Estimating Cloud Application Performance Based on Micro-Benchmark Profiling

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Supported by WASP
Context: Public Infrastructure-as-a-Service Clouds

IaaS
- Applications
- Data
- Runtime
- Middleware
- OS
- Virtualization
- Servers
- Storage
- Networking

PaaS
- Applications
- Data
- Runtime
- Middleware
- OS
- Virtualization
- Servers
- Storage
- Networking

SaaS
- Applications
- Data
- Runtime
- Middleware
- OS
- Virtualization
- Servers
- Storage
- Networking

User-Managed

Provider-Managed

Infrastructure-as-a-Service (IaaS)
Platform-as-a-Service (PaaS)
Software-as-a-Service (SaaS)
Motivation: Capacity Planning in IaaS Clouds

What cloud **provider** should I choose?

https://www.cloudorado.com
Motivation: Capacity Planning in IaaS Clouds

What cloud service (i.e., instance type) should I choose?

→ Impractical to Test all Instance Types

<table>
<thead>
<tr>
<th>Instance Type</th>
<th>vCPU</th>
<th>Memory (GB)</th>
<th>Storage (GB)</th>
<th>Networking Performance</th>
<th>Clock Speed (GHz)</th>
<th>Max Mem. (GB)</th>
<th>Max vCPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>t2.nano</td>
<td>0.05-1</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x1e.32xlarge</td>
<td>128</td>
<td>3904</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$0.006/h

$26.688/hourly
Topic: Performance Benchmarking in the Cloud

“The instance type itself is a very major tunable parameter”

@brendangregg re:Invent’17
https://youtu.be/89fY0o1V2pA?t=5m4s
Background

**Micro Benchmarks**
- CPU
- Memory
- I/O
- Network

**Application Benchmarks**
- Overall performance (e.g., response time)

**Generic**
- Artificial
- Resource-specific

**Domain**
- Workload
- Resource Usage

**Specific**
- Real-World
- Resource-heterogeneous
Problem: Isolation, Reproducibility of Execution

**Micro Benchmarks**
- CPU
- Memory
- I/O
- Network

**Application Benchmarks**
- Overall performance
  (e.g., response time)

**Generic**
- Artificial

**Specific**
- Resource-specific

**Resource-specific**
- Real-World

**Resource-heterogeneous**
Question

Micro Benchmarks
- CPU
- Memory
- I/O
- Network

Generic
Artificial
Resource-specific

Application Benchmarks
Overall performance (e.g., response time)

Specific
Real-World
Resource-heterogeneous

How relevant?
Research Questions

PRE – Performance Variability
Does the performance of equally configured cloud instances vary relevantly?

RQ1 – Estimation Accuracy
How accurate can a set of micro benchmarks estimate application performance?

RQ2 – Micro Benchmark Selection
Which subset of micro benchmarks estimates application performance most accurately?
Idea

Micro Benchmarks
- CPU
- Memory
- I/O
- Network

Overall performance (e.g., response time)

Performance vs. Cost

Application Benchmarks

Evaluate a Prediction Model
Methodology

Benchmark Design

- Micro Benchmarks
  - FIO
  - SystemBench - CPU
  - SystemBench - Network
  - SystemBench - File I/O
  - SystemBench - Memory
  - SystemBench - Threads
  - SystemBench - Malloc
  - geek

- App Benchmarks
  - MDSim

- WP Bench
  - Webserver
  - Database
  - Partition
Micro Benchmarks

Broad resource coverage and specific resource testing

CPU
- sysbench/cpu-single-thread
- sysbench/cpu-multi-thread
- stressng/cpu-callfunc
- stressng/cpu-double
- stressng/cpu-euler
- stressng/cpu-ftt
- stressng/cpu-fibonacci
- stressng/cpu-int64
- stressng/cpu-loop
- stressng/cpu-matrixprod

