Serverless Computing Basics

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Outline

- Overview and major offerings
- Example applications
- Limitations and discussion
- Serverless computing in the wild

- Quiz 2 tentatively scheduled on 2/14 (Happy Valentines Day!)

Acknowledgement: Some of the slides are from Ali Ghodsi and Ion Stoica’s Berkeley lecture notes in 2018, Tyler Harter’s HotCloud’16 OpenLambda talk, and Mohammad Shahrad’s ATC’20 talk
What is Serverless Computing?

- Computing without servers?
- Running applications without the need to manage servers?
- Running functions instead of containers/VMs?
- Infinite scaling?

- The truth: no clear, agreed definition, i.e., no one really knows
One Perspective: How Cloud and Virtualization Evolved
Classic Application Execution

Application

Runtime

OS

Weak Virtualization

Hardware

No Sharing
1st Generation: Virtual Machines

- Application
- Runtime
- OS

Virtual Hardware

Shared Physical Hardware
2nd Generation: Containers

Shared Physical Hardware and OS
3rd Generation: Serverless Computing

Shared Physical Hardware, OS, and Runtime
Evolution of serverless

Decreasing concern (and control) over stack implementation

Increasing focus on business logic

Bare Metal

Virtual machines

Containers

Functions
Serverless means ...

- No server or container management
- Flexible scaling
- High availability
- No idle capacity
What is the essence of “Serverless Computing”? Or, what do people really like about it?

• Management-free

• No need to handle creation, failure, replication, etc.

• Autoscaling

• Spin up/down functions quickly based on load

• Only pay for what you use

• Event triggered

"I didn’t have to worry about building a platform and the concept of a server, capacity planning and all that “yak shaving” was far from my mind... However, these changes are not really the exciting parts. The killer, the gotcha is the billing by the function...

This is like manna from heaven for someone trying to build a business. Certainly I have the investment in developing the code but with application being a variable operational cost then I can make a money printing machine which grows with users..."

source: https://hackernoon.com/why-the-fuss-about-serverless-4370b1596da0
What is Today’s Serverless Computing Like?

- Largely offered as Function as a Service (FaaS)
  - Cloud users write functions and ship them
  - Cloud provider runs and manages them
- Still runs on servers
- Have attractive features but also many limitations
A Related Topic: Microservice

• A software architecture that develops an application as a suite of small services, each of which can be deployed and scaled independently

• When one (micro)service is in large demand, can scale it up

• Different (micro)services can be written and managed by different teams

• Changing one (micro)service will not affect the others
A Related Topic: Microservice

A monolithic application puts all its functionality into a single process...

... and scales by replicating the monolith on multiple servers

A microservices architecture puts each element of functionality into a separate service...

... and scales by distributing these services across servers, replicating as needed.
Basic Architecture
First serverless app: BigQuery

Fully managed Data Warehouse
- “Arbitrarily” large data and queries
- Pay per bytes being processed
- No concept of cluster

Other similar systems
- AWS Athena
- Snowflake
- …
AWS Lambda

• An event-driven, serverless computing FaaS platform introduced in 2014
• Functions can be written in Node.js, Python, Java, Go, Ruby, C#, PowerShell
• Each function allowed to take 128MB - 10GB memory and up to 15min
• Max 50-3000 concurrent functions
• Connected with many other AWS services
Lambda Function Triggering and Billing Model

- Run user handlers in response to events
  - web requests (RPC handlers)
  - database updates (triggers)
  - scheduled events (cron jobs)
- Pay per function invocation
  - No charge when no functions run (no triggering event)
  - Billed by duration of function, configured memory size, and # of functions
    - charge $actual\_time \times memory\_cap$
Serverless Applications

Event source → Lambda function → Services (anything)

- Changes in data state
- Requests to endpoints
- Changes in resource state

Lambda Functions:
- Node.js
- Python
- Java
- C# (.NET Core & Core 2.0)
- Go
- Ruby
- Powershell
- BYR – Bring your own Runtime

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Internal Execution Model

• Developers upload function code to a *handler store* (and associate it with a URL)

• Events trigger functions through RPC (to the URL)

• Load balancers handle RPC requests by starting *handlers* on *workers*
  • Calls to the same function are typically sent to the same worker(s)

• Handlers sandboxed in containers
  • AWS Lambda reuses the same container to execute multiple handlers when possible
Execution Model

load balancers

user

RPC

Load Balancer

Load Balancer

... 

handler store

H1 H2

workers

H2 sandbox

Python

Server

Python

Server

...
Azure Functions

• Debuted in 2016

• Support Python, C#, Java, JavaScript and PowerShell

• Three plans:
   • Consumption, Premium, and Dedicated
   • Dedicated: functions run on dedicated VMs and scaled manually (unlimited duration)
   • Max duration for consumption and premium: 10min and 60min
   • Max memory: 1.5GB - 14GB (depending on plans)
Google Cloud Functions

