---|---|

2

# OBJECTIVES – 10/21

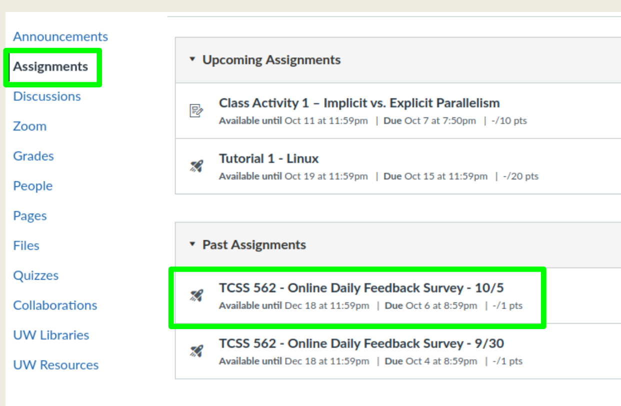
- Questions from 10/19
- Tutorial 3 - Best Practices with EC2
- Tutorial 4 – Intro to FaaS – AWS Lambda
- From: Cloud Computing Concepts, Technology & Architecture: Chapter 4: Cloud Computing Concepts and Models:
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models
- 2nd hour:
  - TCSS 562 Term Project
  - Team Planning - Breakout Rooms

| October 21, 2021 | TCSS562:Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.3 |
|---|---|---|

3

# ONLINE DAILY FEEDBACK SURVEY

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




| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.4 |
|---|---|---|

4

## 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 |



5

## MATERIAL / PACE

- Please classify your perspective on material covered in today's class (24 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 6.00 (↓ - *previous 6.30*)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.54 (↑ - previous 5.33)**



6

# FEEDBACK FROM 10/19

- ***Unclear point: Challenges with shared database but non-shared schema, in the context of multi-tenancy***
  - When a physical database server is shared with many tenants, a key challenge is with resource contention (e.g. CPU, memory, disk, network)
  - Cloud provider resource constraints (limits) can restrict the resources a given user is able to acquire over time
    - For example: AWS Lambda tightly restricts CPU, disk, and network I/O resources for functions depending on their assigned memory
  - Even with resource constraints operations that for example generate excessive page faults and memory cache stress can have a detrimental impact on database performance for "isolated" users



# OBJECTIVES – 10/21

- **Questions from 10/19**
- Tutorial 3 - Best Practices with EC2
- Tutorial 4 – Intro to FaaS – AWS Lambda
- **From: Cloud Computing Concepts, Technology & Architecture: Chapter 4: Cloud Computing Concepts and Models:**
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models
- **2nd hour:**
  - TCSS 562 Term Project
  - Team Planning - Breakout Rooms

# OBJECTIVES – 10/21

- **Questions from 10/19**
- Tutorial 3 - Best Practices with EC2
- Tutorial 4 – Intro to FaaS – AWS Lambda
- **From: Cloud Computing Concepts, Technology & Architecture: Chapter 4: Cloud Computing Concepts and Models:**
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models
- **2nd hour:**
  - TCSS 562 Term Project
  - Team Planning - Breakout Rooms

| October 21, 2021 | TCSS562:Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.9 |
|---|---|---|

9

# CLOUD COMPUTING: CONCEPTS AND MODELS

October 21, 2021 TCSS562: Software Engineering for Cloud Computing [Fall 2021]
School of Engineering and Technology, University of Washington - Tacoma L7.10

10

# OBJECTIVES – 10/21

- **Questions from 10/19**
- Tutorial 3 - Best Practices with EC2
- Tutorial 4 – Intro to FaaS – AWS Lambda
- **From: Cloud Computing Concepts, Technology & Architecture: Chapter 4: Cloud Computing Concepts and Models:**
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models
- **2nd hour:**
  - TCSS 562 Term Project
  - Team Planning - Breakout Rooms



# 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

## 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**

October 24, 2016 TCSS562: Software Engineering for Cloud Computing [Fall 2021] School of Engineering and Technology, University of Washington - Tacoma L10.13

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

13

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**

14

# ELASTICITY

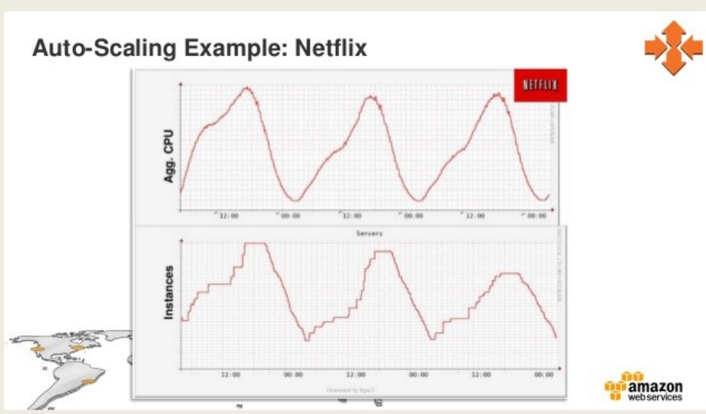
- Automated ability of cloud to transparently scale resources
- Scaling based on runtime conditions or pre-determined by cloud consumer or cloud provider
- Threshold based scaling
  - `CPU-utilization > threshold_A, Response_time > 100ms`
  - Application agnostic vs. application specific thresholds
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

| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.15 |
|---|---|---|

15

# PREDICTABLE DEMAND

- AWS EC2 Scaling Example:




From: Kejariwal, A., 2013, March. Techniques for optimizing cloud footprint. In 2013 IEEE Int. Conf. on Cloud Engineering (IC2E), pp. 258-268.

| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.16 |
|---|---|---|

16

# MEASURED USAGE

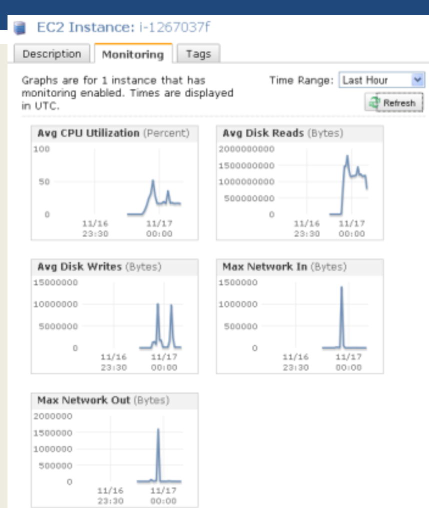
- Cloud platform tracks usage of IT resources
- For billing purposes
- Enables charging only for IT resources actually used
- Can be time-based (millisec, second, minute, hour, day)
  - Granularity is increasing…
- Can be throughput-based (data transfer: MB/sec, GB/sec)
- Can be resource/reservation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

