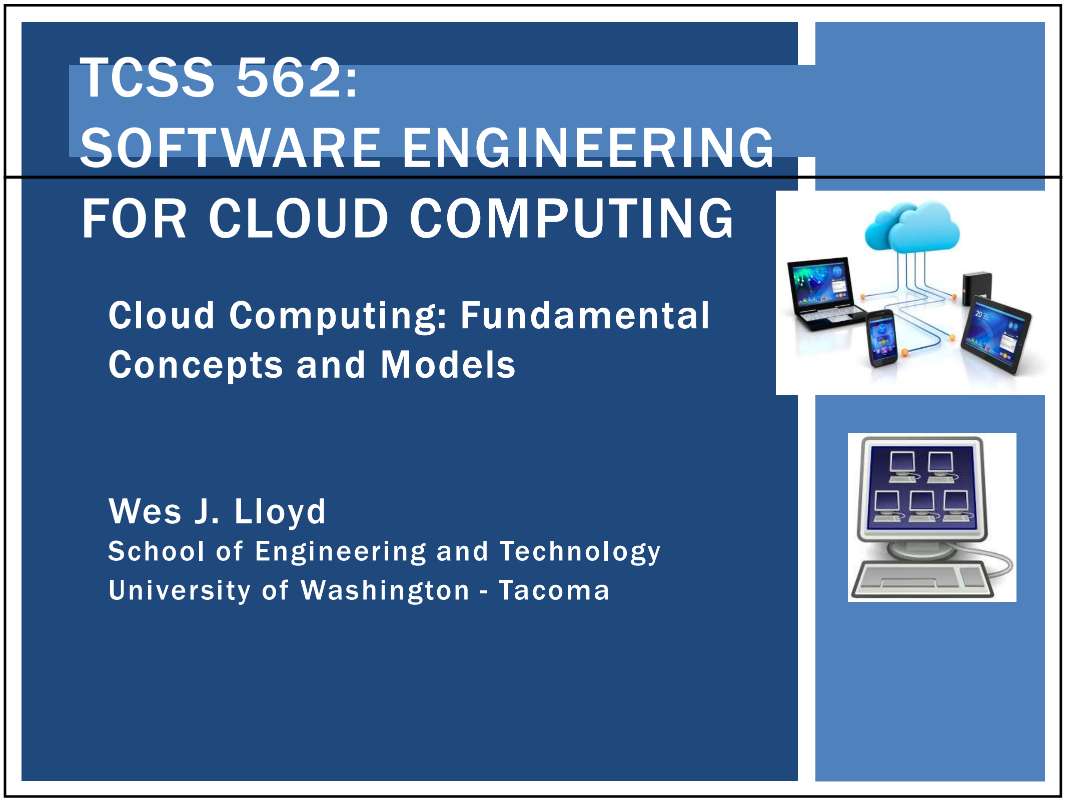
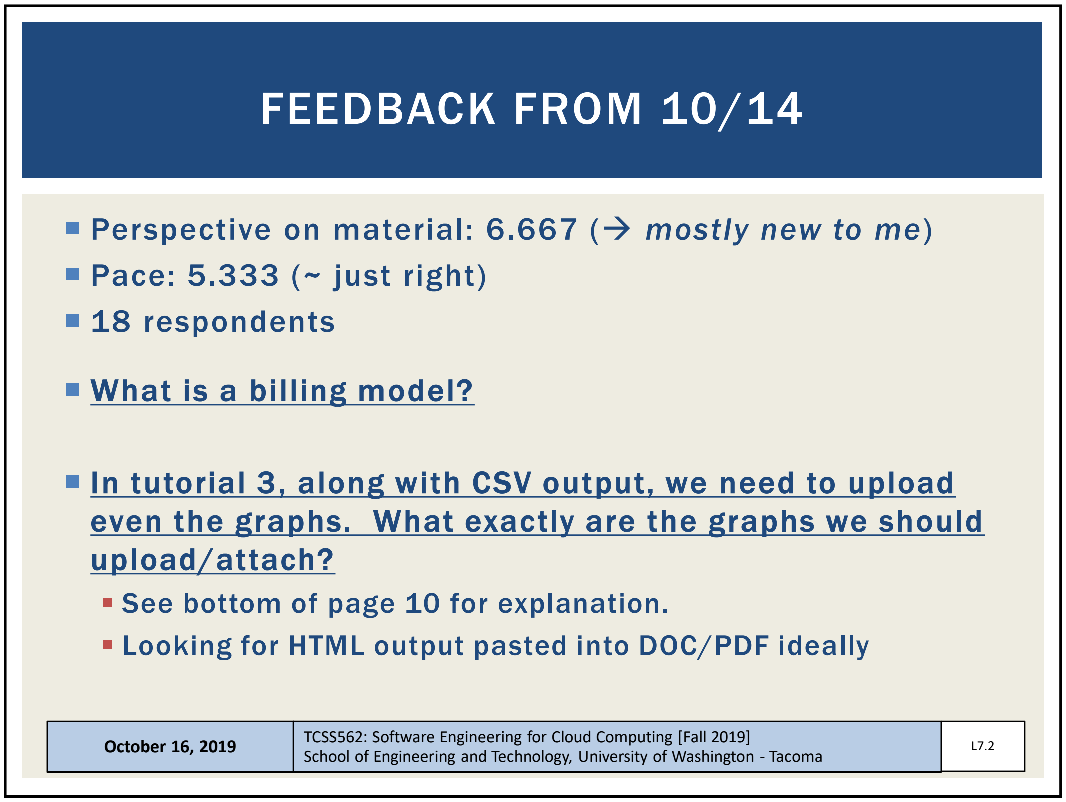


TCSS 562: SOFTWARE ENGINEERING FOR CLOUD COMPUTING

Cloud Computing: Fundamental Concepts and Models

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

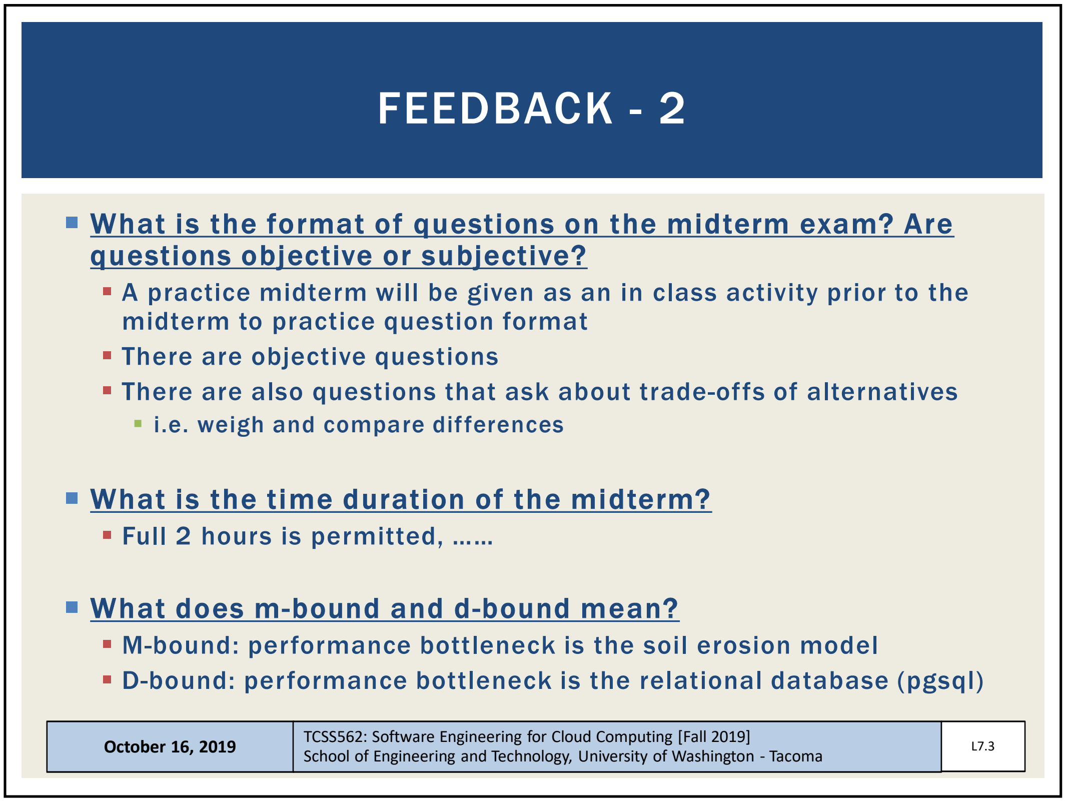
1



FEEDBACK FROM 10/14

- Perspective on material: 6.667 (→ *mostly new to me*)
- Pace: 5.333 (~ just right)
- 18 respondents
- **What is a billing model?**
- **In tutorial 3, along with CSV output, we need to upload even the graphs. What exactly are the graphs we should upload/attach?**
  - See bottom of page 10 for explanation.
  - Looking for HTML output pasted into DOC/PDF ideally

2



FEEDBACK - 2

- **What is the format of questions on the midterm exam? Are questions objective or subjective?**
  - A practice midterm will be given as an in class activity prior to the midterm to practice question format
  - There are objective questions
  - There are also questions that ask about trade-offs of alternatives
    - i.e. weigh and compare differences
- **What is the time duration of the midterm?**
  - Full 2 hours is permitted, ……
- **What does m-bound and d-bound mean?**
  - M-bound: performance bottleneck is the soil erosion model
  - D-bound: performance bottleneck is the relational database (pgsql)

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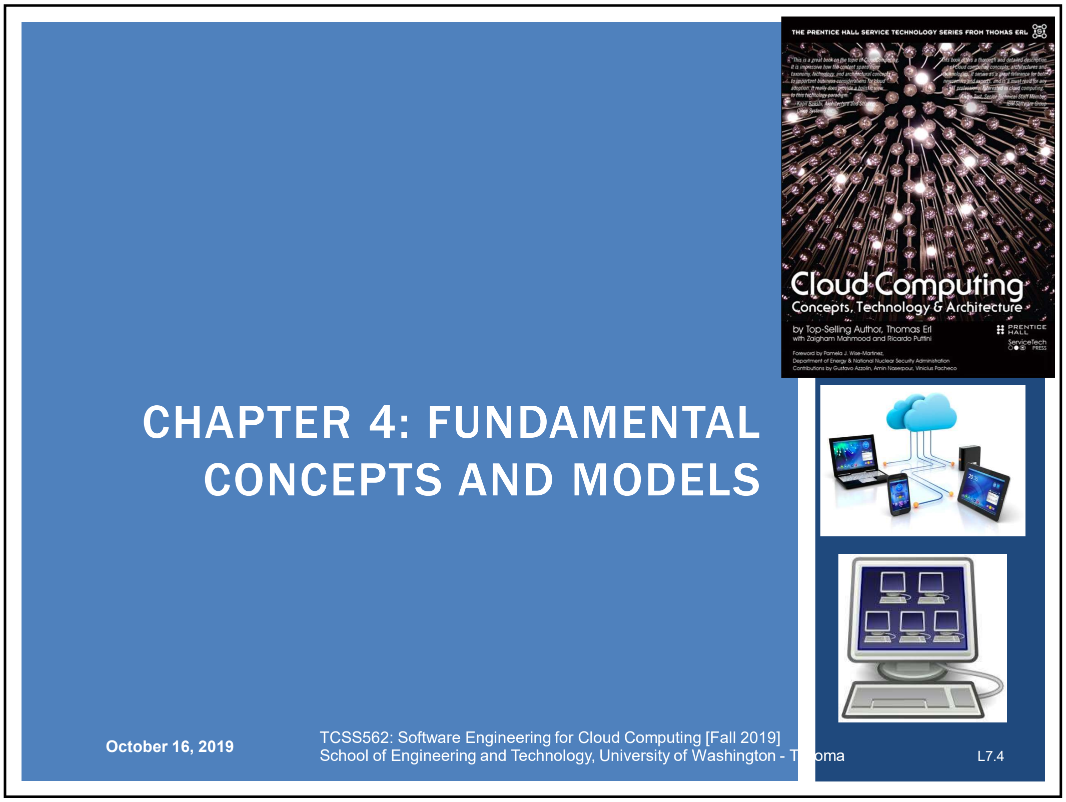
3



CHAPTER 4: FUNDAMENTAL CONCEPTS AND MODELS

THE PRENTICE HALL SERVICE TECHNOLOGY SERIES FROM THOMAS ERL
Cloud Computing
Concepts, Technology & Architecture
by Top-Selling Author, Thomas Erl
with Zaigham Mahmood and Ricardo Puttini
PRENTICE HALL
ServiceTech PRESS

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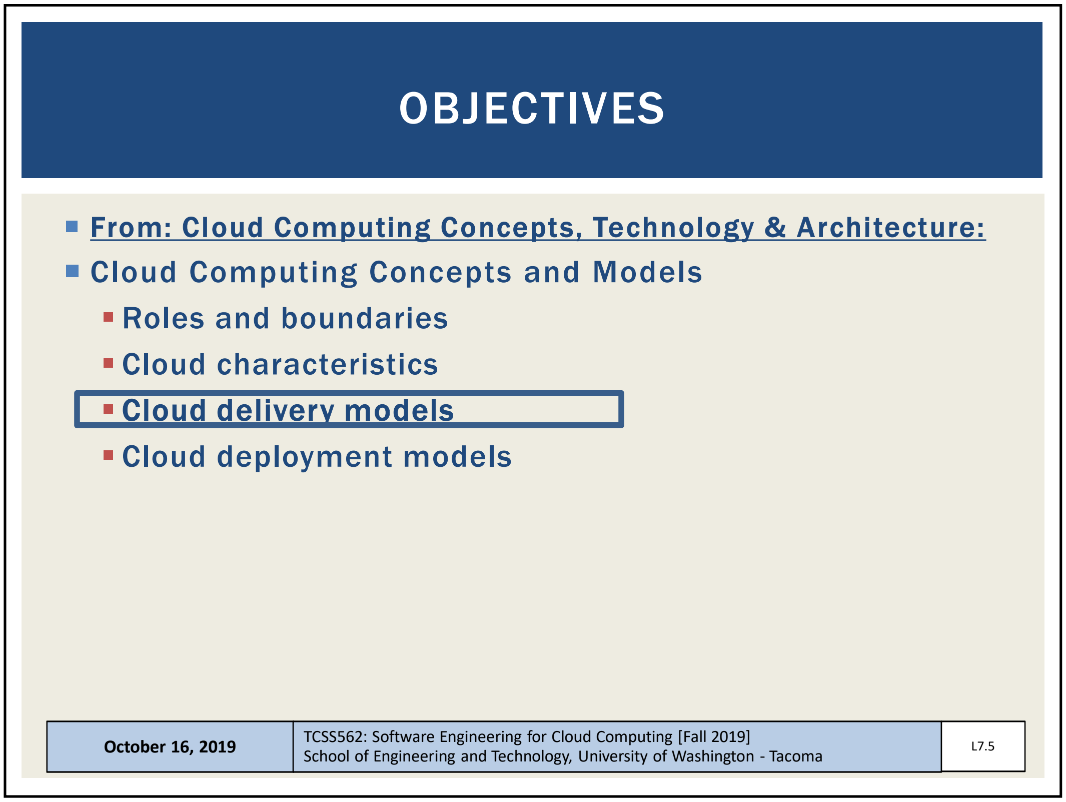
4



OBJECTIVES

- <u>From: Cloud Computing Concepts, Technology & Architecture:</u>
- Cloud Computing Concepts and Models
  - Roles and boundaries
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models

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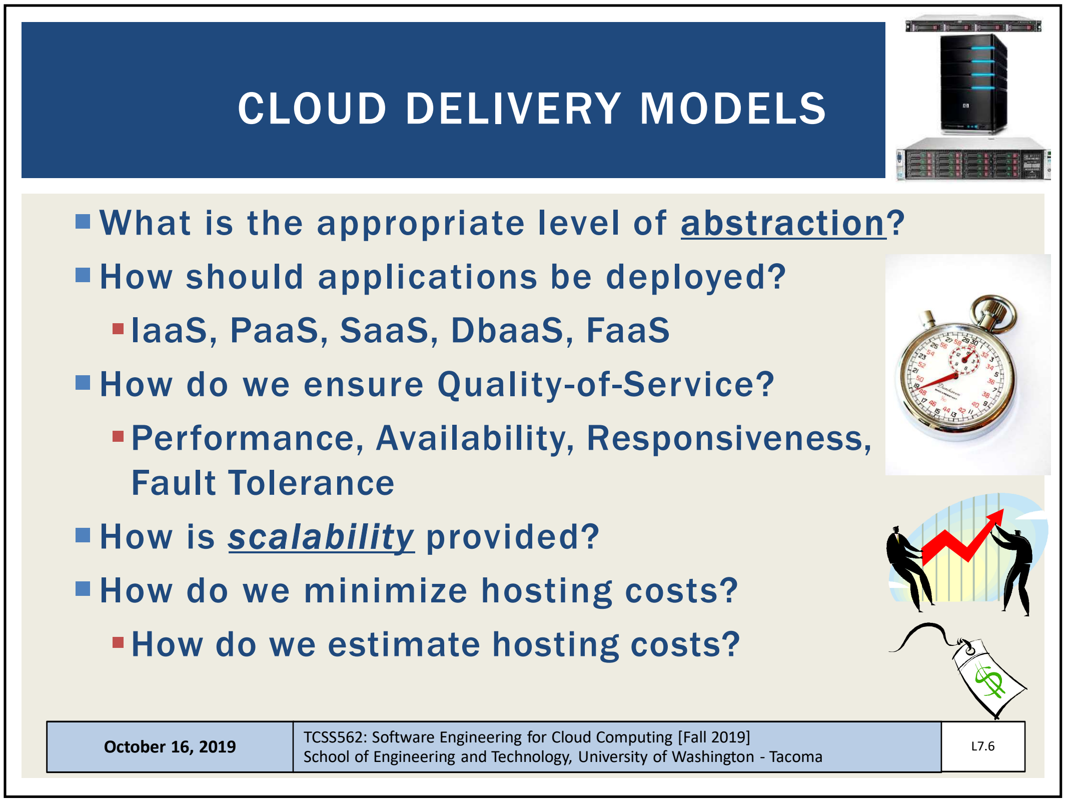

CLOUD DELIVERY MODELS

- 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?
- How do we minimize hosting costs?
  - How do we estimate hosting costs?

