# Serverless Computing

*CS 4740: Cloud Computing*

*Fall 2024*

Lecture 14a

Yue Cheng


Some material taken/derived from:

- Berkeley CS 262a (Spring '18) by Ali Ghodsi and Ion Stoica;
- Tyler Harter's HotCloud '18 OpenLambda talk;

# Motivation

# When to use the cloud?

- Data
  - Large amounts of data – can't store locally
  - Shared data across users
  - Long-term storage

- Compute
  - Need lots of CPUs for data processing
  - Varying computing demands (resources)
  - No admin (for managing your local hardware)

# EC2Instances.info Easy Amazon EC2 Instance Comparison

EC2 RDS

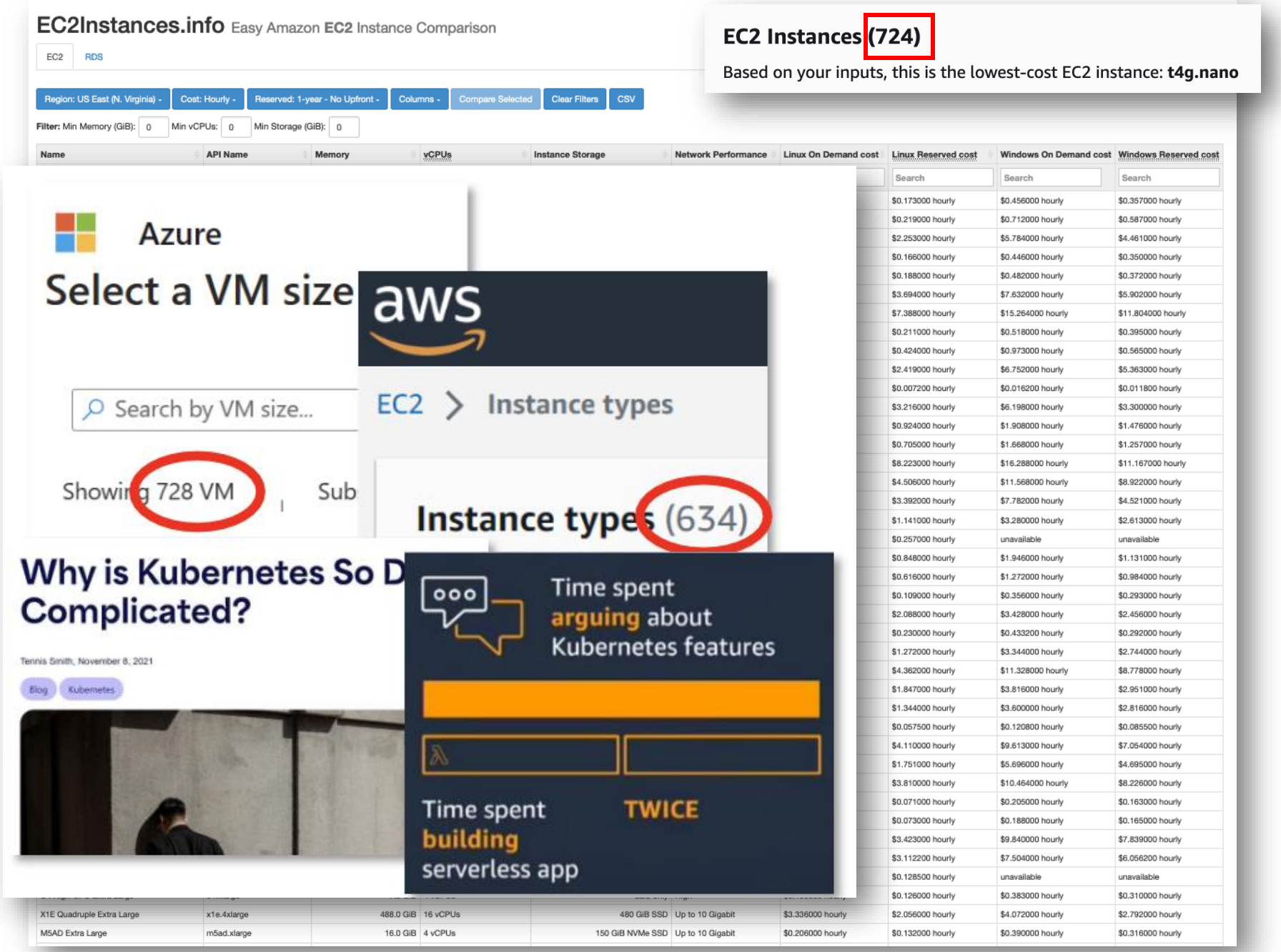
**EC2 Instances (724)**

Based on your inputs, this is the lowest-cost EC2 instance: **t4g.nano**

Region: US East (N. Virginia) - | Cost: Hourly - | Reserved: 1-year - No Upfront - | Columns - | Compare Selected | Clear Filters | CSV

**Filter:** Min Memory (GiB): 0 Min vCPUs: 0 Min Storage (GiB): 0

| Name | API Name | Memory | vCPUs | Instance Storage | Network Performance | Linux On Demand cost | Linux Reserved cost | Windows On Demand cost | Windows Reserved cost |
|---|---|---|---|---|---|---|---|---|---|
| Search | Search | Search | Search | Search | Search | Search | Search | Search | Search |
| M5DN Extra Large | m5dn.xlarge | 16.0 GiB | 4 vCPUs | 150 GiB NVMe SSD | Up to 25 Gigabit | $0.272000 hourly | $0.173000 hourly | $0.456000 hourly | $0.357000 hourly |
| M5A Double Extra Large | m5a.2xlarge | 32.0 GiB | 8 vCPUs | EBS only | Up to 10 Gigabit | $0.344000 hourly | $0.219000 hourly | $0.712000 hourly | $0.587000 hourly |
| R5N 12xlarge | r5n.12xlarge | 384.0 GiB | 48 vCPUs | EBS only | 50 Gigabit | $3.576000 hourly | $2.253000 hourly | $5.784000 hourly | $4.461000 hourly |
| R5AD Extra Large | r5ad.xlarge | 32.0 GiB | 4 vCPUs | 150 GiB NVMe SSD | 10 Gigabit | $0.262000 hourly | $0.166000 hourly | $0.446000 hourly | $0.350000 hourly |
| R5N Extra Large | r5n.xlarge | 32.0 GiB | 4 vCPUs | EBS only | Up to 25 Gigabit | $0.298000 hourly | $0.188000 hourly | $0.482000 hourly | $0.372000 hourly |
| I3EN 12xlarge | i3en.12xlarge | 384.0 GiB | 48 vCPUs | 30000 GiB (4 * 7500 GiB NVMe SSD) | 50 Gigabit | $5.424000 hourly | $3.694000 hourly | $7.632000 hourly | $5.902000 hourly |
| I3EN Metal | i3en.metal | 768.0 GiB | 96 vCPUs | 60000 GiB (8 * 7500 GiB NVMe SSD) | 100 Gigabit | $10.848000 hourly | $7.388000 hourly | $15.264000 hourly | $11.804000 hourly |
| R5DN Extra Large | r5dn.xlarge | 32.0 GiB | 4 vCPUs | 150 GiB NVMe SSD | Up to 25 Gigabit | $0.334000 hourly | $0.211000 hourly | $0.518000 hourly | $0.395000 hourly |
| I2 Extra Large | i2.xlarge | 30.5 GiB | 4 vCPUs | 800 GiB SSD | Moderate | $0.853000 hourly | $0.424000 hourly | $0.973000 hourly | $0.565000 hourly |
| M5N 16xlarge | m5n.16xlarge | 256.0 GiB | 64 vCPUs | EBS only | 75 Gigabit | $3.808000 hourly | $2.419000 hourly | $6.752000 hourly | $5.363000 hourly |
| T2 Micro | t2.micro | 1.0 GiB | 1 vCPUs for a 2h 24m burst | EBS only | Low to Moderate | $0.011600 hourly | $0.007200 hourly | $0.016200 hourly | $0.011800 hourly |
| D2 Eight Extra Large | d2.8xlarge | 244.0 GiB | 36 vCPUs | 48000 GiB (24 * 2000 GiB HDD) | 10 Gigabit | $5.520000 hourly | $3.216000 hourly | $6.198000 hourly | $3.300000 hourly |
| I3EN 3xlarge | i3en.3xlarge | 96.0 GiB | 12 vCPUs | 7500 GiB NVMe SSD | Up to 25 Gigabit | $1.356000 hourly | $0.924000 hourly | $1.908000 hourly | $1.476000 hourly |
| Z1D 3xlarge | z1d.3xlarge | 96.0 GiB | 12 vCPUs | 450 GiB NVMe SSD | Up to 10 Gigabit | $1.116000 hourly | $0.705000 hourly | $1.668000 hourly | $1.257000 hourly |
| X1E 16xlarge | x1e.16xlarge | 1952.0 GiB | 64 vCPUs | 1920 GiB SSD | 10 Gigabit | $13.344000 hourly | $8.223000 hourly | $16.288000 hourly | $11.167000 hourly |
| R5N 24xlarge | r5n.24xlarge | 768.0 GiB | 96 vCPUs | EBS only | 100 Gigabit | $7.152000 hourly | $4.506000 hourly | $11.568000 hourly | $8.922000 hourly |
| I2 Eight Extra Large | i2.8xlarge | 244.0 GiB | 32 vCPUs | 6400 GiB (8 * 800 GiB SSD) | 10 Gigabit | $6.820000 hourly | $3.392000 hourly | $7.782000 hourly | $4.521000 hourly |
| R5A Eight Extra Large | r5a.8xlarge | 256.0 GiB | 32 vCPUs | EBS only | Up to 10 Gigabit | $1.808000 hourly | $1.141000 hourly | $3.280000 hourly | $2.613000 hourly |
| A1 Metal | a1.metal | 32.0 GiB | 16 vCPUs | EBS only | Up to 10 Gigabit | $0.408000 hourly | $0.257000 hourly | unavailable | unavailable |
| I2 Double Extra Large | i2.2xlarge | 61.0 GiB | 8 vCPUs | 1600 GiB (2 * 800 GiB SSD) | High | $1.705000 hourly | $0.848000 hourly | $1.946000 hourly | $1.131000 hourly |
| I3EN Double Extra Large | i3en.2xlarge | 64.0 GiB | 8 vCPUs | 5000 GiB (2 * 2500 GiB NVMe SSD) | Up to 25 Gigabit | $0.904000 hourly | $0.616000 hourly | $1.272000 hourly | $0.984000 hourly |
| M5A Extra Large | m5a.xlarge | 16.0 GiB | 4 vCPUs | EBS only | Up to 10 Gigabit | $0.172000 hourly | $0.109000 hourly | $0.356000 hourly | $0.293000 hourly |
| P3 Double Extra Large | p3.2xlarge | 61.0 GiB | 8 vCPUs | EBS only | Up to 10 Gigabit | $3.060000 hourly | $2.088000 hourly | $3.428000 hourly | $2.456000 hourly |
| T2 Double Extra Large | t2.2xlarge | 32.0 GiB | 8 vCPUs for a 4h 4.8m burst | EBS only | Moderate | $0.371200 hourly | $0.230000 hourly | $0.433200 hourly | $0.292000 hourly |
| H1 Eight Extra Large | h1.8xlarge | 128.0 GiB | 32 vCPUs | 8000 GiB (4 * 2000 GiB HDD) | 10 Gigabit | $1.872000 hourly | $1.272000 hourly | $3.344000 hourly | $2.744000 hourly |
| R5D 24xlarge | r5d.24xlarge | 768.0 GiB | 96 vCPUs | 3600 GiB (4 * 900 GiB NVMe SSD) | 25 Gigabit | $6.912000 hourly | $4.362000 hourly | $11.328000 hourly | $8.778000 hourly |
| I3EN 6xlarge | i3en.6xlarge | 192.0 GiB | 24 vCPUs | 15000 GiB (2 * 7500 GiB NVMe SSD) | 25 Gigabit | $2.712000 hourly | $1.847000 hourly | $3.816000 hourly | $2.951000 hourly |
| R4 High-Memory Eight Extra Large | r4.8xlarge | 244.0 GiB | 32 vCPUs | EBS only | 10 Gigabit | $2.128000 hourly | $1.344000 hourly | $3.600000 hourly | $2.816000 hourly |
| T2 Large | t2.large | 8.0 GiB | 2 vCPUs for a 7h 12m burst | EBS only | Low to Moderate | $0.092800 hourly | $0.057500 hourly | $0.120800 hourly | $0.085500 hourly |
| X1 Extra High-Memory 16xlarge | x1.16xlarge | 976.0 GiB | 64 vCPUs | 1920 GiB SSD | High | $6.669000 hourly | $4.110000 hourly | $9.613000 hourly | $7.054000 hourly |
| M5A 16xlarge | m5a.16xlarge | 256.0 GiB | 64 vCPUs | EBS only | 12 Gigabit | $2.752000 hourly | $1.751000 hourly | $5.696000 hourly | $4.695000 hourly |
| R5 Metal | r5.metal | 768.0 GiB | 96 vCPUs | EBS only | 25 Gigabit | $6.048000 hourly | $3.810000 hourly | $10.464000 hourly | $8.226000 hourly |
| R5A Large | r5a.large | 16.0 GiB | 2 vCPUs | EBS only | 10 Gigabit | $0.113000 hourly | $0.071000 hourly | $0.205000 hourly | $0.163000 hourly |
| C3 High-CPU Large | c3.large | 3.75 GiB | 2 vCPUs | 32 GiB (2 * 16 GiB SSD) | Moderate | $0.105000 hourly | $0.073000 hourly | $0.188000 hourly | $0.165000 hourly |
| R5A 24xlarge | r5a.24xlarge | 768.0 GiB | 96 vCPUs | EBS only | 20 Gigabit | $5.424000 hourly | $3.423000 hourly | $9.840000 hourly | $7.839000 hourly |
| G3 16xlarge | g3.16xlarge | 488.0 GiB | 64 vCPUs | EBS only | 20 Gigabit | $4.560000 hourly | $3.112200 hourly | $7.504000 hourly | $6.056200 hourly |
| A1 Double Extra Large | a1.2xlarge | 16.0 GiB | 8 vCPUs | EBS only | Up to 10 Gigabit | $0.204000 hourly | $0.128500 hourly | unavailable | unavailable |
| C4 High-CPU Extra Large | c4.xlarge | 7.5 GiB | 4 vCPUs | EBS only | High | $0.199000 hourly | $0.126000 hourly | $0.383000 hourly | $0.310000 hourly |
| X1E Quadruple Extra Large | x1e.4xlarge | 488.0 GiB | 16 vCPUs | 480 GiB SSD | Up to 10 Gigabit | $3.336000 hourly | $2.056000 hourly | $4.072000 hourly | $2.792000 hourly |
| M5AD Extra Large | m5ad.xlarge | 16.0 GiB | 4 vCPUs | 150 GiB NVMe SSD | Up to 10 Gigabit | $0.206000 hourly | $0.132000 hourly | $0.390000 hourly | $0.316000 hourly |