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



17

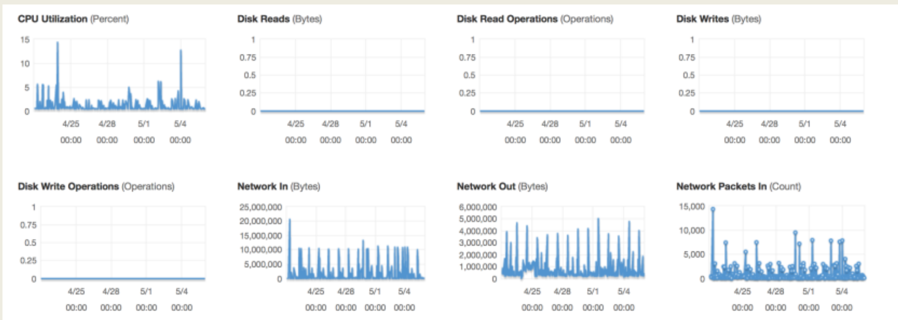
# EC2 CLOUDWATCH METRICS






18

# EC2 CLOUDWATCH METRICS

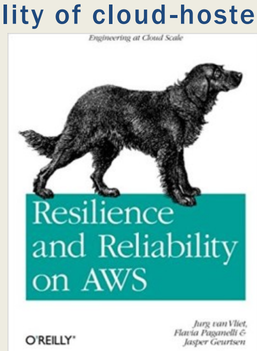



| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.19 |
|---|---|---|

19

# 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




| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.20 |
|---|---|---|

20

# OBJECTIVES – 10/21

- **Questions from 10/19**
- Tutorial 3 - Best Practices with EC2
- Tutorial 4 – Intro to FaaS – AWS Lambda
- **From: Cloud Computing Concepts, Technology & Architecture: Chapter 4: Cloud Computing Concepts and Models:**
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models
- **2nd hour:**
  - TCSS 562 Term Project
  - Team Planning - Breakout Rooms



# 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

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

**<u>Virtual Machines</u> are the building blocks for "Cloud Service Delivery Models"**

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

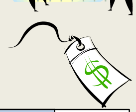
*cloud 1.0*



25

## CLOUD DELIVERY MODELS

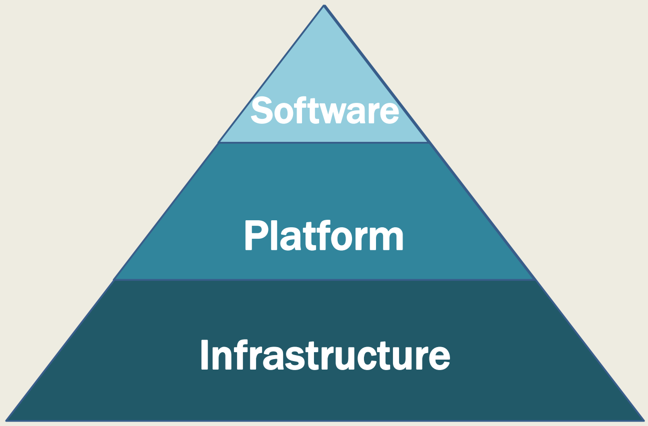
- What is the appropriate level of **<u>abstraction</u>**?
- How should applications be deployed?
  - IaaS, PaaS, SaaS, DbaaS, FaaS
- How do we ensure Quality-of-Service?
  - Performance, Availability, Responsiveness, Fault Tolerance
- How is ***<u>scalability</u>*** provided?
- As users, how do we minimize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





