Managing Vertical Memory Elasticity in Containers

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Talk Outline

- Motivation
- Horizontal vs Vertical Container Elasticity
- Related Work
- VEMoC - Vertical Elasticity Management of Containers
- Evaluation Results
- Conclusions and Future Work

Motivation

- Latest research (2018) suggests that the energy consumption of data centres (DCs) accounts for 1% of the energy produced worldwide
  - Although consumption has been rising over the last 2 decades, this percentage is the same as it was in 2010!
  - Due in part to the transitioning to more efficient cloud DCs
- Commercial cloud DCs have strong financial incentives to focus on optimising efficiency
  - While they have achieved significant gains over the last decade, it is getting harder
- Smaller edge DCs have fewer available resources and are thus driven to support multi-tenancy and higher degrees of resource sharing

Motivation

- One aspect of efficiency in cloud computing is resource allocation
  - How much of each physical resource should be allocated to each hosted virtual environment?
  - Very difficult to answer without prior knowledge of the application's behavior.
- Both under- and over-provisioning lead to problems
  - Deterioration in performance and/or possible malfunctions in the application.
    - Unnecessary additional costs for the user
  - Idle or underutilized resources on the side of the provider.
- Different applications have different demands that generally vary over time
  - Elastic environments expand and contract allocations to meet demand.

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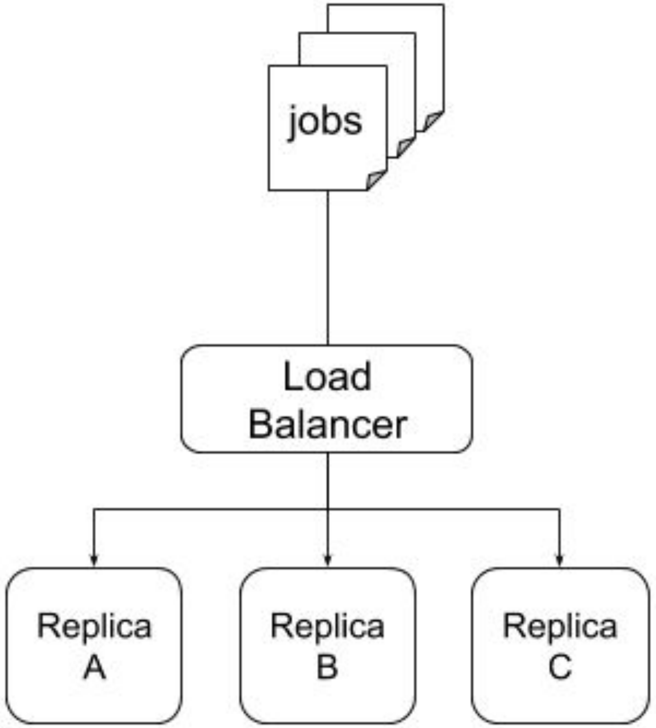
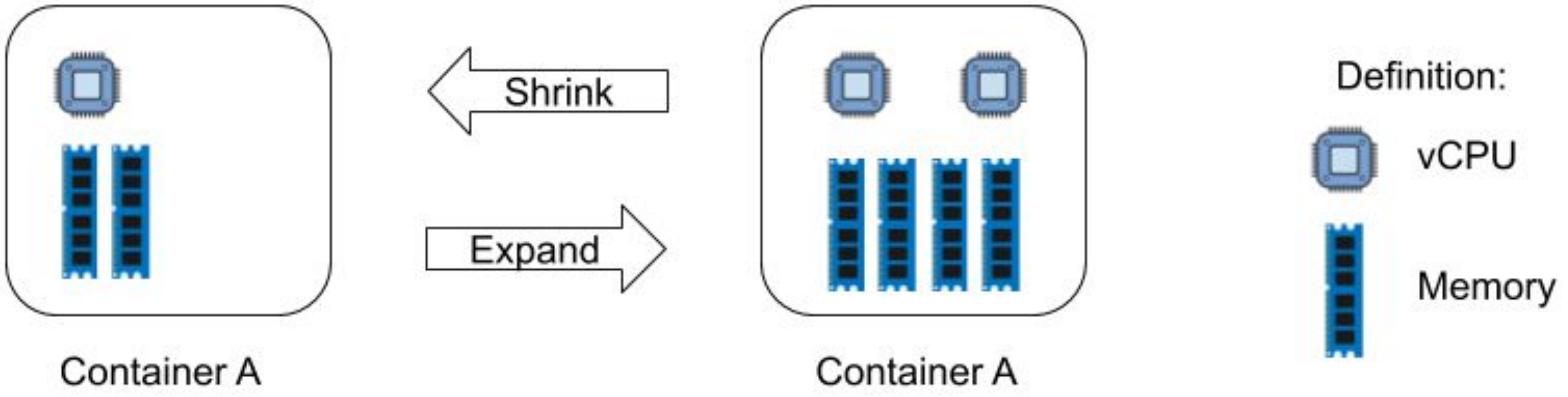
Horizontal Resource Elasticity