EC2Instances.info Easy Amazon EC2 Instance Comparison
EC2
RDS
Region: US East (N. Virginia)
Cost: Hourly
Reserved: 1-year - No Upfront
Columns
Compare Selected
Clear Filters
CSV
Filter: Min Memory (GiB): 0 Min vCPUs: 0 Min Storage (GiB): 0
EC2 Instances (724)
Based on your inputs, this is the lowest-cost EC2 instance: t4g.nano
Name
API Name
Memory
vCPUs
Instance Storage
Network Performance
Linux On Demand cost
Linux Reserved cost
Windows On Demand cost
Windows Reserved cost
Search
Search
Search
$0.173000 hourly $0.456000 hourly $0.357000 hourly
$0.219000 hourly $0.712000 hourly $0.587000 hourly
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$1.141000 hourly $3.280000 hourly $2.613000 hourly
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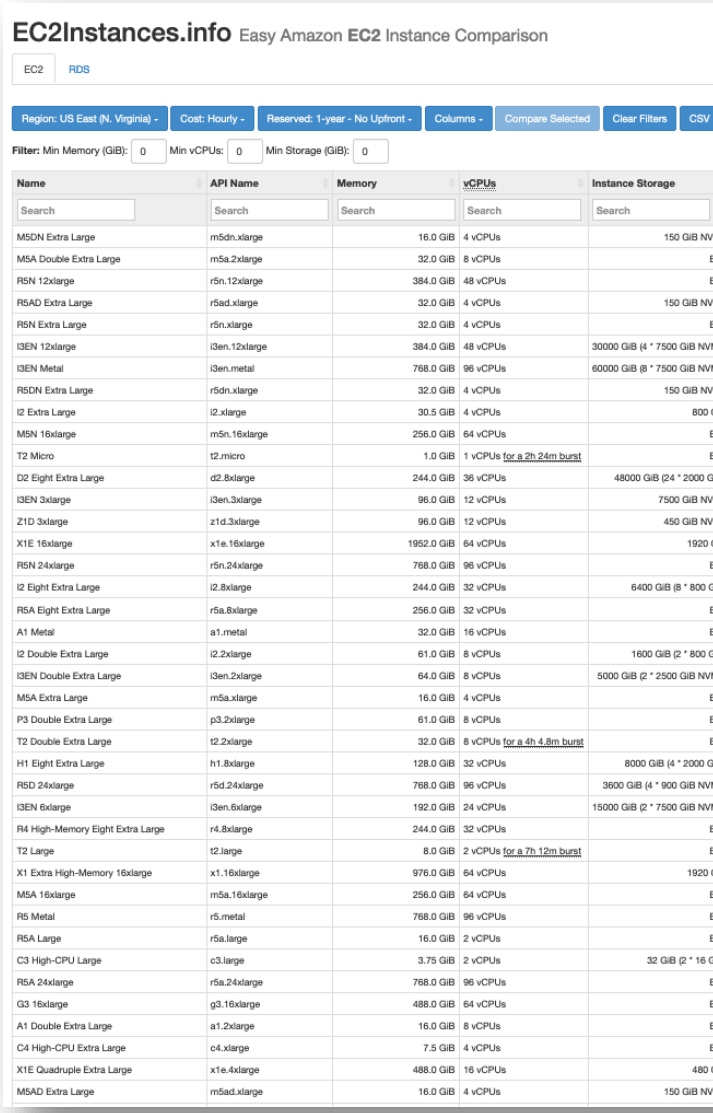
Azure
Select a VM size
Search by VM size...
Showing 728 VM
Sub
aws
EC2 > Instance types
Instance types (634)
Why is Kubernetes So D
Complicated?
Tennis Smith, November 8, 2021
Blog
Kubernetes
Time spent arguing about Kubernetes features
Time spent building serverless app
TWICE

# #thecloudistoodamnhard

1. What type of instances?



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| M5N 16xlarge | m5n.16xlarge | 256.0 GiB | 64 vCPUs | E |
| T2 Micro | t2.micro | 1.0 GiB | 1 vCPUs for a 2h 24m burst | E |
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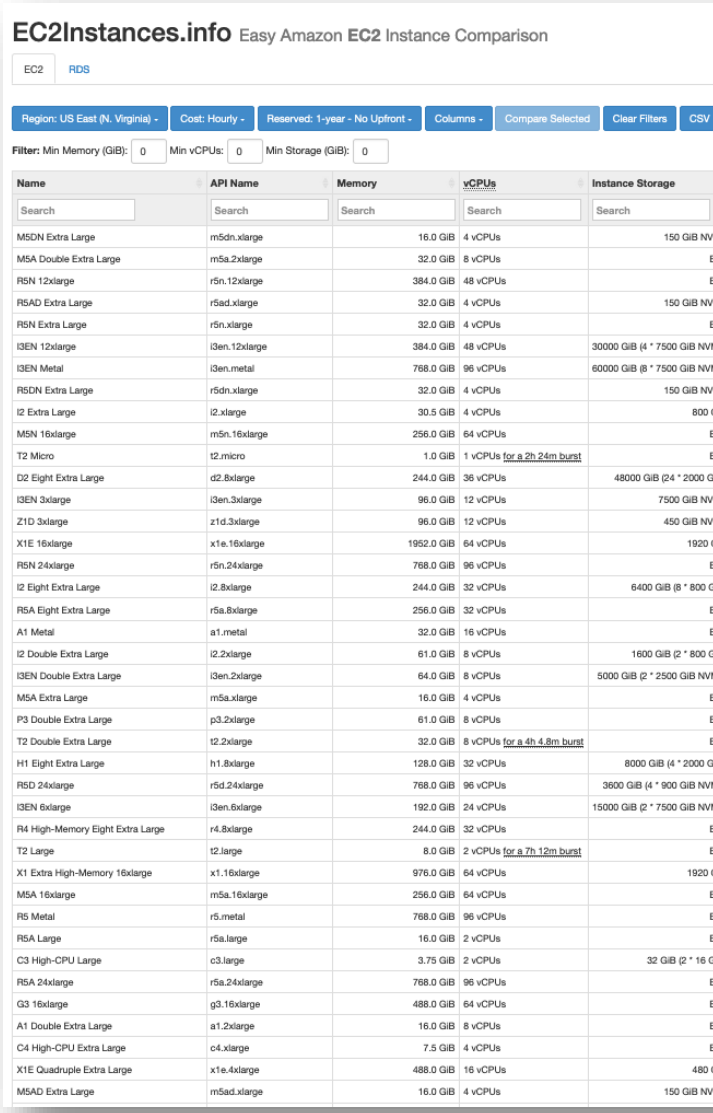
# #thecloudistoodamnhard