26

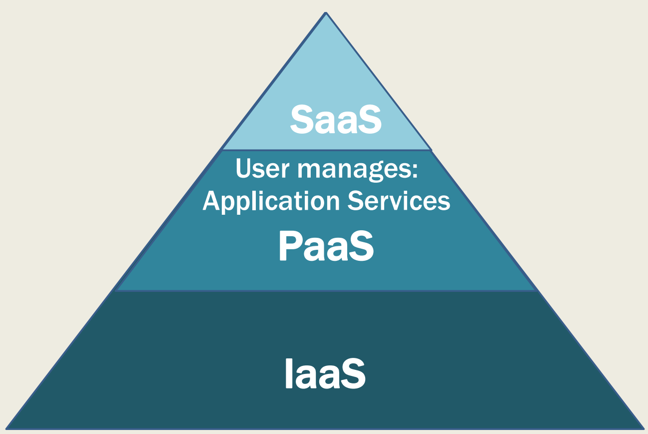
# CLASSIC CLOUD DELIVERY MODELS






27

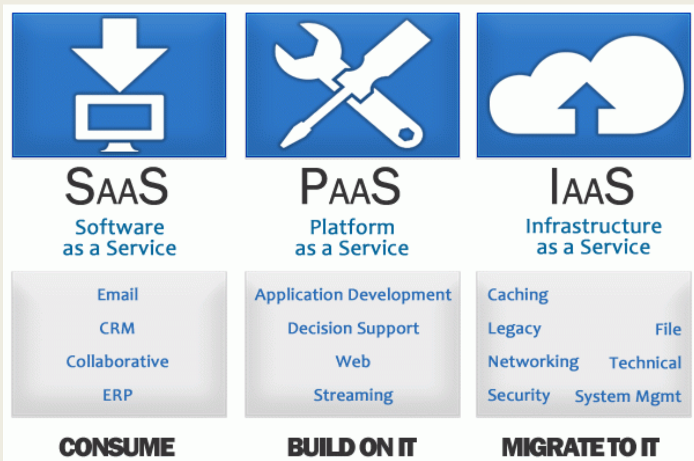
# CLASSIC CLOUD DELIVERY MODELS





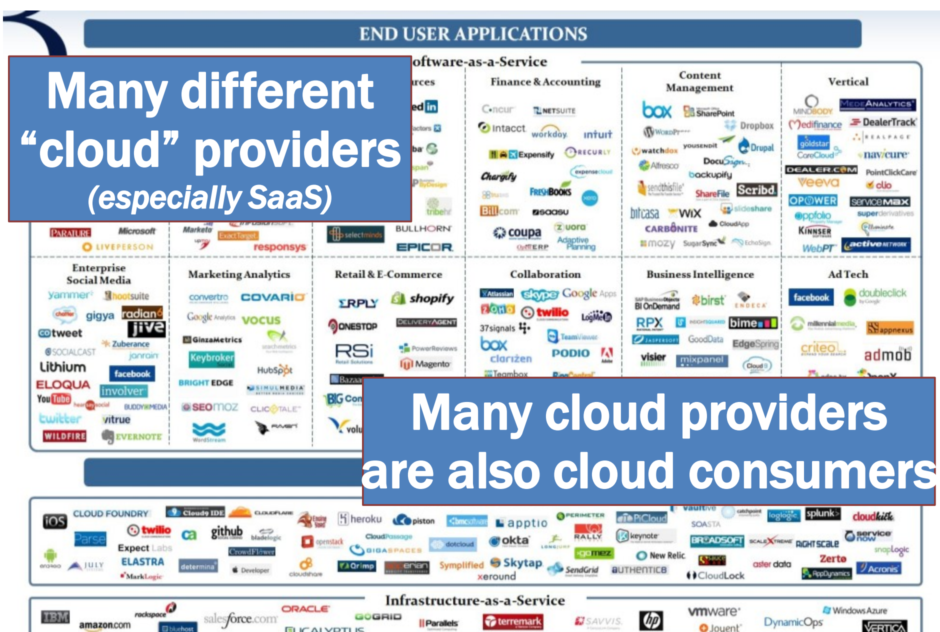

28

# EXAMPLE CLOUD SERVICES




| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.29 |
|---|---|---|

29




| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.30 |
|---|---|---|

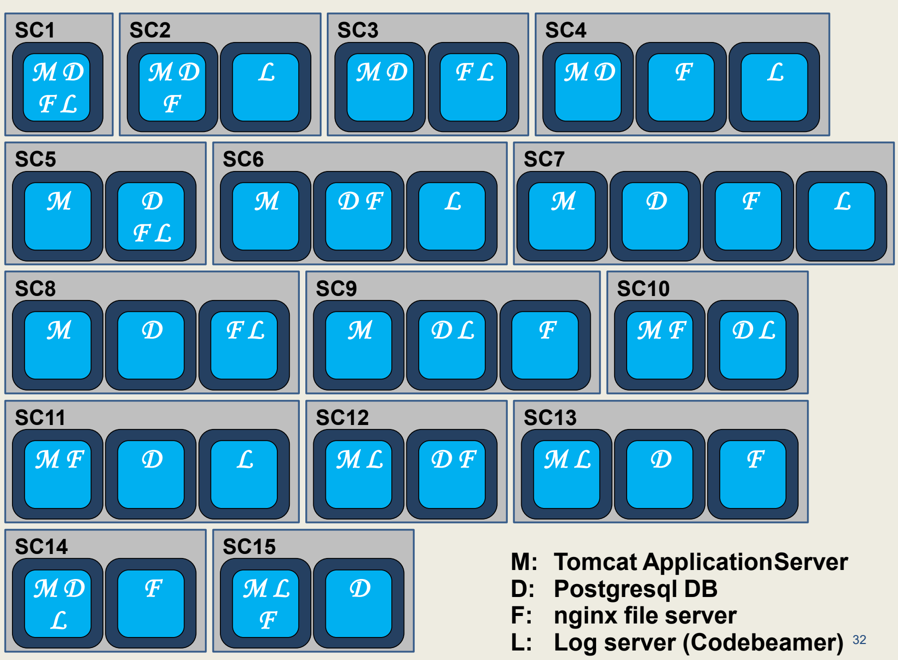
30

# 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



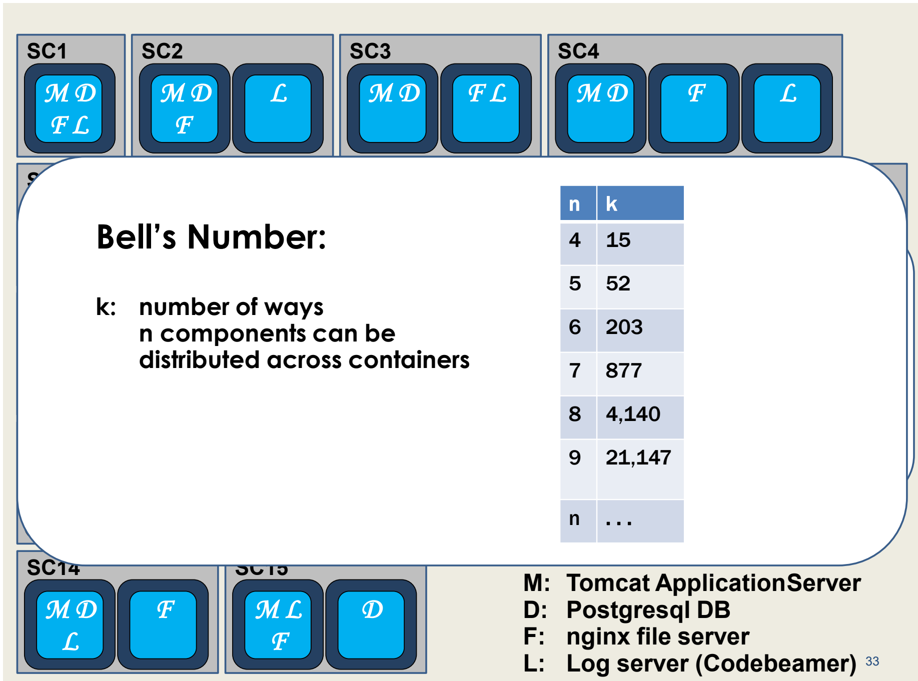