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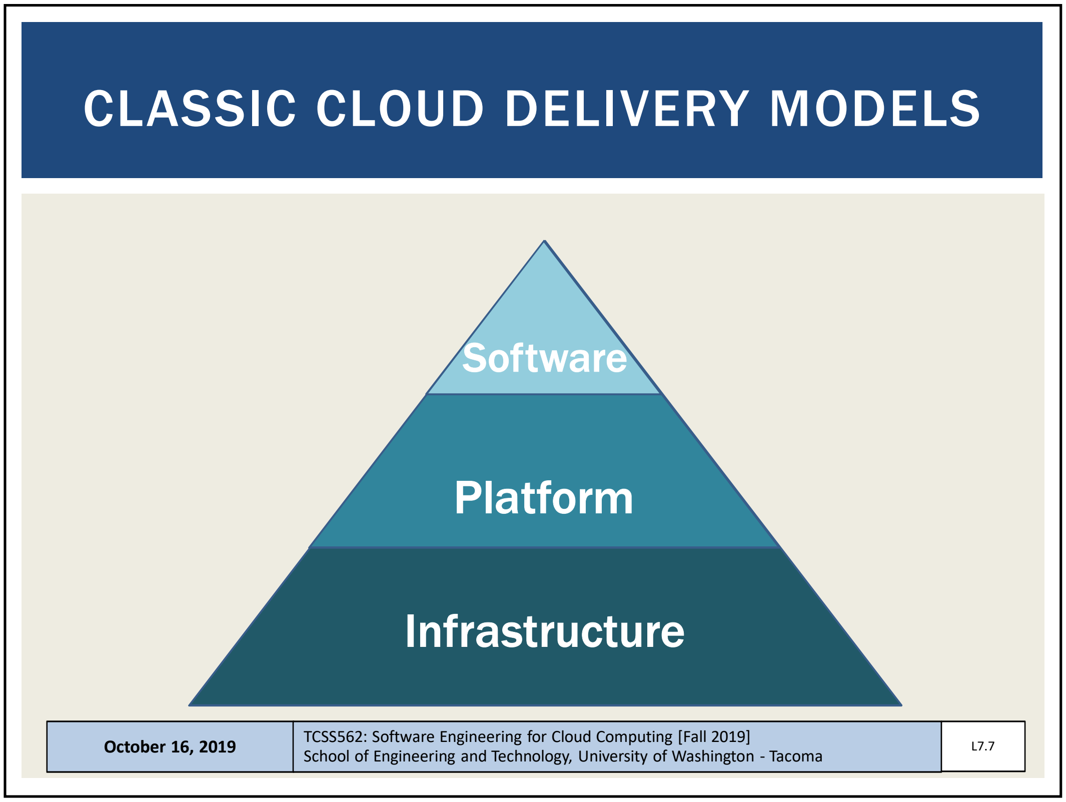
6



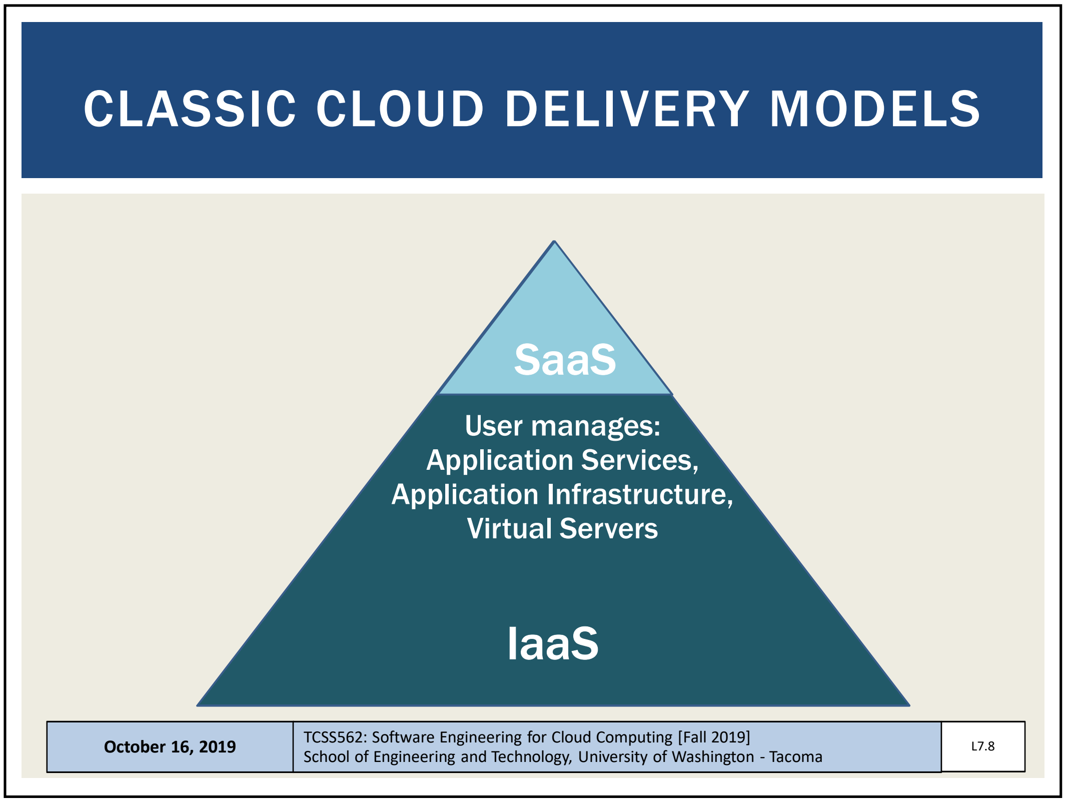
CLASSIC CLOUD DELIVERY MODELS

Software

Platform

Infrastructure

7



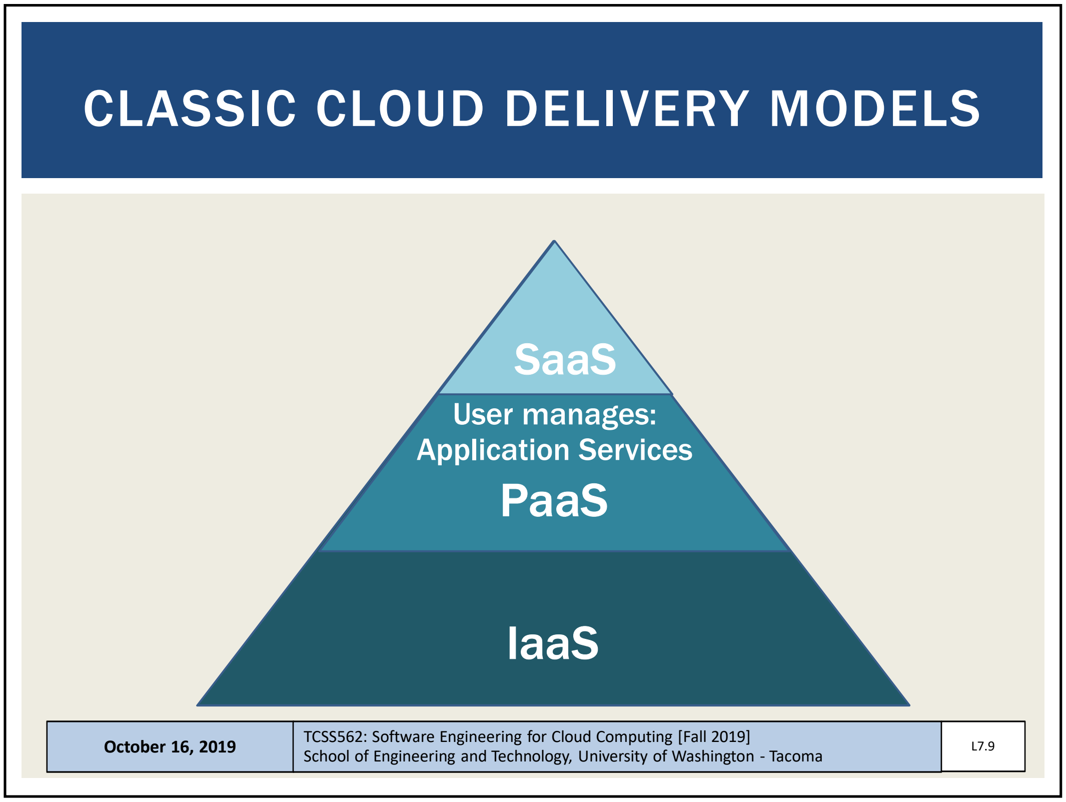
CLASSIC CLOUD DELIVERY MODELS

SaaS

User manages:
Application Services,
Application Infrastructure,
Virtual Servers

IaaS

8



CLASSIC CLOUD DELIVERY MODELS

SaaS

User manages:
Application Services

PaaS

IaaS

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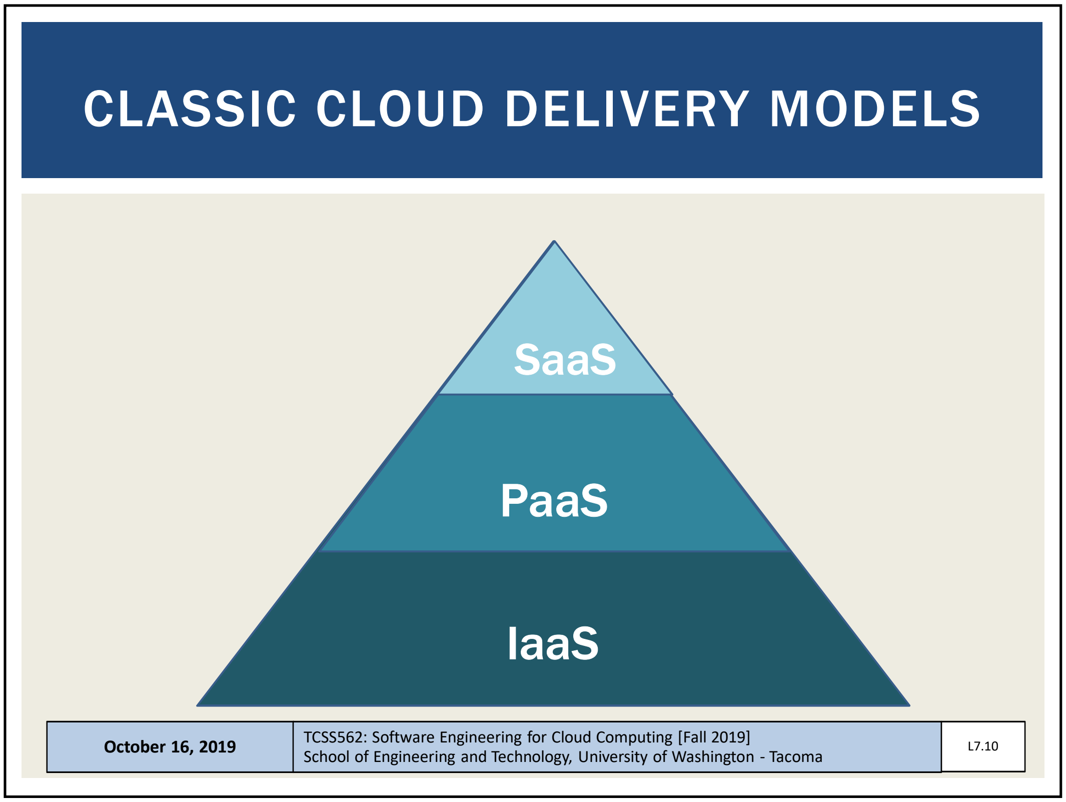

CLASSIC CLOUD DELIVERY MODELS

SaaS

PaaS

IaaS

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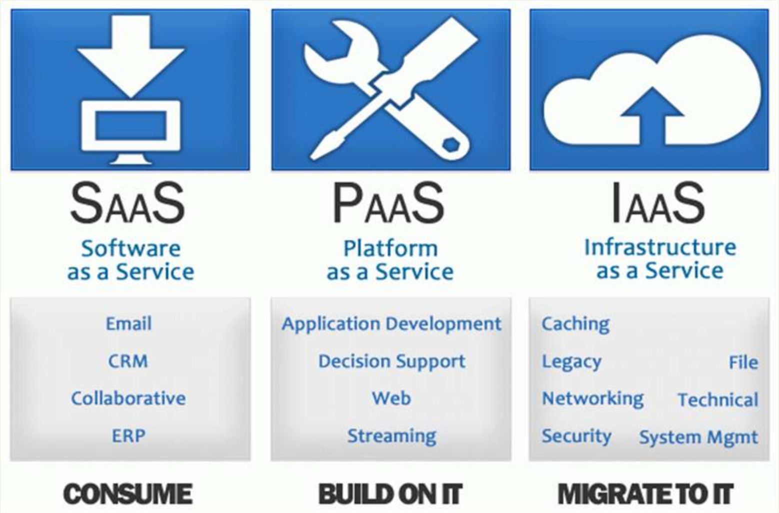
EXAMPLE CLOUD SERVICES



SAAS
Software as a Service

- Email
- CRM
- Collaborative
- ERP

CONSUME

PAAS
Platform as a Service

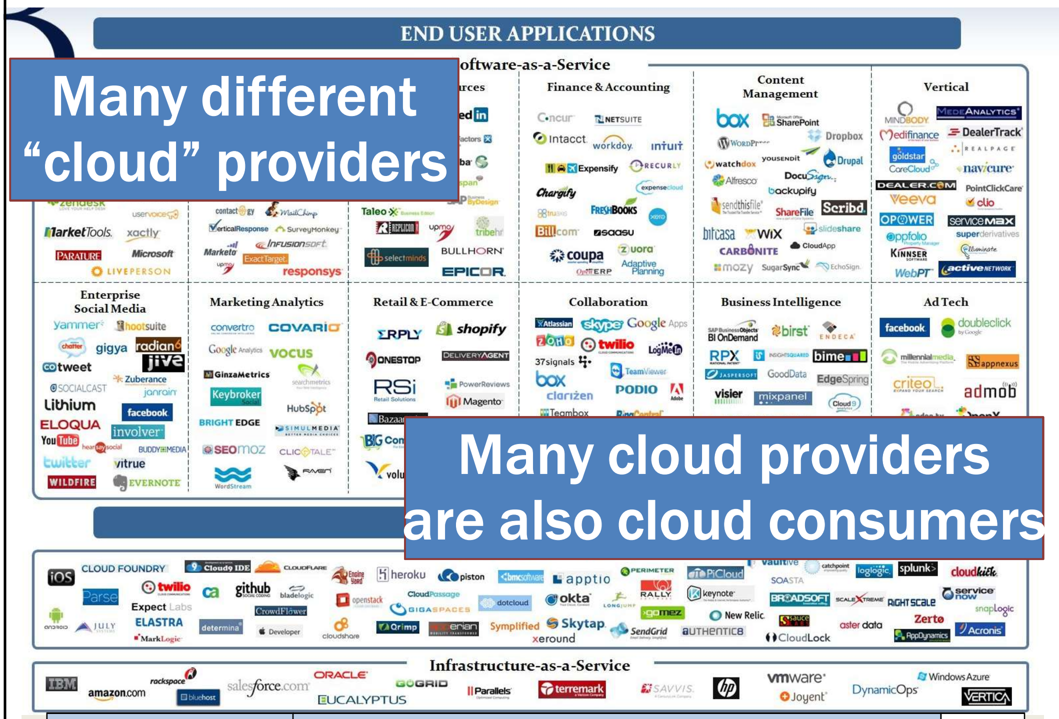
- Application Development
- Decision Support
- Web
- Streaming

BUILD ON IT

IAAS
Infrastructure as a Service

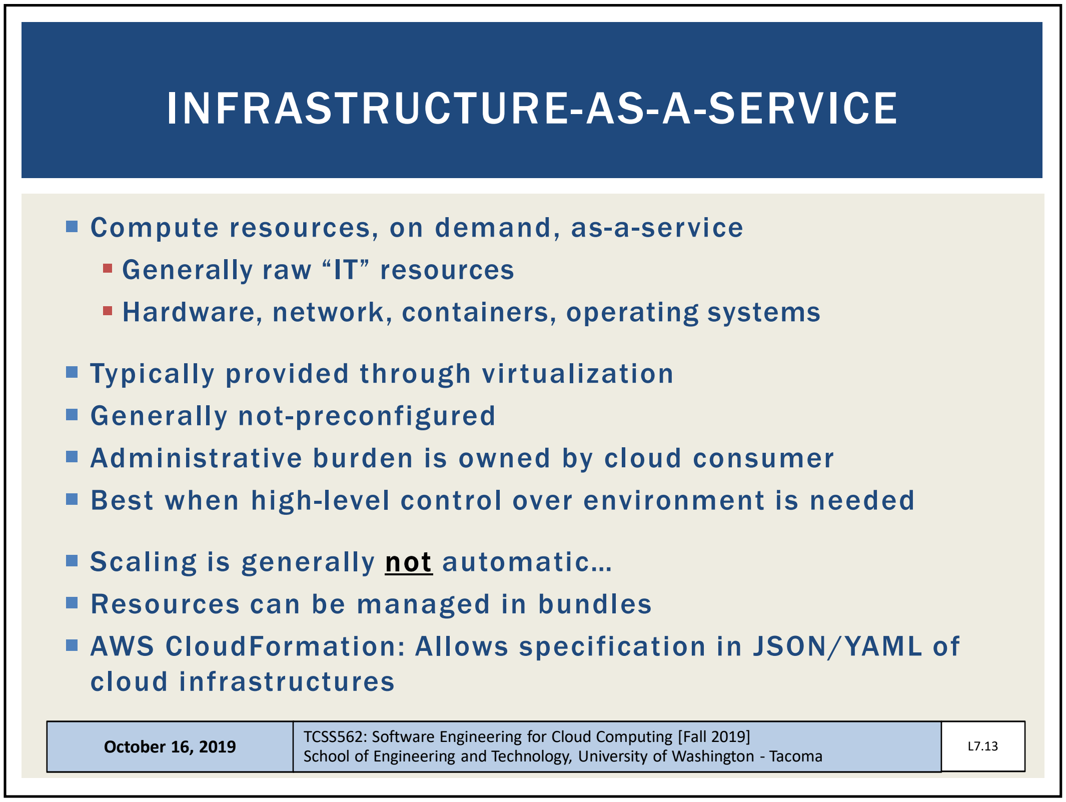
- Caching
- Legacy
- File
- Networking
- Technical
- Security
- System Mgmt

MIGRATE TO IT



Many different "cloud" providers

Many cloud providers are also cloud consumers



INFRASTRUCTURE-AS-A-SERVICE

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

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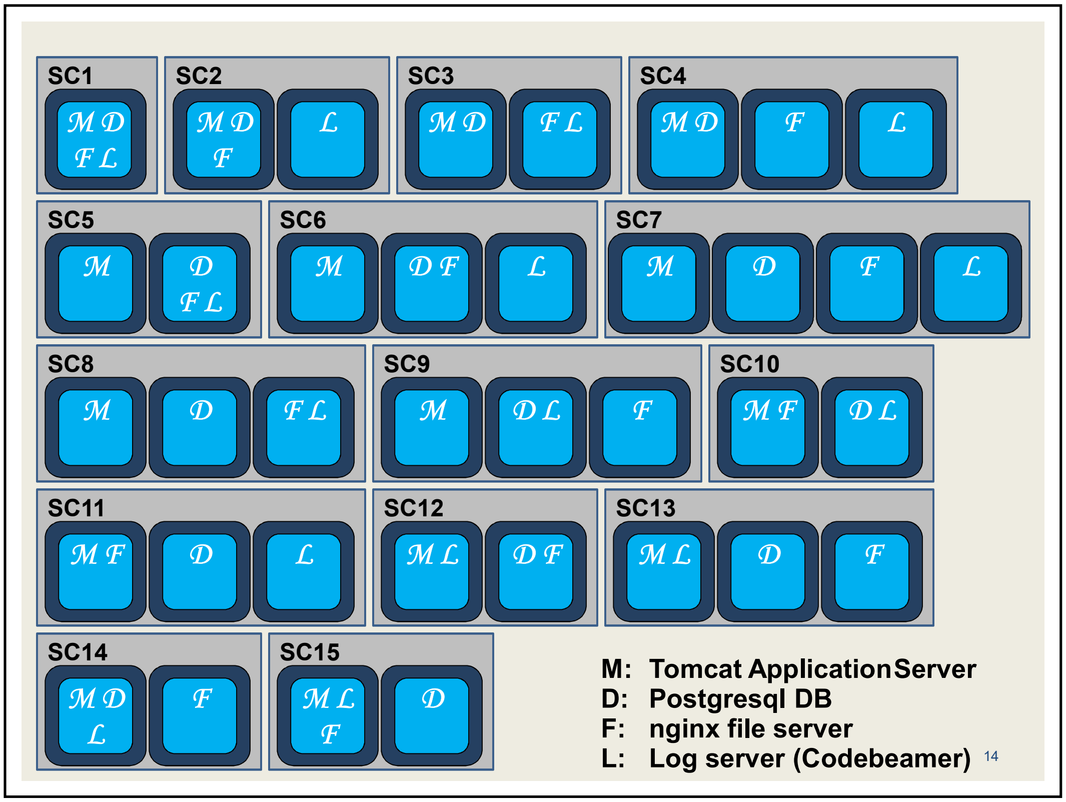
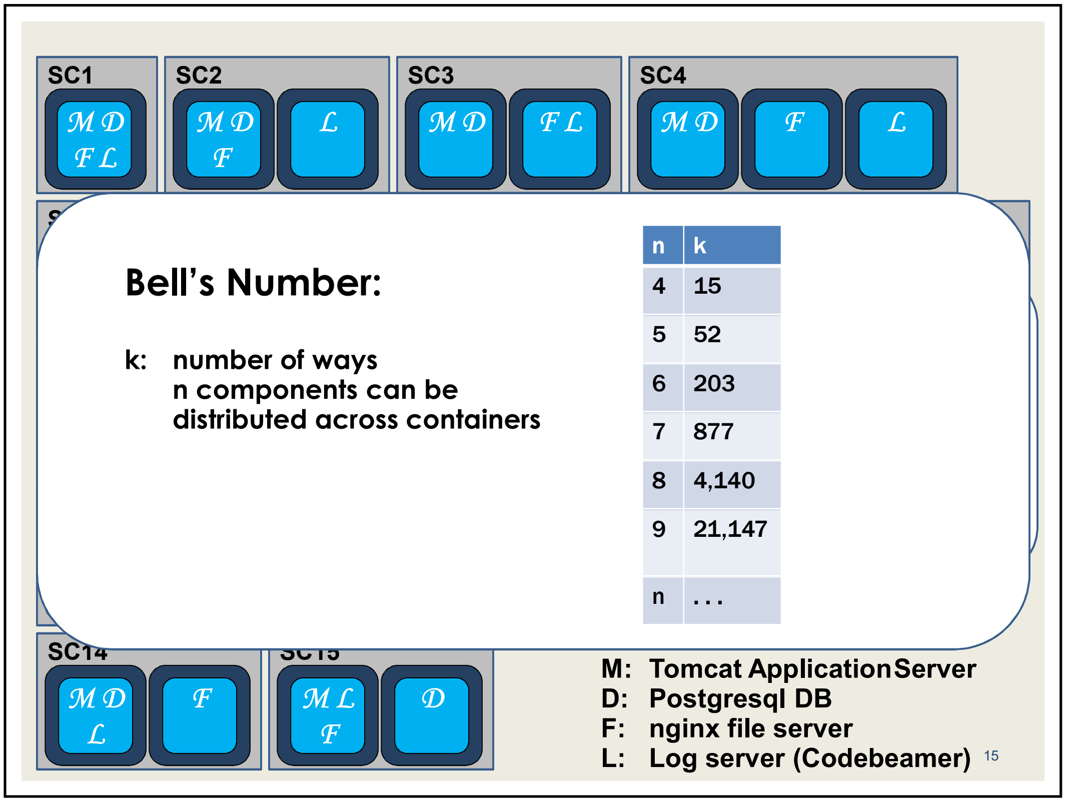


