Dynamic Vertical Memory Scalability for OpenJDK Cloud Applications

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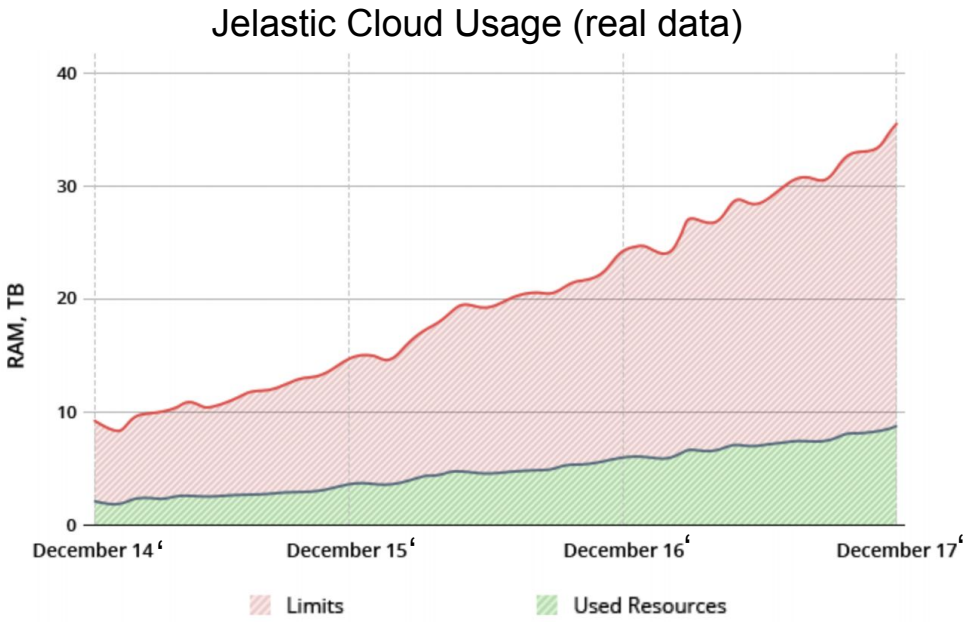
Unused Resources in the Cloud



- Real data from Jelastic cloud provider between 2014 and 2017
- More than 25 TBs of unused RAM in 2017
- Most cloud providers charge for reserved resources
  - Users are paying for resources that are not used!
- Cloud users are forced to overprovision
  - memory requirements not known
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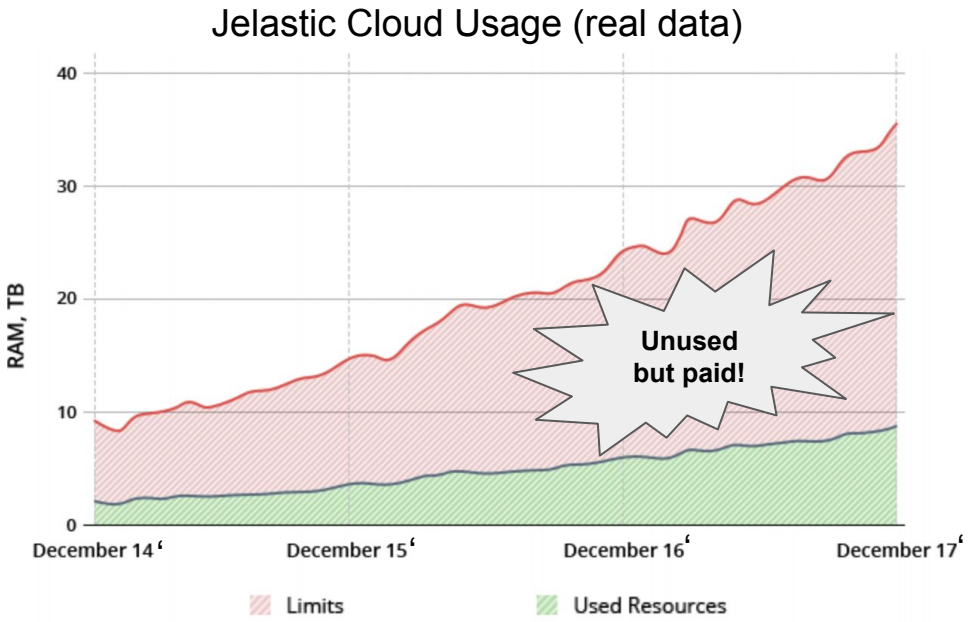

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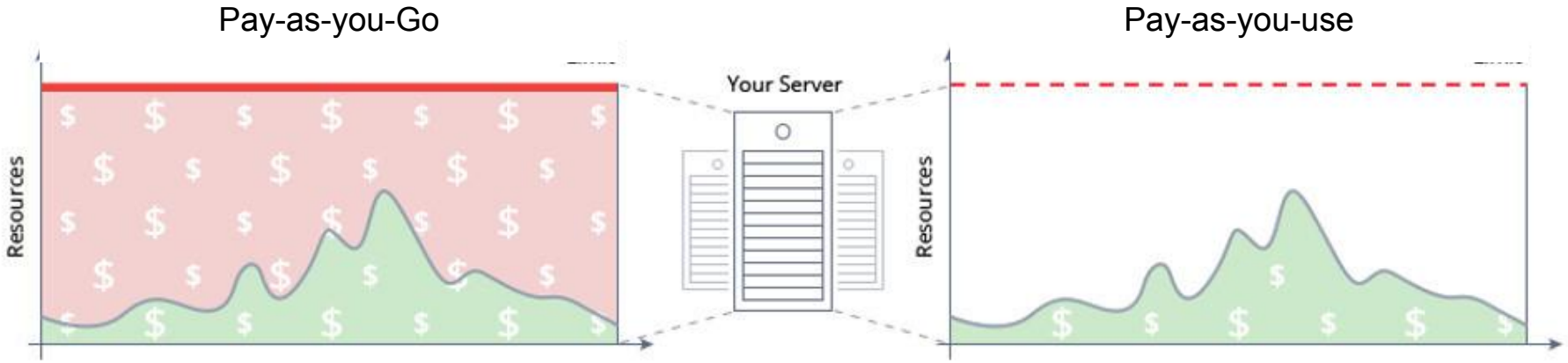
“Pay-as-you-Go” vs “Pay-as-you-Use”