1. What type of instances?
2. How many to spin up?



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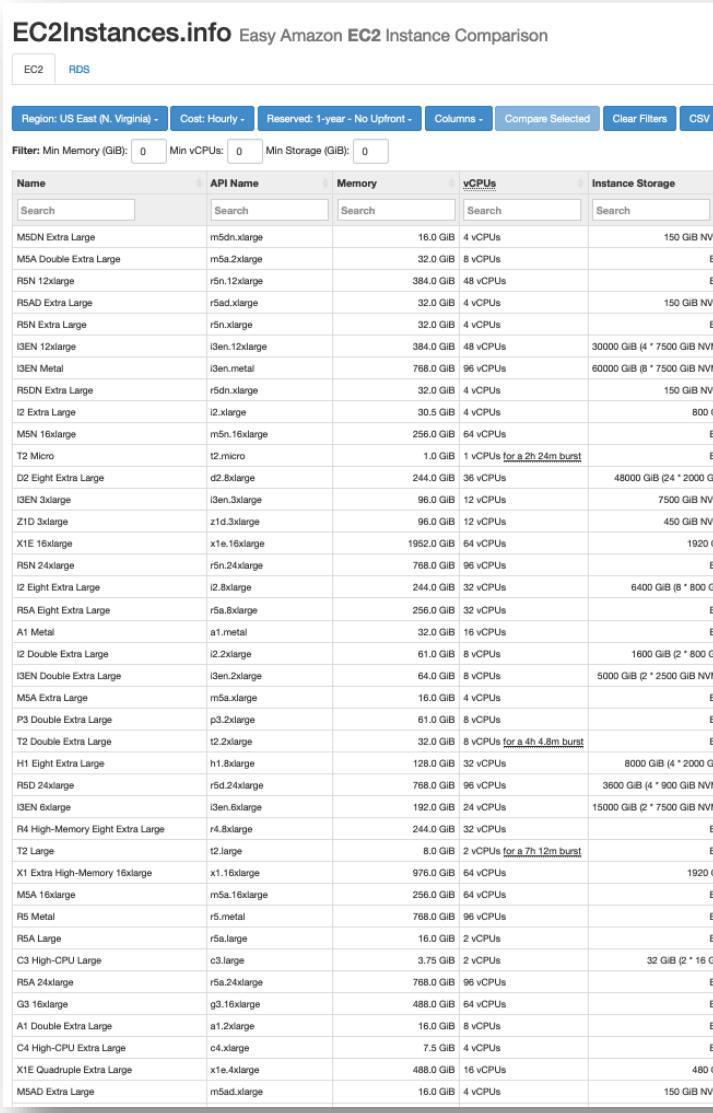
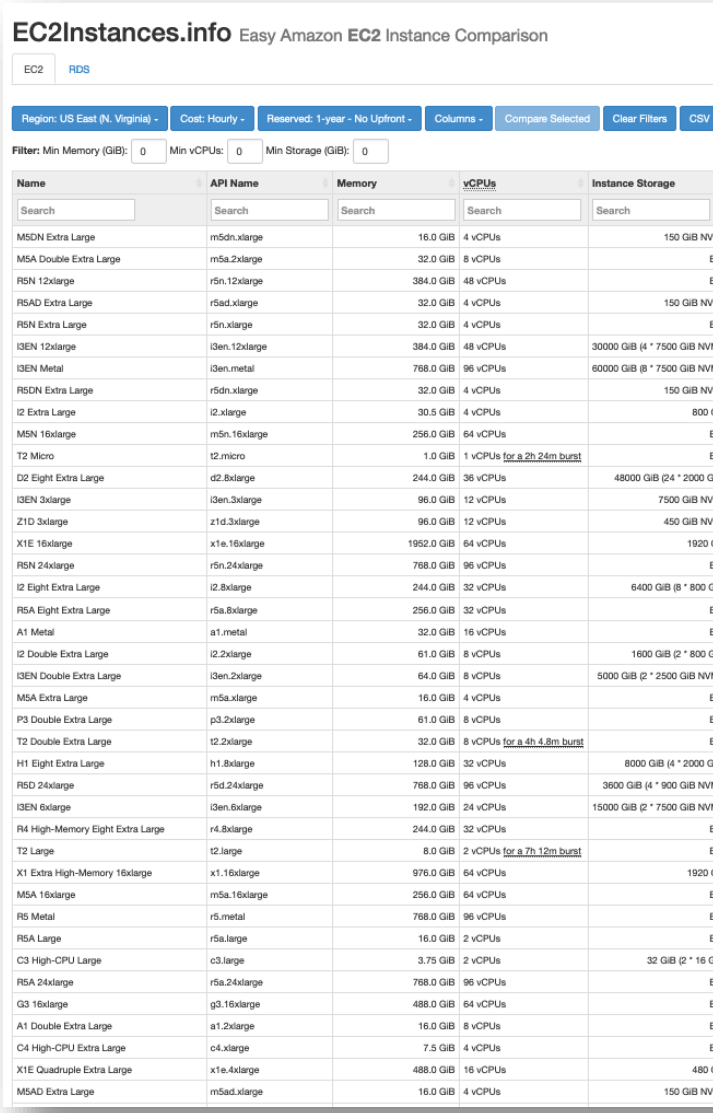
# #thecloudistoodamnhard

1. What type of instances?
2. How many to spin up?
3. What base image?



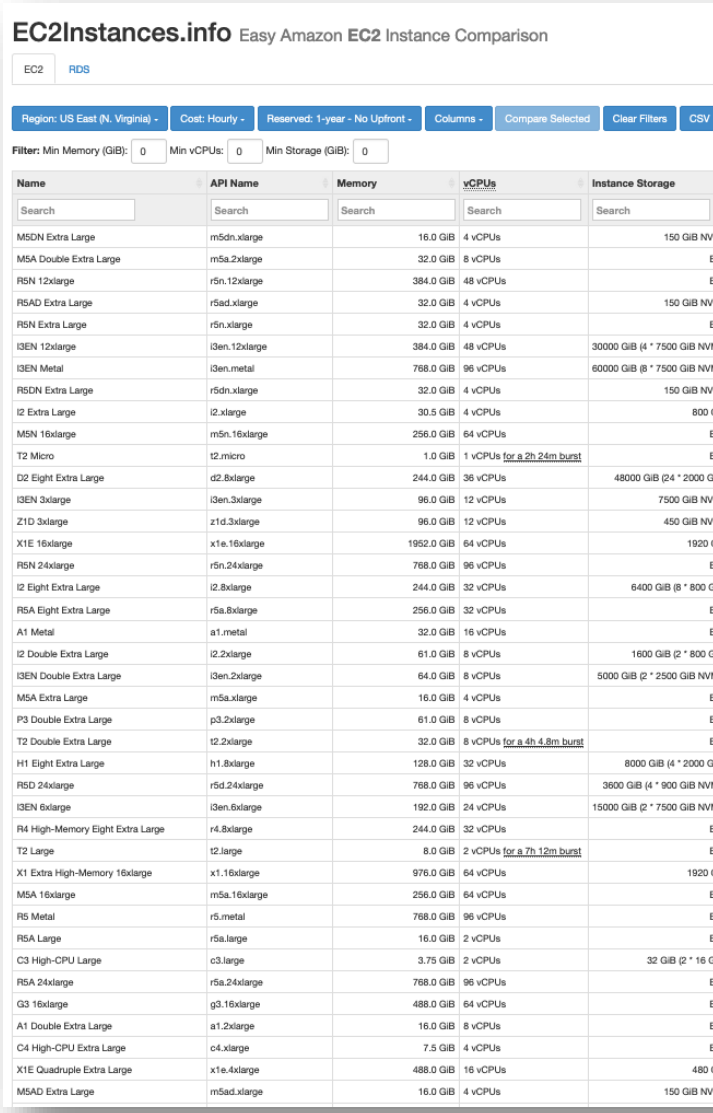
# #thecloudistoodamnhard

1. What type of instances?
2. How many to spin up?
3. What base image?
4. On-demand or spot?



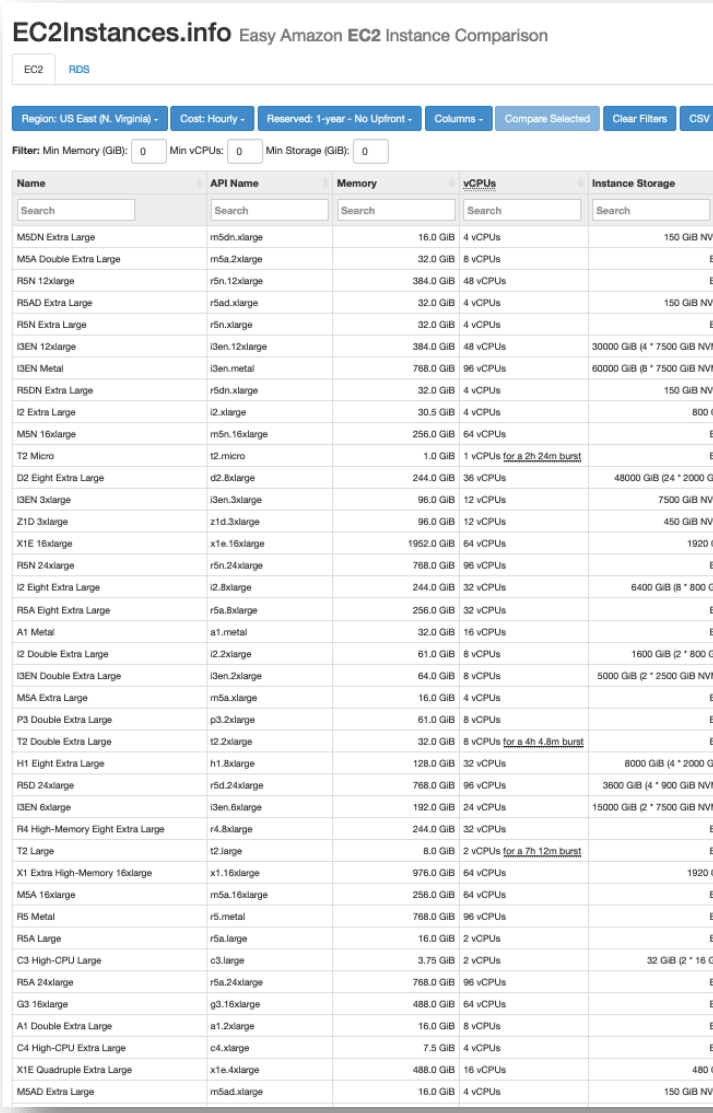
# #thecloudistoodamnhard

1. What type of instances?
2. How many to spin up?
3. What base image?
4. On-demand or spot?
5. What storage service to use?



