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A Methodology and Framework to Determine the Isolation Capabilities of Virtualisation Technologies

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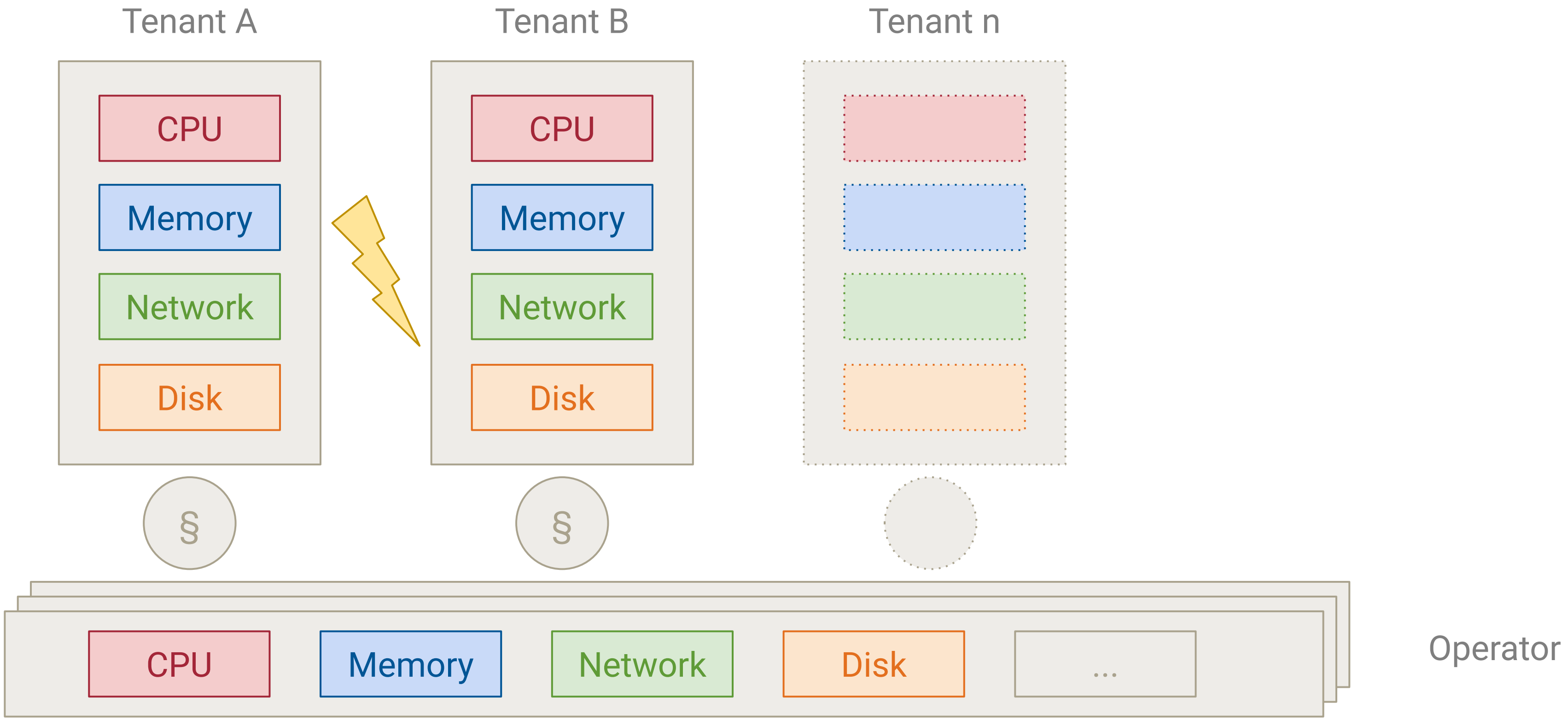
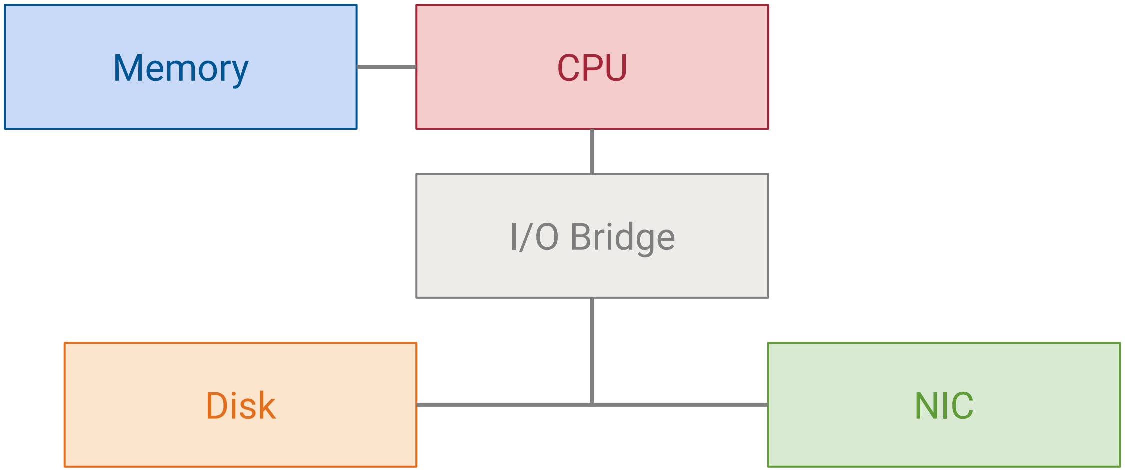
Motivation