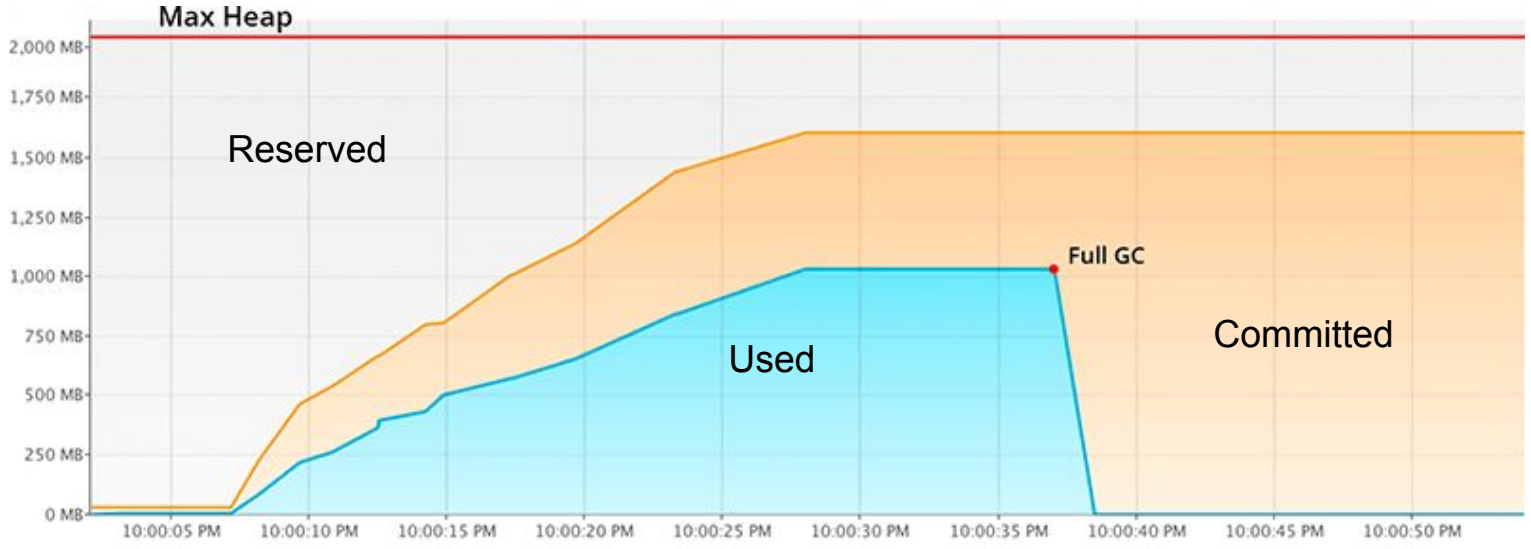


Pay for statically-sized instances

Pay for used resources

“Pay-as-you-Use” for JVM Applications

- Proof-of-concept experiment, 1 instance, one task processed after startup and then idle



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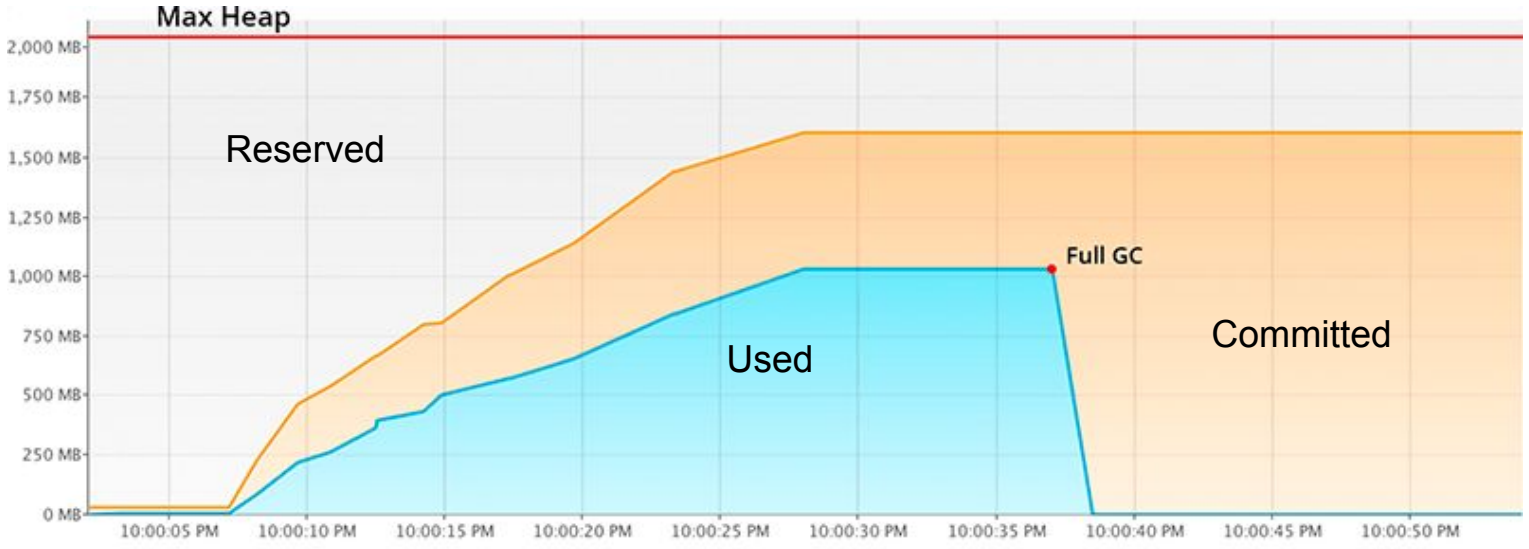

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Problem 2: Applications cannot scale beyond Max Heap limit!

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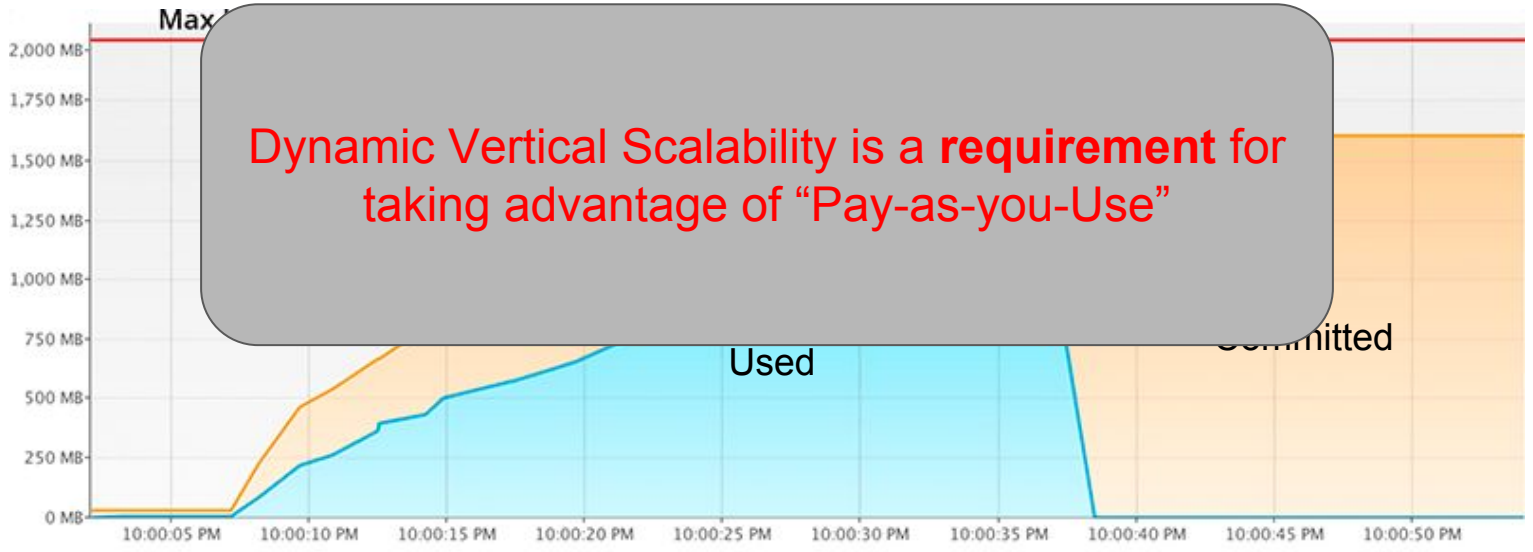

Dynamic Vertical Scalability is a **requirement** for taking advantage of “Pay-as-you-Use”

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Goal 5: no changes to the host engine/OS

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Reason 3: Setting a very high memory limit for the JVM solves the lack of memory problem but worsens reason 1;

Reason 4: Rebooting the JVM to adjust the memory limit takes a long time leading to service unavailability, which is prohibitive for many applications.