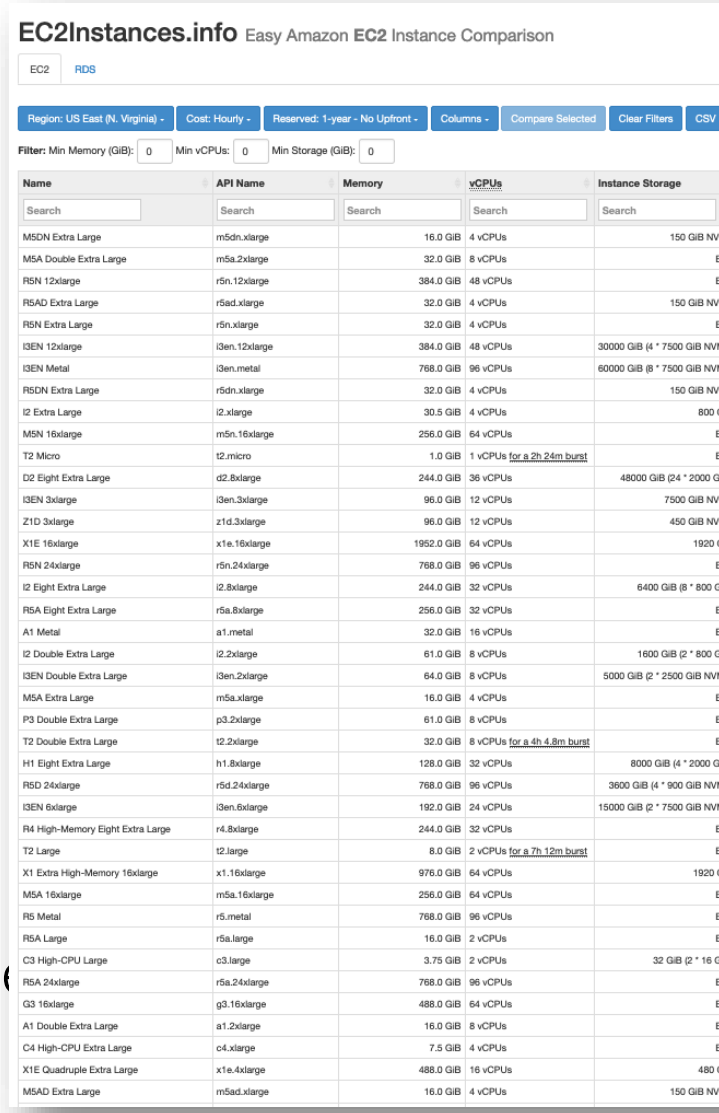
# #thecloudistoodamnhard

1. What type of instances?
2. How many to spin up?
3. What base image?
4. On-demand or spot?
5. What storage service to use?
6. And then wait to start…



# #thecloudistoodamnhard

1. What type of instances?
2. How many to spin up?
3. What base image?
4. On-demand or spot?
5. What storage service to use?
6. And then wait to start…
7. Not the end of the horror story:
   1. When to scale out?
   2. When to scale in?
   3. When to switch to different instance types?



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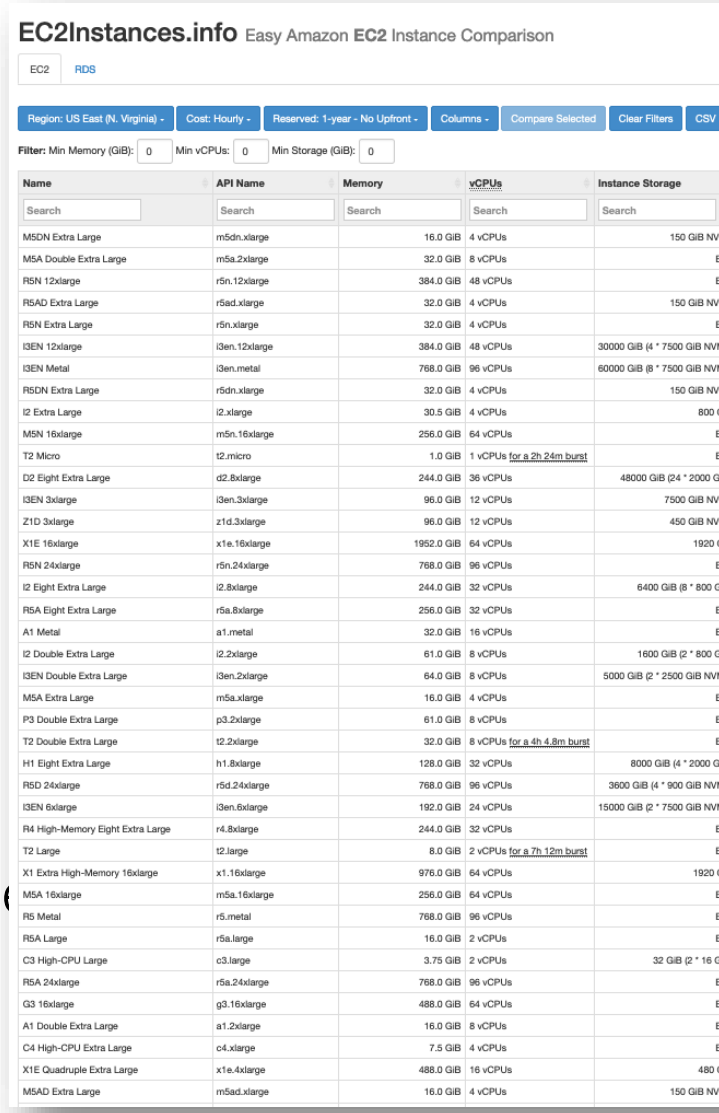
8. Go back to Step 1…



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| | | | | |
|---|---|---|---|---|
| R5A Eight Extra Large | r5a.8xlarge | 256.0 GiB | 32 vCPUs | E |
| A1 Metal | a1.metal | 32.0 GiB | 16 vCPUs | E |
| I2 Double Extra Large | i2.2xlarge | 61.0 GiB | 8 vCPUs | 1600 GiB (2 * 800 G |
| I3EN Double Extra Large | i3en.2xlarge | 64.0 GiB | 8 vCPUs | 5000 GiB (2 * 2500 GiB NVI |
| M5A Extra Large | m5a.xlarge | 16.0 GiB | 4 vCPUs | E |
| P3 Double Extra Large | p3.2xlarge | 61.0 GiB | 8 vCPUs | E |
| T2 Double Extra Large | t2.2xlarge | 32.0 GiB | 8 vCPUs for a 4h 4.8m burst | E |
| H1 Eight Extra Large | h1.8xlarge | 128.0 GiB | 32 vCPUs | 8000 GiB (4 * 2000 G |
| R5D 24xlarge | r5d.24xlarge | 768.0 GiB | 96 vCPUs | 3600 GiB (4 * 900 GiB NVI |
| I3EN 6xlarge | i3en.6xlarge | 192.0 GiB | 24 vCPUs | 15000 GiB (2 * 7500 GiB NVI |
| R4 High-Memory Eight Extra Large | r4.8xlarge | 244.0 GiB | 32 vCPUs | E |
| T2 Large | t2.large | 8.0 GiB | 2 vCPUs for a 7h 12m burst | E |
| X1 Extra High-Memory 16xlarge | x1.16xlarge | 976.0 GiB | 64 vCPUs | 1920 G |
| M5A 16xlarge | m5a.16xlarge | 256.0 GiB | 64 vCPUs | E |
| R5 Metal | r5.metal | [illegible] | 96 vCPUs | E |
| R5A Large | r5a.large | [illegible] | [illegible] | E |
| [illegible] | [illegible] | [illegible] | [illegible] | 32 GiB (2 * 16 G |
| [illegible] | [illegible] | [illegible] | [illegible] | E |
| [illegible] | [illegible] | [illegible] | [illegible] | E |
| [illegible] | [illegible] | [illegible] | [illegible] | E |
| [illegible] | [illegible] | [illegible] | [illegible] | E |
| [illegible] | [illegible] | [illegible] | [illegible] | 480 G |
| M5AD Extra Large | m5ad.xlarge | [illegible] | [illegible] | 150 GiB NV |

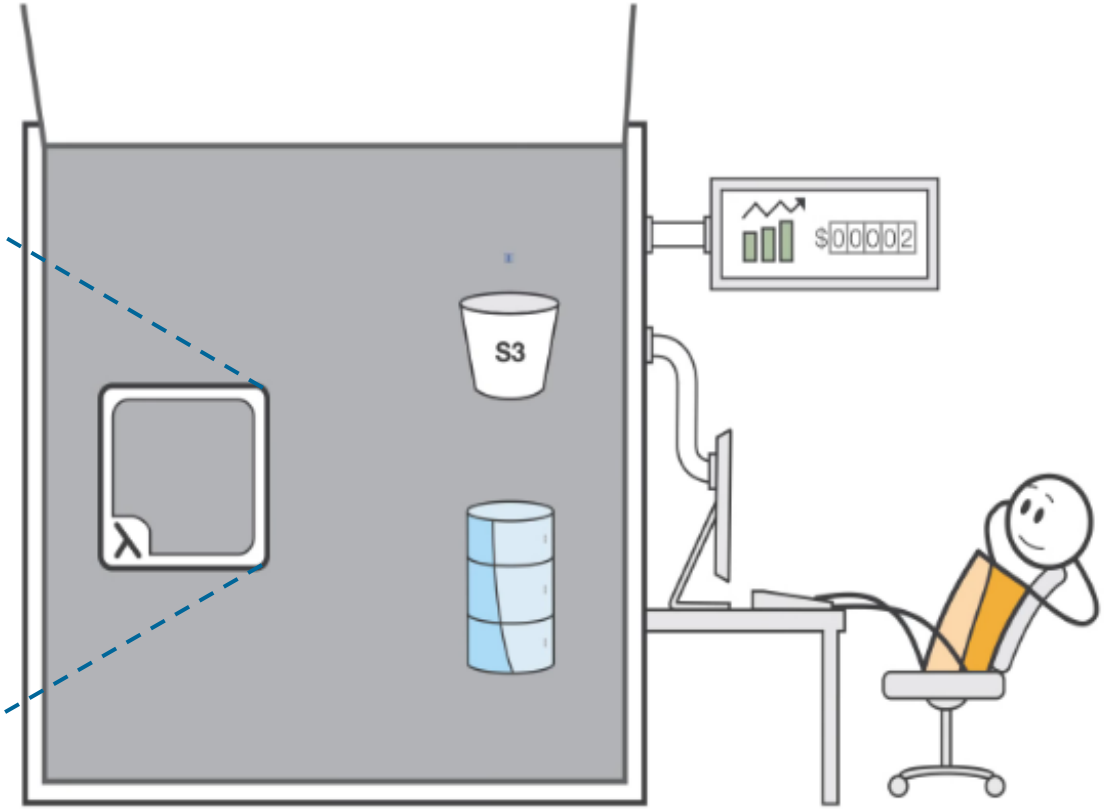
**Why is there no “cloud button”?**

# ~~Decision paralysis??~~
# Go for Serverless!

Amazon
**Lambda**

Google Cloud Functions

Microsoft Azure Functions



# What is serverless computing?

# What is serverless computing?

Serverless computing (Function-as-a-Service, or FaaS) is a programming abstraction that enables users to upload programs, run them at (virtually) any scale, and pay only for the resources used

# A car analogy


https://www.slideshare.net/loige/building-a-serverless-company-with-nodejs-react-and-the-serverless-framework-jsday-2017-verona