- Horizontal elasticity is achieved by replicating containers
  - Appropriate for **online** applications compatible with replication
  - Used extensively by enterprise cloud orchestrators
  - Focuses more on maintaining a given service QoS than maximizing resource utilization efficiency



Vertical Resource Elasticity

- Expand or shrink the resources allocated to a single container
  - Involves changing the resource allocation limits
  - Changes are made at runtime, without having to stop and restart the container
- Known to be useful for **non-distributed** applications



Challenges/Goals

- Improving resource utilization and maximising throughput are two of many goals service providers strive for to reduce operating costs
- While containers consume resources elastically, frameworks are still required to:
  - ***Allocate*** resources according to availability, and;
  - ***Limit*** resource allocations to avoid interference.
- This work aims to manage vertical memory elasticity in containers
  - "Task scheduling" and "Resource allocation" in unison
  - To help providers increase server utilization without incurring significant degradations in performance of individual co-allocated containers

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Related Work

- Enterprise Orchestrators: Docker swarm, Kubernetes, Openshift
  - Focus mostly on horizontal resource elasticity
  - Need user interaction and environment configuration
- In the literature:
  - Vertical Elasticity of Memory based on upper/lower threshold limits;
  - With fixed elasticity adjustment ratios;
  - Long scheduling cycles (> 20 seconds) can mean approaches are more susceptible to making decisions too late.

Vertical Elasticity Management of Containers - VEMoC

- An architecture to manage the life cycles of co-located containers
- This paper focuses on the distribution of host memory
  - Manipulating *Container Memory Limit* (CML) at runtime
- The predicted memory requirement of container is based on:
  - Fine-grained monitoring of container and host metrics
  - Optimised use of rates of changes to determine consumption trends
- If host memory becomes scarce or insufficient to meet demand
  - Containers may "collaborate" by donating some (or be suspended and donate all) of their memory allocation to others in need