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2-step solution:

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Step 2:

1. JVM heap sizing strategy that sizes the heap according to the application's used memory
2. Even if no GC is triggered, the heap size should be checked

Step 1: Current Max Heap Size

- We introduce a new JVM variable: `CurrentMaxHeapSize`
  - can be set at launch time or at runtime, no need to guess the heap size beforehand
  - once set, the heap cannot grow beyond its value
- Max heap size can be set to a conservatively high value (only affects reserved memory not committed memory)

Algorithm 1 Set Current Maximum Heap Size

```
1:  procedure SET_CURRENT_MAX_MEMORY(new_max)
2:      committed_mem ← CommittedMemory
3:      reserved_mem ← MaxMemory
4:      if new_max > reserved_mem then
5:          return failure
6:      if new_max < committed_mem then
7:          trigger GC
8:          committed_mem ← CommittedMemory
9:          if new_max < committed_mem then
10:             return failure
11:     CurrentMaxMemory ← new_max
12:     return success
```

Step 2: Periodic Heap Resizing Checks

- **if...**
  - unused heap memory is large (line 6)
  - last GC was a long ago (line 8)
- **do…** heap resize

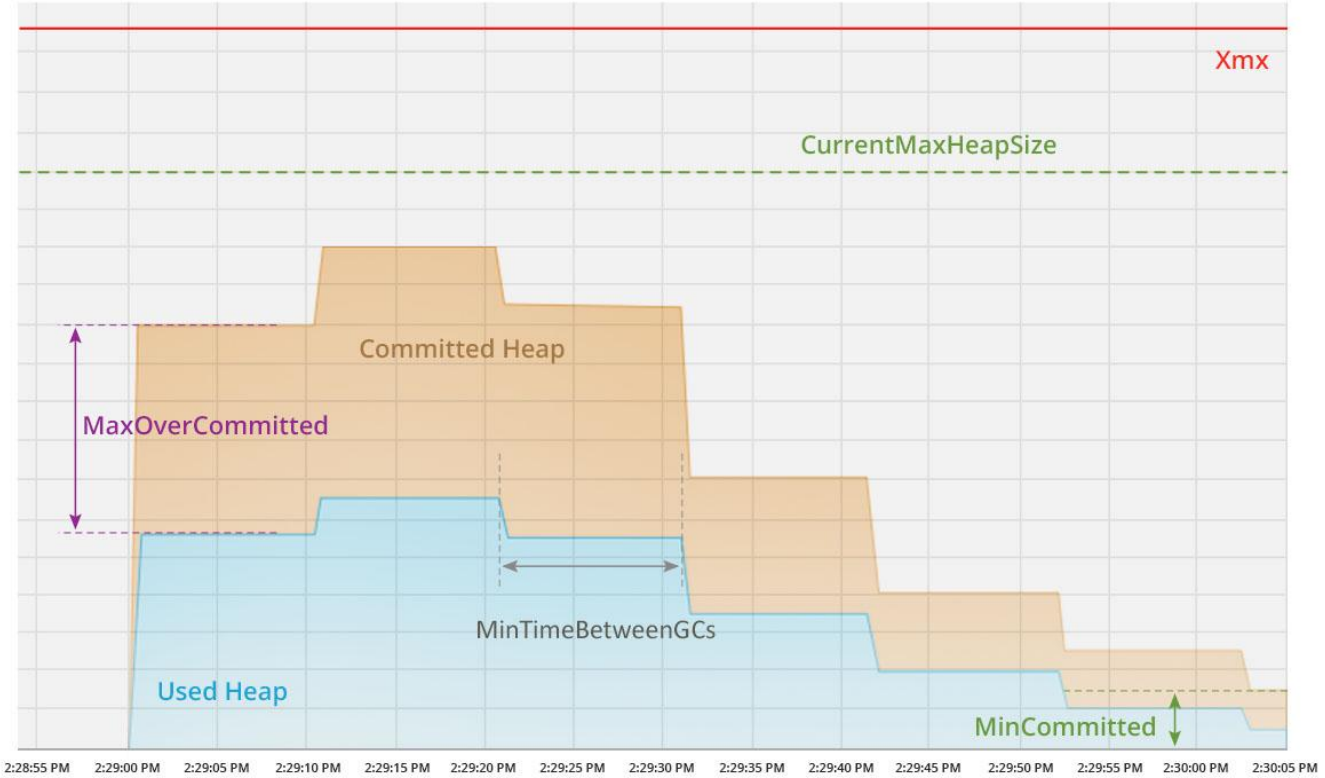
- `MaxOverCommittedMem` and `MinTimeBetweenGCs` can be set at launch time or at runtime

- We do not implement a new heap sizing algorithm, the JVM already has advanced ergonomic policies
  - we “just” determine when to run it

Algorithm 2 Should Resize Heap Check

```
1:  procedure SHOULD_RESIZE_HEAP
2:      commit_mem ← CommittedMemory
3:      used_mem ← UsedMemory
4:      time_since_gc ← TimeSinceLastGC
5:      over_commit ← commit_mem − used_mem
6:      if over_commit < MaxOverCommittedMem then
7:          return false
8:      if time_since_gc < MinTimeBetweenGCs then
9:          return false
10:     return true
```

Execution Memory Usage log



Implementation

- Solution implemented in the OpenJDK 9 HotSpot JVM
- `CurrentMaxHeapSize`, `MaxOverCommittedMem`, and `MinTimeBetweenGCs` are runtime variables that can be set at JVM launch time or at runtime;
- Periodic heap sizing checks are integrated in the VM control thread loop (executed nearly every second);
- JVM allocation path and heap growing respects `CurrentMaxHeapSize`
- Two collectors supported:
  - Garbage First, most advanced GC, the new by-default
  - Parallel Scavenge, widely used parallel collector
- We reuse the ergonomics code already added into the GC to implement the heap sizing operation

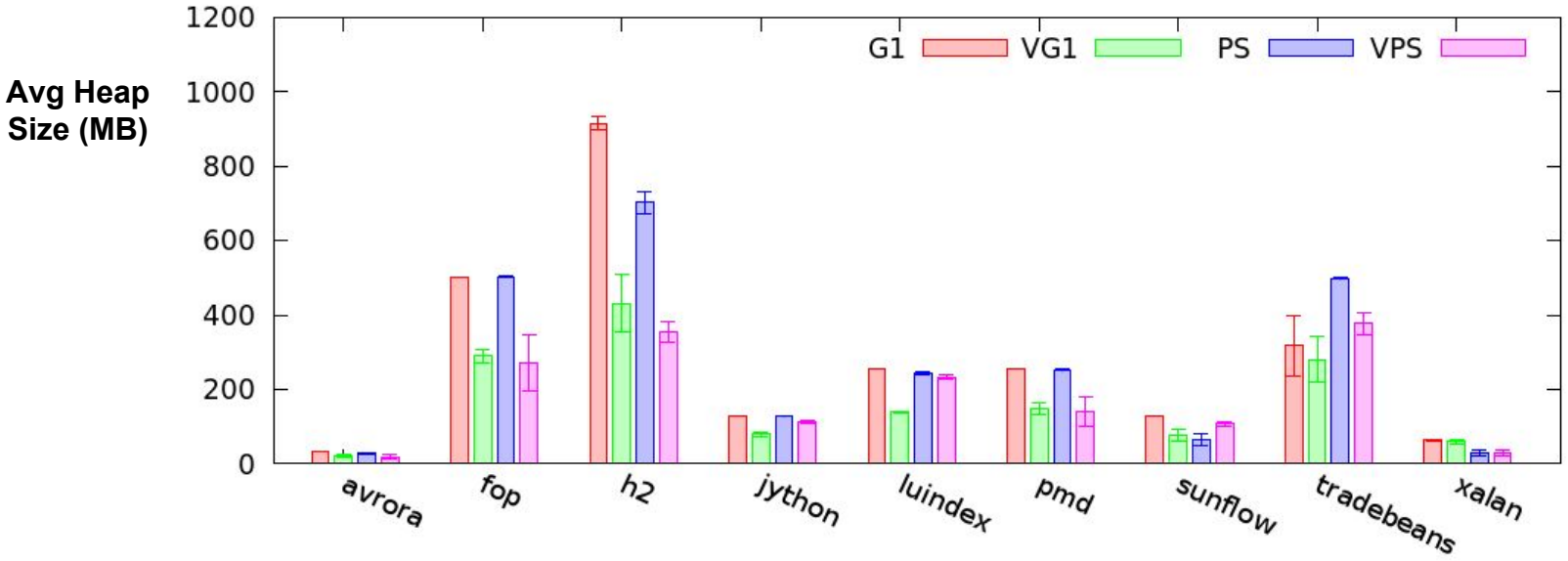
Evaluation

- Compare: G1 vs VG1 (vertical G1); PS vs VPS (vertical PS)
- Benchmarks: DaCapo 9.12 and Tomcat web server (real workload)
- Host node: Intel(R) Core(TM) i7-5820K CPU @ 3.30GHz, 32GBs DDR4 of RAM, Linux 4.9
- Host engine: Docker 17.12
- Each JVM runs in an isolated container