Memory
- sysbench/memory-4k-block-size
- sysbench/memory-1m-block-size

I/O
- [file I/O] sysbench/fileio-1m-seq-write
- [file I/O] sysbench/fileio-4k-rand-read
- [disk I/O] fio/4k-seq-write
- [disk I/O] fio/8k-rand-read

Network
- iperf/single-thread-bandwidth
- iperf/multi-thread-bandwidth
- stressng/network-epoll
- stressng/network-icmp
- stressng/network-sockfd
- stressng/network-udp

Software (OS)
- sysbench/mutex
- sysbench/thread-lock-1
- sysbench/thread-lock-128
Application Benchmarks

Molecular Dynamics Simulation (MDSim)

WordPress Benchmark (WPBench)

Multiple short blogging session scenarios (read, search, comment)
A Cloud Benchmark Suite Combining Micro and Applications Benchmarks

QUDOS@ICPE'18, Scheuner and Leitner
Execution Methodology

- **Benchmark Manager**
- **Provider API**
- **Cloud Instance**

**Acquire Resources** → **Provision VM** → **Start Benchmarks** → **Run Benchmark** → **Benchmark Results** → **Release Resources**

**D) Randomized Multiple Interleaved Trials (RMIT)** [1]

- 30 benchmark scenarios
- 3 trials
- ~2-3h runtime

[1] A. Abedi and T. Brecht. Conducting repeatable experiments in highly variable cloud computing environments. ICPE'17
Benchmark Manager

Cloud WorkBench (CWB)

Tool for scheduling cloud experiments

sealuzh/cloud-workbench

Cloud Work Bench – Infrastructure-as-Code Based Cloud Benchmarking
CloudCom’14, Scheuner, Leitner, Cito, and Gall

Cloud WorkBench: Benchmarking IaaS Providers based on Infrastructure-as-Code
Demo@WWW’15, Scheuner, Cito, Leitner, and Gall
Methodology

A Cloud Benchmark Suite Combining Micro and Applications Benchmarks
QUDOS@ICPE’18, Scheuner and Leitner

Estimating Cloud Application Performance Based on Micro Benchmark Profiling
CLOUD’18, Scheuner and Leitner
Performance Data Set

<table>
<thead>
<tr>
<th>Instance Type</th>
<th>vCPU</th>
<th>ECU*</th>
<th>RAM [GiB]</th>
<th>Virtualization</th>
<th>Network Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>m1.small</td>
<td>1</td>
<td>1</td>
<td>1.7</td>
<td>PV</td>
<td>Low</td>
</tr>
<tr>
<td>m1.medium</td>
<td>1</td>
<td>2</td>
<td>3.75</td>
<td>PV</td>
<td>Moderate</td>
</tr>
<tr>
<td>m3.medium</td>
<td>1</td>
<td>3</td>
<td>3.75</td>
<td>PV /HVM</td>
<td>Moderate</td>
</tr>
<tr>
<td>m1.large</td>
<td>2</td>
<td>4</td>
<td>7.5</td>
<td>PV</td>
<td>Moderate</td>
</tr>
<tr>
<td>m3.large</td>
<td>2</td>
<td>6.5</td>
<td>7.5</td>
<td>HVM</td>
<td>Moderate</td>
</tr>
<tr>
<td>m4.large</td>
<td>2</td>
<td>6.5</td>
<td>8.0</td>
<td>HVM</td>
<td>Moderate</td>
</tr>
<tr>
<td>c3.large</td>
<td>2</td>
<td>7</td>
<td>3.75</td>
<td>HVM</td>
<td>Moderate</td>
</tr>
<tr>
<td>c4.large</td>
<td>2</td>
<td>8</td>
<td>3.75</td>
<td>HVM</td>
<td>Moderate</td>
</tr>
<tr>
<td>c3.xlarge</td>
<td>4</td>
<td>14</td>
<td>7.5</td>
<td>HVM</td>
<td>Moderate</td>
</tr>
<tr>
<td>c4.xlarge</td>
<td>4</td>
<td>16</td>
<td>7.5</td>
<td>HVM</td>
<td>High</td>
</tr>
<tr>
<td>c1.xlarge</td>
<td>8</td>
<td>20</td>
<td>7</td>
<td>PV</td>
<td>High</td>
</tr>
</tbody>
</table>