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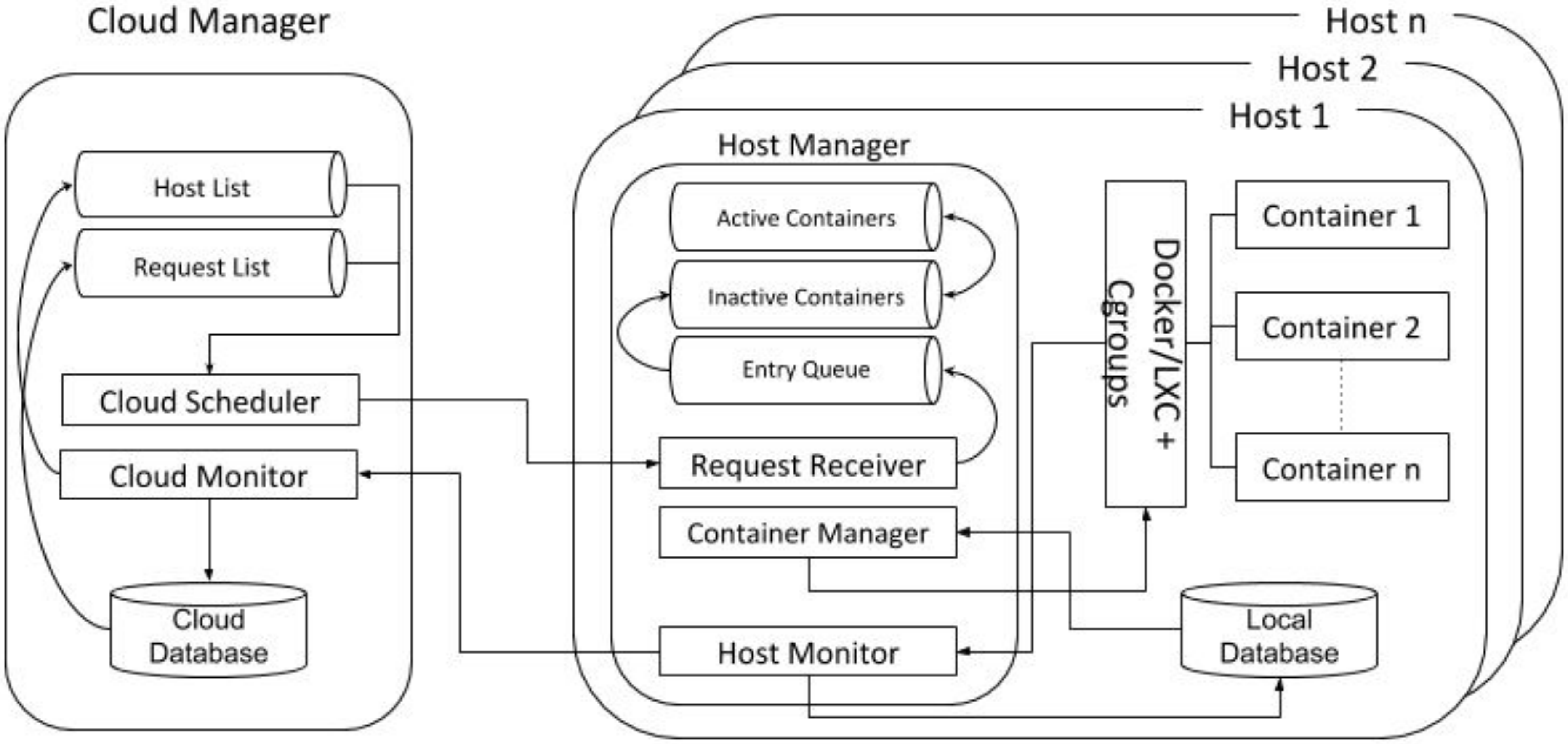
VEMoC Architecture



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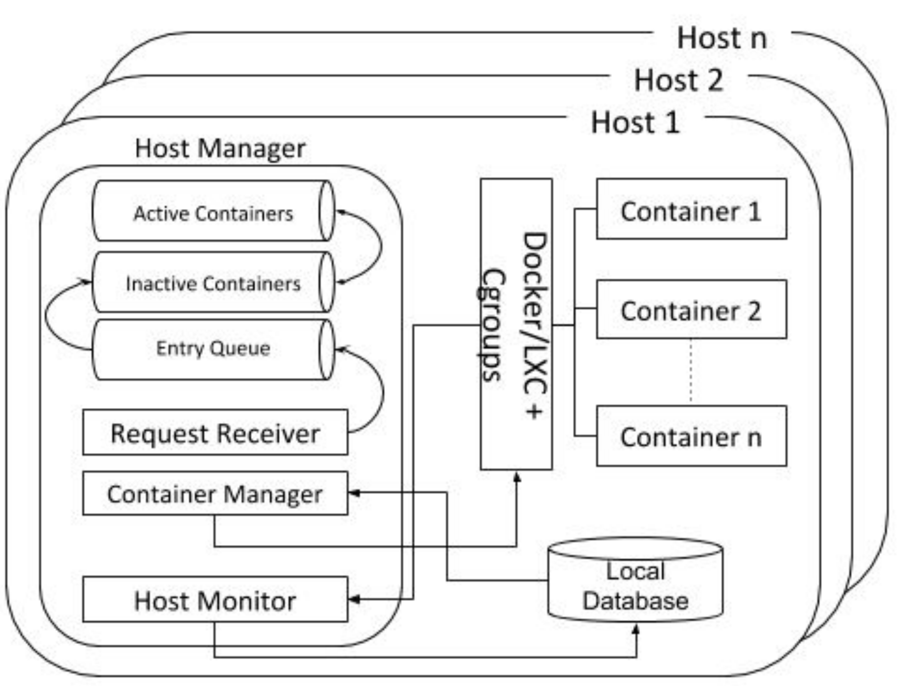
Host Manager