31




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

32

32

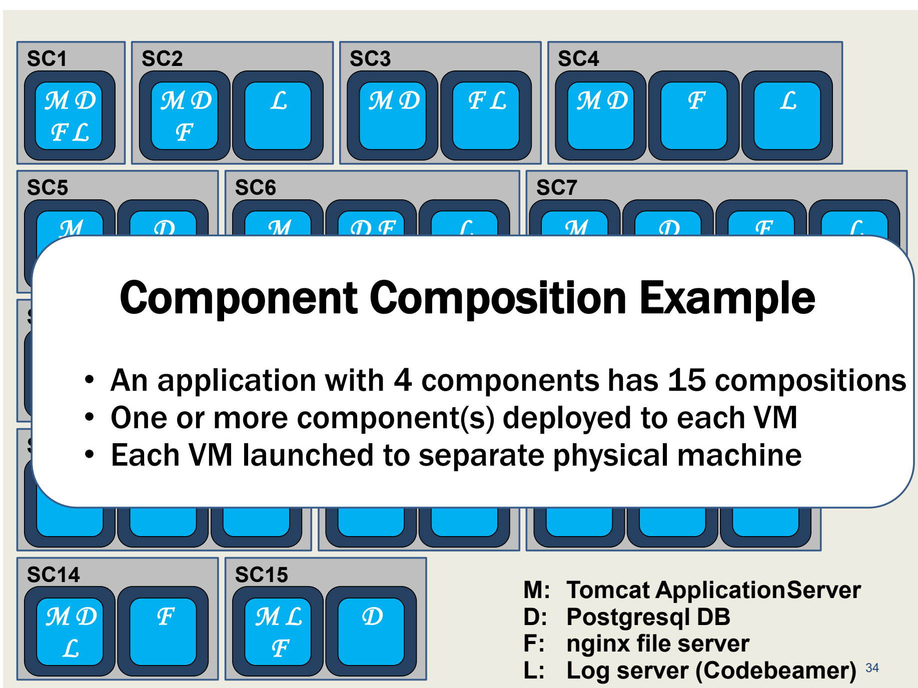



**Bell's Number:**

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 | . . . |

33

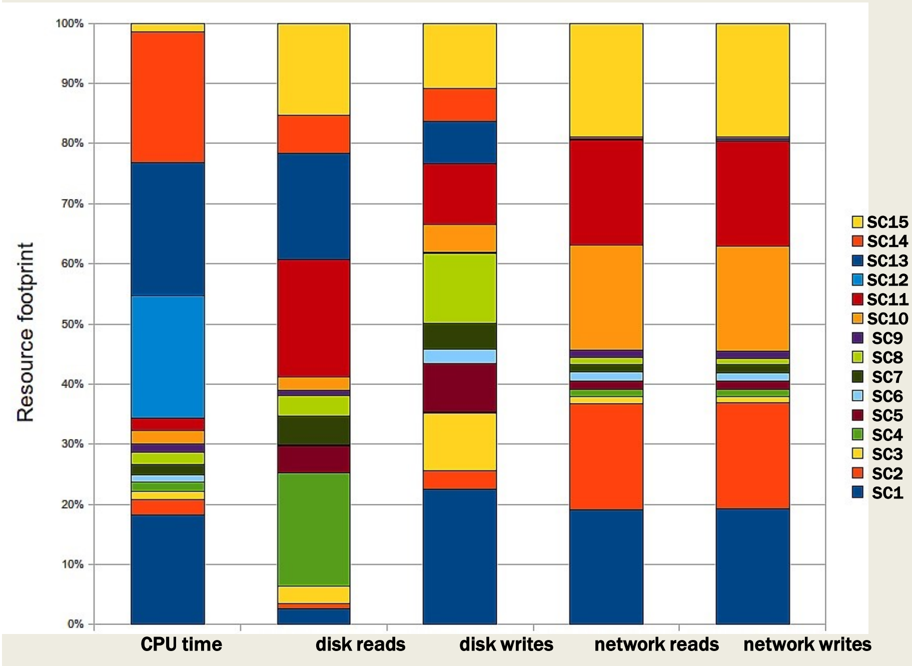



## Component Composition Example

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

34

35



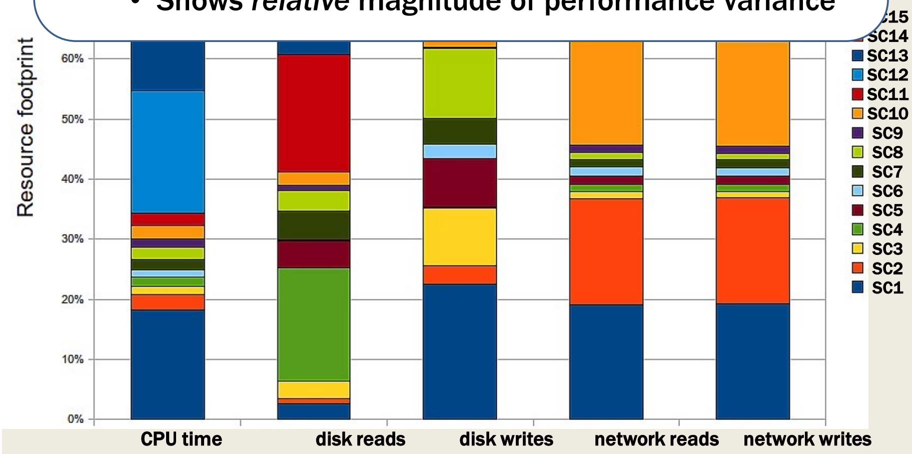

35

36

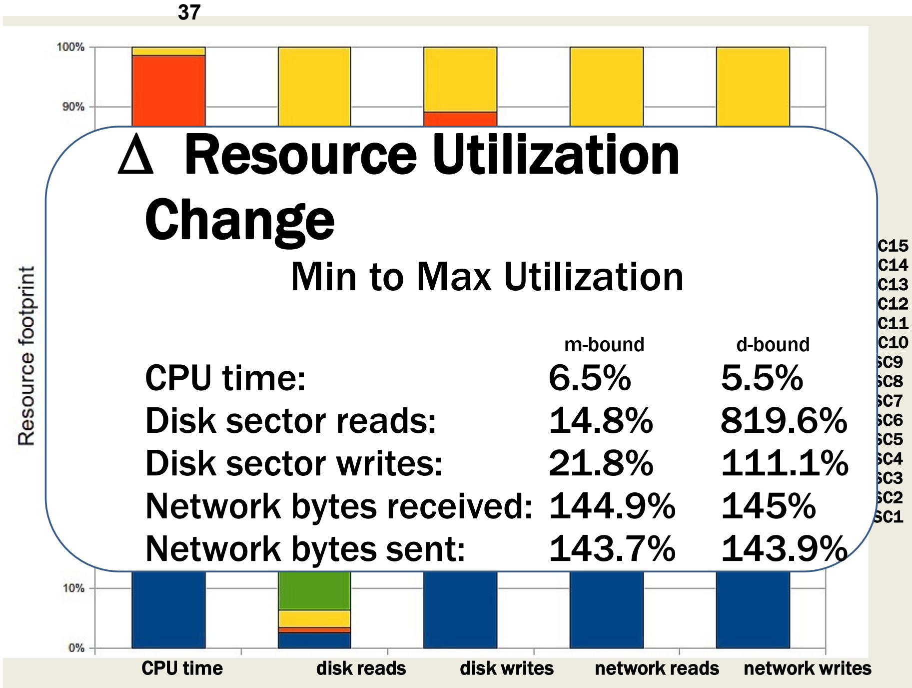
## Resource utilization profile changes from component composition