# Concept of serverless is not new

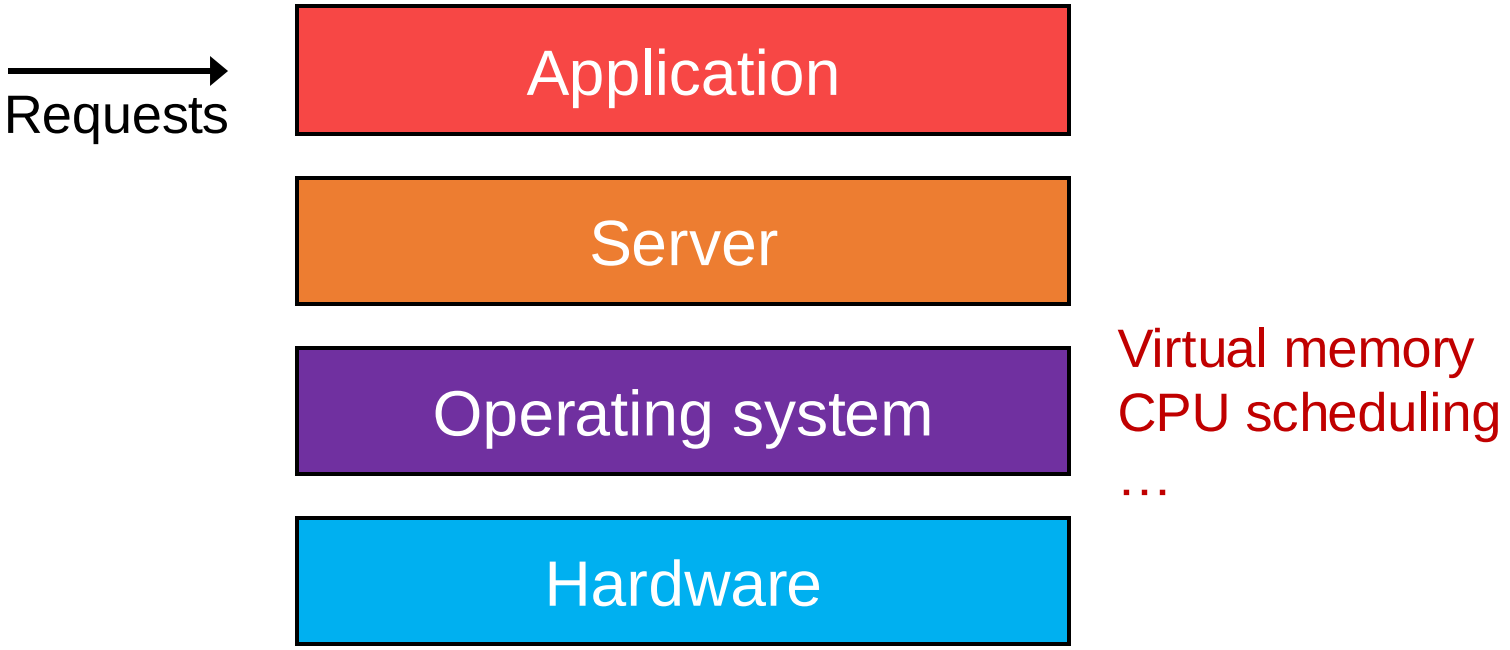
- Google App Engine
  - Fully managed platform as a service (PaaS) for developing and hosting web applications


- Google BigQuery
  - Fully managed data warehouse
  - “Arbitrarily” large data and queries
  - Pay per byte being processed
  - No concept of server or cluster

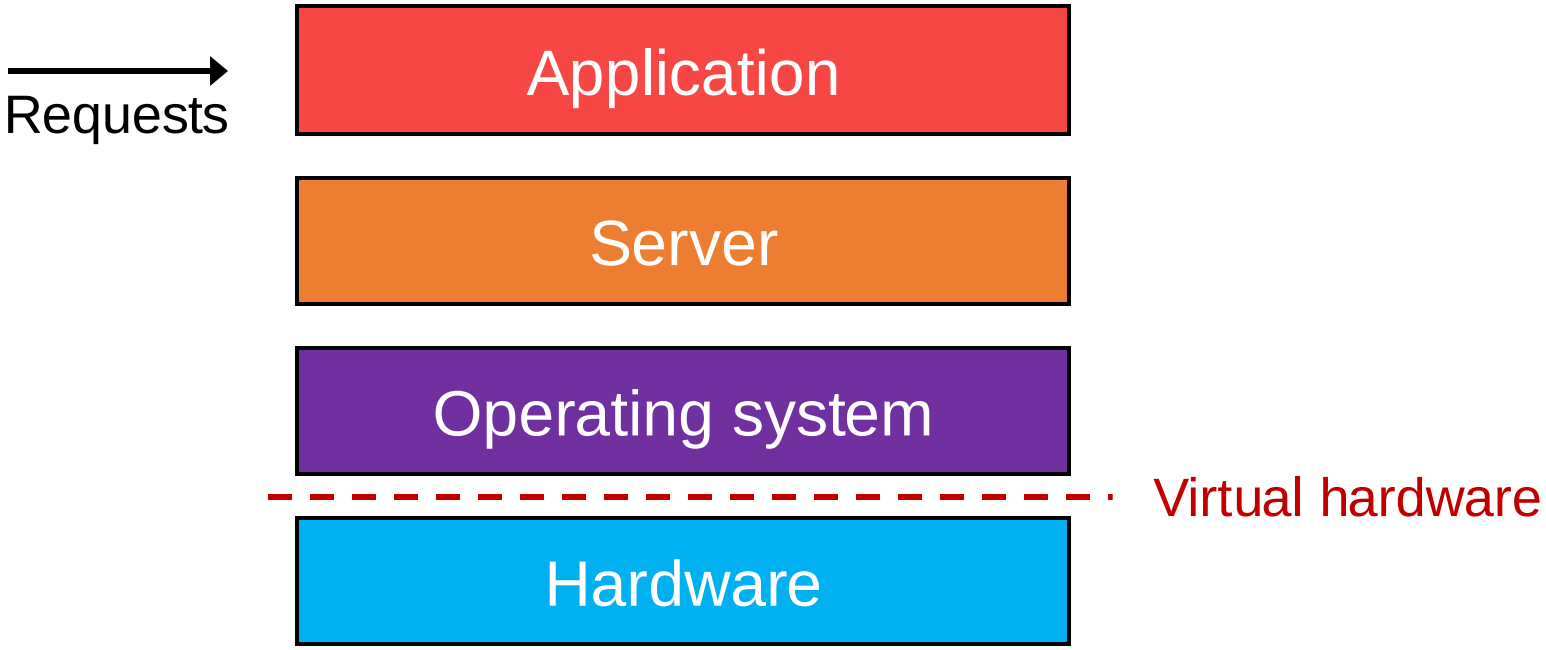

- AWS S3
  - Fully managed object storage service
  - Pay per byte being stored and written
  - No server maintenance or resource scaling