- Host Monitor
  - Obtains monitoring data;
- Request Receiver
  - Receives new jobs from Cloud Manager;
  - “Creates” and queues the container request
- Container Manager
  - Manages the distribution of the host’s memory amongst containers
  - Manages the life cycle of containers allocated to this host

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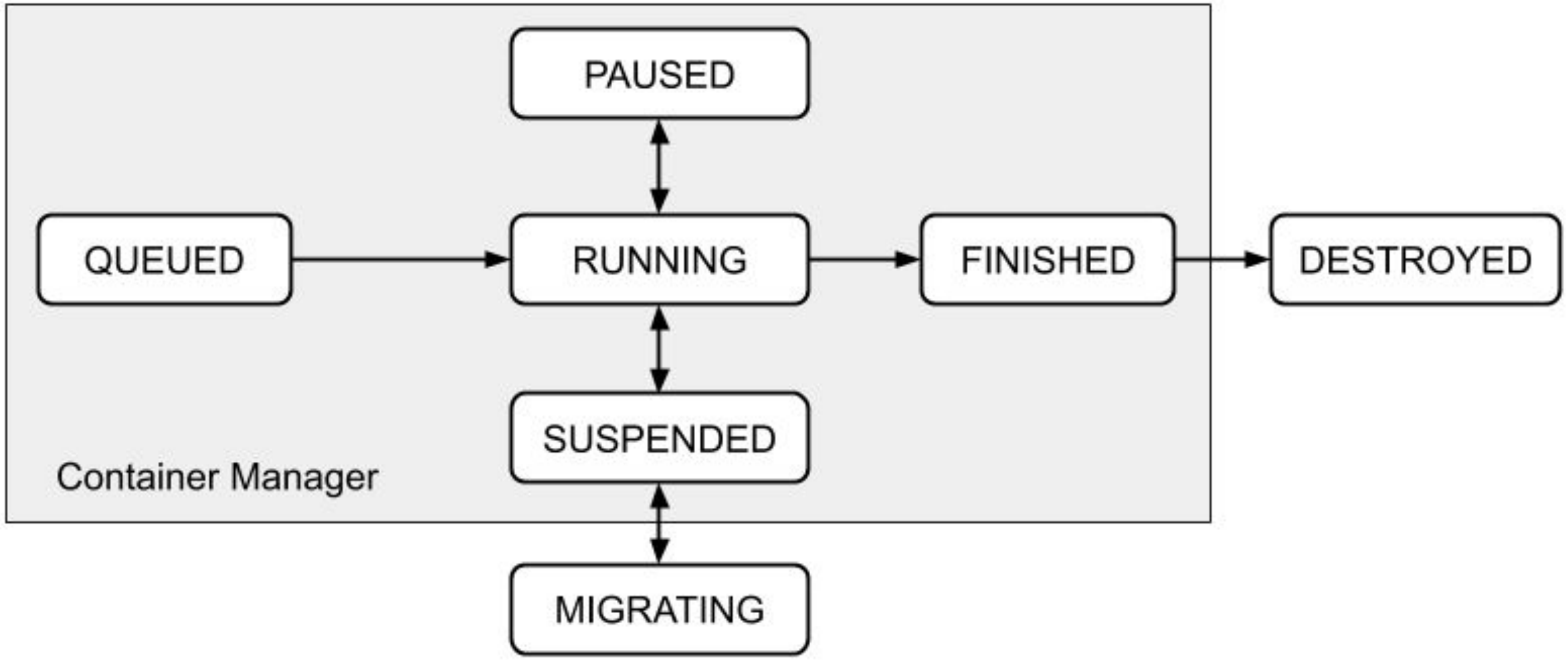
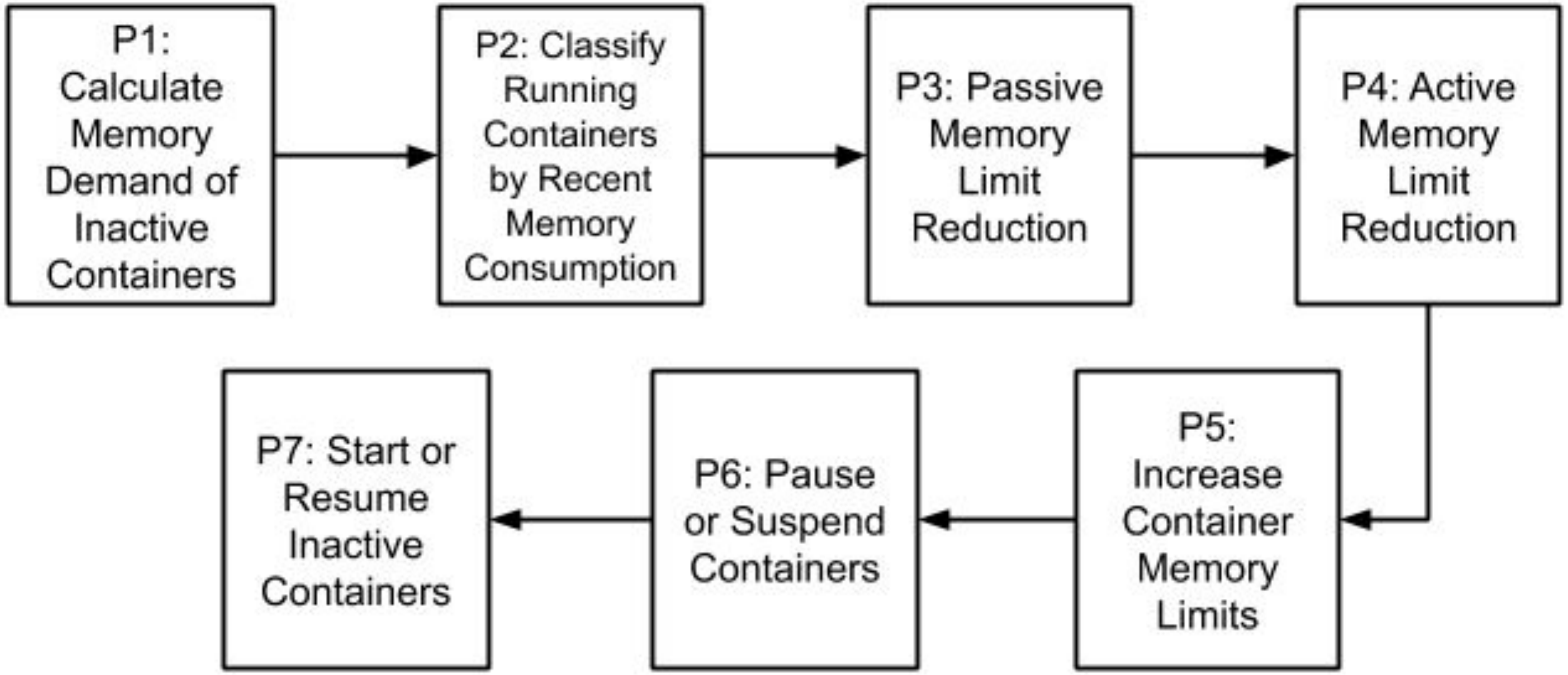
Container Life-Cycle