**M-bound RUSLE2 Soil Erosion Model**

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




36




## Δ Resource Utilization Change

Min to Max Utilization

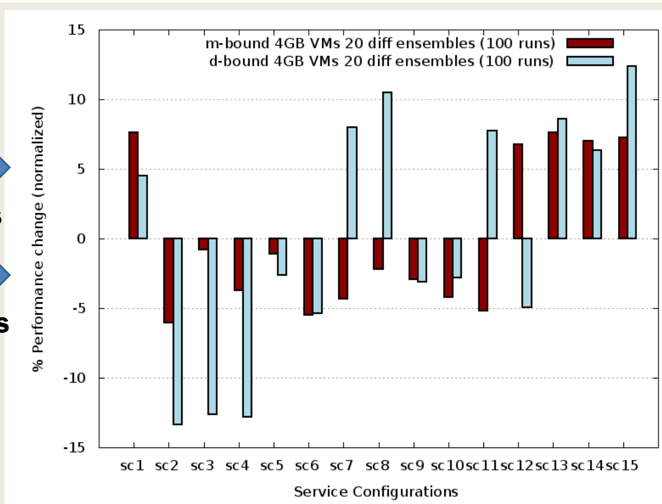
| | m-bound | d-bound |
|---|---|---|
| CPU time: | 6.5% | 5.5% |
| Disk sector reads: | 14.8% | 819.6% |
| Disk sector writes: | 21.8% | 111.1% |
| Network bytes received: | 144.9% | 145% |
| Network bytes sent: | 143.7% | 143.9% |

37

## PERFORMANCE IMPLICATIONS OF APPLICATION DEPLOYMENTS

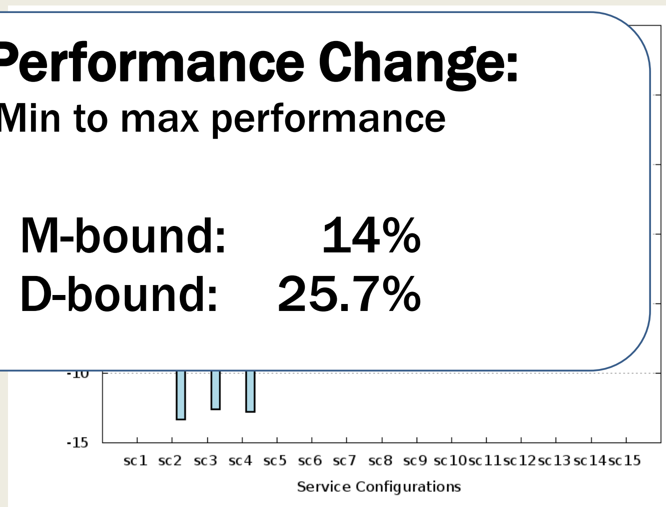
**Slower deployments**

**Faster deployments**




38

## PERFORMANCE IMPLICATIONS OF APPLICATION DEPLOYMENTS




**Δ Performance Change:**

Min to max performance

M-bound: 14%
D-bound: 25.7%

39

## 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

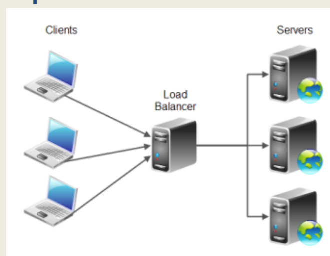


40

# 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

## CLOUD COMPUTING DELIVERY MODELS

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

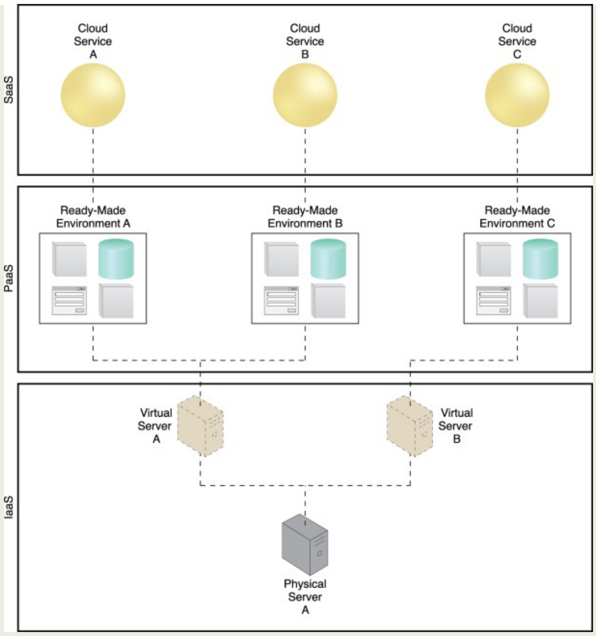
Serverless Computing:

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



## 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






45

# 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



46

# SERVERLESS COMPUTING

## Introducing Cloud 2.0


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

47

# SERVERLESS COMPUTING

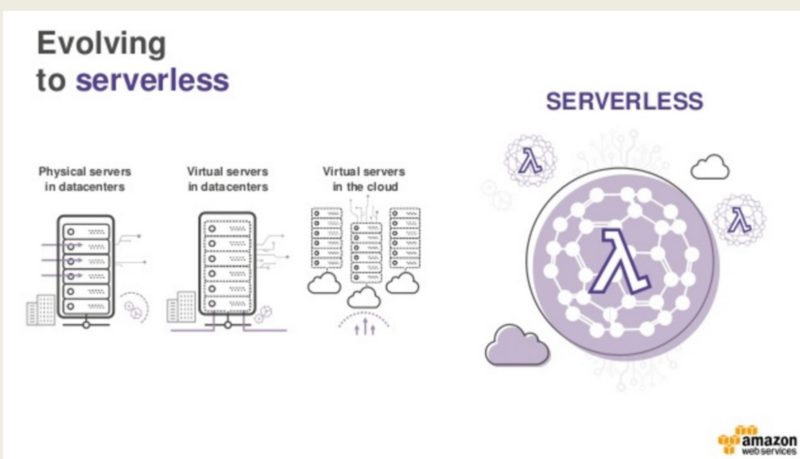

48

# SERVERLESS COMPUTING


| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.49 |
|---|---|---|

49

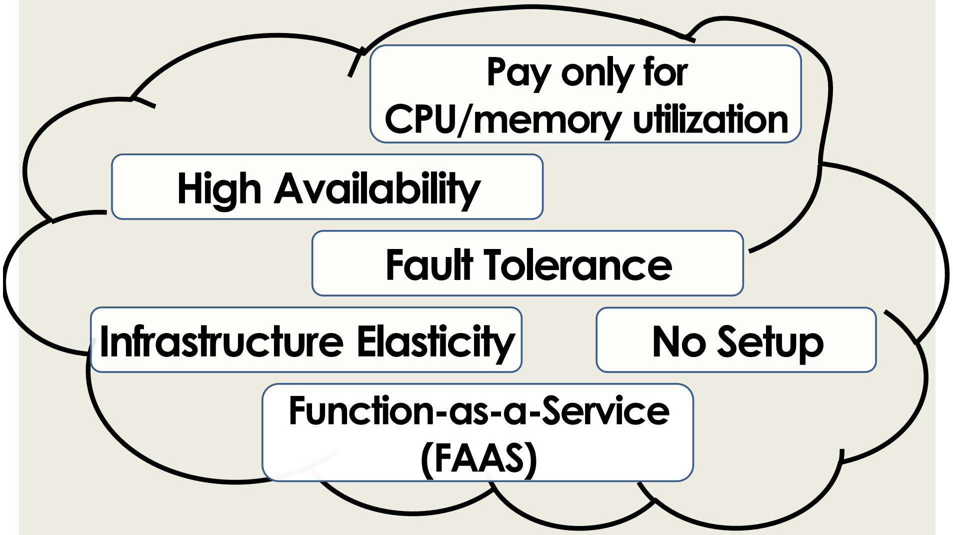
# SERVERLESS COMPUTING - 2




| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.50 |
|---|---|---|

50

## SERVERLESS COMPUTING




51

## SERVERLESS COMPUTING

**Why Serverless Computing?**

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

*…they are built into the platform*

52

## 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



53

## SERVERLESS VS. FAAS

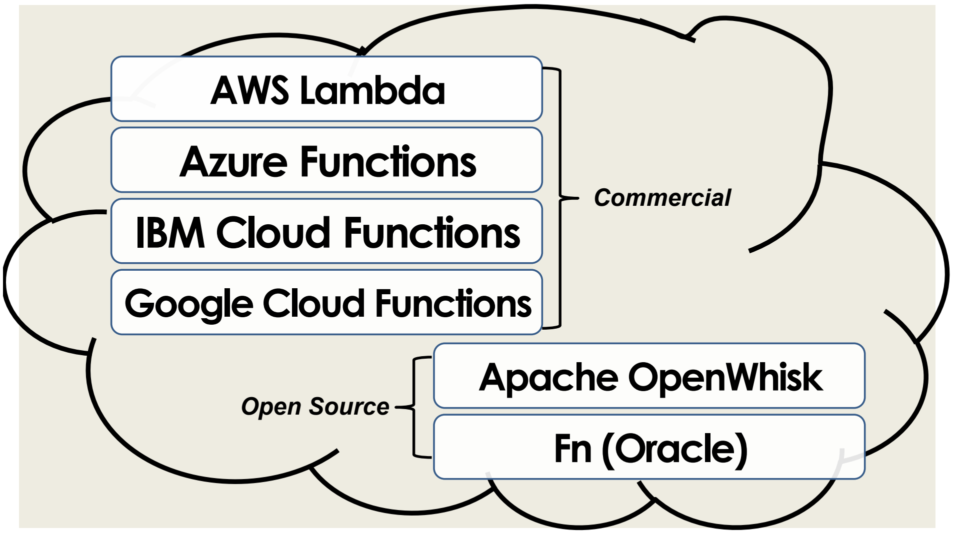
- **Serverless Computing**
- Refers to the avoidance of managing servers
- Can pertain to a number of "as-a-service" cloud offerings
- Function-as-a-Service (FaaS)
  - Developers write small code snippets (microservices) which are deployed separately
- Database-as-a-Service (DBaaS)
- Container-as-a-Service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

- Serverless is a buzzword
- This space is evolving…



54

## FAAS PLATFORMS




55

## AWS LAMBDA

### Using AWS Lambda

**Bring your own code**

- Node.js, Java, Python, C#
- Bring your own libraries (even native ones)

**Simple resource model**

- Select power rating from 128 MB to 3 GB
- CPU and network allocated proportionately

**Flexible use**

- Synchronous or asynchronous
- Integrated with other AWS services

**Flexible authorization**

- Securely grant access to resources and VPCs
- Fine-grained control for invoking your functions

Images credit: aws.amazon.com

56

## 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

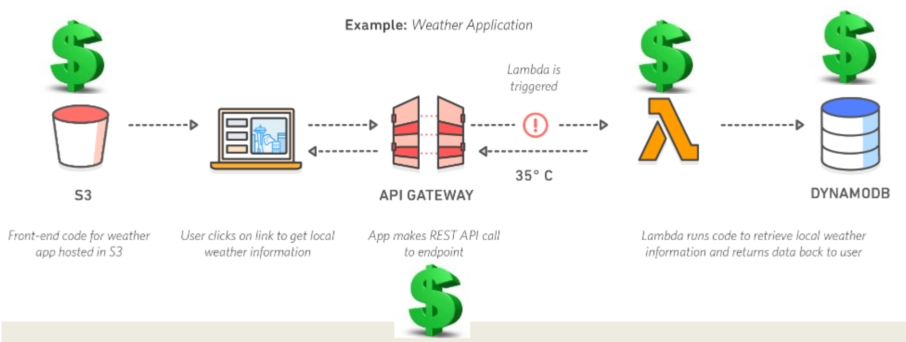


## FAAS PLATFORMS - 3

- 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




| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.59 |
|---|---|---|

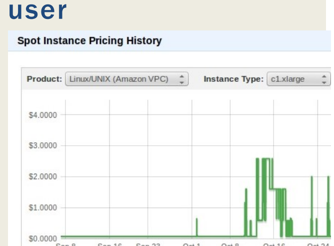
59

# 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 →




| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.60 |
|---|---|---|

60

## 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

| | | |
|---|---|---|
| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.61 |

61

## 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?**

| | | |
|---|---|---|
| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.62 |

62

## PRICING OBFUSCATION

**Worst-case scenario = ~2.32x !**

AWS EC2: **$72.00**
AWS Lambda: **$167.01**

Break Even: **4,319,136 GB-sec**

Two threads @2GB-ea: **~12.5 days**

- **BREAK-EVEN POINT: ~4,319,136 GB-sec-month ~12.5 days 2 concurrent clients @ 2GB**