# Recap: Cloud evolution history – A virtualization story

# Classic cloud app stack



# 1st generation: virtual machine (VM)



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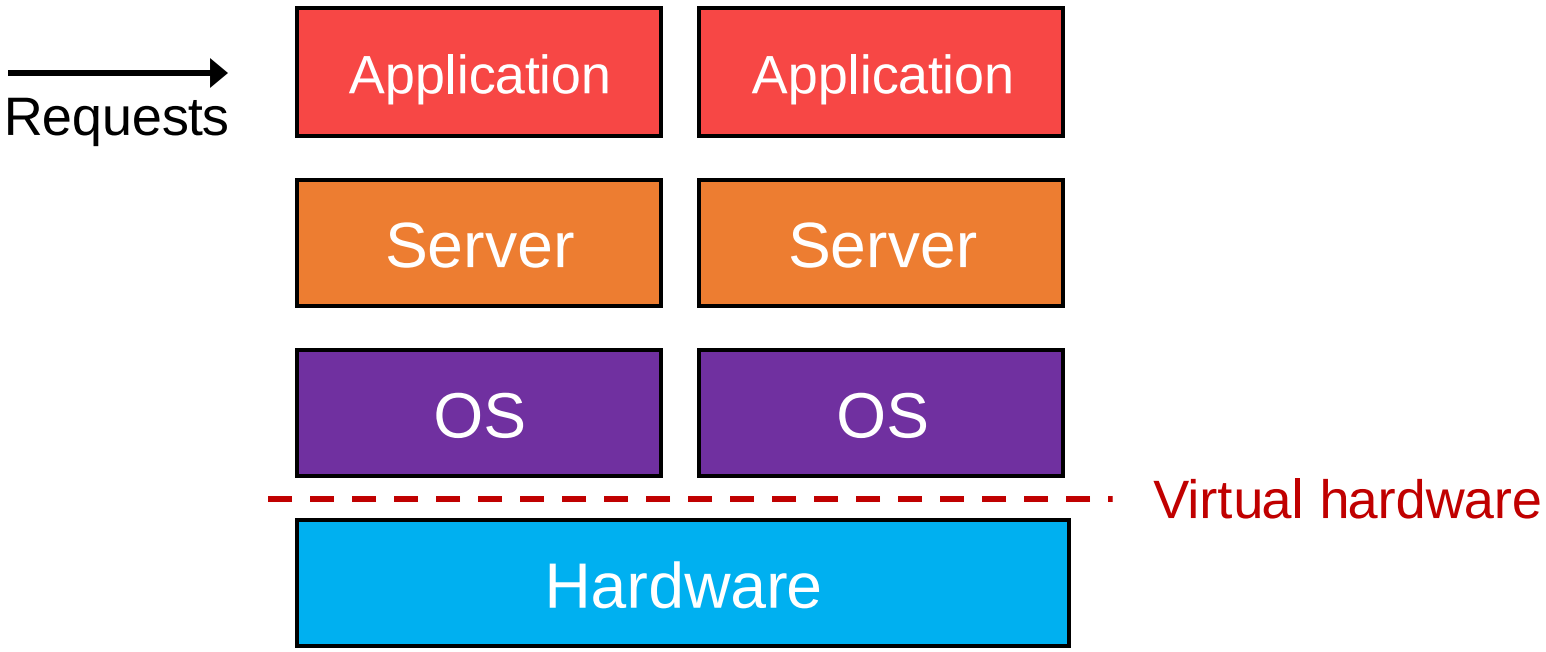
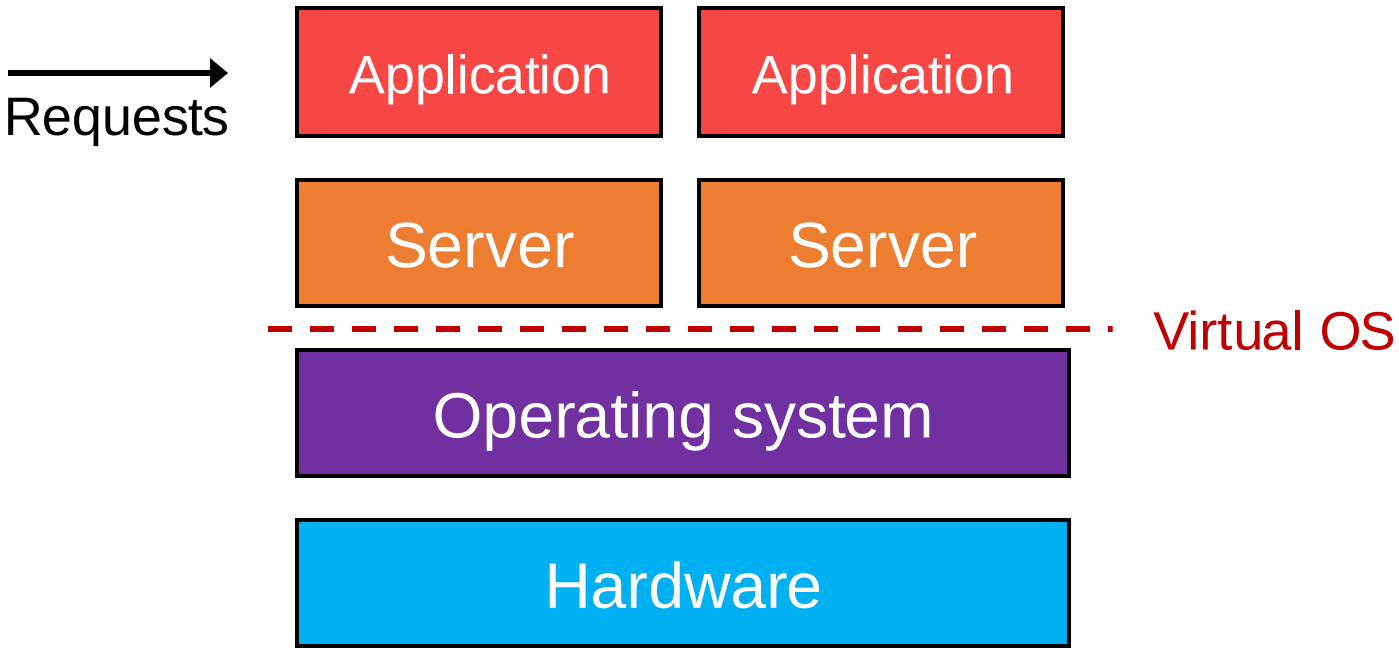
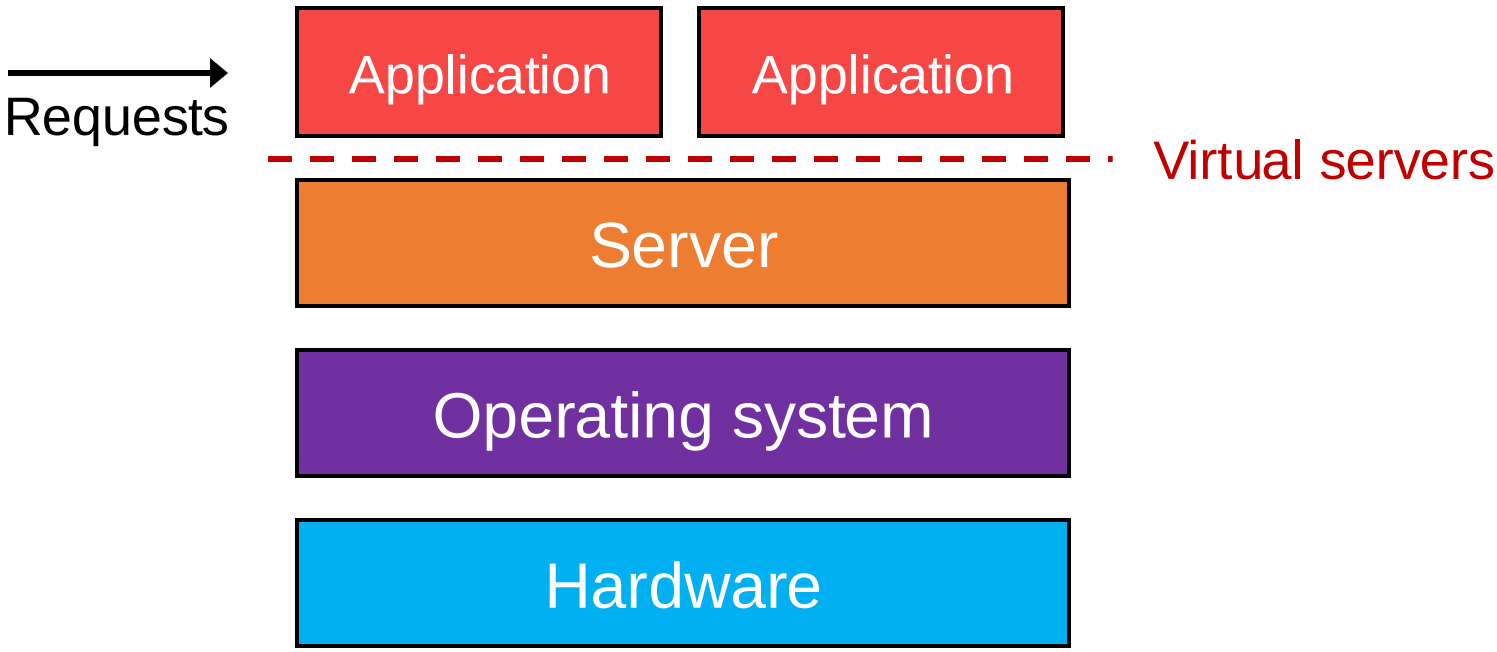


# 2nd generation: containers



# 3rd generation: serverless functions



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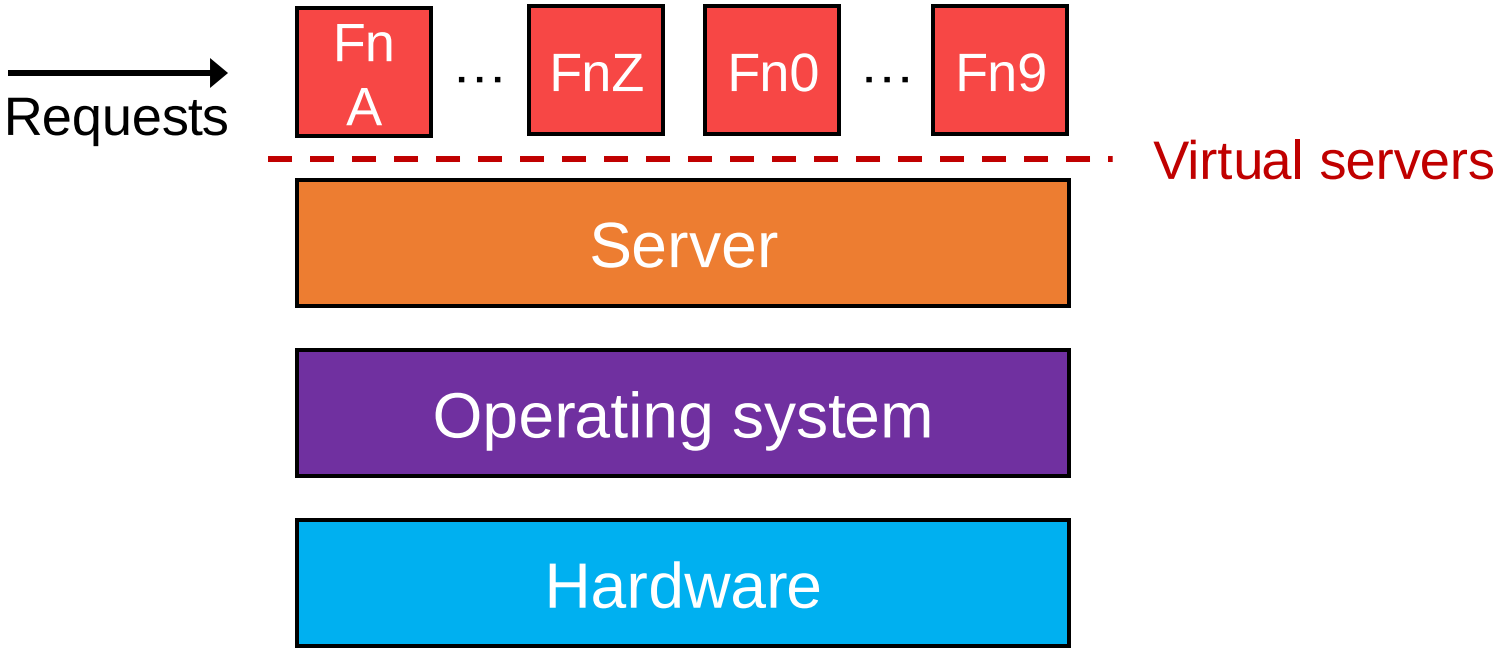

# Tradeoff discussion

| Serverless functions (AWS Lambdas) | Containers | VMs | |
|---|---|---|---|
| ++ | + | +++ | ***Isolation?*** |
| + | ++ | +++ | ***Flexibility?*** |
| + | ++ | +++ | ***Overhead?*** |

# Above the surface: Core capability

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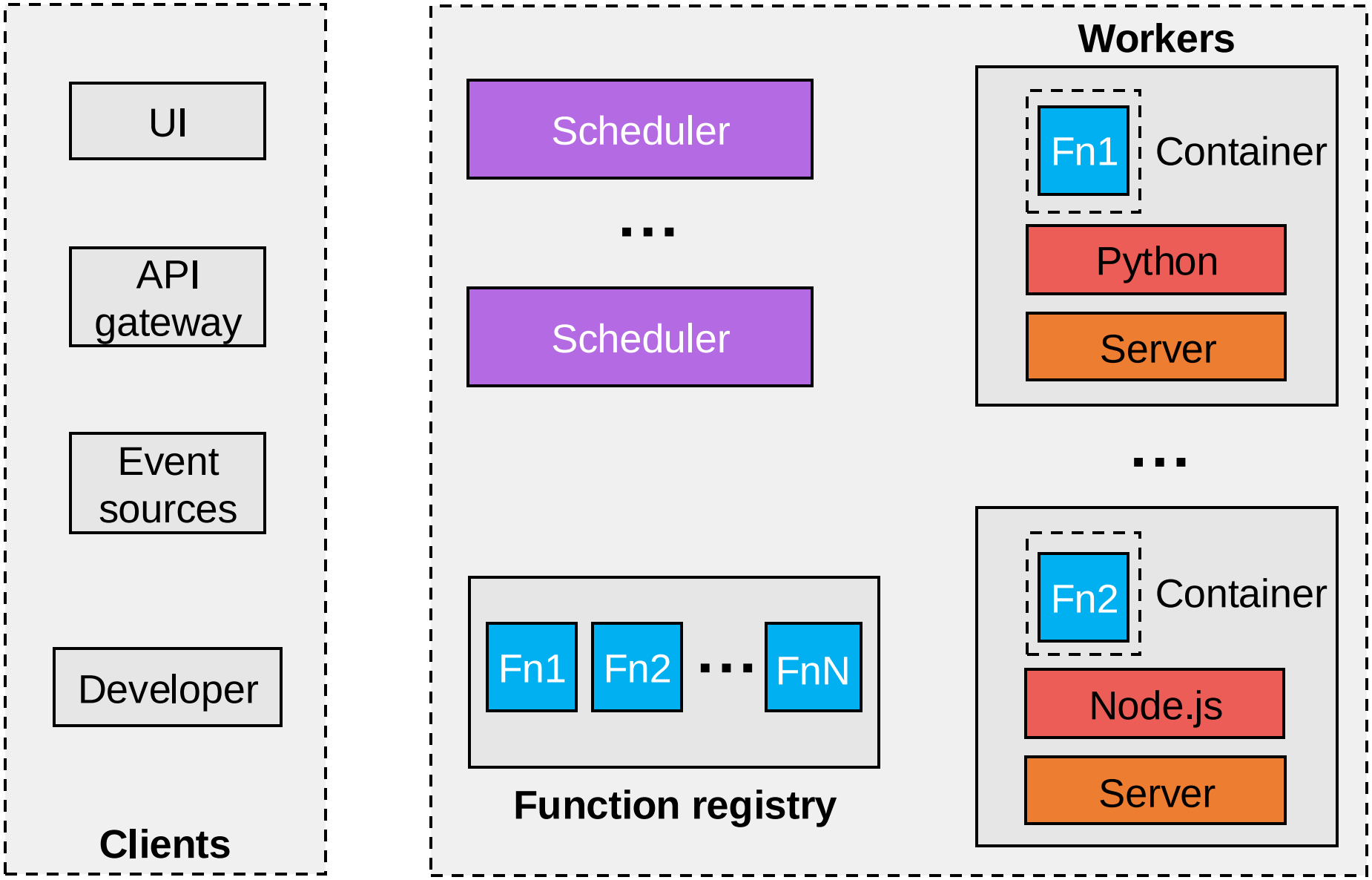
6. Wait for a response
7. Gather execution logs
8. Make the response available to the user
9. Stop the function when the execution terminates