DaCapo 9.12 Benchmarks

Benchmark	Description	Iterations	CMaxMem	MaxOCMem	MinTimeGCs
avrora	AVR microcontrollers	5	32 MB	16 MB	10 sec
fop	XSL-FO to PDF	200	512 MB	32 MB	10 sec
h2	JDBCbench-like in-memory	5	1024 MB	256 MB	10 sec
jython	interprets the pybench	5	128 MB	32 MB	10 sec
luindex	lucene indexing	100	256 MB	32 MB	10 sec
pmd	searches code problems	10	256 MB	32 MB	10 sec
sunflow	ray tracing	5	128 MB	16 MB	10 sec
tradebeans	daytrader benchmark	5	512 MB	128 MB	10 sec
xalan	XML to HTML	5	64 MB	16 MB	10 sec

Memory Scalability - JVM Heap Size (MB)



Lower is Better

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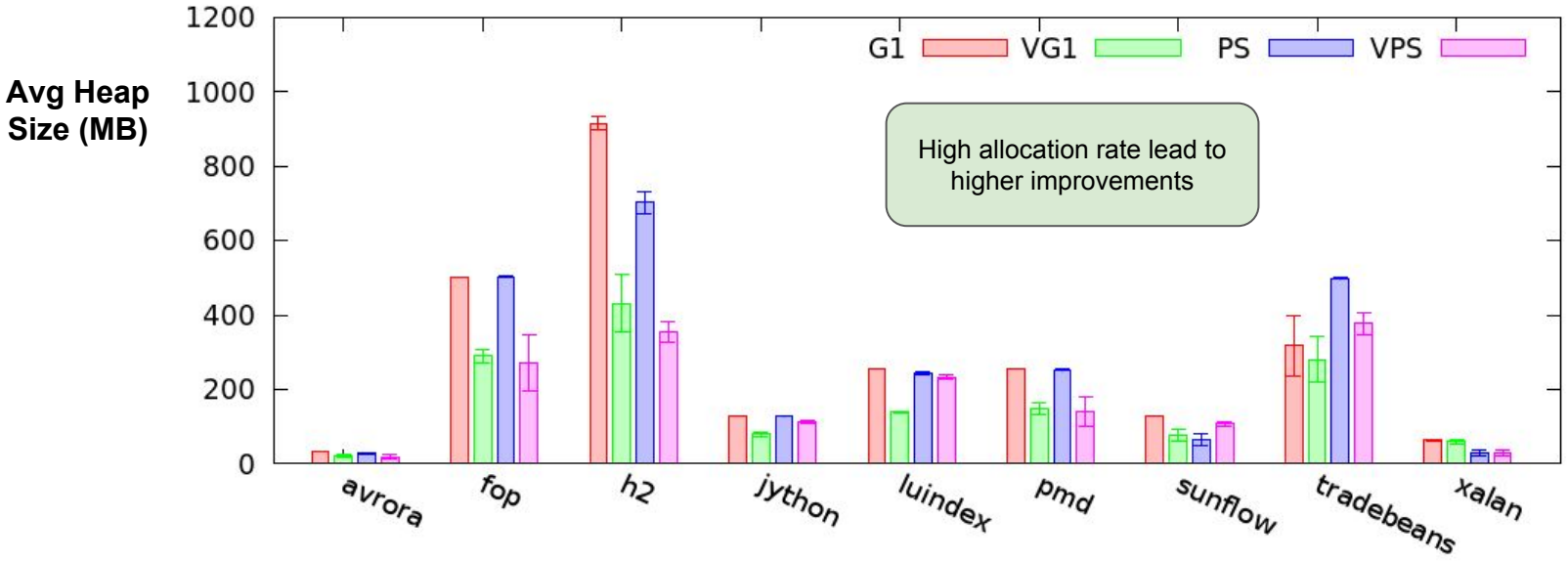

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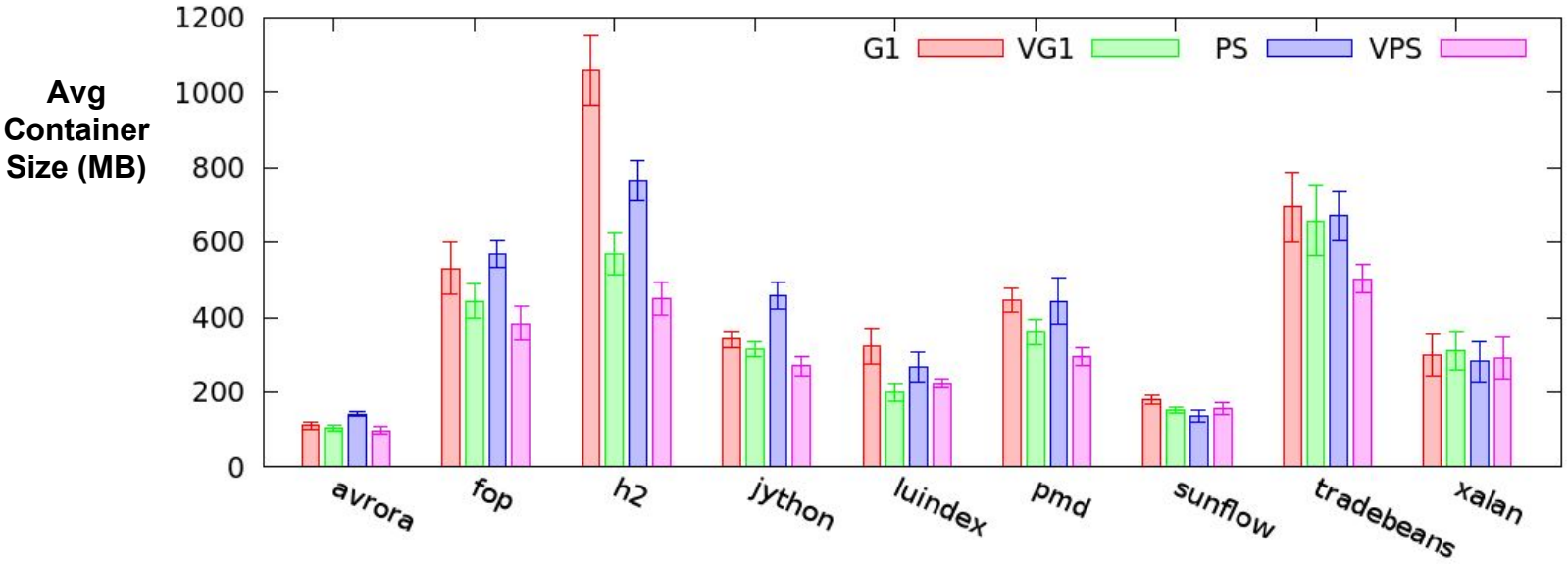
Memory Scalability - Container Mem Usage (MB)