* ECU := Elastic Compute Unit (i.e., Amazon’s metric for CPU performance)

>240 Virtual Machines (VMs) à 3 Iterations $\rightarrow$ ~750 VM hours

>60’000 Measurements (258 per instance)
**PRE – Performance Variability**

Does the performance of equally configured cloud instances vary relevantly?

![Graph showing performance variability across different configurations.](image)

**Results**

- **Threads Latency**
  - Fileio Random
- **Network**
  - Fileio Seq.

**Configuration [Instance Type (Region)]**

- m1.small (eu)
- m1.small (us)
- m3.medium (eu)
- m3.medium (us)
- m3.large (eu)

**Relative Standard Deviation (RSD) [%]**

- m1.small (eu): 4.41
- m1.small (us): 4.3
- m3.medium (eu): 3.16
- m3.medium (us): 3.32
- m3.large (eu): 4.14

2 outliers
- 54% and 56%
RQ1 – Estimation Accuracy

How accurate can a set of micro benchmarks estimate application performance?

Instance Type$_1$
(m1.small)

Instance Type$_2$

Instance Type$_{12}$
(c1.xlarge)

micro$_1$, micro$_2$, ..., micro$_N$

app$_1$, app$_2$

Linear Regression Model

Forward feature selection to optimize relative error
RQ1 – Estimation Accuracy
How accurate can a set of micro benchmarks estimate application performance?

Relative Error (RE) = 12.5%
$R^2 = 99.2%$
RQ2 – Micro Benchmark Selection

Which subset of micro benchmarks estimates application performance most accurately?

<table>
<thead>
<tr>
<th>Micro Benchmark</th>
<th>Relative Error [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sysbench – CPU Multi Thread</td>
<td>12</td>
</tr>
<tr>
<td>Sysbench – CPU Single Thread</td>
<td>454</td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
</tr>
<tr>
<td>vCPUs</td>
<td>616</td>
</tr>
<tr>
<td>ECU (i.e., Amazon’s metric for CPU performance)</td>
<td>359</td>
</tr>
<tr>
<td>Cost</td>
<td>663</td>
</tr>
</tbody>
</table>
RQ – Implications

- Suitability of **selected** micro benchmarks to estimate application performance

- Benchmarks cannot be used interchangeable → Configuration is important

- Baseline metrics vCPU and ECU are insufficient
Threats to Validity

**Construct Validity**
Almost 100% of benchmarking reports are wrong because benchmarking is "very very error-prone"\(^1\)
[senior performance architect @Netflix]
→ Guidelines, rationalization, open source

**Internal Validity**
The extent to which cloud environmental factors, such as multi-tenancy, evolving infrastructure, or dynamic resource limits, affect the performance level of a VM instance
→ Variability PRE, stop interfering process

**External Validity (Generalizability)**
Other cloud providers?
Larger instance types?
Other application domains?
→ Future work

**Reproducibility**
the extent to which the methodology and analysis is repeatable at any time for anyone and thereby leads to the same conclusions
⚠️ dynamic cloud environment
→ Fully automated execution, open source

\(^1\) [Link](https://www.youtube.com/watch?v=vm1GJMp0QN4&feature=youtu.be&t=18m29s)
Related Work

• System-level resource monitoring [1,2]
• Compiler-level program similarity [3]

• Trace and reply with Cloud-Prophet [4,5]
• Bayesian cloud configuration refinement for big data analytics [6]

Conclusion

Motivation: Capacity Planning in IaaS Clouds

What cloud service (i.e., instance type) should I choose?

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Methodology

RQ – Implications

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