# Under the hood: FaaS architecture



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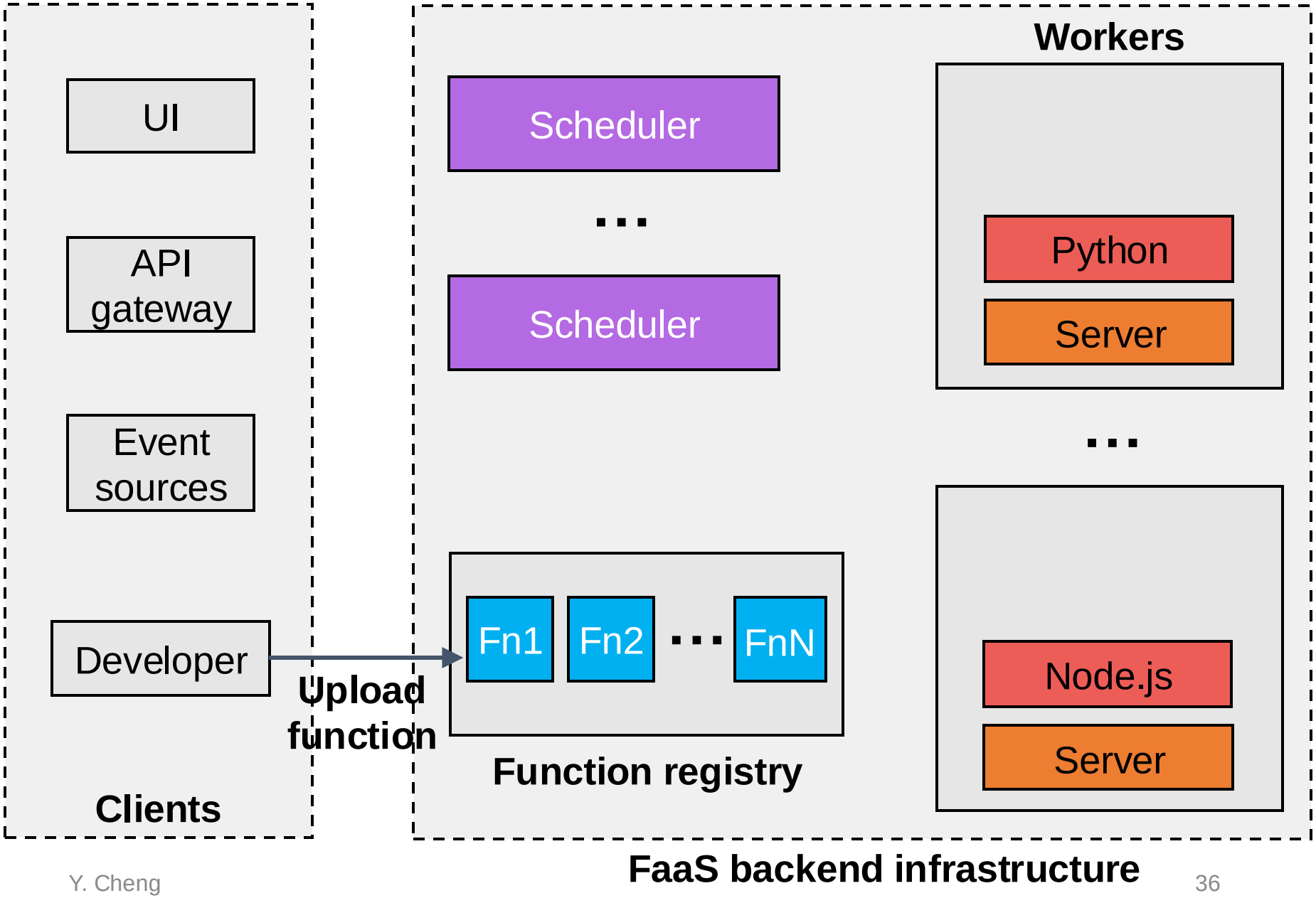

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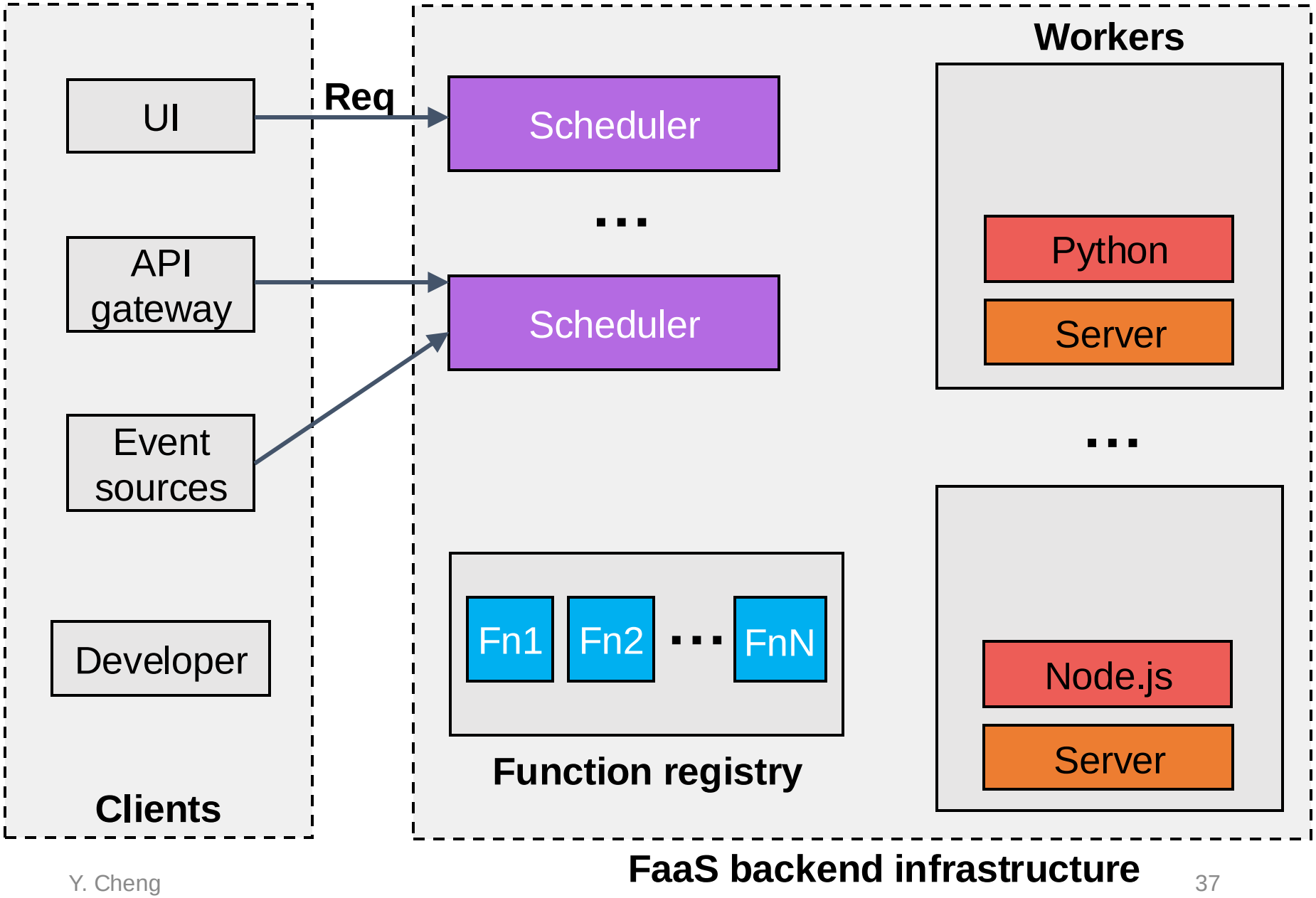

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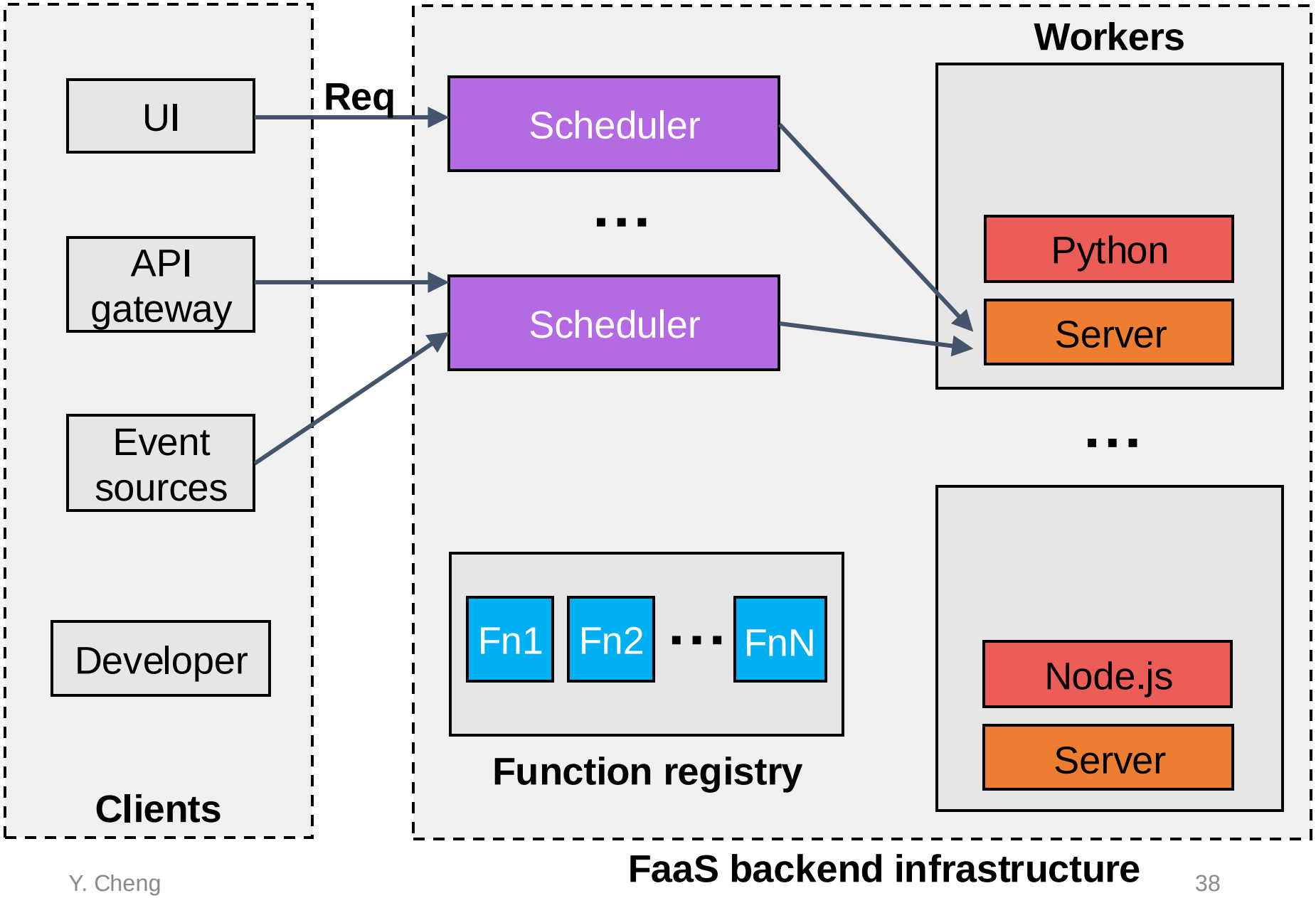