Tenant A
Tenant B
Tenant n
CPU
Memory
Network
Disk
CPU
Memory
Network
Disk
§
§
CPU
Memory
Network
Disk
...
Operator

System Model

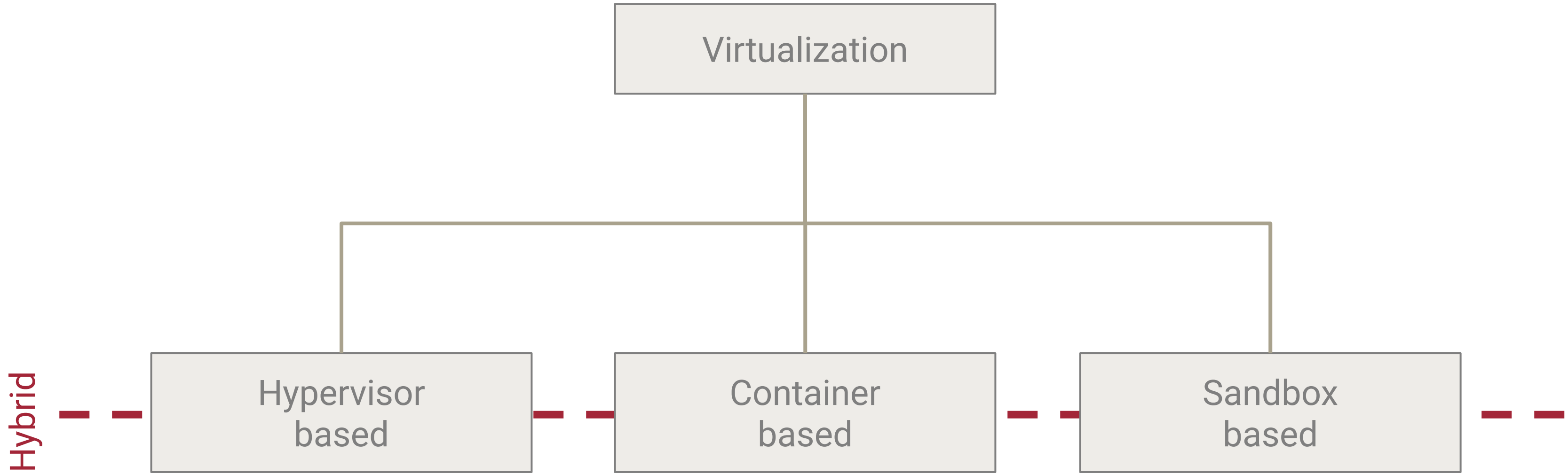


Virtualization Model

- Hypervisor based [15]
  Type 1&2, Paravirtualization, Hardware-assisted- & Full-virtualization
- Container Based [14]
  Cgroups (CPU, Memory, ...), namespaces (PID, Network, Mount, ...), capabilities
- Sandbox Based [43]
  System call filtering
- Hybrid
  Arbitrary combinations of the above