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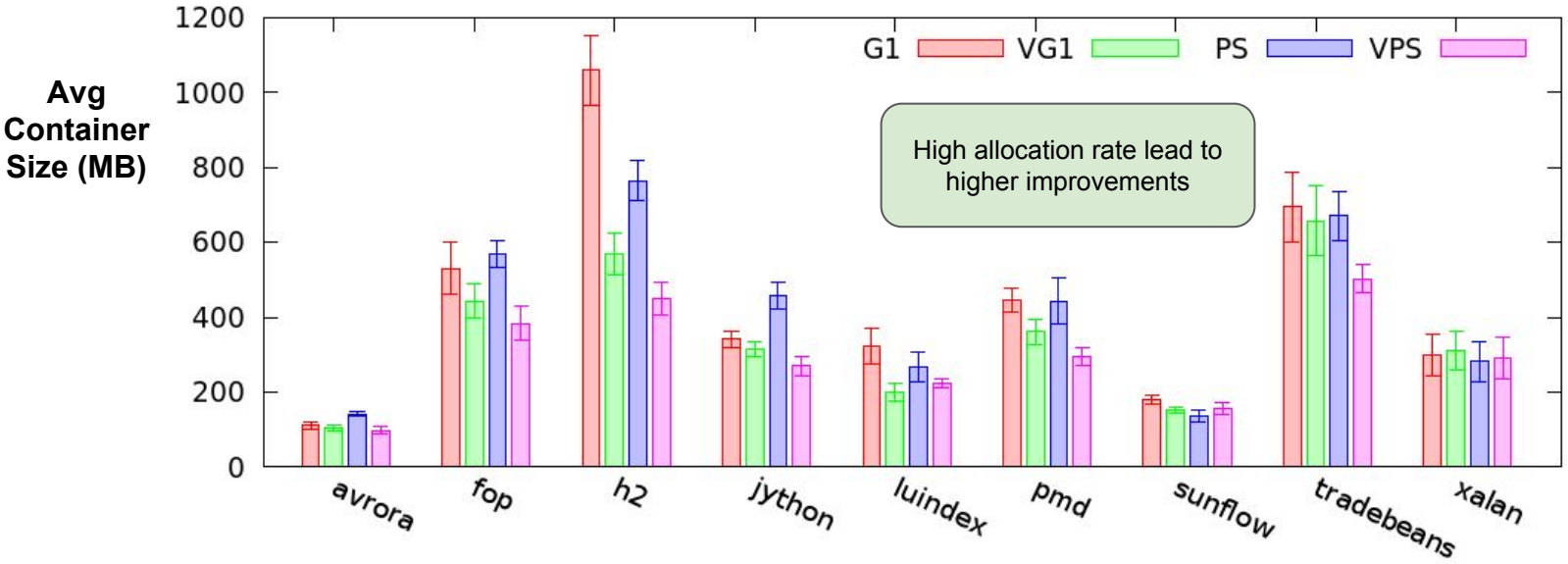

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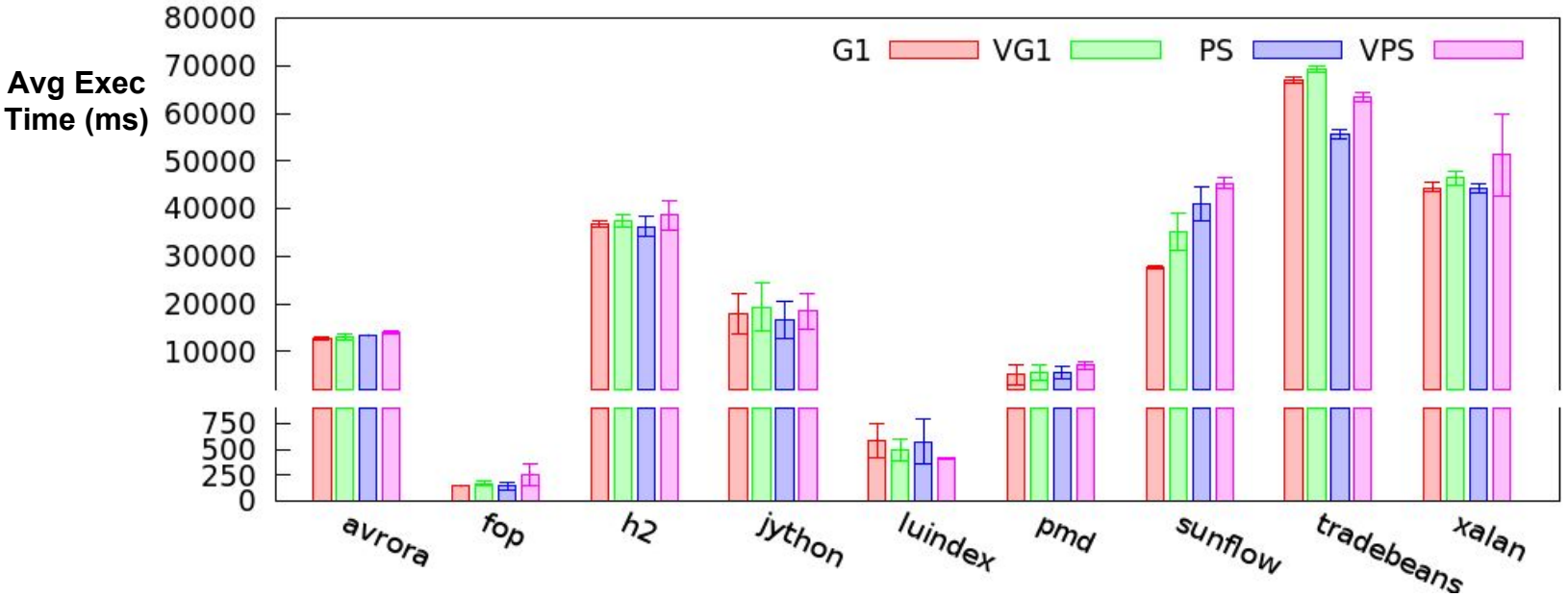
Execution Time (ms)