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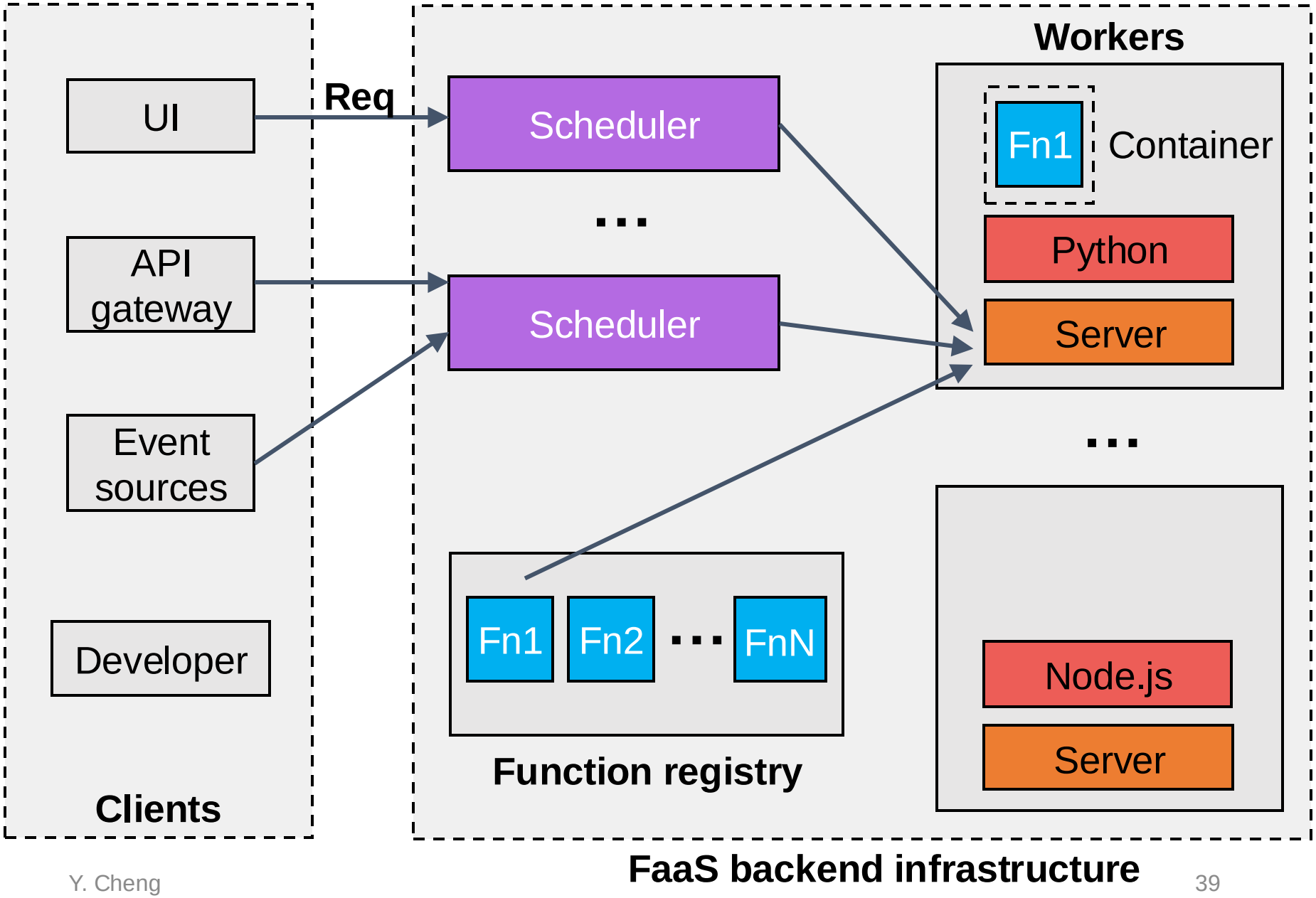

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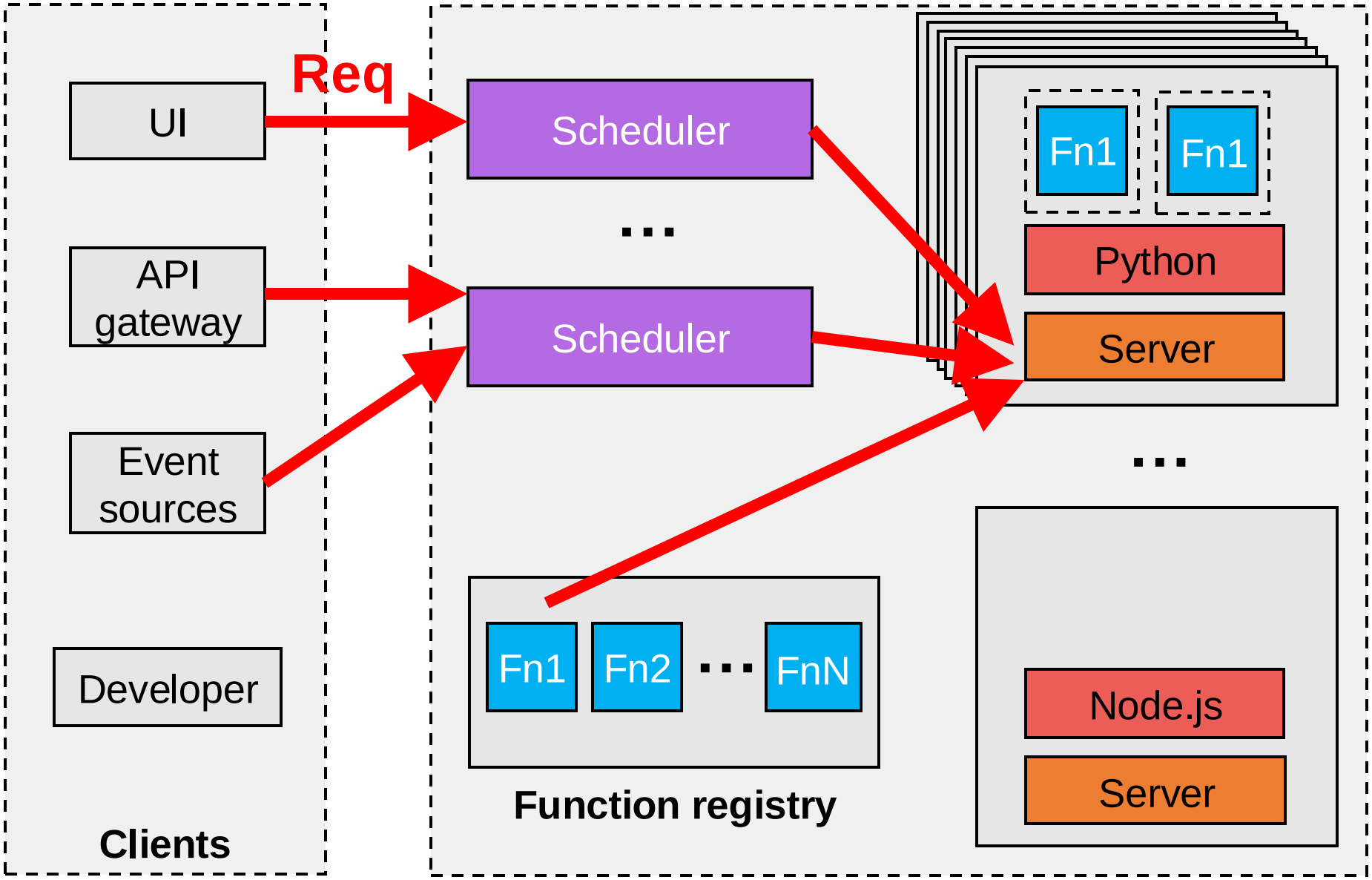

# AWS Lambda

- Lambda capacity config keeps **evolving**:

1st gen:
- ~~300 seconds~~ 900 seconds (15 minutes)
- ~~single-core~~ ~~two-core~~ → up to 6 cores
- ~~1.5 GB~~ → 10 GB memory
- ~~512 MB~~ → up to 10GB of /tmp file system

**Current offering**

Python, Java, Node.js, Go, …

Pricing:

- Fine-grained billing: 1-millisecond billed duration
- $0.20 per 1M requests (invocations charge $)
- $0.0000166667 for every GB-second (compute time charges $$)
- 6,000 1 GB Lambda functions for one second: 10¢

# Desirable properties

- Operationally
  - "No-ops" – (almost) no configuration
  - Autoscaling down to 0
  - Closer to pay-per-use (rather than pay-per-allocation)
  - Fine-grained billing

# FaaS today

- FaaS is used mostly for simple or coarse-grained tasks
  - Stateless, embarrassingly parallel tasks, simple workflows
    - ETL, software testing, API middleware, image processing, etc.
  - Glue to other serverless backends

- Lots of problems are limiting FaaS' scope
  - Poor performance (vs. time to run actual code) at scale
  - Mismatch of infrastructure support (e.g., today's OS not designed for FaaS)
  - Rule-breaking research needed to reimagine/broaden the scope
  - Very resource-inefficient and costly for serverless providers
  - Lack of support for accelerators
  - …
- **Orders of magnitude slower and inefficient for many "killer" apps**
  - ML inference, microservices, …

# Limitations

- **Banned** inbound network
- **No guaranteed** data availability
- Lambdas are **resource-constrained**
- Lambdas have **limited execution time**
- **High cold startup cost** and **invocation cost**