M: Tomcat Application Server
D: Postgresql DB
F: nginx file server
L: Log server (Codebeamer)

14

14



Bell's Number:

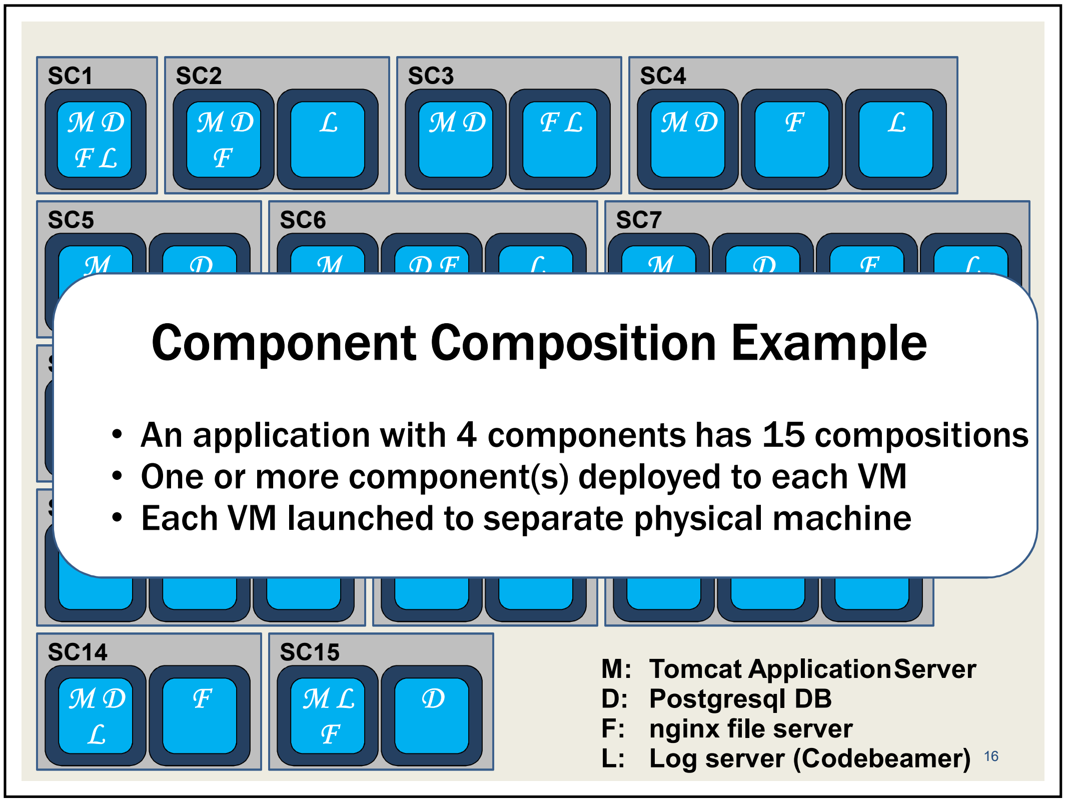
k: number of ways n components can be distributed across containers

n	k
4	15
5	52
6	203
7	877
8	4,140
9	21,147
n	. . .

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

15

15



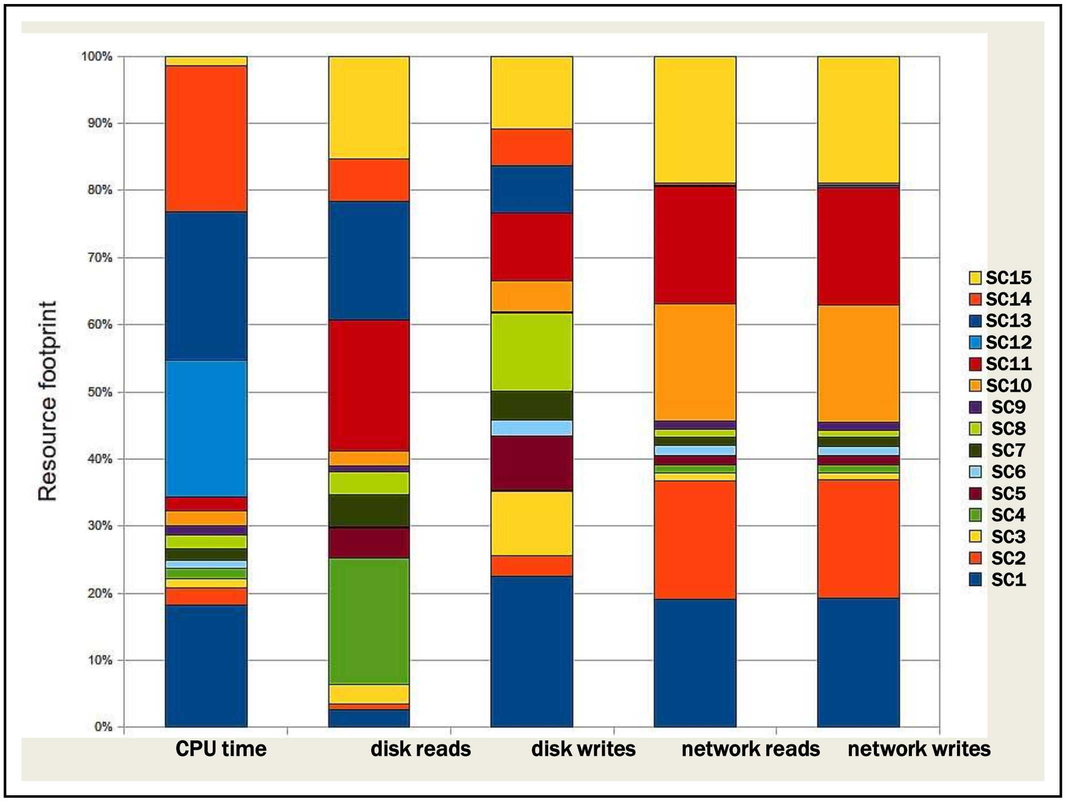
Component Composition Example

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

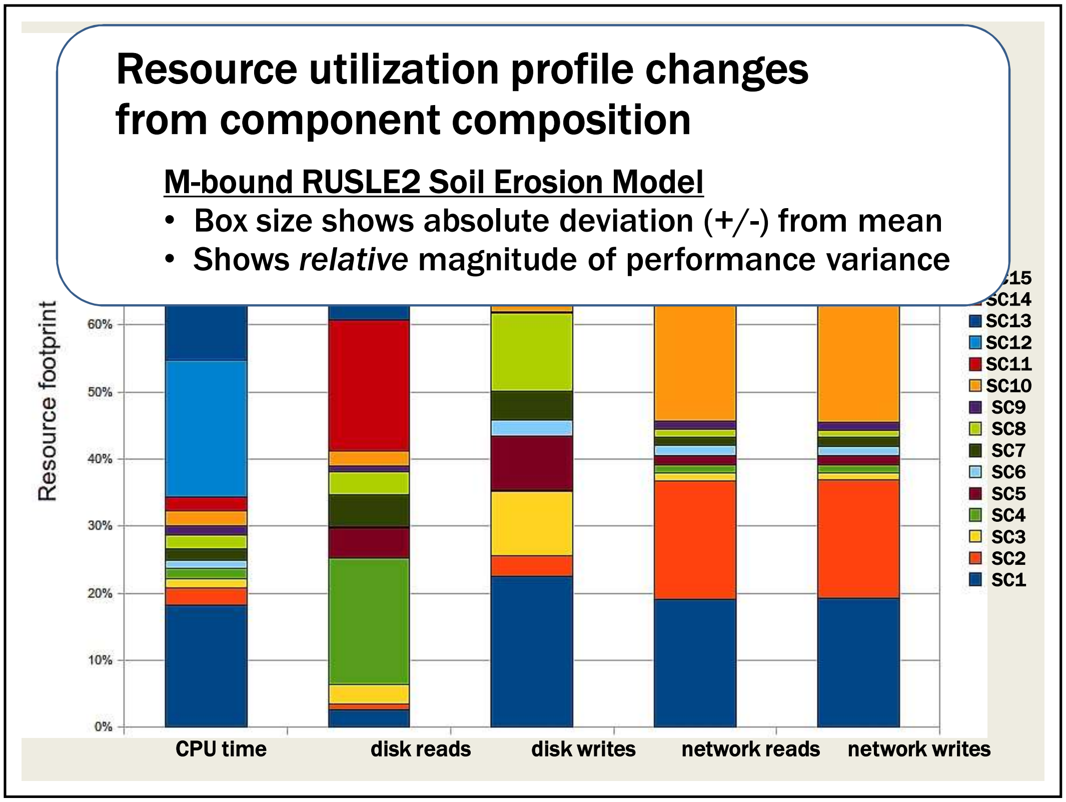
M: Tomcat Application Server
D: Postgresql DB
F: nginx file server
L: Log server (Codebeamer)

16

16



17



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

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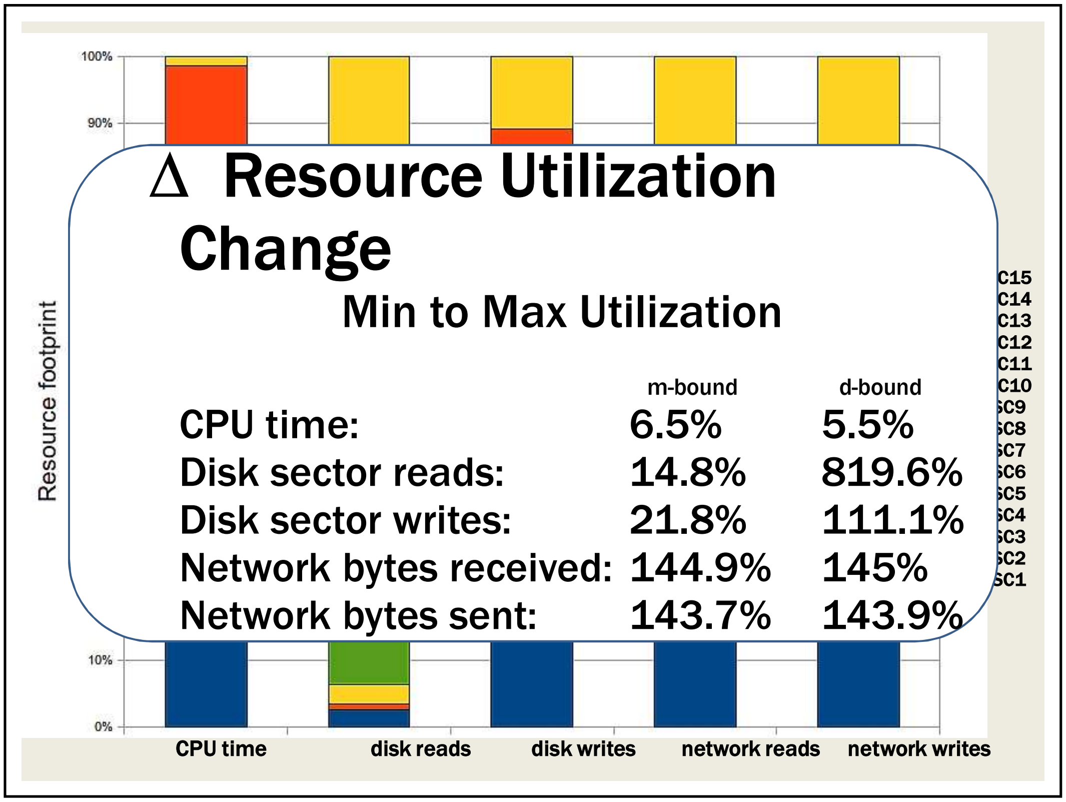
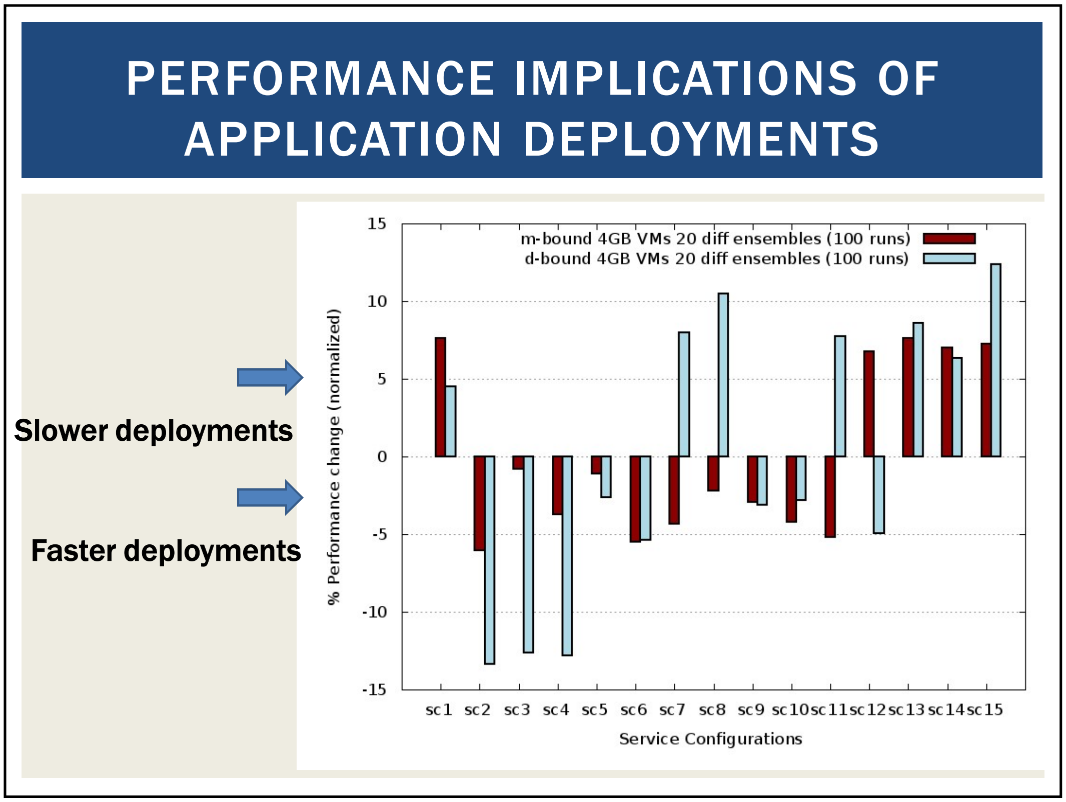


∆ Resource Utilization Change

Min to Max Utilization

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

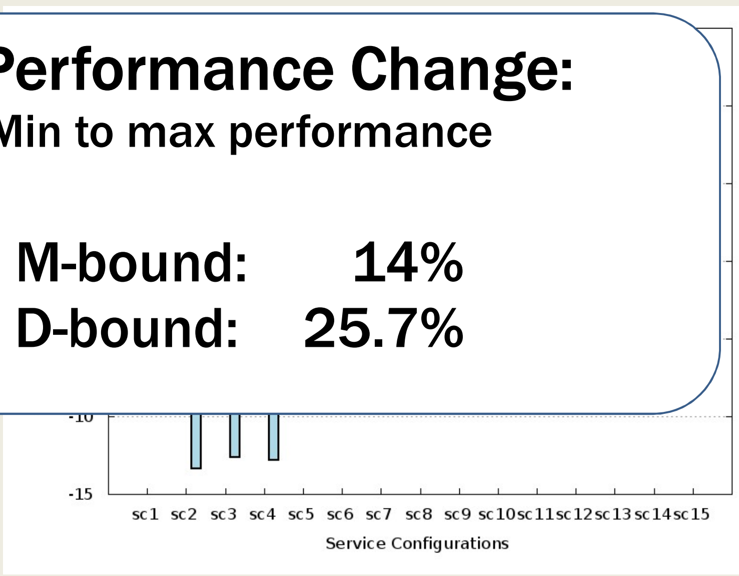


PERFORMANCE IMPLICATIONS OF APPLICATION DEPLOYMENTS

Slower deployments

Faster deployments

PERFORMANCE IMPLICATIONS OF APPLICATION DEPLOYMENTS



Δ Performance Change:

Min to max performance

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

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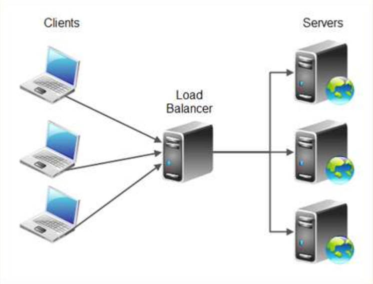
PLATFORM-AS-A-SERVICE

- 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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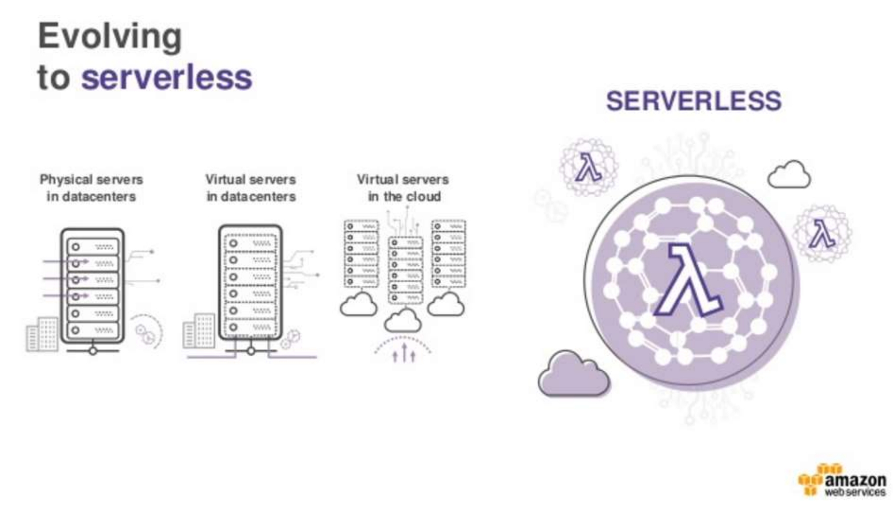
USES FOR PAAS