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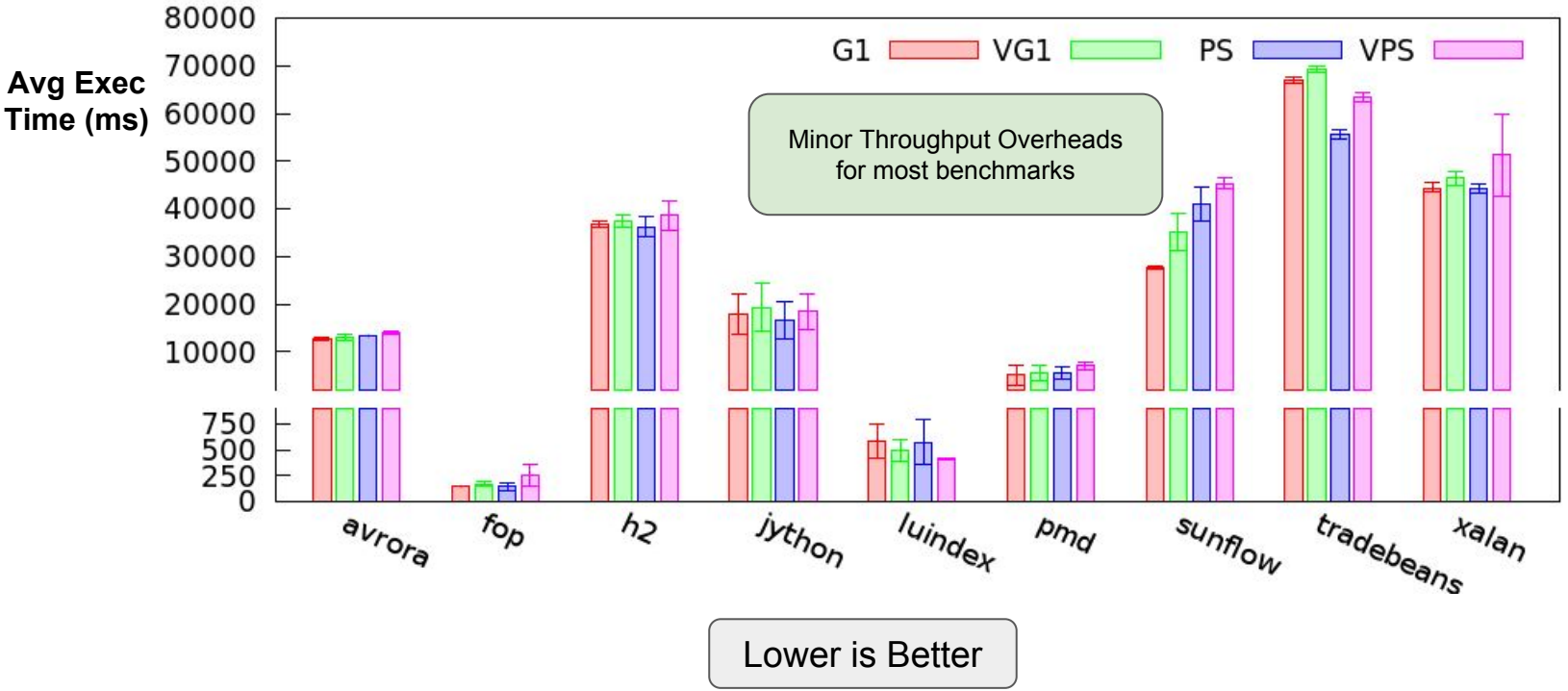
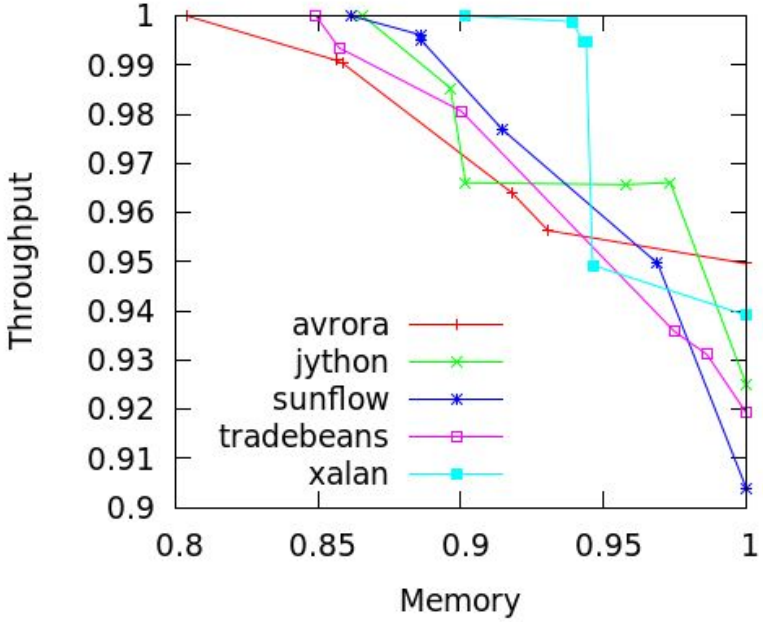
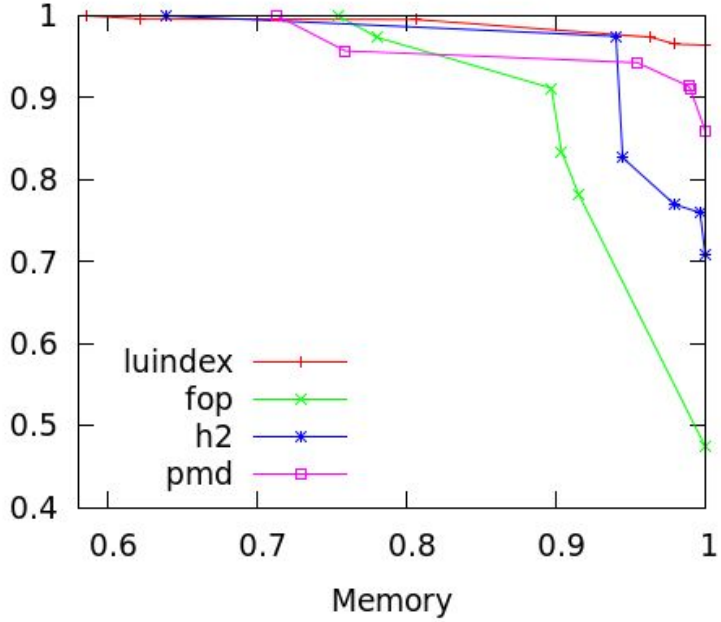


Throughput vs Memory Tradeoff





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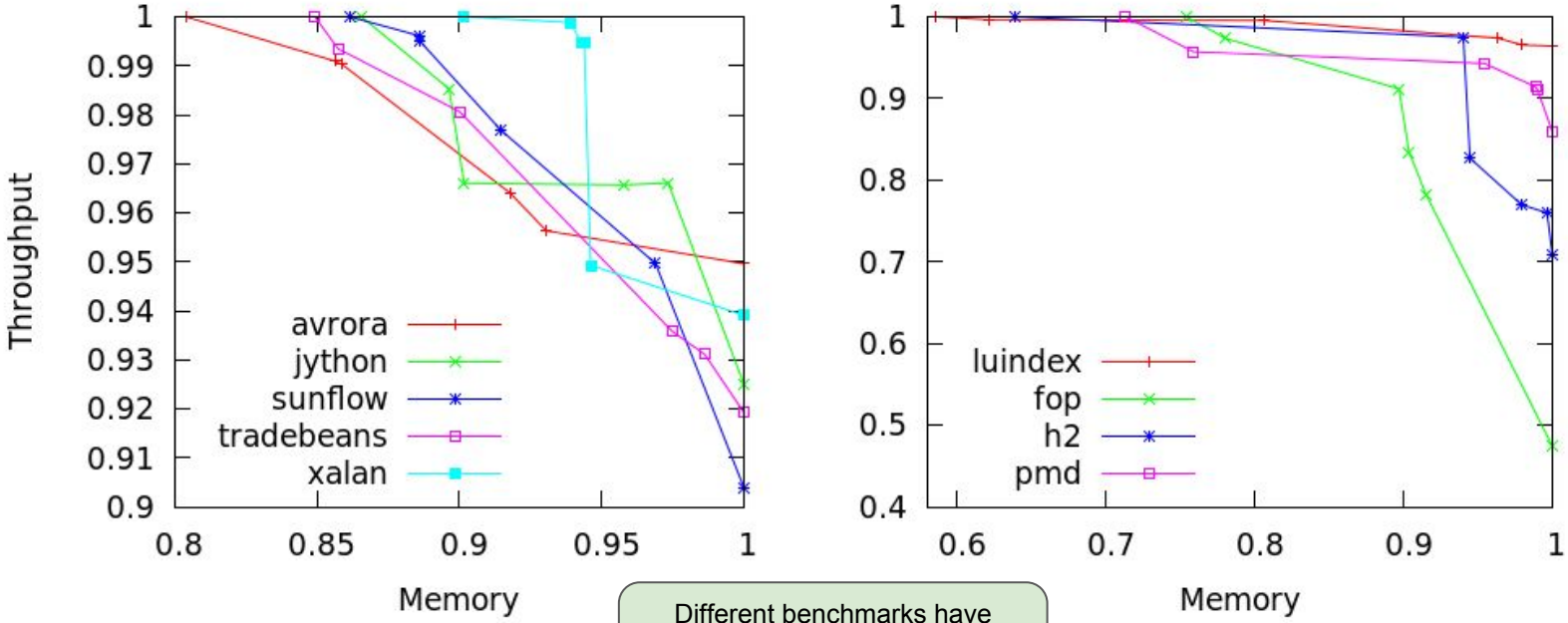
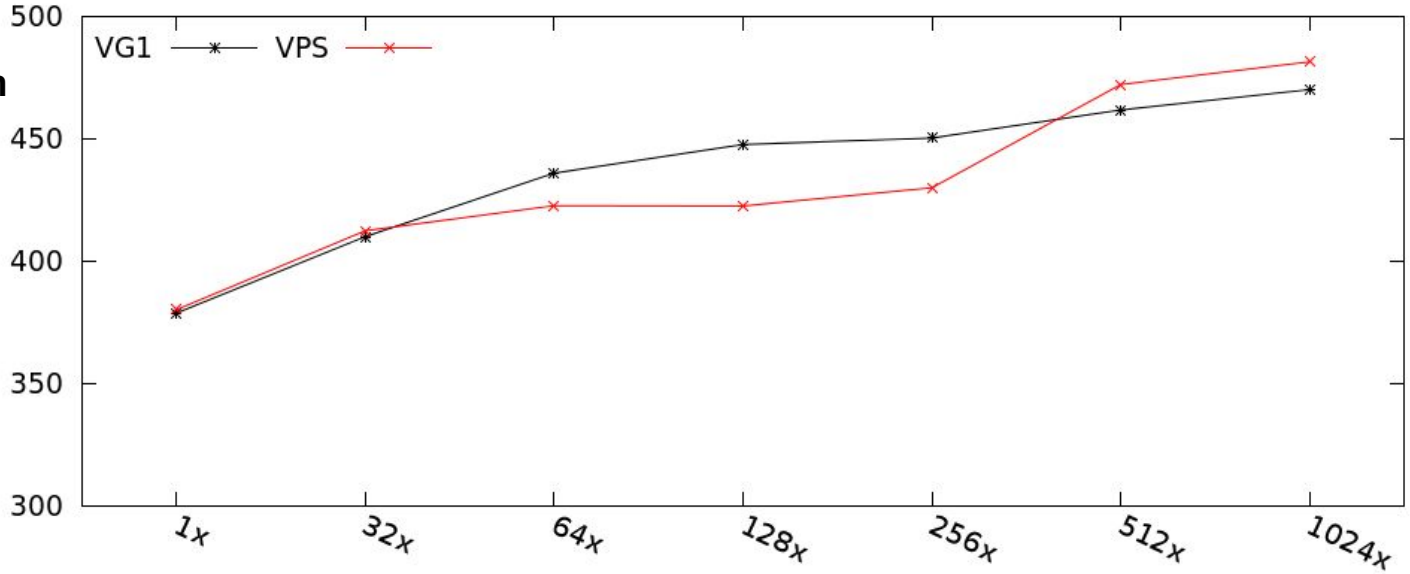