[15] Jinho Hwang et al. “A component-based performance comparison of four hypervisors.” In: 2013 IFIP/IEEE International Symposium on Integrated Network Management (IM 2013). ISSN: 1573-0077. May 2013
[14] Tejun Heo et al. “Control group v2” In: kernel.org/doc, 2015
[43] Wan, Zhiyuan, et al. "Practical and effective sandboxing for Linux containers." Empirical Software Engineering 24.6 (2019)

Virtualization Model



Research Questions

- RQ1 **which benchmarks** are suitable for driving such an evaluation and **which resources** should be considered?
- RQ2 which measurement technologies are available to support measuring isolation for a **wide range of virtualisation technologies**?
- RQ3 which evaluation methodology **reduces disturbances** and **increases repeatability**?

Isolation Measurement Methodology - Requirements

- **R1** Isolation Measurement
  Measurements of isolation by applying a sensible isolation determination model
- **R2** Load Generation
  Flexible generation of very specific load
- **R3** Data Acquisition
  Acquisition of data independent of virtualization technology and load generation
- **R4** Reproducibility
  Experiments need to be reproducible on a given system
- **R5** Automation
  Capabilities for automation

R1 Isolation Measurement Methodology - Quantification

- Many different models in academia
- Goal: measure the performance loss for a specific static workload

Measure the "Performance Loss Rate" [20, 39, 44]

$$I_{plr} = \frac{|p_a - p_b|}{p_a}$$

p_a Baseline Performance

p_b Contended Performance

[20] Samuel Kounev et al. Systems Benchmarking: For Scientists and Engineers. Springer International Publishing, 2020
[39] Xuehai Tang et al. Performance Evaluation of Light-Weighted Virtualization for PaaS in Clouds. Algorithms and Architectures for Parallel Processing, 2014
[44] Xingyu Wang et al. Performance and isolation analysis of RunC, gVisor and Kata Containers runtimes. Cluster Computing, 2022

R1 Isolation Measurement Methodology - Utilization

- Resources
  - CPU, Memory, Disk I/O, Memory I/O
- Calculation of capacity based utilization per resource