- 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

SERVERLESS COMPUTING

SERVERLESS COMPUTING - 2


Evolving
to serverless
SERVERLESS
Physical servers in datacenters
Virtual servers in datacenters
Virtual servers in the cloud
amazon web services

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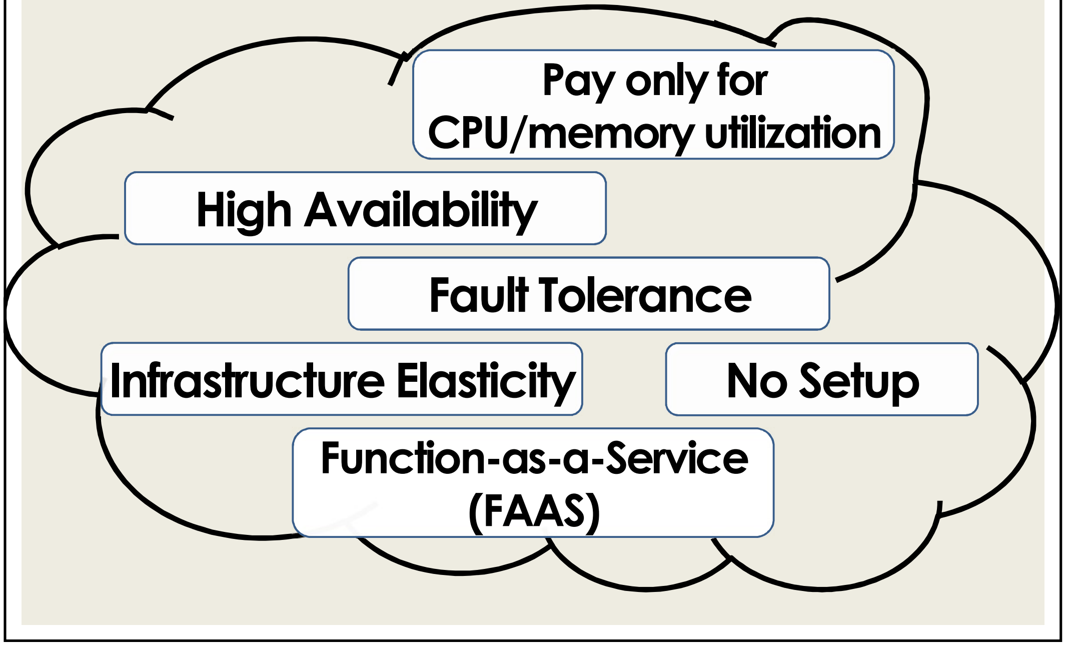
SERVERLESS COMPUTING



Pay only for CPU/memory utilization

High Availability

Fault Tolerance

Infrastructure Elasticity

No Setup

Function-as-a-Service (FAAS)

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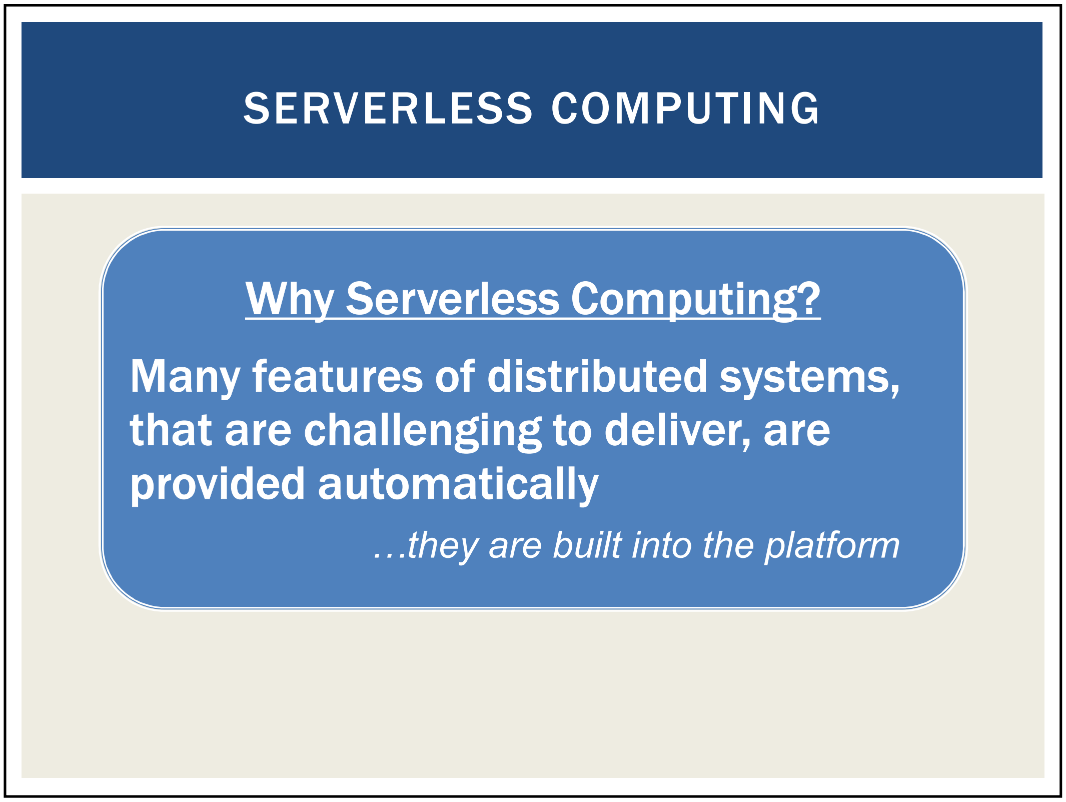

SERVERLESS COMPUTING

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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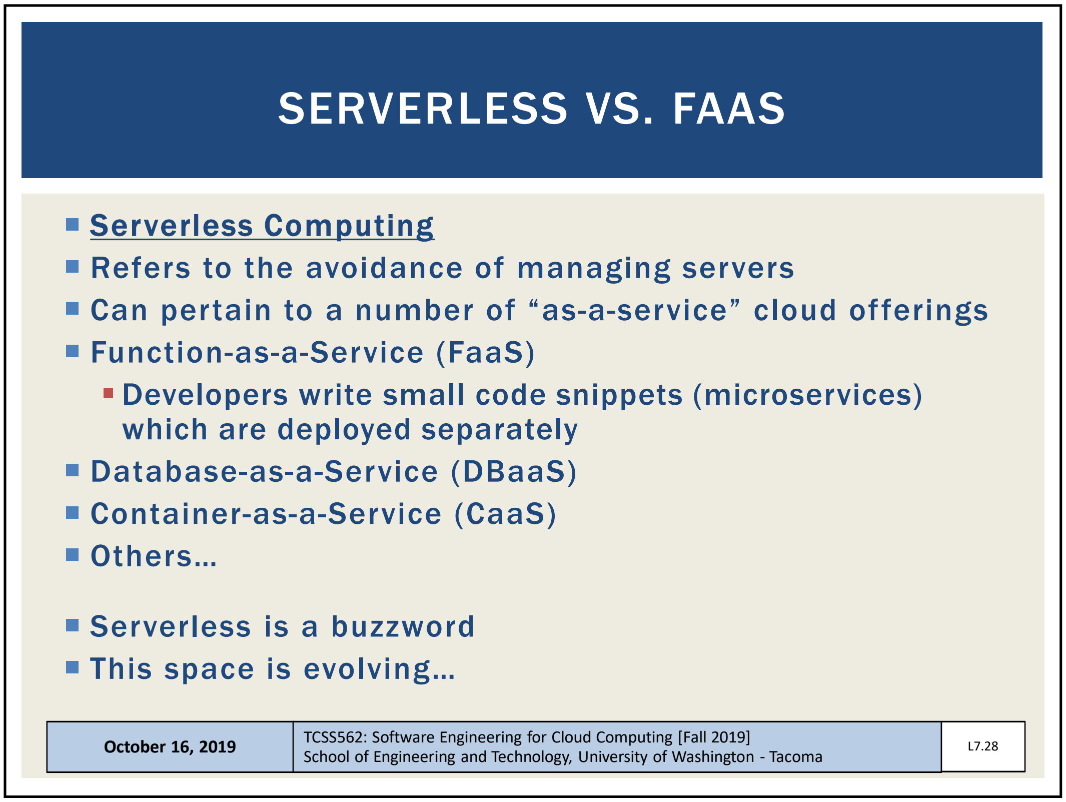

SERVERLESS VS. FAAS

- **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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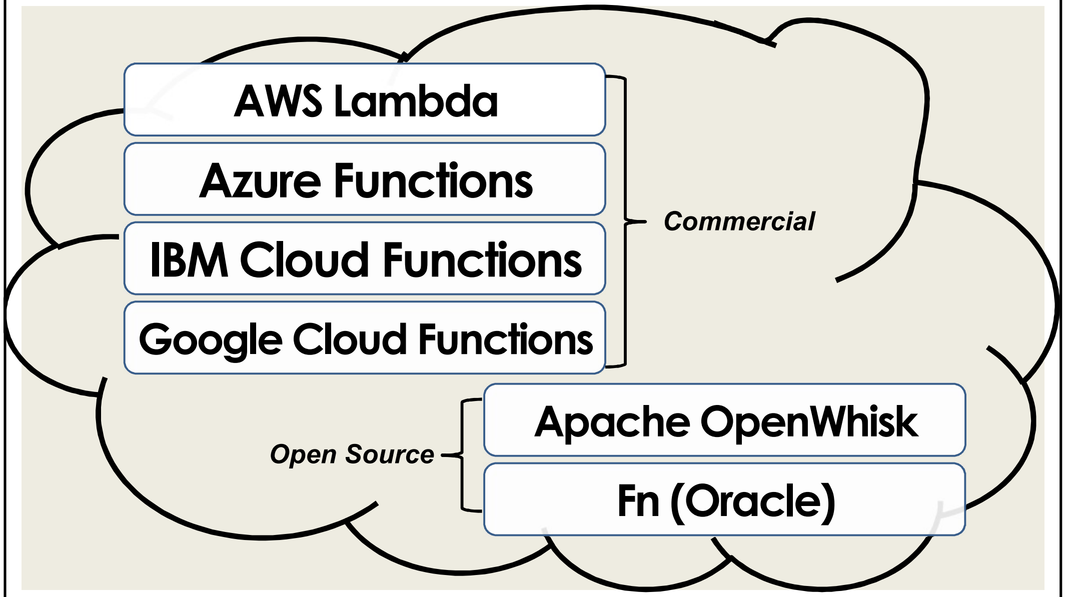
FAAS PLATFORMS



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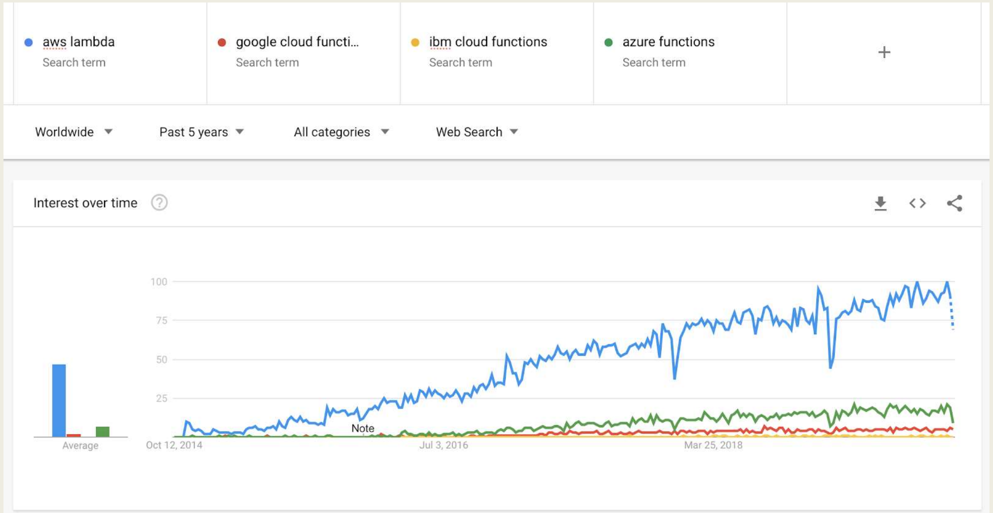
GOOGLE TRENDS: FAAS PLATFORMS



- aws lambda (Search term)
- google cloud functi... (Search term)
- ibm cloud functions (Search term)
- azure functions (Search term)

Worldwide ▾ | Past 5 years ▾ | All categories ▾ | Web Search ▾

Interest over time

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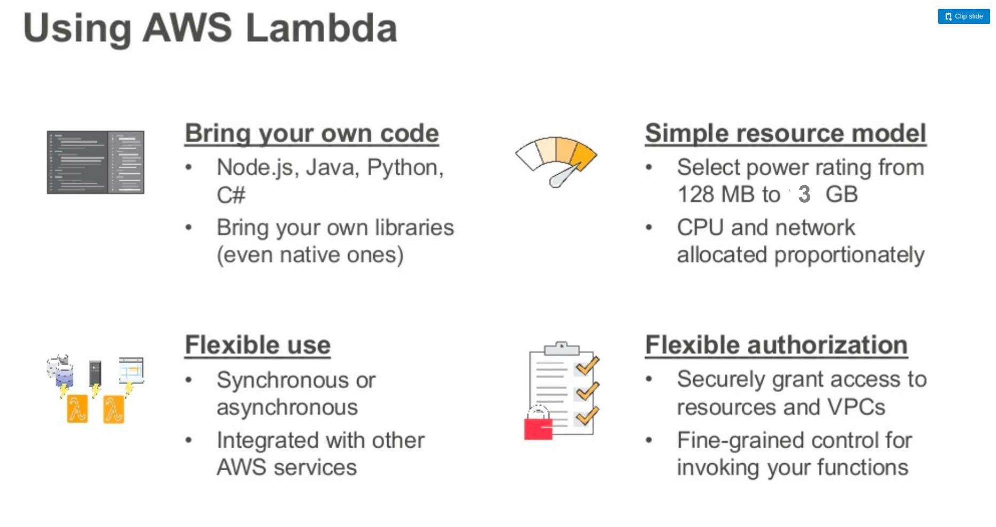
OPEN SOURCE FAAS FRAMEWORKS

Nuclio graphic

- Deployable to Docker container(s) or a Kubernetes cluster
- Fission: https://fission.io/
- Kubeless: https://kubeless.io/
- Nuclio: https://nuclio.io/
- OpenFaaS: https://www.openfaas.com/

- Supports cloud native development principles
- Building a cloud application by adopting a "deploy it yourself" framework avoids vendor lock-in
- Requires common medium of Kubernetes

AWS LAMBDA



Using AWS Lambda

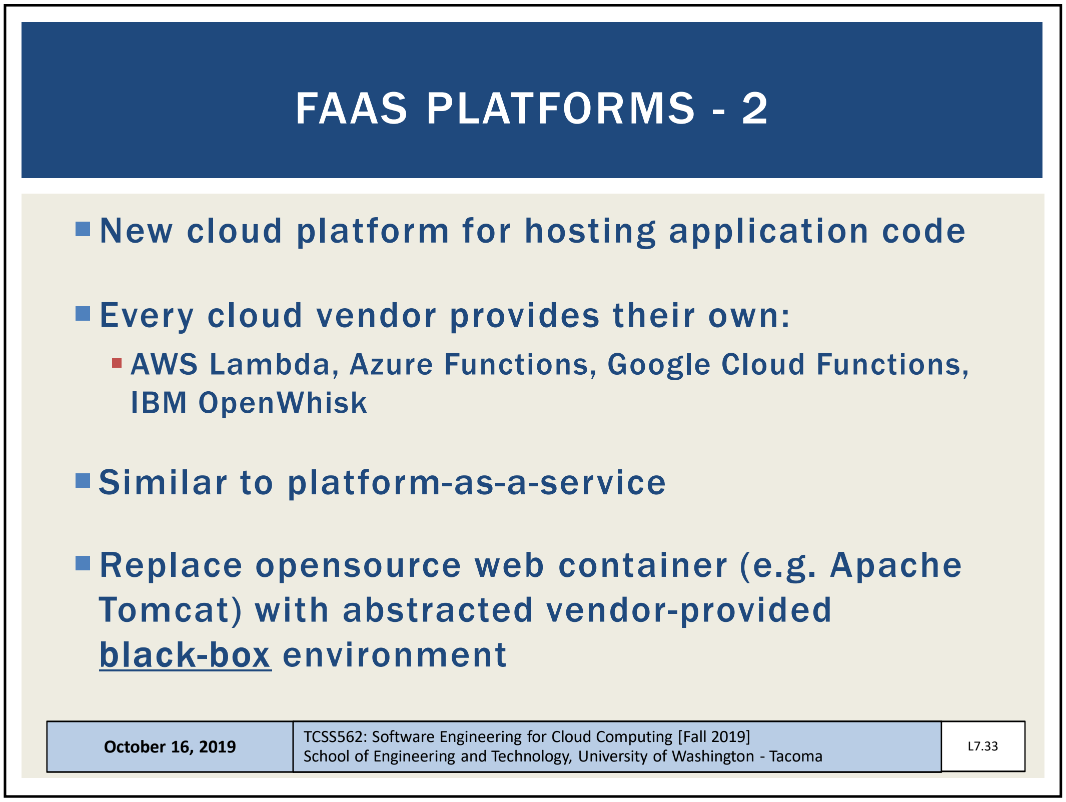
Bring your own code
- Node.js, Java, Python, C#
- Bring your own libraries (even native ones)

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

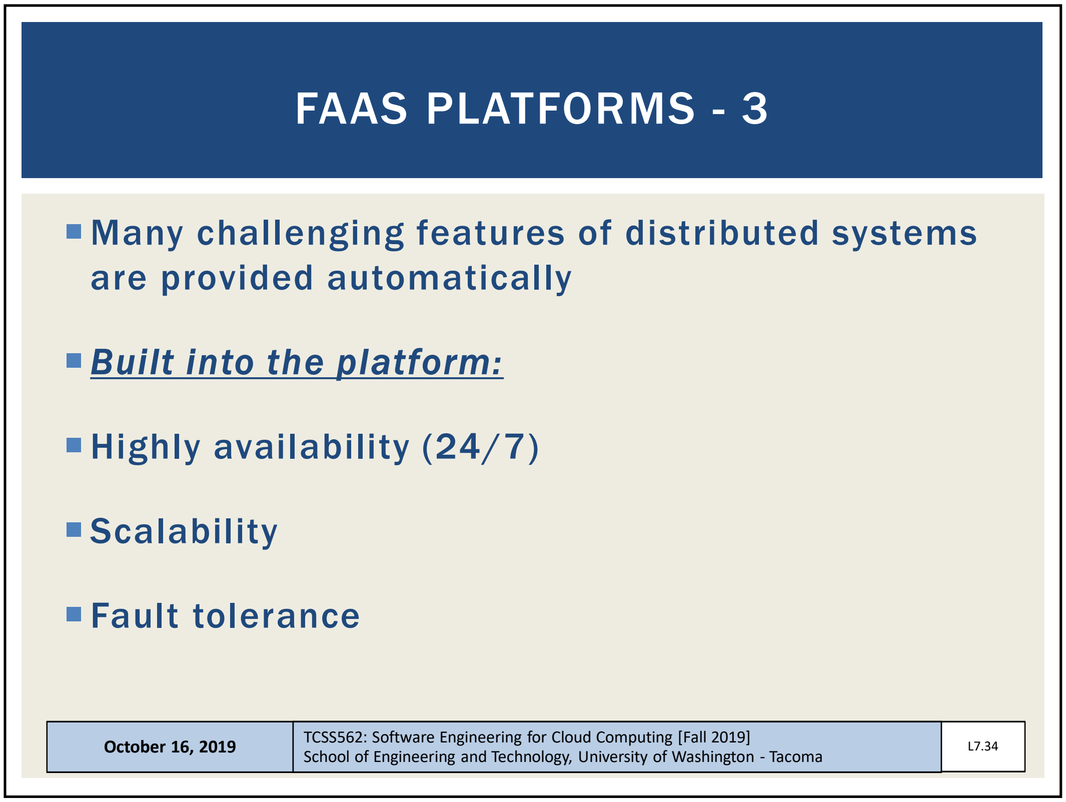
Flexible authorization
- Securely grant access to resources and VPCs
- Fine-grained control for invoking your functions