VEMoC Algorithm



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Phase 1

- Receive and queue container requests from Cloud Manager
- Calculates the amount of memory required to start all currently inactive containers
  - This includes containers in the state QUEUED or SUSPENDED
- Calculate the amount of non allocated memory is available on the host

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Phase 2

- Classifies active containers by extrapolating their memory consumption from the previous scheduling interval
  - Containers are classified as RISING, FALLING or STABLE based on their major page faults, page-in, page-out rates and memory and swap usage
  - Predicts the amount of memory expected to be consumed by a container until the CML can be updated again during the following scheduling interval

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Phases 3 and 4

- In general, CML is defined to include a reserve to cover any unforeseen spike in memory consumption during the next scheduling interval
- Phase 3 remove any over-estimation of the CML of STABLE and FALLING containers
- Phase 4 repossess memory from candidate STABLE containers
  - Reducing the CML below a container’s memory consumption to force it to swap-out some of its inactive memory
  - The suitability of containers is determined soon after they become STABLE

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Phase 5

- Phases 1 and 2 determine the total memory demand for current scheduling interval
- If the host does not have enough available memory to meet the demand, Phases 3 and 4 tries to extract additional memory
- Phase 5 thus distributes this memory to those containers that need theirs CMLs to be increased in accordance to the following priority:
  1. Paused Containers;
  2. Containers that brought in pages from swap during the last interval;
  3. Other containers whose consumption is expected to exceed their current CML.