Different benchmarks have different memory throughput tradeoffs!

High Max Heap Limit Memory Overhead (h2 benchmark)



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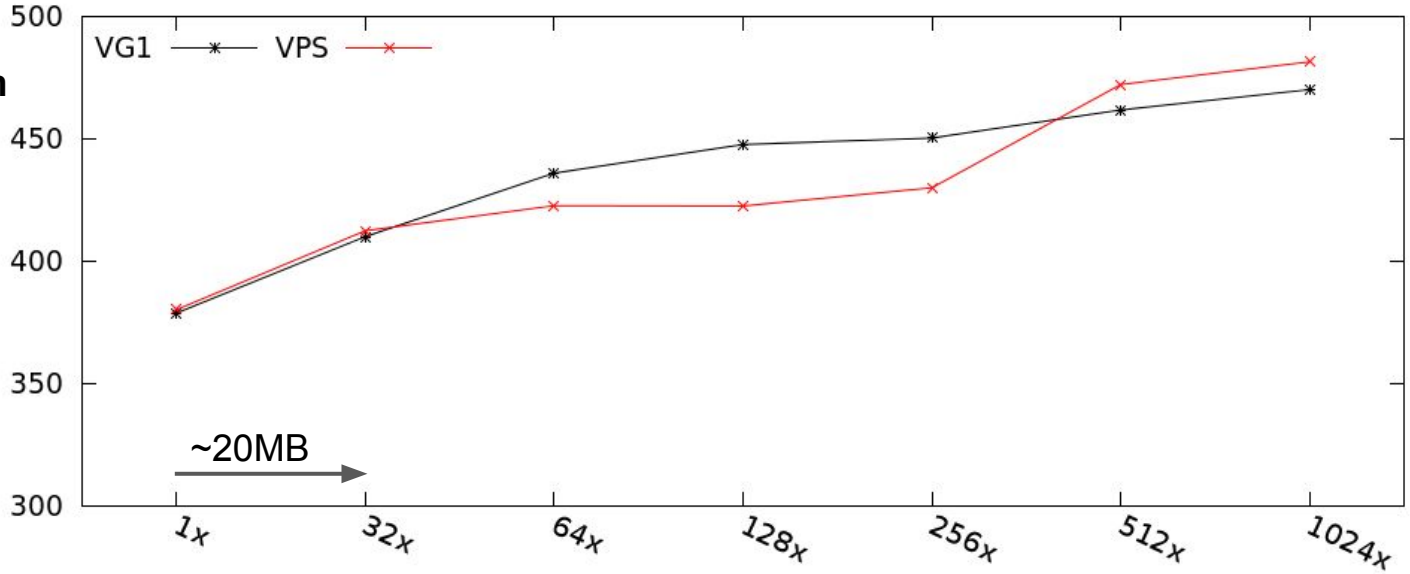

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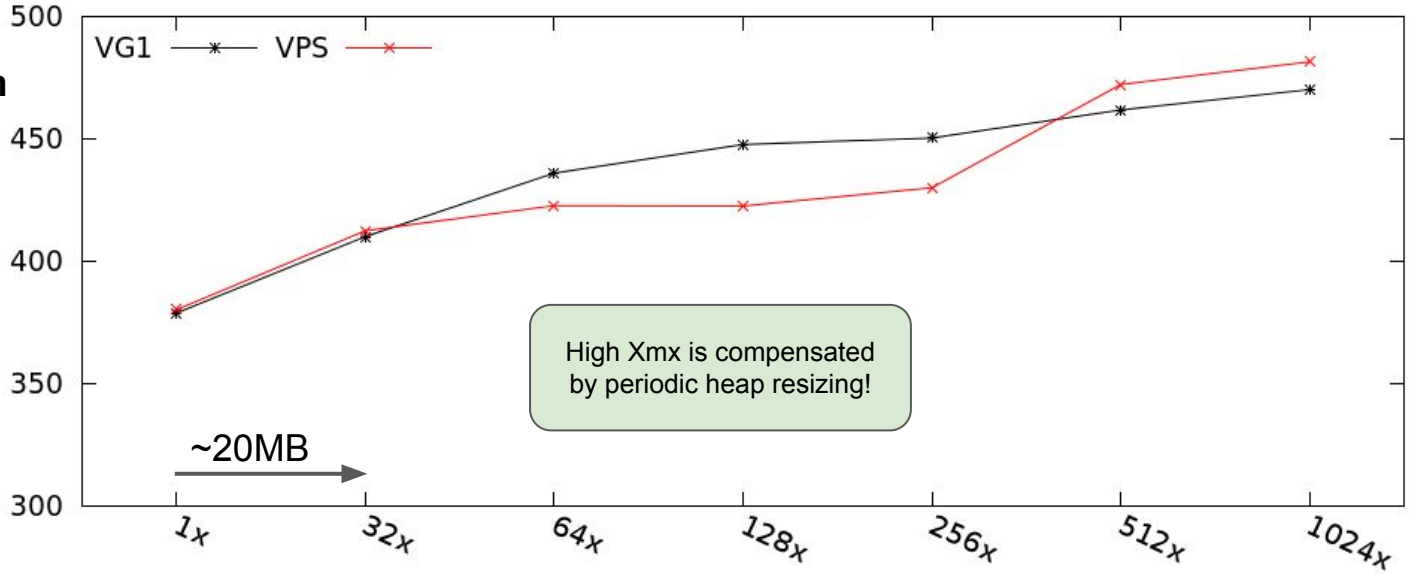