Images credit: aws.amazon.com



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

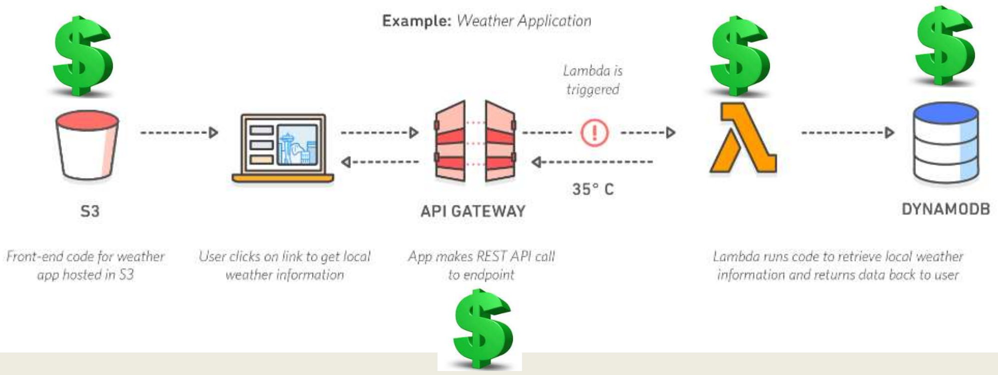


FAAS PLATFORMS - 3

- 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

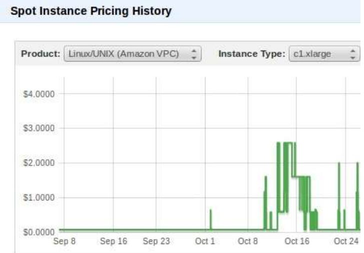

Example: Weather Application
$
S3
Front-end code for weather app hosted in S3
User clicks on link to get local weather information
API GATEWAY
App makes REST API call to endpoint
$
Lambda is triggered
35° C
$
Lambda runs code to retrieve local weather information and returns data back to user
$
DYNAMODB

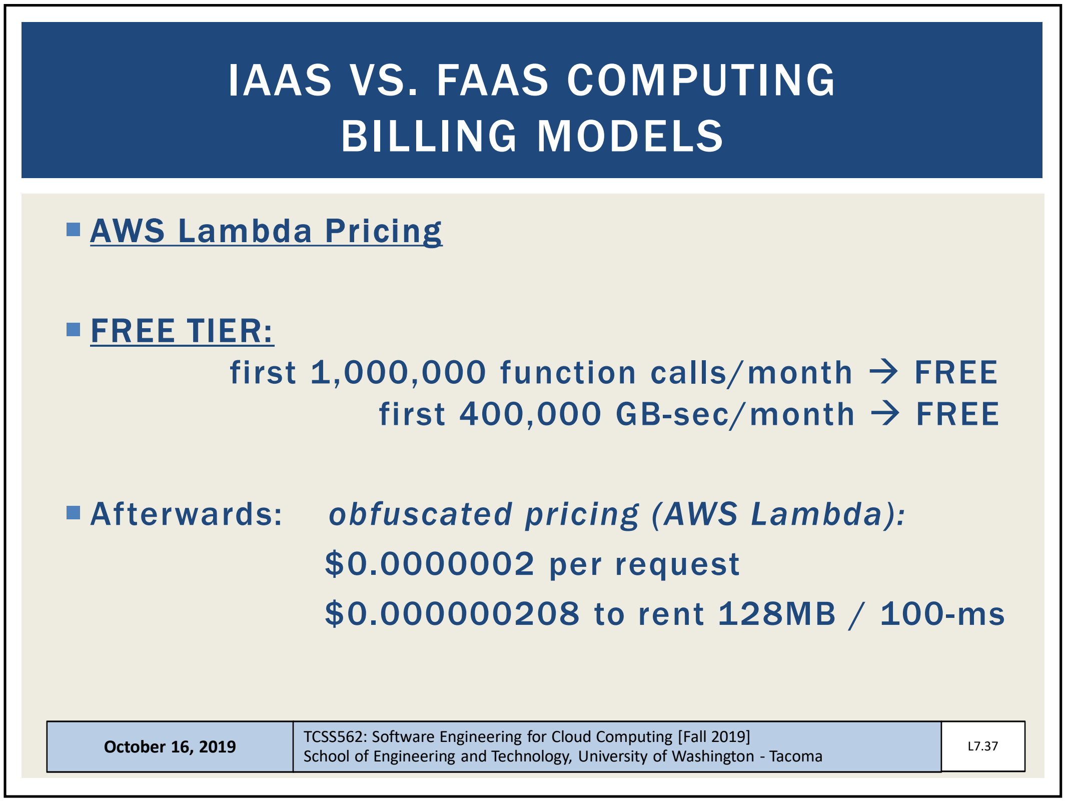
IAAS BILLING MODELS

- 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 →





IAAS VS. FAAS COMPUTING BILLING MODELS

- **AWS Lambda Pricing**
- **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

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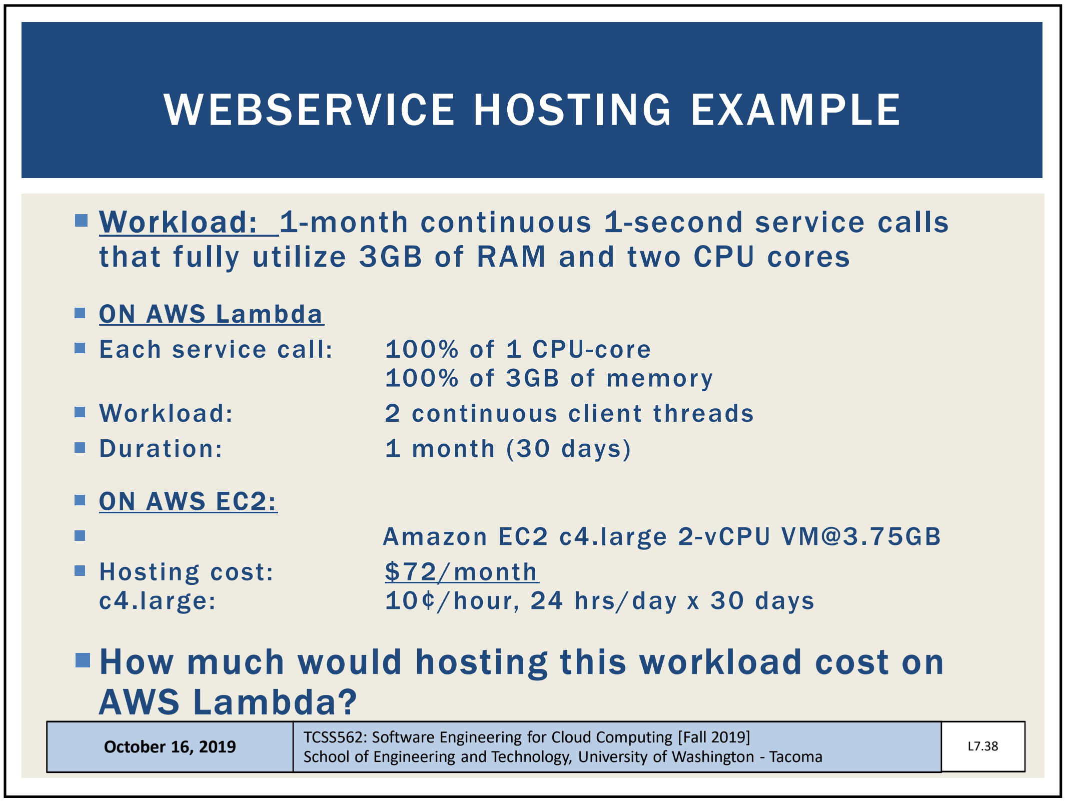

WEBSERVICE HOSTING EXAMPLE

- **Workload:** 1-month continuous 1-second service calls that fully utilize 3GB of RAM and two CPU cores
- **ON AWS Lambda**
- Each service call: 100% of 1 CPU-core
  100% of 3GB of memory
- Workload: 2 continuous client threads
- Duration: 1 month (30 days)
- **ON AWS EC2:**
- Amazon EC2 c4.large 2-vCPU VM@3.75GB
- Hosting cost: $72/month
  c4.large: 10¢/hour, 24 hrs/day x 30 days
- **How much would hosting this workload cost on AWS Lambda?**

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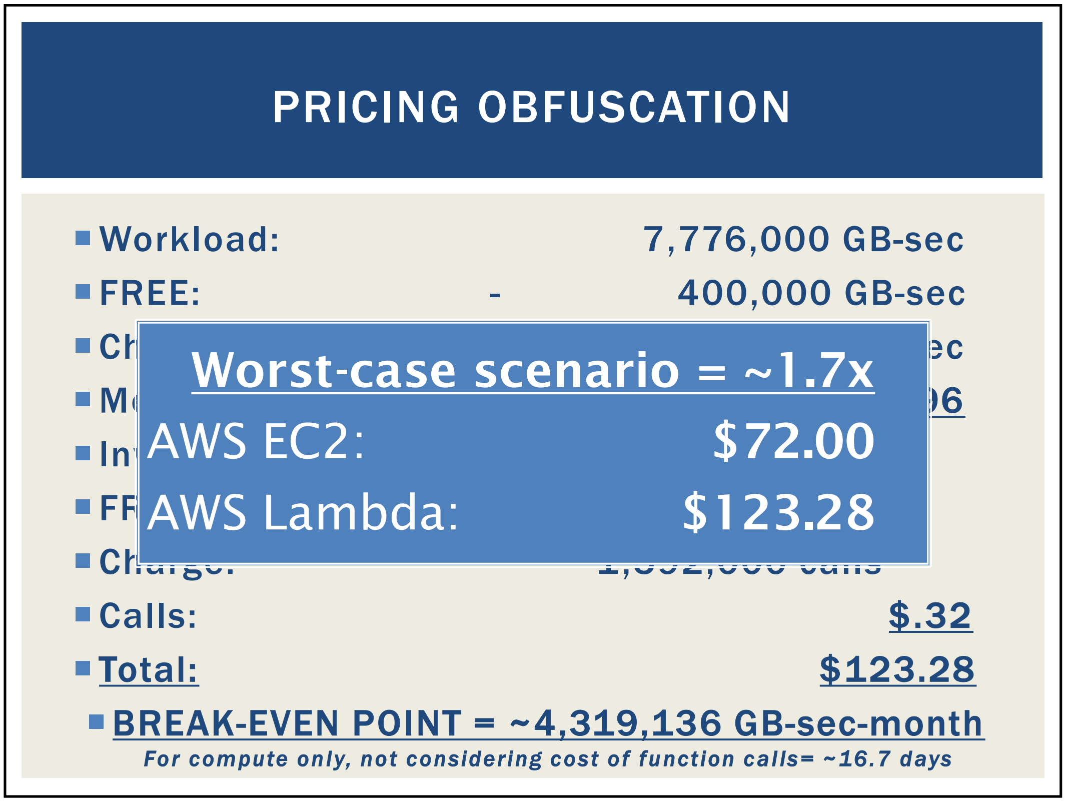

PRICING OBFUSCATION

- Workload: 7,776,000 GB-sec
- FREE: - 400,000 GB-sec
- Ch ec
- M <u>96</u>
- In
- FR
- Charge: 1,592,000 calls
- Calls: <u>$.32</u>
- <u>Total:</u> <u>$123.28</u>
  - <u>BREAK-EVEN POINT = ~4,319,136 GB-sec-month</u>

For compute only, not considering cost of function calls= ~16.7 days

<u>**Worst-case scenario = ~1.7x**</u>

AWS EC2: **$72.00**

AWS Lambda: **$123.28**

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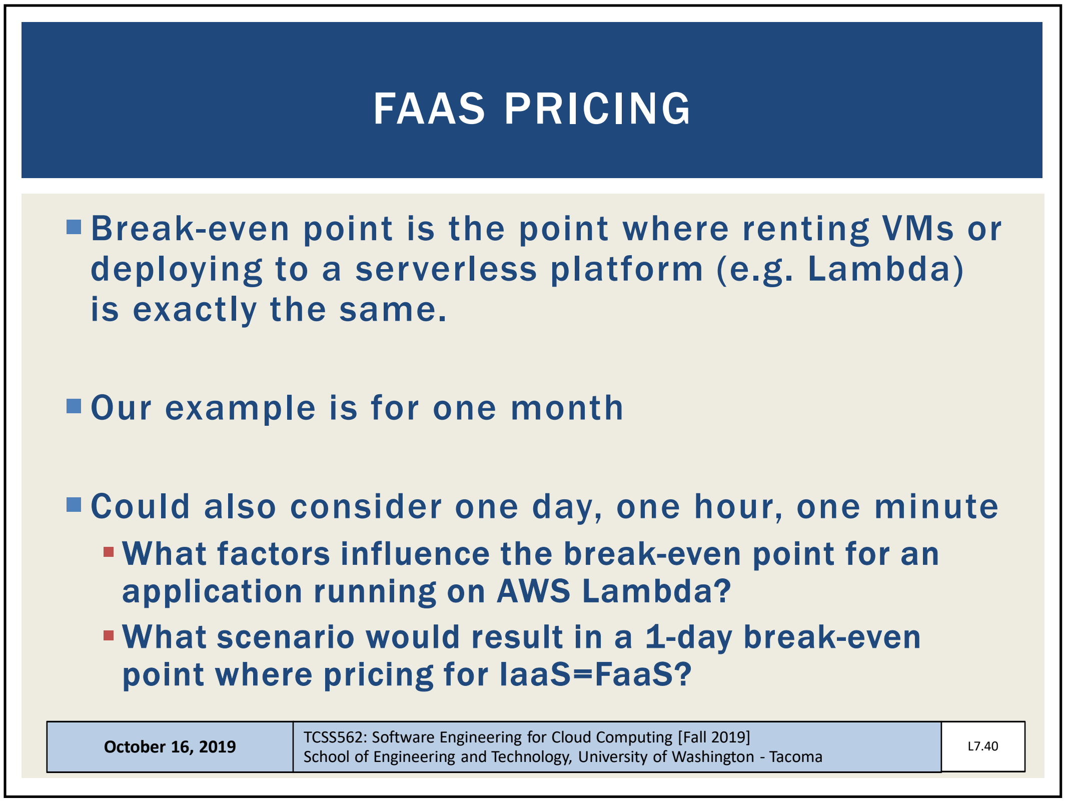

FAAS PRICING

- 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?
  - What scenario would result in a 1-day break-even point where pricing for IaaS=FaaS?

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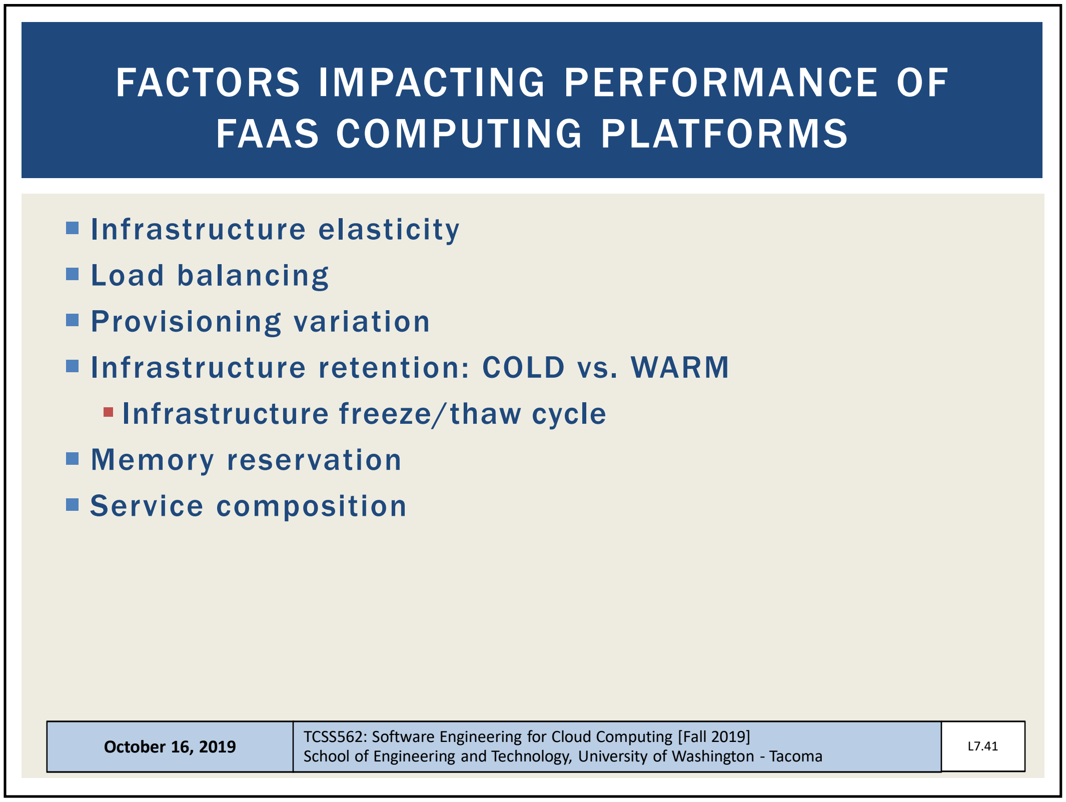

FACTORS IMPACTING PERFORMANCE OF FAAS COMPUTING PLATFORMS

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

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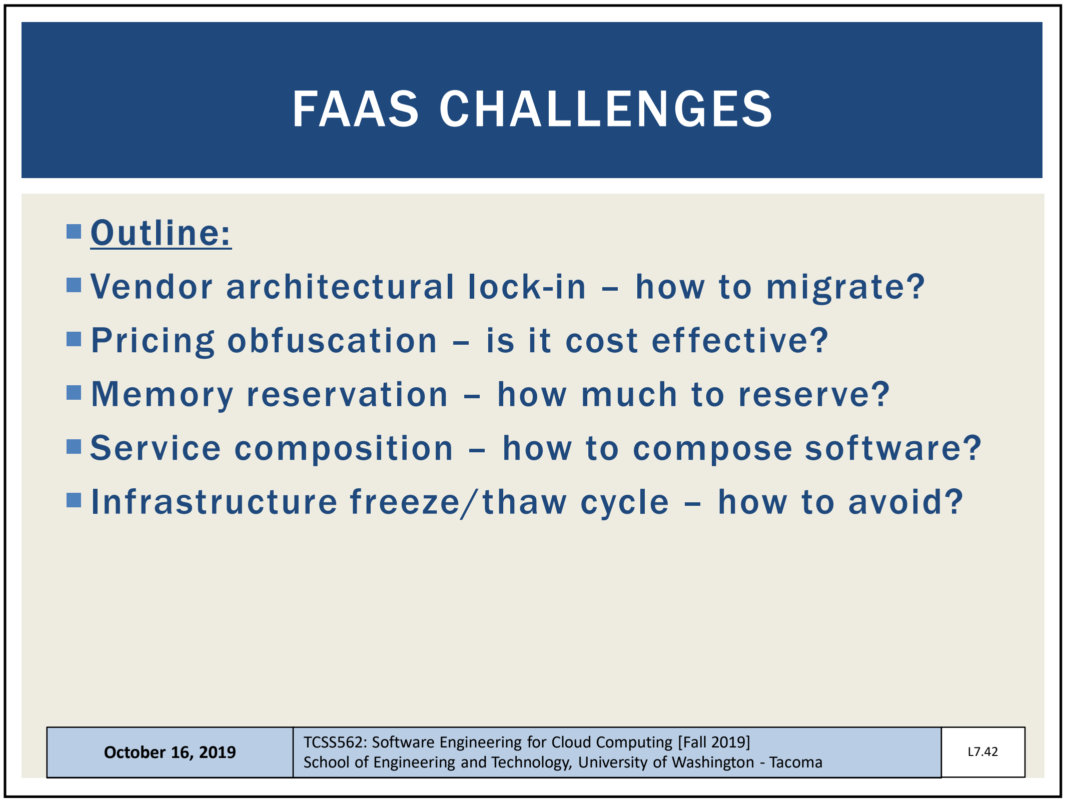

FAAS CHALLENGES

- <u>Outline:</u>
- 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?