Phase 6

- If Phase 5 cannot meet the needs of the active containers, Phase 6 considers preempting containers
- Of the remaining unsatisfied containers, some may need to be:
  - Paused to prevent excessive performance degradation due to swap utilisation, or be;
  - Suspended in order to free up enough memory for other containers in need.

Phase 7

- Considers initiating inactive containers if there was no need for Phase 6
- First, available memory permitting, VEMoC attempts to
  - Resume suspended containers, then
  - Start queued containers awaiting execution
- Priority in each group, is given to the container with longest runtime or wait time

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Experiments

- Our tests were executed on a host with:
  - 2x 6 core/12 threads Intel Xeon X5650 @ 2.67GHz;
  - 24 GiB of DDR3 RAM memory;
  - 8 GiB of swap memory;
  - 2 TB of SATA disk;
- CentOS Linux 7.7, kernel 4.20.11 and LXC 3.2.1
- Executing two synthetic jobs:
  - J1 – iterates over the elements a given vector of size s
  - J2 – similar to J1, but exploits data locality by dividing and processing the vector in blocks of size s/n, block by block.

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Experiments

- VEMoC performance is compared with three commonly adopted forms of defining CMLs (loosely based on Kubernetes QoS terminology):
  - **Guaranteed** - The CML is set *a priori* to the maximum amount of memory required, and the job can only be submitted when that amount is available - effectively, the required amount of memory is pre-reserved;
  - **Fair Share** - Prior to execution, the available memory is divided equally among the jobs to be executed;
  - **Best Effort** - Runs jobs as they arrive if the minimum memory limit is available. During execution, containers can use whatever free memory is available, up to their maximum memory limit.

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Experiments

- The comparisons are based on five metrics:
  - **Total Scenario Execution Time** (**TSET**) is the wallclock time from first job submission to end of the last job’s execution, in seconds;
  - **Average Job Turnaround Time** (**AJTT**) in seconds;
  - **Average Memory Utilization** (**MemUtil**) is the average of the average percentage memory utilisation of each job;
  - **Total Memory-Time Product** (**TMTP**) is a cost metric (in millions of page-seconds) for clients, which considers the duration the memory was reserved for in that scenario;
  - The **Average Host Memory Utilization** (**AHMU**) percentage represents the effective use of host memory during the scenario's execution, i.e., over the period TSET.

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Results – Scenario 1

- Executes two J1 jobs of 4GiB, with an interval of 50 seconds between them, on a host with 6GiB of available memory
- There is not enough memory, so who gets what?

	TSET (s)	AJTT (s)	MemUtil (%)	TMTP	AHMU (%)
Guaranteed	843.2 (4.9%)	606.3 (2.6%)	87.1 (10.1%)	886.98 (10.9%)	58.1 (5.7%)
Fair Share	1245.2 (54.9%)	1193.2 (101.8%)	96.4 (0.5%)	1876.71 (134.6%)	92.2 (49.7%)
Best Effort	1284.0 (59.7%)	1236.9 (109.2%)	95.2 (1.8%)	2019.6 (152.5%)	92.8 (50.6%)
VEMoC	804.0	591.2	96.9	799.8	61.6

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Results – Scenario 2

- Executes a J2 job of 4GiB, followed by a J1 job also of 4GiB, 100 seconds later, on a host with 6 GiB of available memory
- Still not enough memory, can we get some from thin air?

	TSET (s)	AJTT (s)	MemUtil (%)	TMTP	AHMU (%)
Guaranteed	841.1 (58.8%)	582.8 (36.7%)	73.1 (22.3%)	884.8 (50.6%)	48.8 (28.0%)
Fair Share	793.2 (49.8%)	561.8 (31.8%)	83.1 (11.7%)	883.6 (50.4%)	60.5 (10.8%)
Best Effort	637.9 (20.4%)	483.1 (13.2%)	71.1 (24.4%)	1002.7 (70.7%)	65.3 (3.7%)
VEMoC	529.7	426.2	94.1	587.5	67.8

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Results – Scenario 3

- Execute a J2 jobs with 4GiB, followed by five J1 jobs with 4GiB, at 10 seconds interval, using the 24 GiB of host memory
- What happens under extreme stress?