- Support Node.js, Python, and Go
- Memory size 128MB - 2GB
- Max function duration 9min
- Max number of functions per project: 1000
- Bill CPU and memory separately
Open-Source Projects

- OpenWhisk
  - Originally developed by IBM and the core technology behind IBM Cloud Functions
- Cloudburst
  - Stateful serverless framework built on top of the Anna key-value store
Limitations of Today’s Serverless Offerings

• Difficult and slow to manage states
  • Have to use (slow) cloud storage or other VMs!
• No easy or fast way to communicate across functions
  • Have to go through cloud storage or other services
• Functions can only use limited resources, and resources have “fixed ratios”
• No control over function placement or locality
  • e.g., starting functions on “cold” machines can be slow
• Billing model does not fit all needs
Cold Start Time of Different Languages/Offerings

source: https://mikhail.io/serverless/coldstarts/big3/
Cold Start Time with Different Package Sizes

Comparison of cold start durations per deployment size (zipped)

source: https://mikhail.io/serverless/coldstarts/big3/
Good and Bad Use Cases

• Some good ones:
  • Parallel, independent, stateless tasks
  • Orchestrating functions
  • Function composition

• Some bad ones:
  • Stateful applications
  • Distributed applications and protocols
  • Applications that demand more resources (esp. memory)
First characterization of production serverless workloads

Many new insights

Released production traces of Azure Functions:

- [https://github.com/Azure/AzurePublicDataset](https://github.com/Azure/AzurePublicDataset)

A new adaptive serverless management scheme

- New angle: going after eliminating cold starts instead of reducing cold start overhead
- Improves the user experience, reduces the underlying resource usage
- Deployed in production
Invocations per Application

This graph is from a representative subset of the workload. See paper for details.
Invocations per Application

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Invocations per Application

- 18% >1/min
- 99.6% of invocations!
- 82% <1/min
- 0.4% of invocations

This graph is from a representative subset of the workload. See paper for details.
Who should you design/optimize the system for?

**18% of applications that constitute 99.6% of invocations**

- Can lead to immediate cost reductions for the provider.
- Keeps the big users happy and prevents them from migrating to competitors.

Or

**82% of applications that constitute 0.4% of invocations**

- Can incentivize more users to shift to serverless. Potentially higher long-term profit.
- Seems reasonable when user valuation of service/QoS is unknown.

Mixing both?
Average Invocations Do Not Tell the Entire Story
It is all about trade-offs!

Conflicting Goals

Performant Serverless
- Short Execution
- Low Cold Start
- Fewer Cold Starts
- Minimum Wait Time

Efficient Serverless
- High Co-tenancy
- Minimal Resource Wastage
- High Cluster Utilization

41
Cold Starts and Resource Wastage
Figure 9: Timelines showing a warm start with keep alives and no pre-warming (top); a warm start following a pre-warm (middle); and two cold starts, before a pre-warm, and after a keep alive (bottom).
Cold Starts and Resource Wastage

- Keeping functions in memory indefinitely.
- Removing function instance from memory after invocation.
- Removing function instance from memory after invocation.

\[ O(\text{execution time}) = O(\text{cold start overhead}) \]

→ Cold starts cannot be neglected.

- Keeping functions in memory indefinitely.

  Memory usage not negligible.

  → Can’t be kept in memory forever.
What do serverless providers do?

Amazon Lambda
- Fixed 10-minute keep-alive.

Azure Functions
- Fixed 20-minute keep-alive.

Mikhail Shilkov, Cold Starts in Serverless Functions, [https://mikhail.io/serverless/coldstarts/](https://mikhail.io/serverless/coldstarts/)
Fixed Keep-Alive Policy

Results from simulation of the entire workload for a week.
A Histogram Policy To Learn Idle Times

Minute-long bins

Limited number of bins (e.g., 240 bins for 4-hours)
The Hybrid Histogram Policy

We can afford to run complex predictors given the low arrival rate.
A histogram might be too wasteful.
Decision Tree for the Hybrid Histogram Policy

ARIMA: Autoregressive Integrated Moving Average
More Optimal Pareto Frontier

![Graph showing normalized wasted memory time vs. 3rd quartile app cold start percentage.]

- Fixed
- 120-min
- 90-min
- 60-min
- 45-min
- 30-min
- 20-min
- 10-min
- 5-min

_normalized wasted memory time (%) vs. 3rd quartile app cold start (%)_
Container memory reduction: 15.6%
Average exec time reduction: 32.5%
99th–percentile exec time reduction: 82.4%
Latency overhead: < 1ms (~800 µs)

Production possible thanks to the dedication of Íñigo Goiri, Gohar Chaudhry, and the Azure Functions team.