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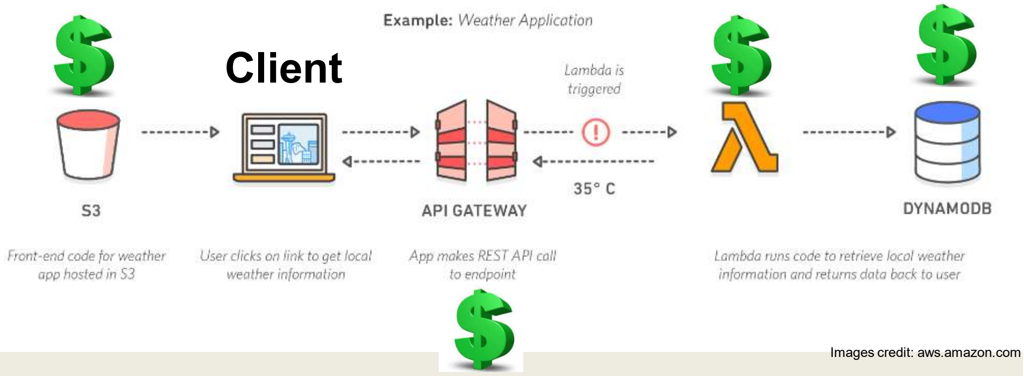
VENDOR ARCHITECTURAL LOCK-IN

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


Example: Weather Application
Client
Lambda is triggered
35° C
S3
API GATEWAY
DYNAMODB
Front-end code for weather app hosted in S3
User clicks on link to get local weather information
App makes REST API call to endpoint
Lambda runs code to retrieve local weather information and returns data back to user

Images credit: aws.amazon.com

- Increased dependencies → increased hosting costs

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PRICING OBFUSCATION

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

AWS Lambda Pricing

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

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

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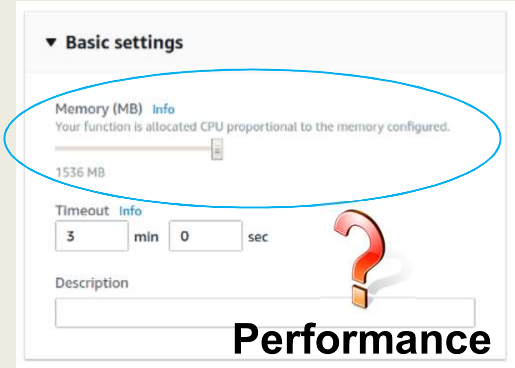
MEMORY RESERVATION QUEST

- 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?



▾ **Basic settings**

Memory (MB) Info
Your function is allocated CPU proportional to the memory configured.
1536 MB

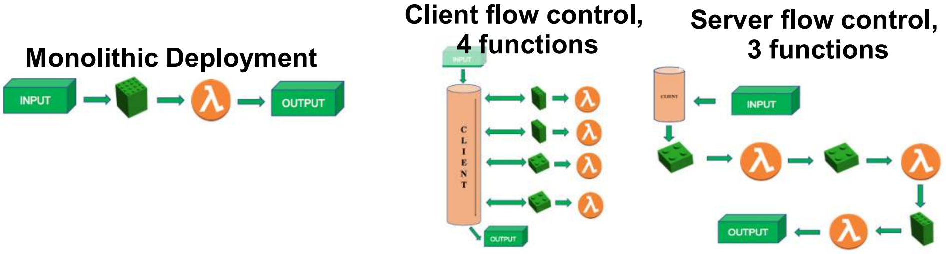
Timeout Info
3 min 0 sec

Description

Performance

SERVICE COMPOSITION

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



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

Performance

INFRASTRUCTURE FREEZE/THAW CYCLE

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

Performance

Image from: Denver7 – The Denver Channel News

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FUNCTION-AS-A-SERVICE

AWS
Lambda
Demo

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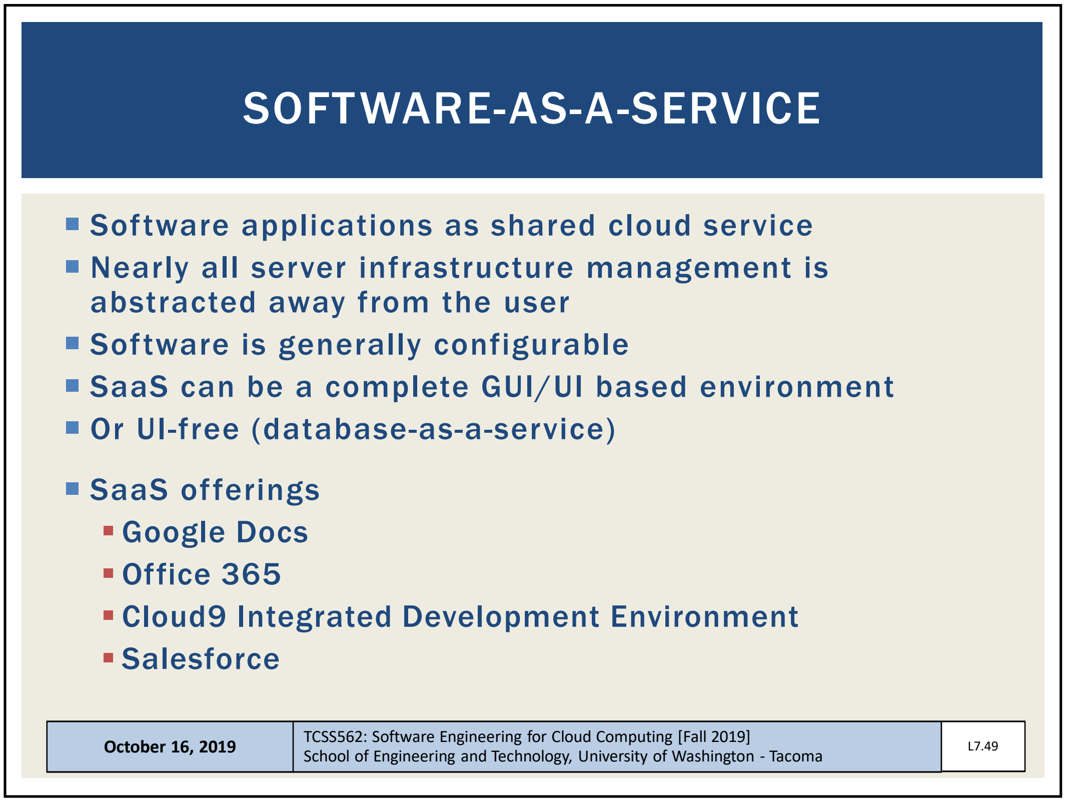

SOFTWARE-AS-A-SERVICE

- 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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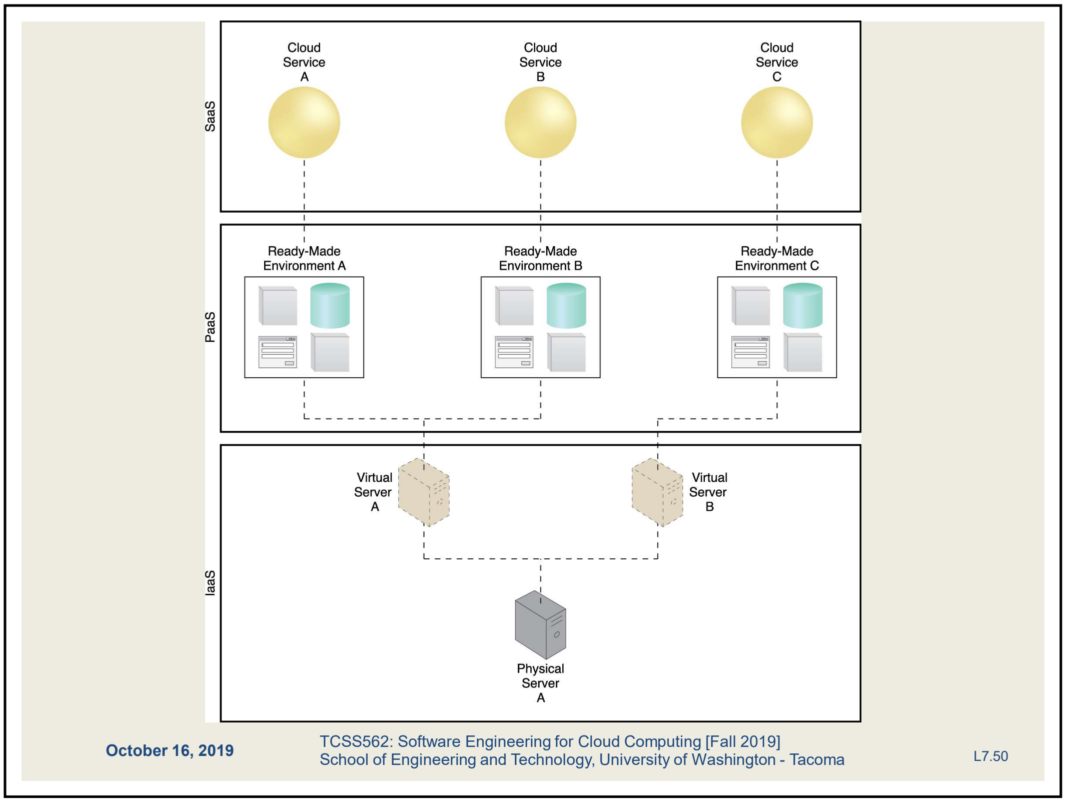

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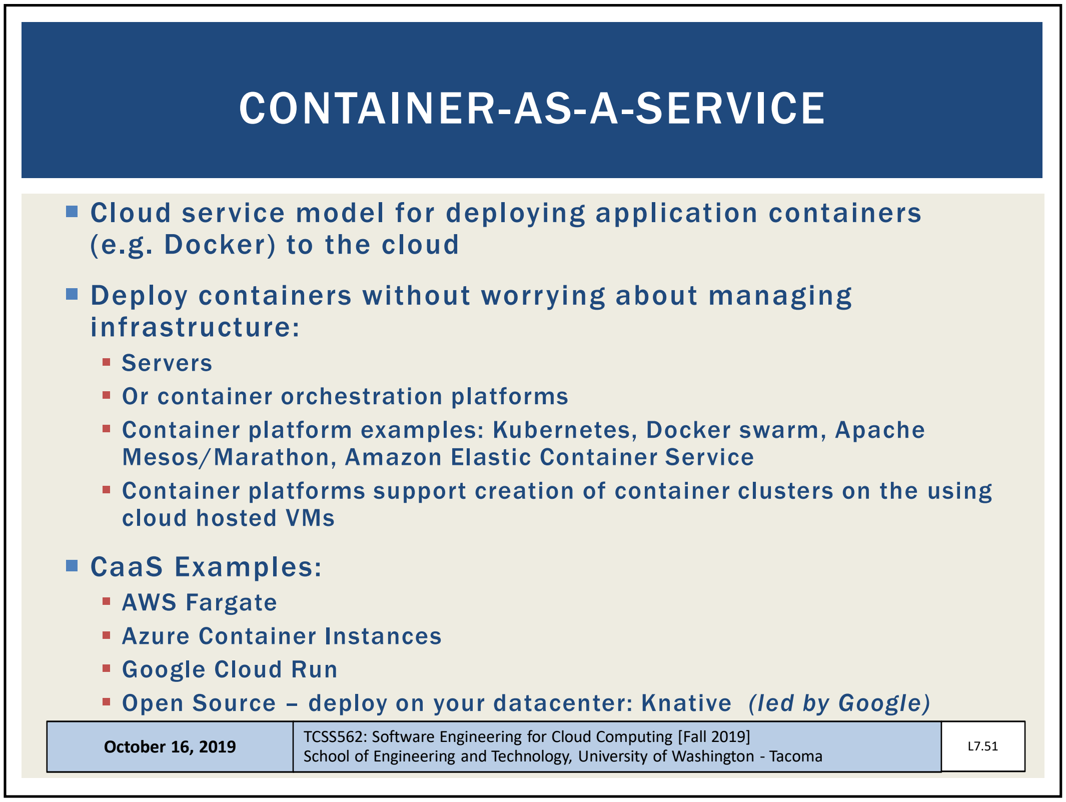

CONTAINER-AS-A-SERVICE

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

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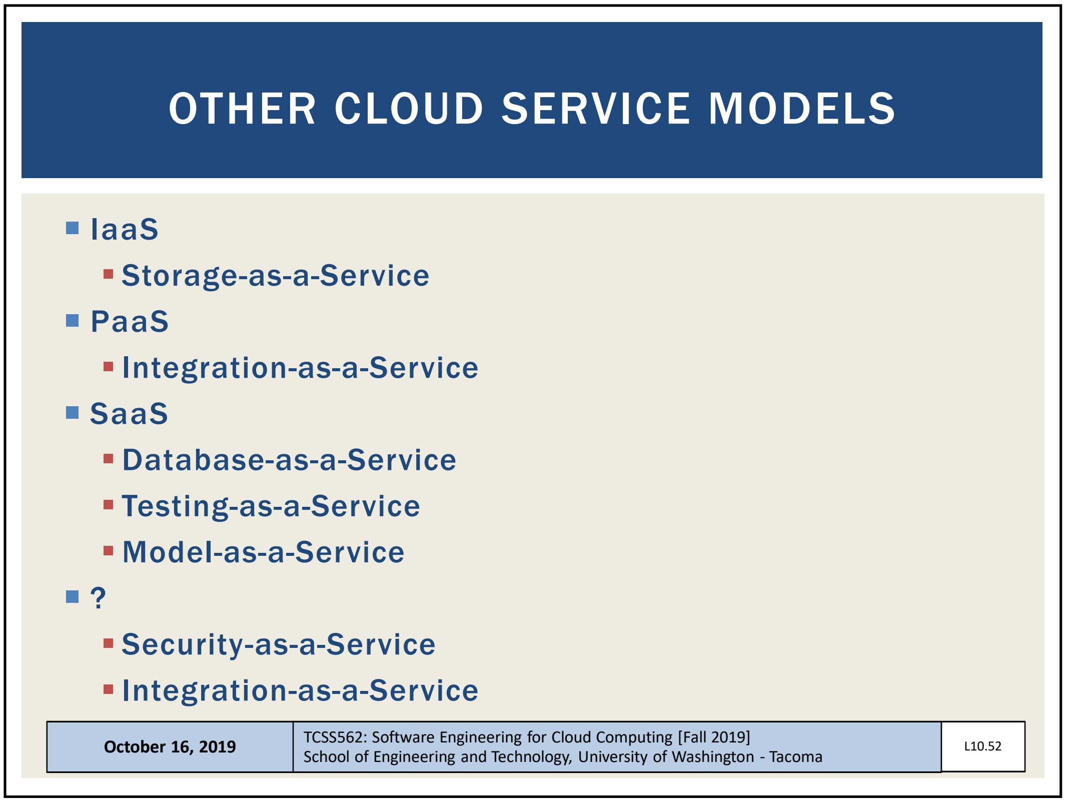

OTHER CLOUD SERVICE MODELS

- 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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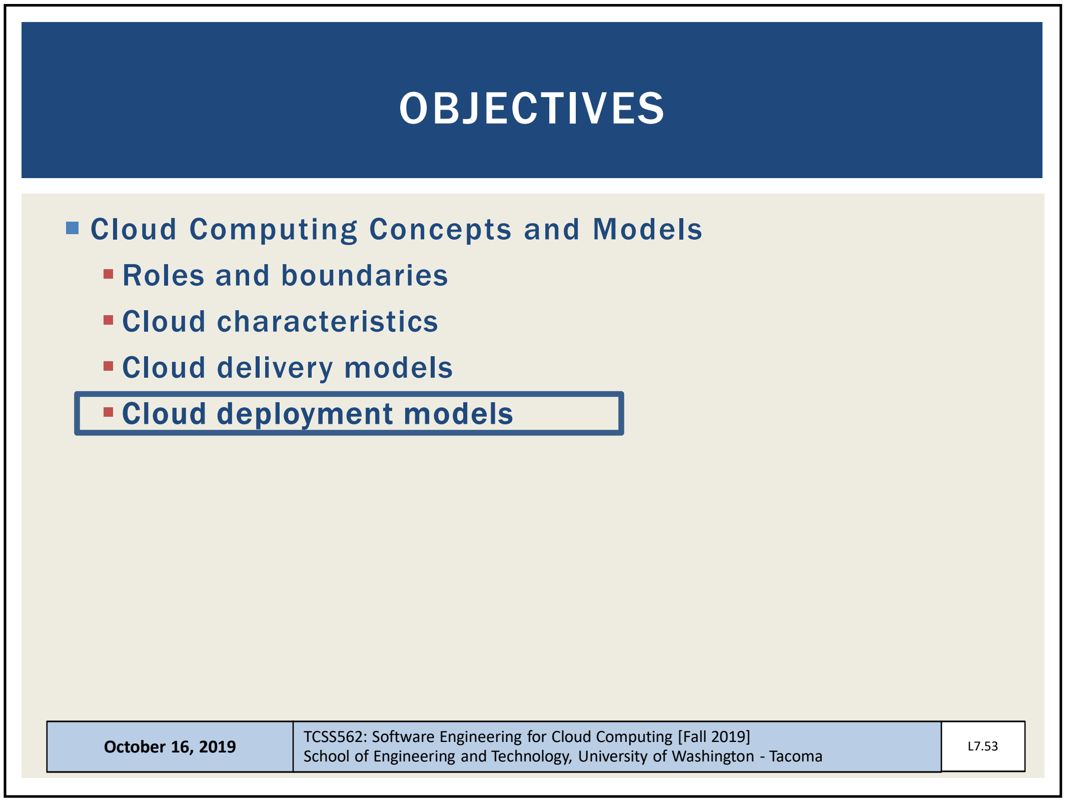

OBJECTIVES

- Cloud Computing Concepts and Models
  - Roles and boundaries
  - Cloud characteristics
  - Cloud delivery models
  - Cloud deployment models

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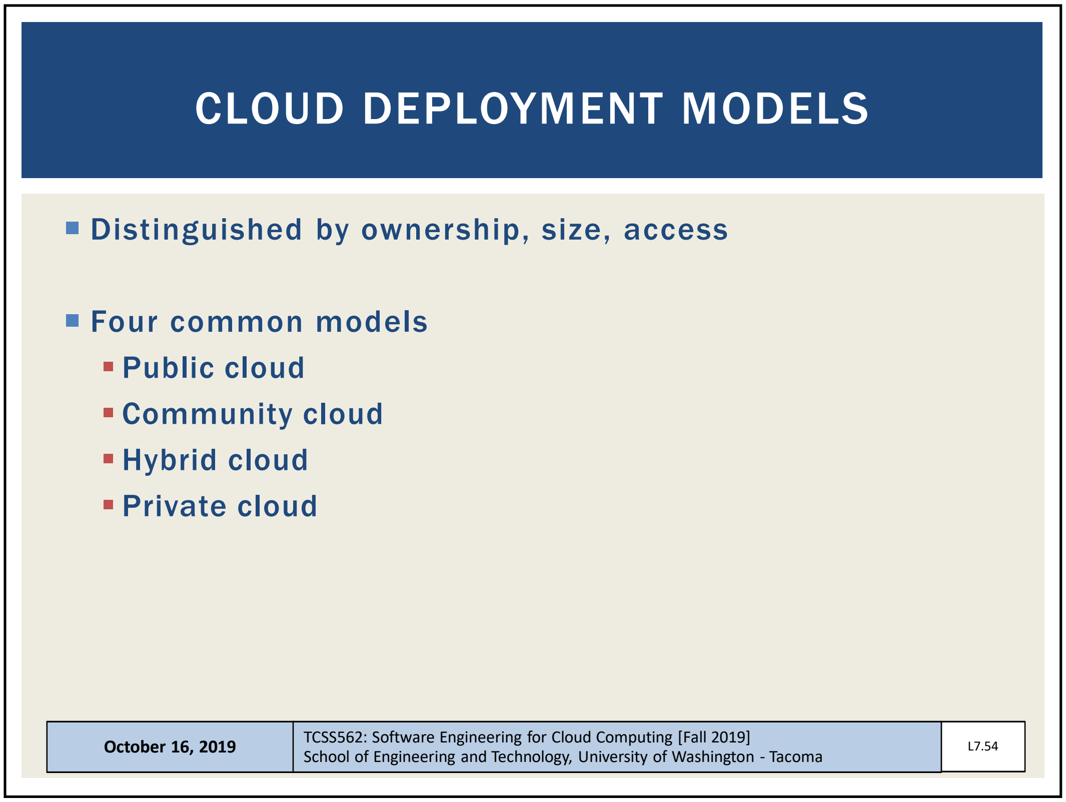