	TSET (s)	AJTT (s)	MemUtil (%)	TMTP	AHMU (%)
Guaranteed	867.8 (59.6%)	506.9 (3.1%)	82.6 (11.8%)	2788.4 (5.4%)	42.8 (42.2%)
Fair Share	779.6 (43.4%)	663.6 (35.0%)	84.9 (9.3%)	4093.0 (54.7%)	73.7 (0.4%)
Best Effort	715.1 (31.5%)	543.4 (10.5%)	72.6 (22.4%)	4407.8 (66.7%)	63.0 (14.9%)
VEMoC	543.6	491.7	93.6	2644.9	74.0

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Conclusions

- VEMoC obtains better utilization:
  - by using page level predicted memory consumption rates;
  - using fine grain vertical elasticity of memory;
  - combining techniques of memory stealing and container preemption.
- VEMoC also demonstrated higher efficiencies for the service provider, and better performances and lower costs for the client.
- As future work, intend to investigate:
  - Alternative libraries that implement container suspension;
  - the impact of scheduling policies on memory utilization efficiencies, and;
  - With VEMoCs elastic management of CPU, integrate CPU throttling with the management of vertical memory elasticity.

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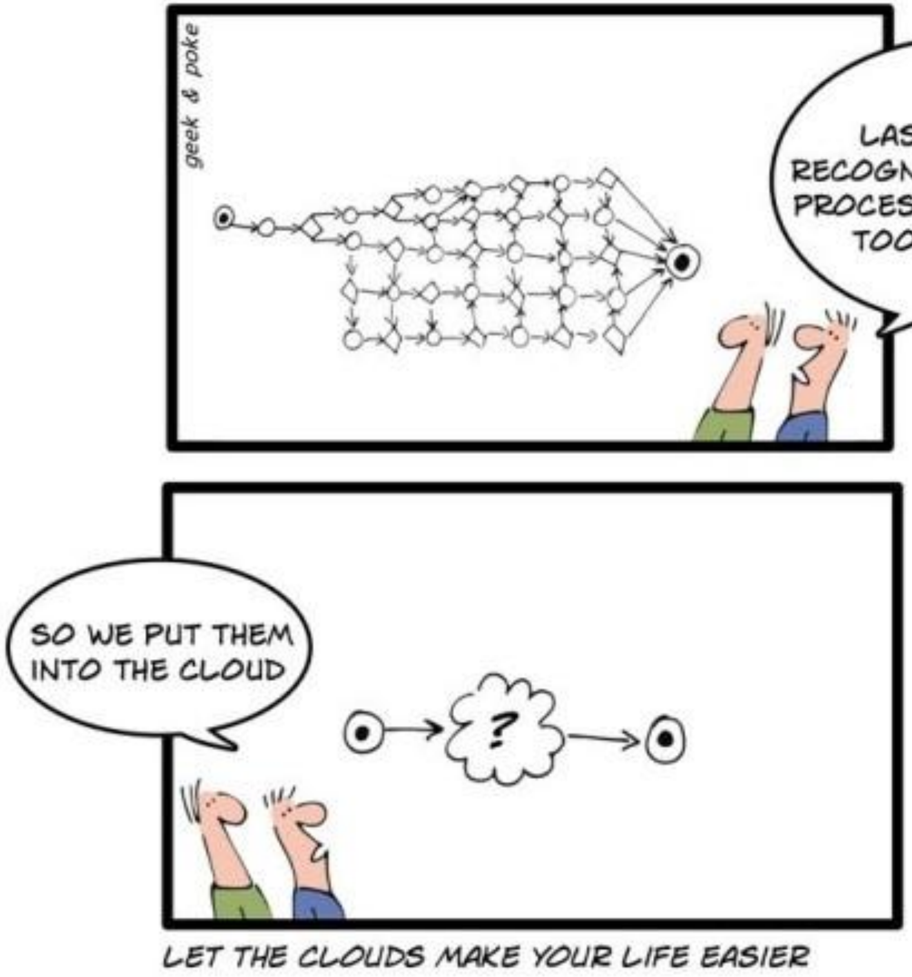
Any Questions?



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