63

## 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?**



64

## 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

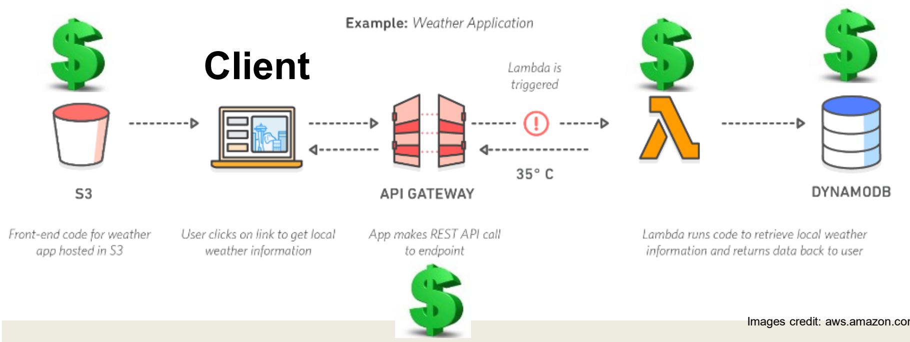


## FAAS CHALLENGES

- 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

67

# 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 400,000 GB-sec/month → FREE

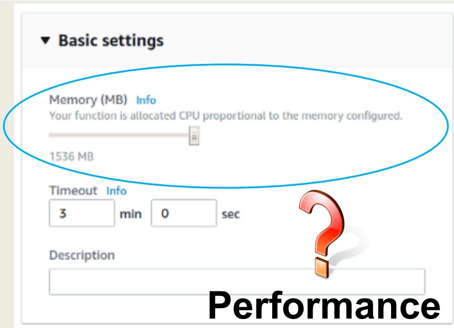
- Afterwards: $0.0000002 per request
$0.000000208 to rent 128MB / 100-ms

| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.68 |
|---|---|---|

68

# 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…"*

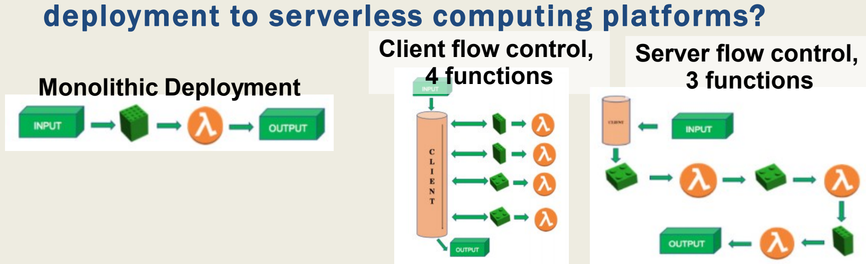



- **But how much memory do model services require?**

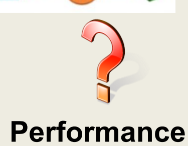


# SERVICE COMPOSITION

- **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?**

## 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

71

## FUNCTION-AS-A-SERVICE

AWS Lambda Demo

72

72

# 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





# 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 – 10/21

- **Questions from 10/19**
- Tutorial 3 - Best Practices with EC2
- Tutorial 4 – Intro to FaaS – AWS Lambda
- **From: Cloud Computing Concepts, Technology & Architecture: Chapter 4: Cloud Computing Concepts and Models:**
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models
- **2nd hour:**
  - TCSS 562 Term Project
  - Team Planning - Breakout Rooms

| October 21, 2021 | TCSS562:Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.77 |
|---|---|---|

77

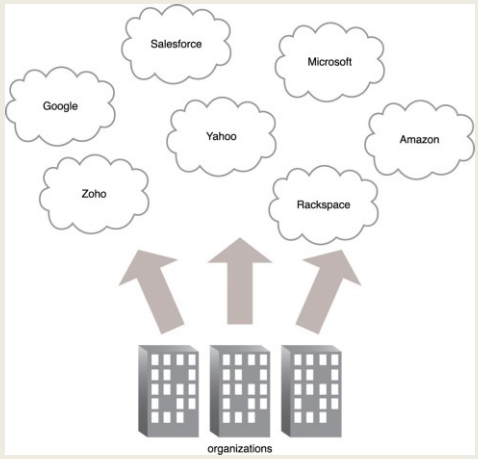
# CLOUD DEPLOYMENT MODELS

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

| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.78 |
|---|---|---|

78

# PUBLIC CLOUDS

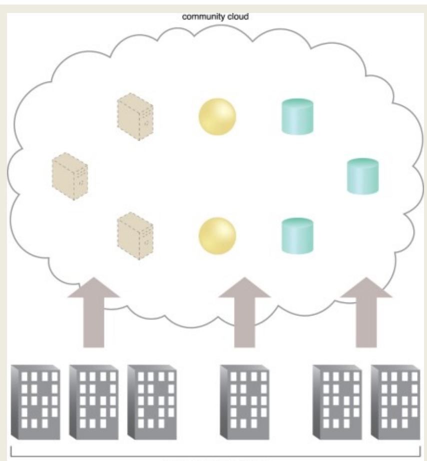





79

# 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

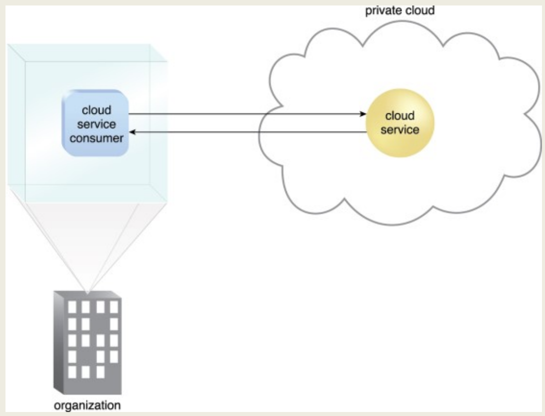





80

# PRIVATE CLOUD

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

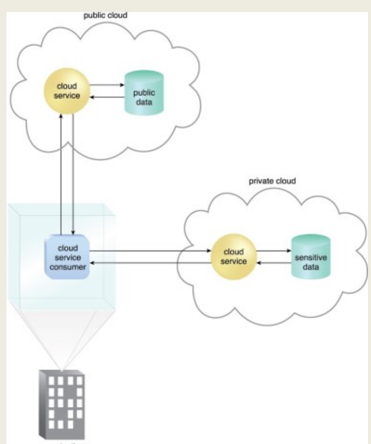





81

# 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






82

# 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



83

# WE WILL RETURN AT 6:20 PM

84

# OBJECTIVES – 10/21

- **Questions from 10/19**
- Tutorial 3 - Best Practices with EC2
- Tutorial 4 – Intro to FaaS – AWS Lambda
- **From: Cloud Computing Concepts, Technology & Architecture: Chapter 4: Cloud Computing Concepts and Models:**
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models
- **2nd hour:**
  - TCSS 562 Term Project
  - Team Planning - Breakout Rooms