CLOUD DEPLOYMENT MODELS

- Distinguished by ownership, size, access

- Four common models
  - Public cloud
  - Community cloud
  - Hybrid cloud
  - Private cloud

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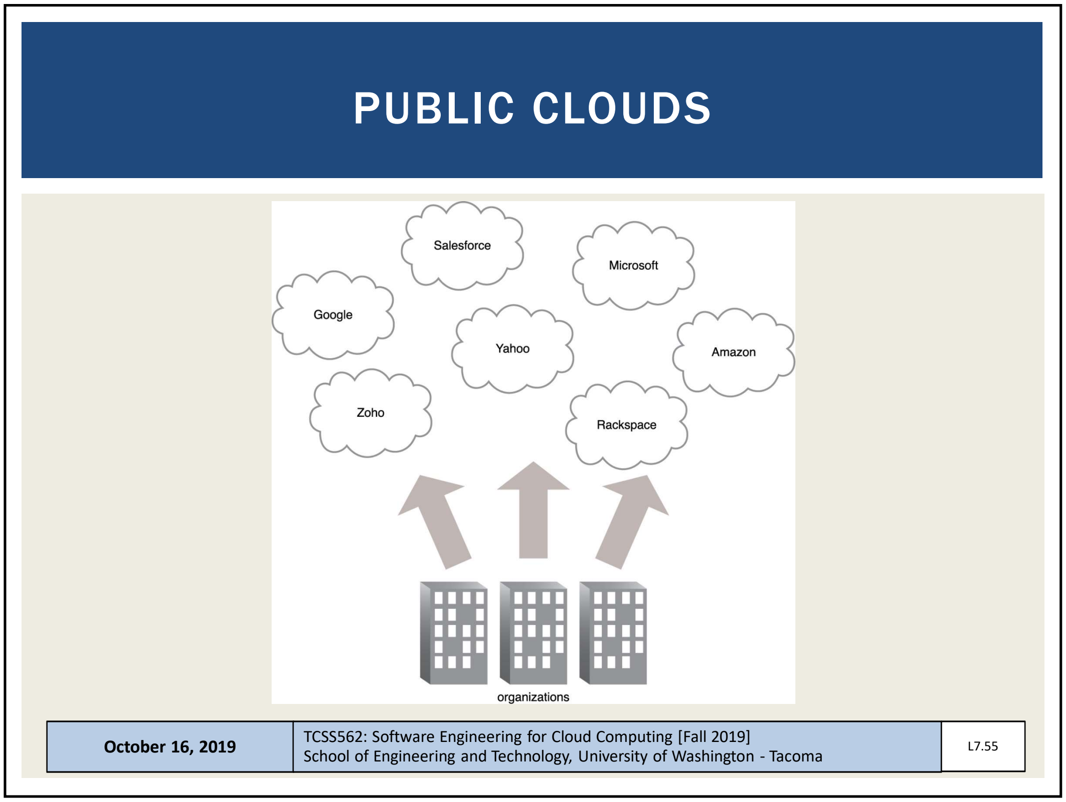

PUBLIC CLOUDS

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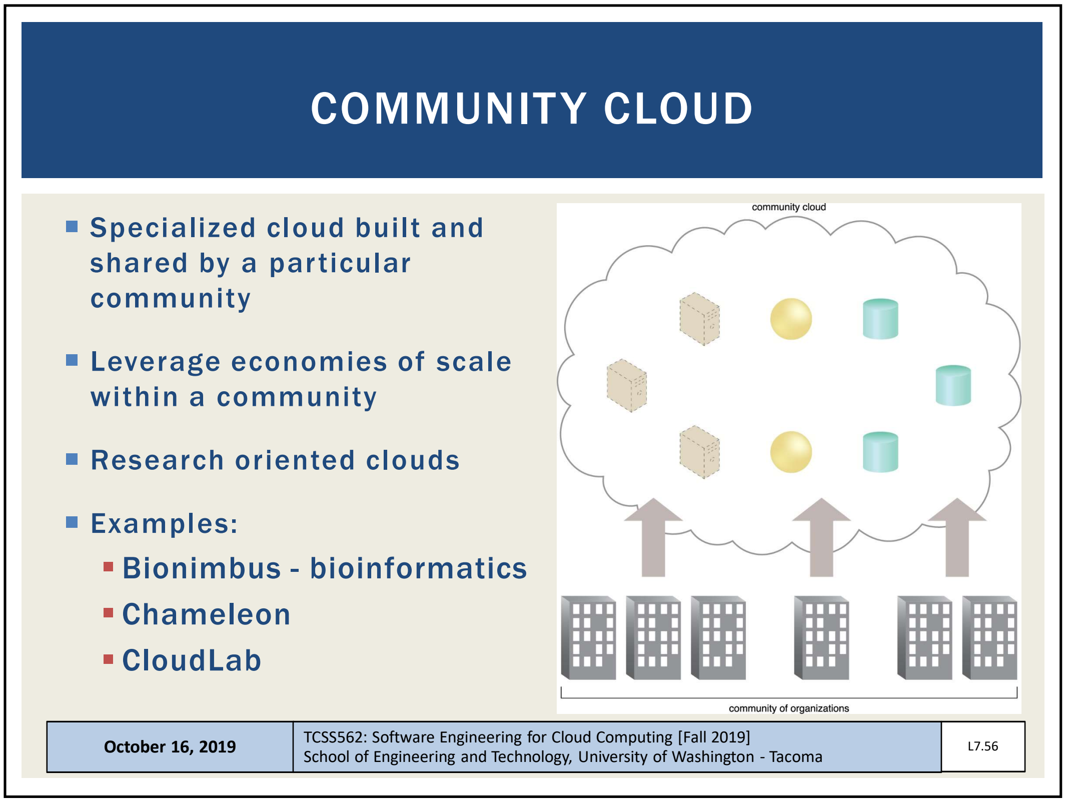

COMMUNITY CLOUD

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

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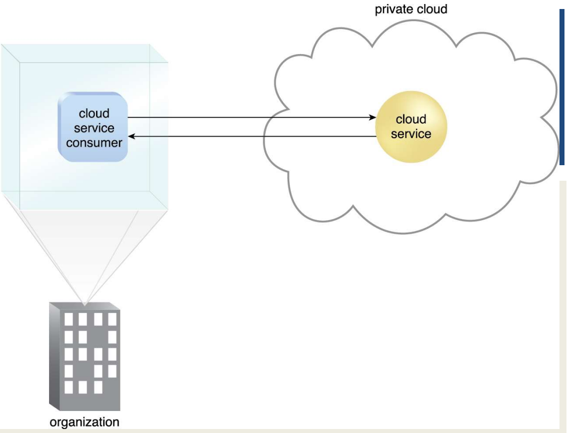
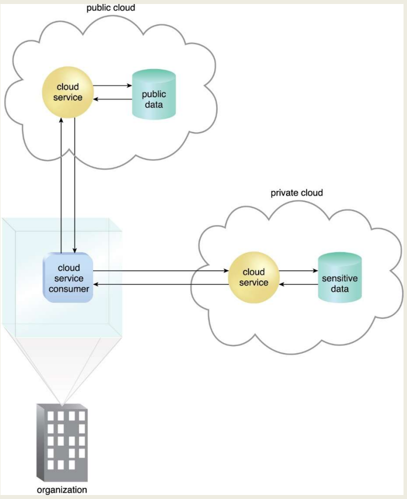
PRIVATE CLOUD

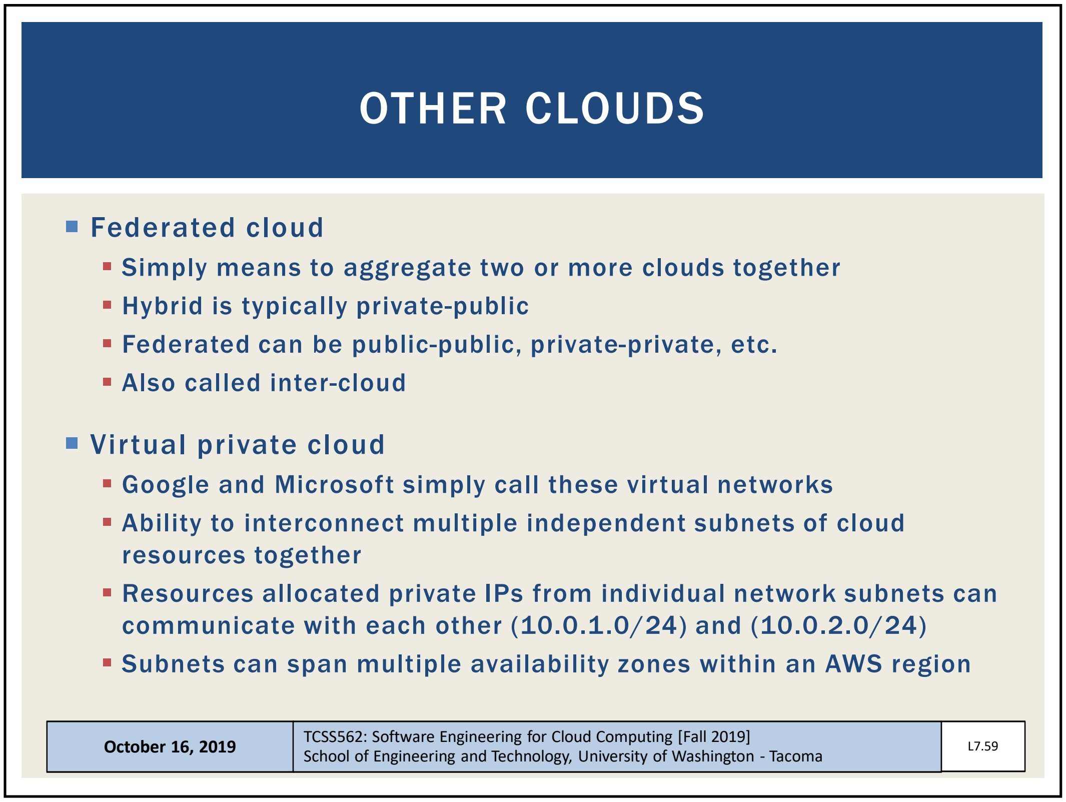


- Compute clusters configured as IaaS cloud
- Open source frameworks:
- Openstack:
- https://www.openstack.org/
- Eucalyptus:
- https://www.eucalyptus.cloud/
- Apache Cloudstack: https://cloudstack.apache.org/
- Nimbus:
- http://www.nimbusproject.org/
- Various virtualization hypervisors: Opensource: XEN, KVM   Commercial: VMWare, etc.

HYBRID CLOUD

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





OTHER CLOUDS

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

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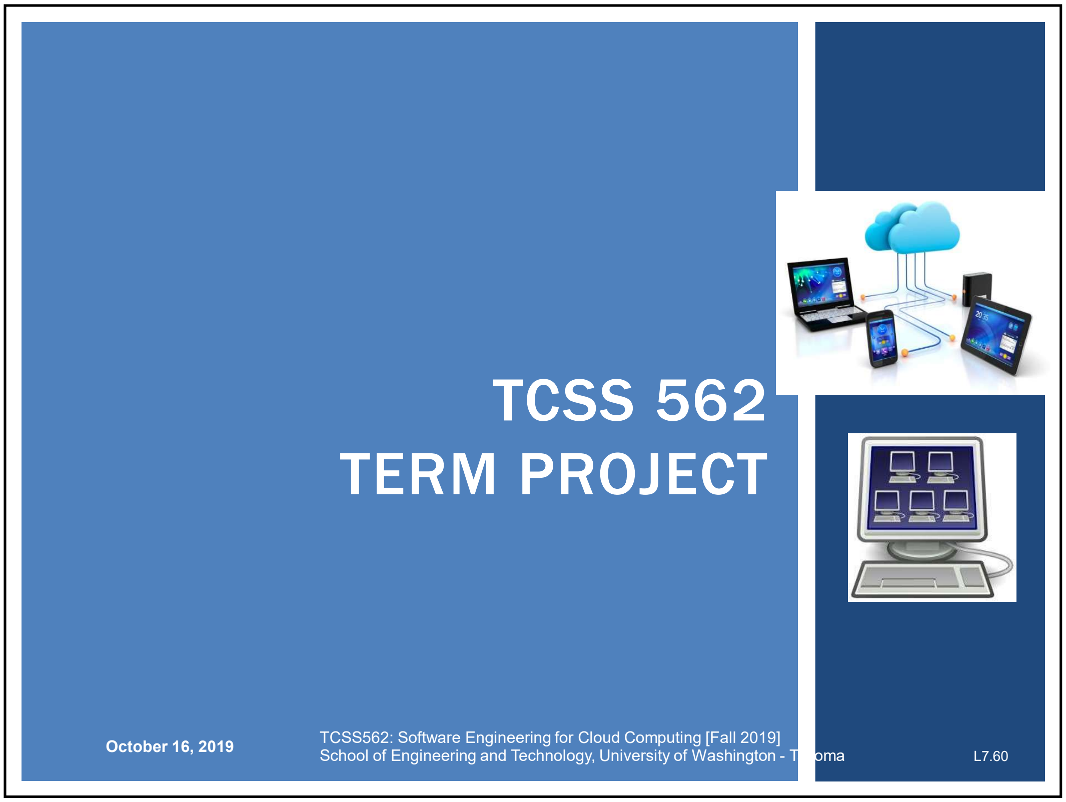

TCSS 562
TERM PROJECT

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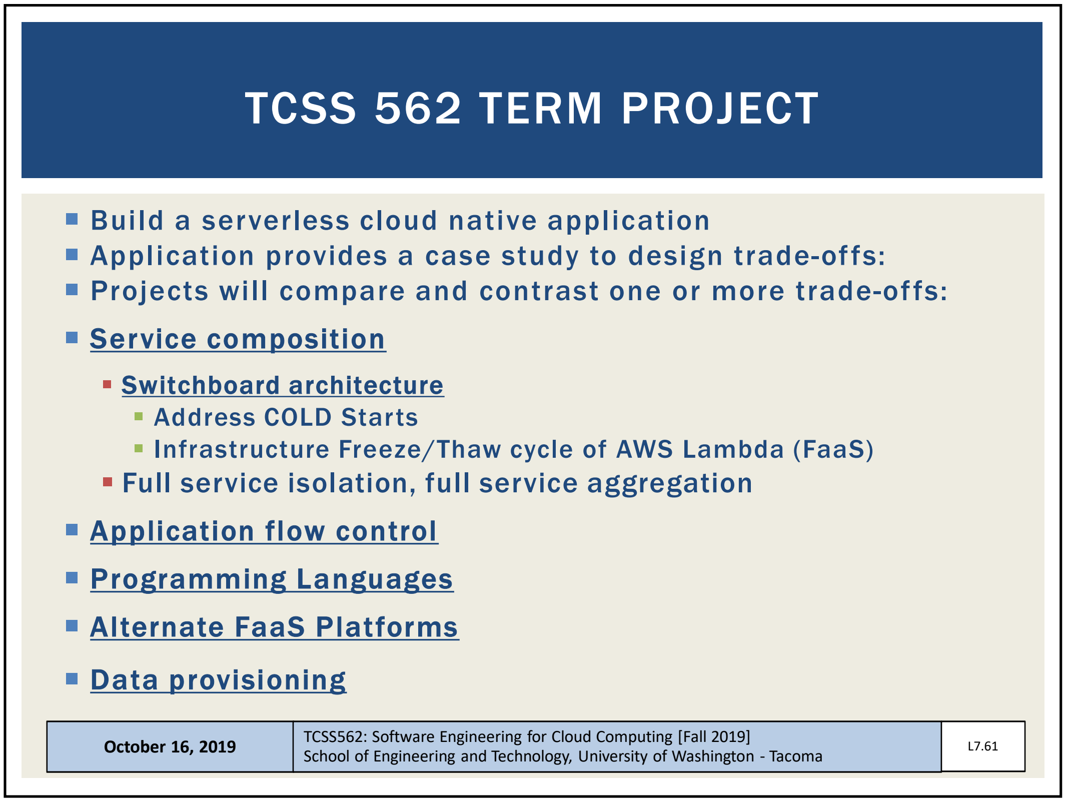

TCSS 562 TERM PROJECT

- Build a serverless cloud native application
- Application provides a case study to design trade-offs:
- Projects will compare and contrast one or more trade-offs:
- Service composition
  - Switchboard architecture
    - Address COLD Starts
    - Infrastructure Freeze/Thaw cycle of AWS Lambda (FaaS)
  - Full service isolation, full service aggregation
- Application flow control
- Programming Languages
- Alternate FaaS Platforms
- Data provisioning

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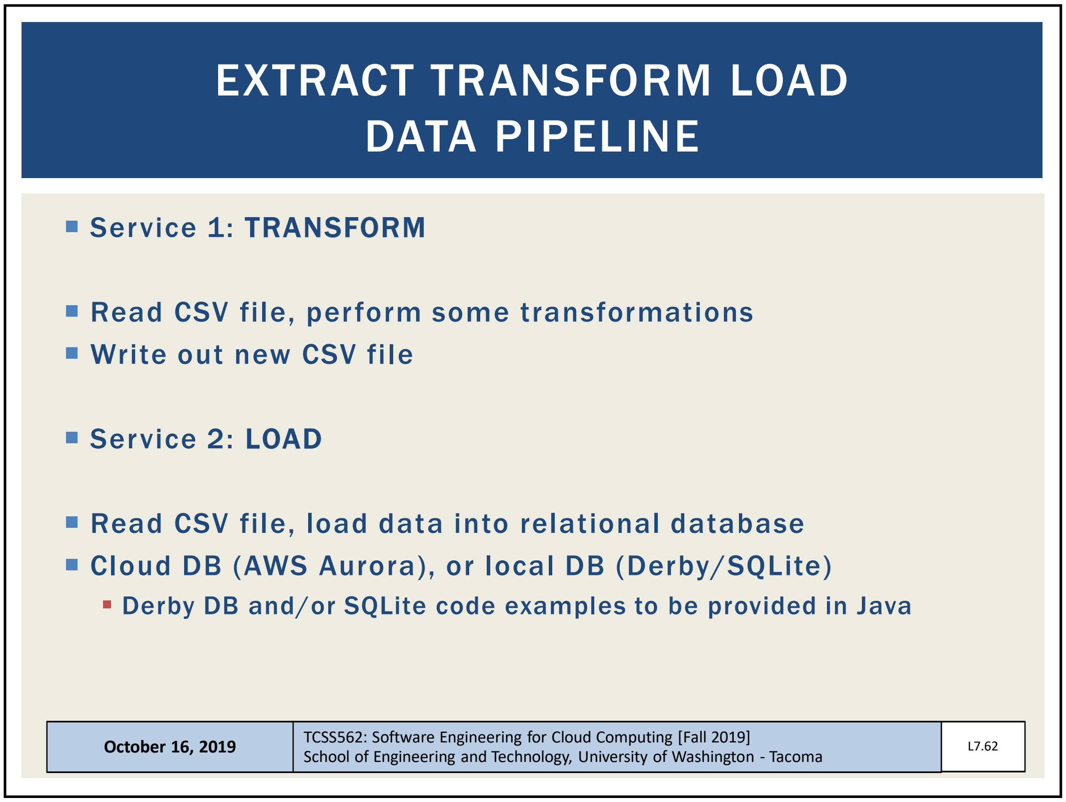