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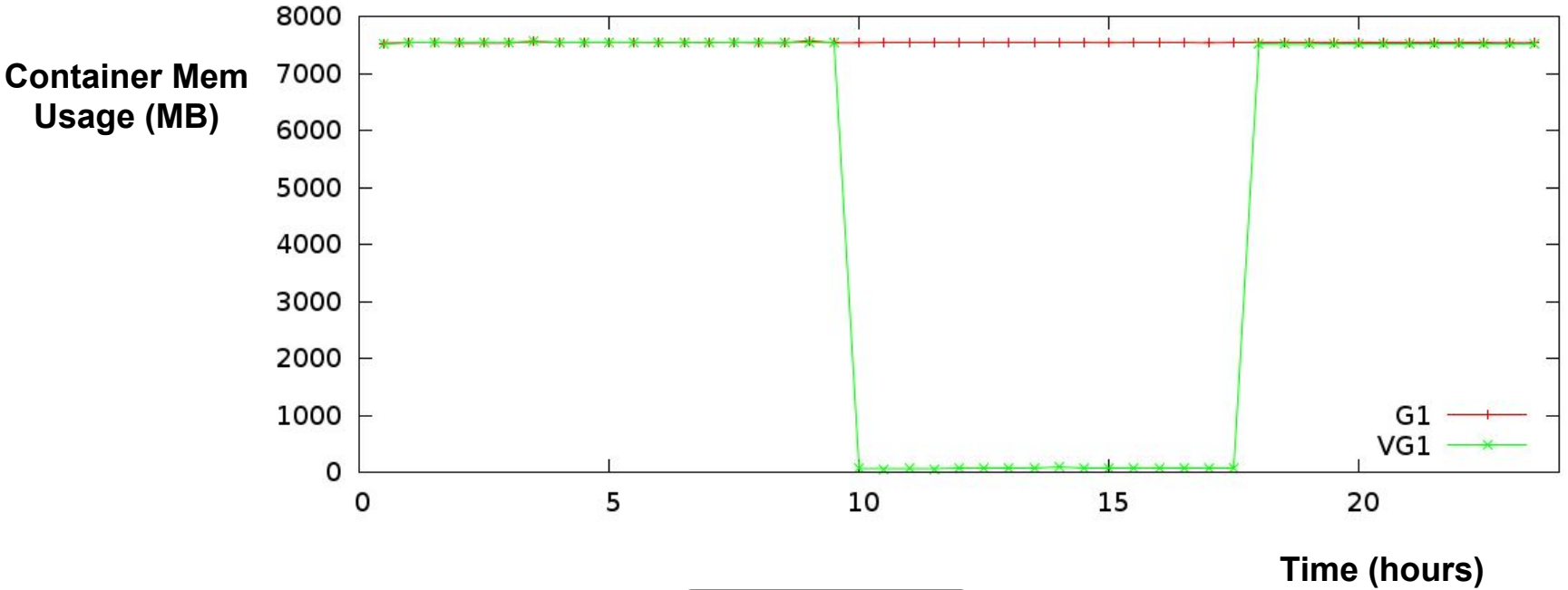
Real-world Scenario Experiment

- **Tomcat web server with 4-16GBs (based on real Jelastic clients' workloads)**
  - utilized mostly during the day; at night (8 hours) the server is mostly idle
  - user sessions (which occupy most of the memory) timeout after 10 min
  - monthly cost estimation using Amazon EC2 (Ohio datacenter)
    - assuming one could change the instance resources on the fly

Real-world Scenario Experiment (mem utilization)



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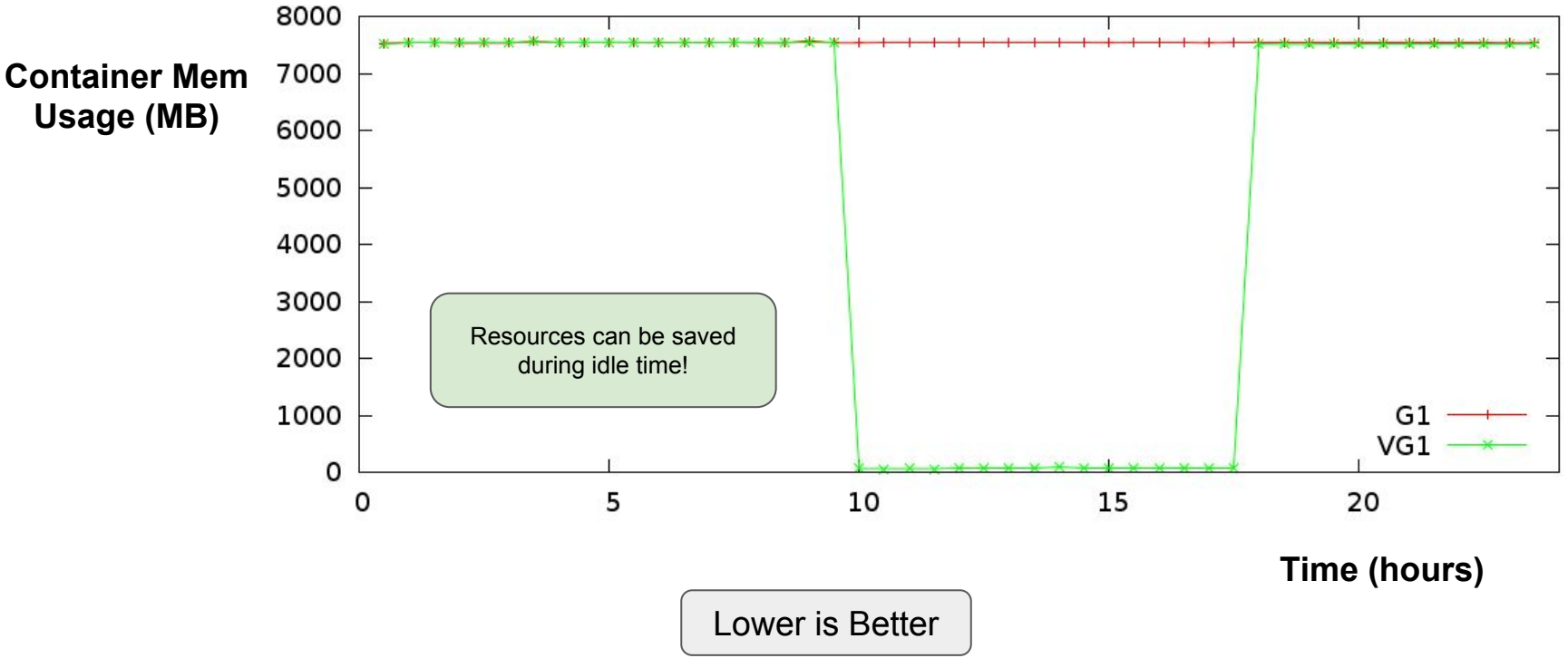

Real-world Scenario Experiment (cost)

Approach	During Day	During Night	Total	Savings
4GB-JVM	23.01$	11.53$	34.00$	
4GB-VJVM		1.44$	24.44$	**29.40%**
8GB-JVM	46.03$	23.01$	69.04$	
8GB-VJVM		1.44$	47.47$	**31.00%**
16GB-JVM	92.06$	46.03$	138.00$	
16GB-VJVM		1.44$	93.50$	**32.60%**
32GB-JVM	184.12$	92.06$	276.00$	
32GB-VJVM		1.44$	185.00$	**33.00%**

Conclusion

- Vertical Memory Scalability is an enabler for the “Pay-as-you-Use” model
- It can be implemented in the JVM with
  - negligible throughput cost
  - very promising footprint reductions
- Implementation can be easily ported to other GCs
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Thank you for your time!
Questions?

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