October 21, 2021 | TCSS562:Software Engineering for Cloud Computing [Fall 2021] School of Engineering and Technology, University of Washington - Tacoma | L7.85

85

# TCSS 562 TERM PROJECT

October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021] School of Engineering and Technology, University of Washington - Tacoma | L7.86

86

# 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
- Alternate 1: Cloud Computing Related Research Project
- Alternate 2: Literature Survey/Gap Analysis

**- as an individual project*



# 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
- Docker container image integration with AWS Lambda – performance & scalability
- Resource contention study using CpuSteal metric
  - Investigate the degree of CpuSteal on FaaS platforms
    - What is the extent? Min, max, average
    - When does it occur?
    - Does it correlate with performance outcomes?
    - Is contention self-inflicted?
- & 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
  - What throughput (records/sec) can Lambda ingest directly?
  - Comparison with 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 claims multiple GB/sec throughput
    - What is the cost difference?



# SERVERLESS APPLICATIONS - 2

- **Map-Reduce Style Application**
  - Function 1: split data into chunks, usually sequentially
  - Function 2: process individual chunks concurrently (in parallel)
    - Data processing is considered to be Embarrassingly Parallel
  - Function 3: aggregate and summarize results
- **Image Classification Pipeline**
  - Deploy pretrained image classifiers in a multi-stage pipeline
- **Machine Learning**
  - Multi-stage inferencing pipelines
  - Natural Language Processing (NLP) pipelines
  - Training (?)

# AWS LAMBDA PLATFORM LIMITATIONS

- Maximum 10 GB memory per function instance
- Maximum 15-minutes execution per function instance
- Access to 500 MB of temporary disk space for local I/O
- Access up to 6 vCPUs depending on memory reservation size
- 1,000 concurrent function executions inside account (default)
- Function payload: 6MB (synchronous), 256KB (asynchronous)
- Deployment package: 50MB (compressed), 250MB (unzipped)
- Container image size: 10 GB
- Processes/threads: 1024
- File descriptors: 1024

- See: https://docs.aws.amazon.com/lambda/latest/dg/gettingstarted-limits.html



# EXTRACT TRANSFORM LOAD DATA PIPELINE

- Service 1: **TRANSFORM**

- Read CSV file, perform some transformations
- Write out new CSV file

- Service 2: **LOAD**

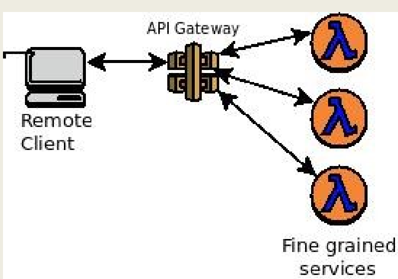
- Read CSV file, load data into relational database
- Cloud DB (AWS Aurora), or local DB (Derby/SQLite)
  - Derby DB and/or SQLite code examples to be provided in Java

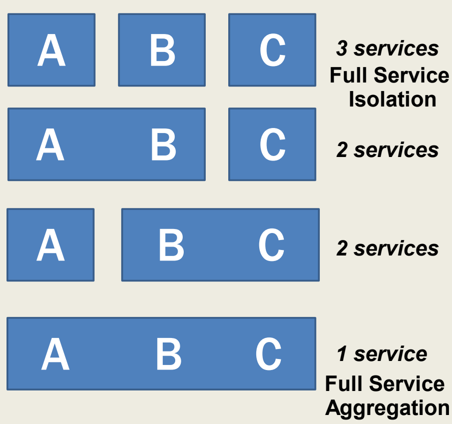
# EXTRACT TRANSFORM LOAD DATA PIPELINE - 2

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



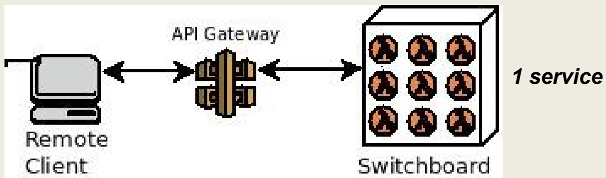
# SERVICE COMPOSITION




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

# SWITCH-BOARD ARCHITECTURE




**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

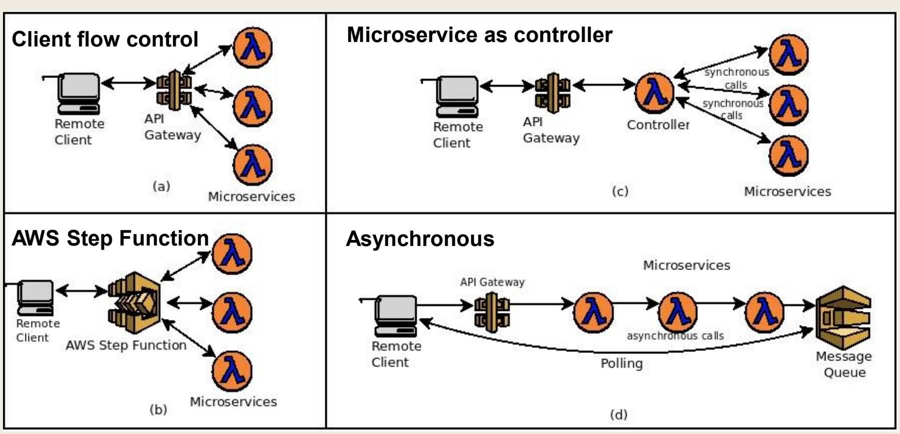
- **Synchronous web service:**
- Client calls service
- Client blocks (freezes) and waits for server to complete call
- Connection is maintained in the "OPEN" state
- Problematic if service runtime is long!
  - Connections are notoriously dropped
  - System timeouts reached
- Client can't do anything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

| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.105 |
|---|---|---|

105

## *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

| October 21, 2021 | TCSS562: Software Engineering for Cloud Computing [Fall 2021]<br>School of Engineering and Technology, University of Washington - Tacoma | L7.106 |
|---|---|---|

106

## 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?



107

## QUESTIONS



108