EXTRACT TRANSFORM LOAD DATA PIPELINE

- 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

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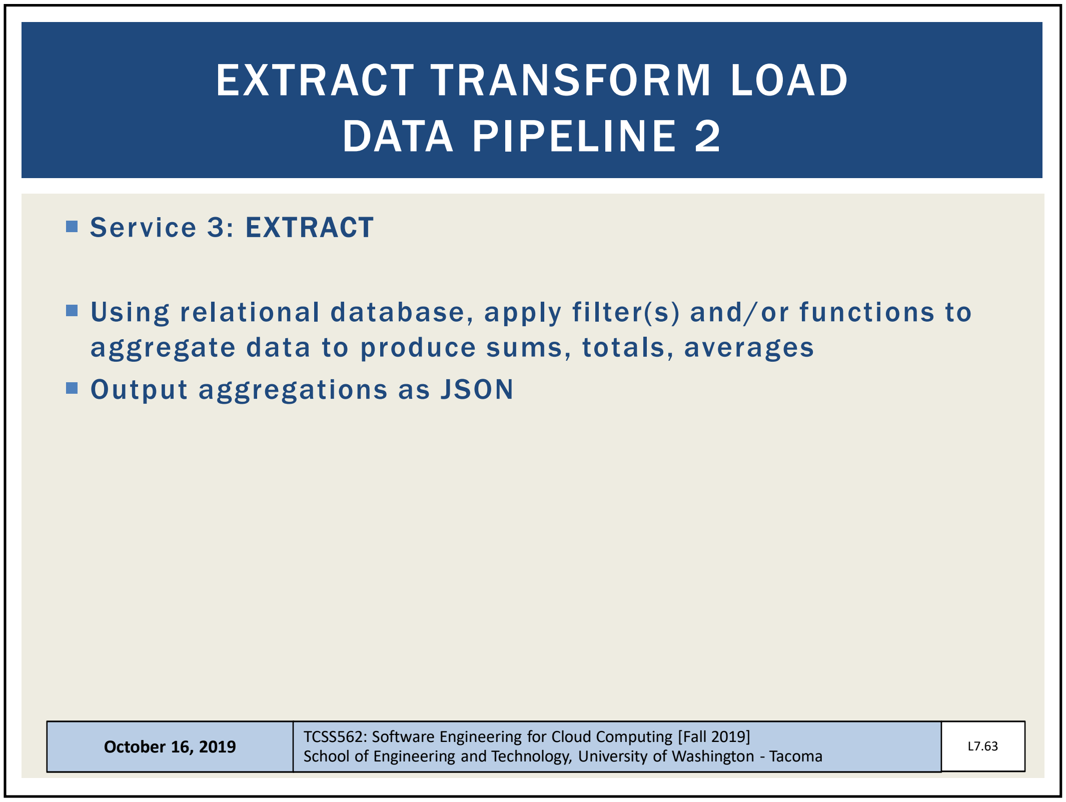
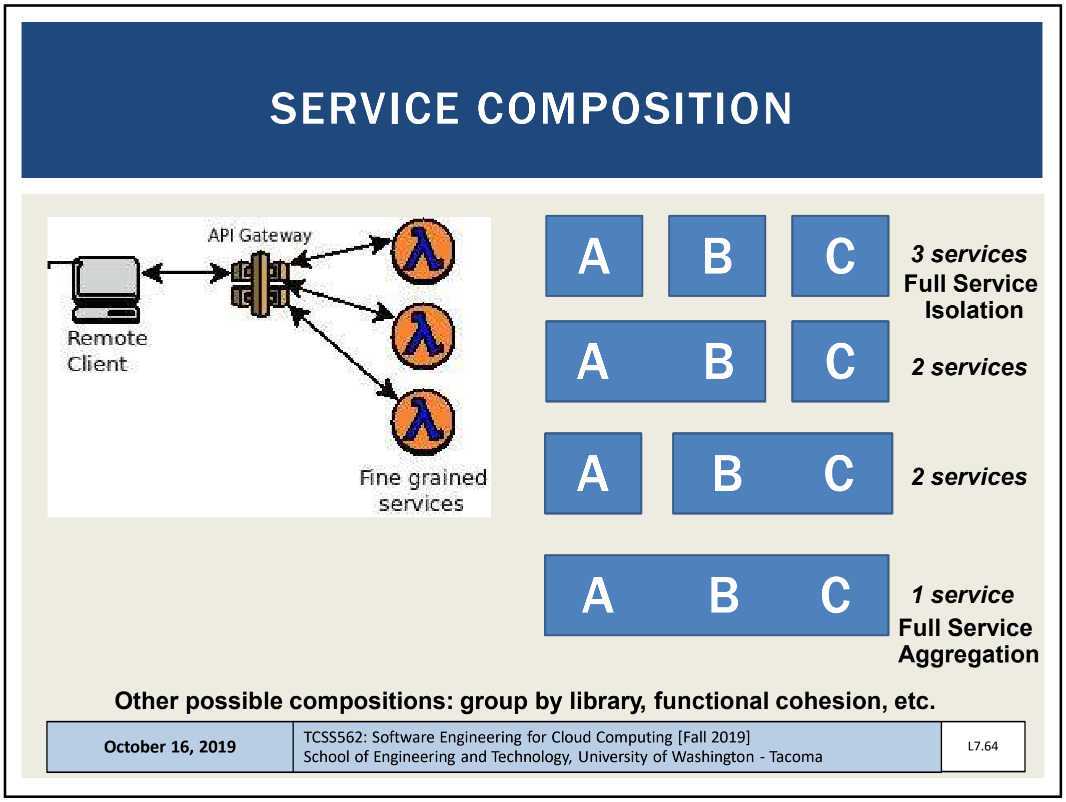


EXTRACT TRANSFORM LOAD DATA PIPELINE 2

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



SERVICE COMPOSITION

A B C — *3 services* **Full Service Isolation**

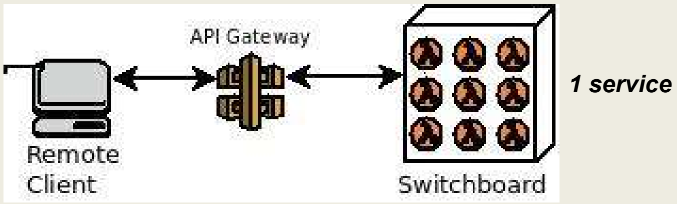
AB C — *2 services*

A BC — *2 services*

ABC — *1 service* **Full Service Aggregation**

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

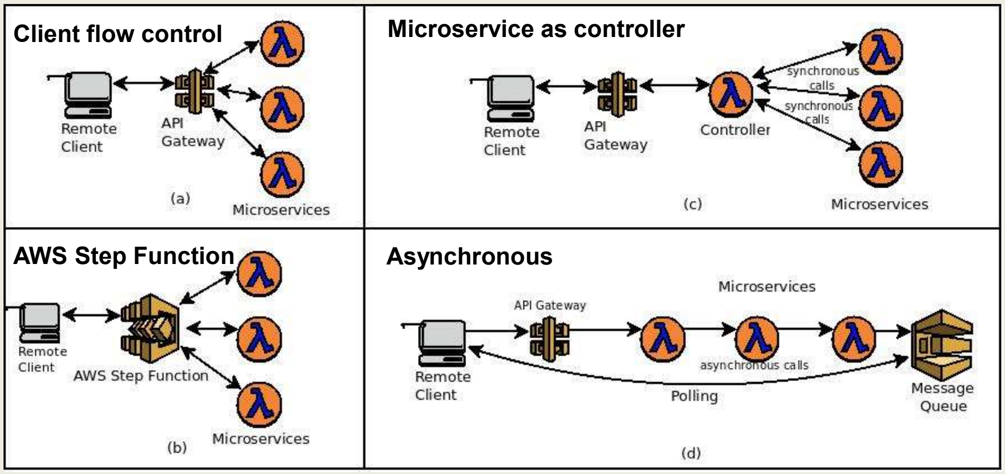
- Serverless Computing:
- AWS Lambda (FAAS: Function-as-a-Service)
- Provides HTTP/REST like web services
- Client/Server paradigm

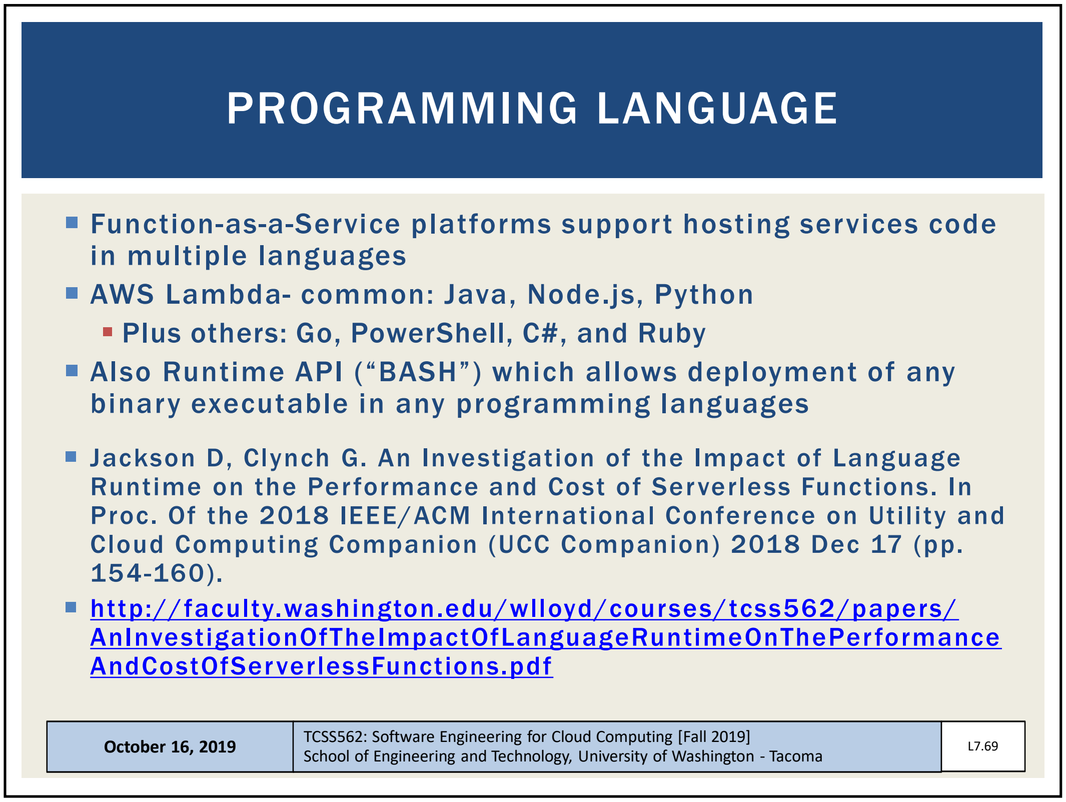
- Synchronous web service:
- Client calls service
- Client blocks (freezes) and waits for server to complete call
- Connection is maintained in the "OPEN" state
- Problematic if service runtime is long!
  - Connections are notoriously dropped
  - System timeouts reached
- Client can't do anything while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

- Function-as-a-Service platforms support hosting services 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 any binary executable in any programming languages
- Jackson D, Clynch G. An Investigation of the Impact of Language Runtime on the Performance and Cost of Serverless Functions. In Proc. Of the 2018 IEEE/ACM International Conference on Utility and Cloud Computing Companion (UCC Companion) 2018 Dec 17 (pp. 154-160).
- http://faculty.washington.edu/wlloyd/courses/tcss562/papers/AnInvestigationOfTheImpactOfLanguageRuntimeOnThePerformanceAndCostOfServerlessFunctions.pdf

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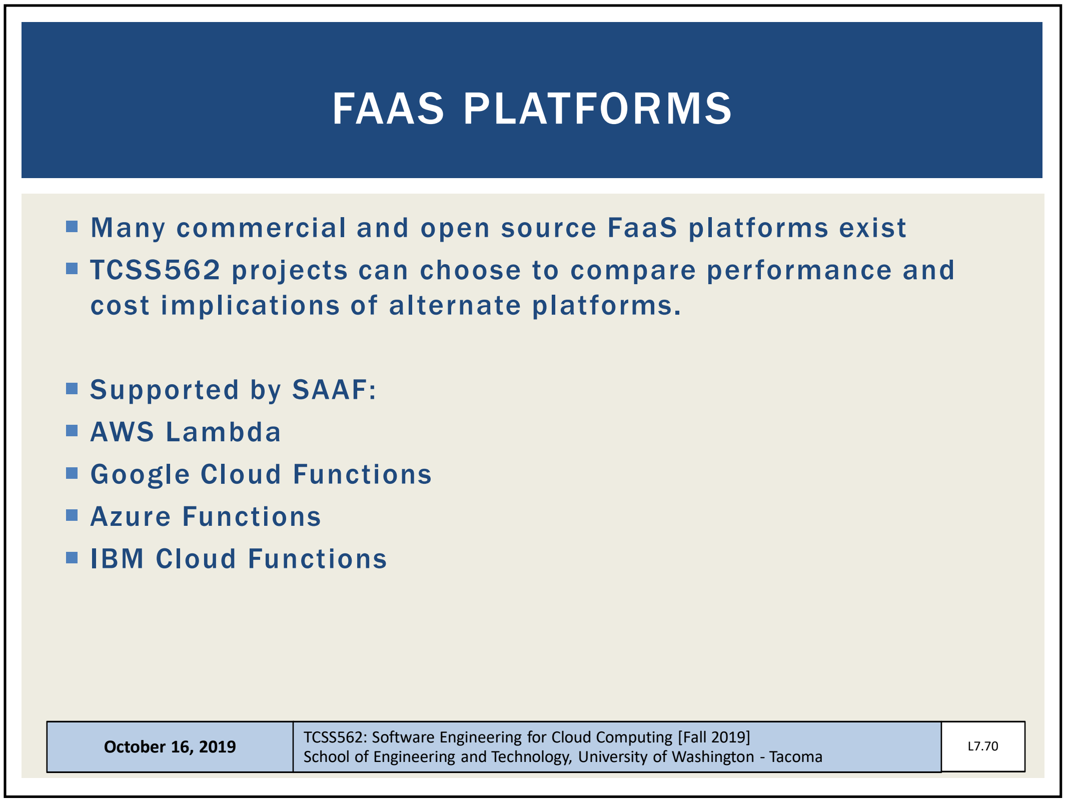

FAAS PLATFORMS

- 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

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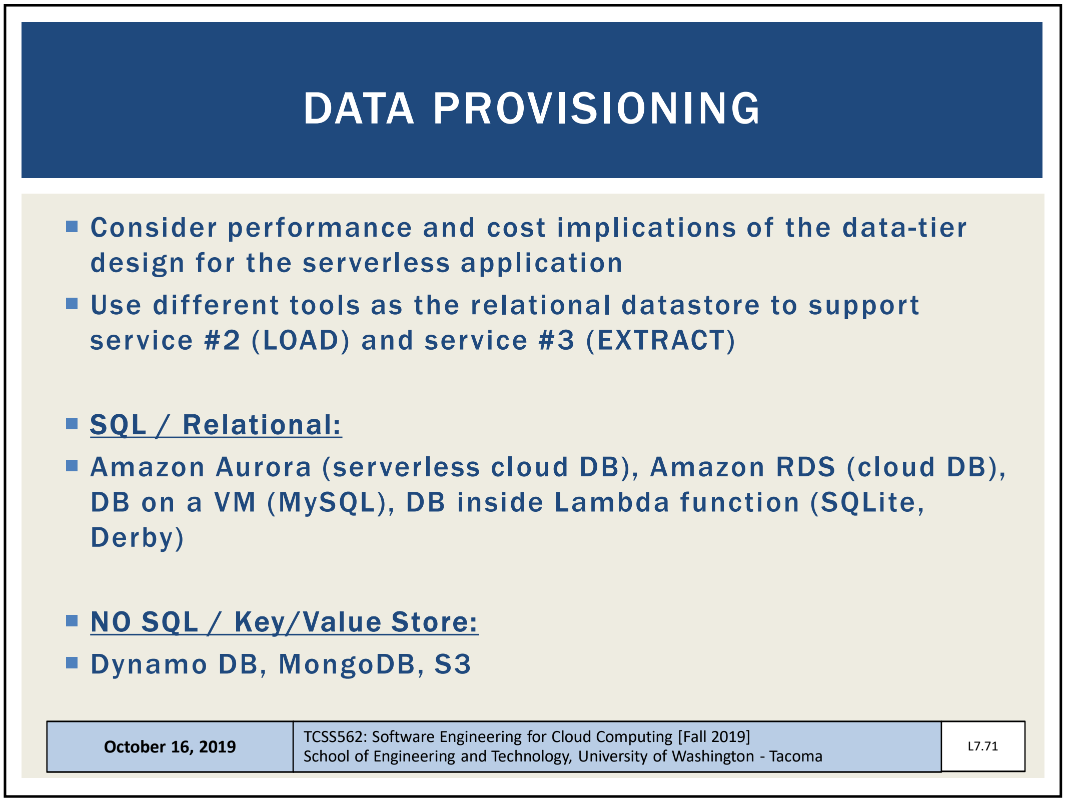

DATA PROVISIONING

- 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

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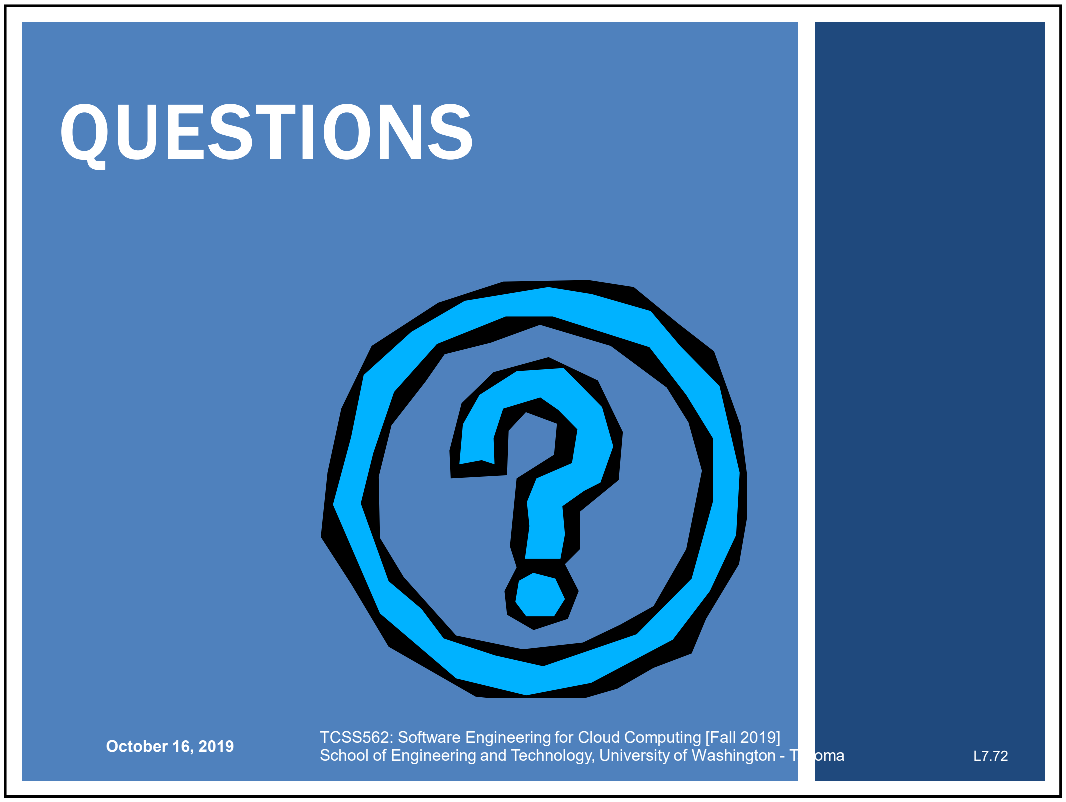

QUESTIONS

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