CPU

$$U_c = \frac{c_b}{c_b + c_i}$$

Memory

$$U_m = \frac{m_u}{m_u + m_f}$$

Network

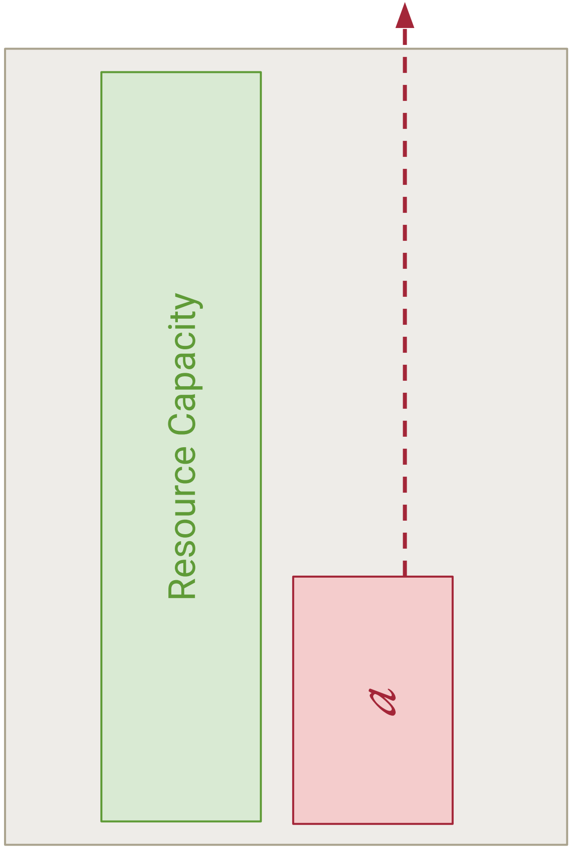
$$U_n = \frac{n_a}{n_m}$$

Disk

$$U_d = \frac{iops_a}{iops_m}$$

R1 Measurement Scenario - Baseline

- *a* runs workload below limit
  undercommitted
- *a* runs workload at limit
  saturated
- *a* runs workload above limit
  overcommitted
- *a* runs workload without limit
  unrestricted

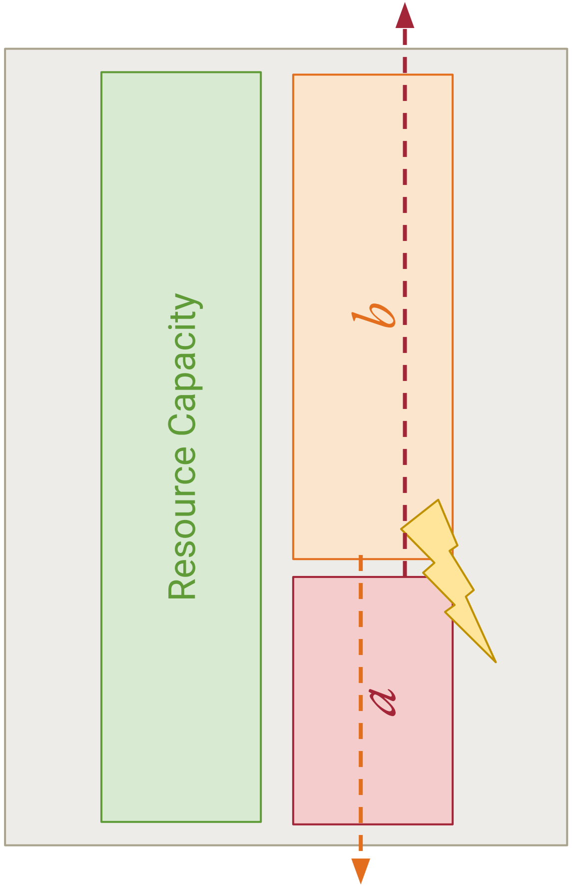


R1 Measurement Scenario - Contended

- a runs workload below limit
  undercommitted
- a runs workload at limit
  saturated
- a runs workload above limit
  overcommitted
- a runs workload without limit
  unrestricted

- Rerun each step with b
  undercommitted, saturated, overcommitted, unrestricted

Determine "Performance Loss Ratio" for every scenario

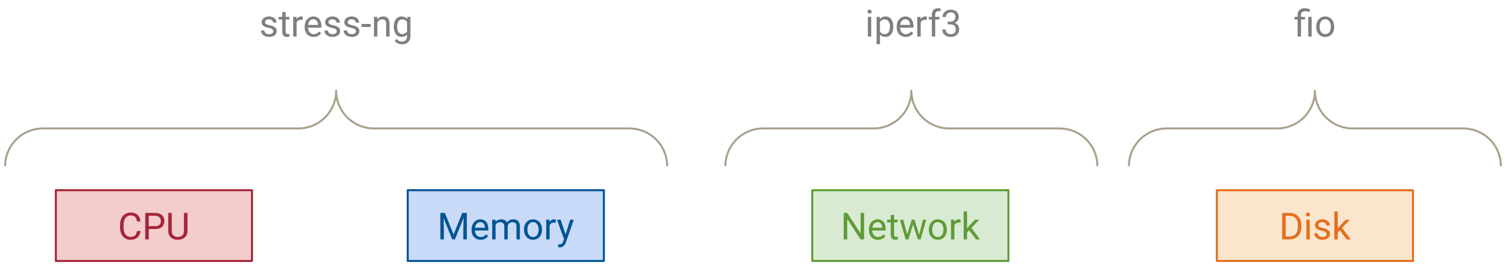


R1 Experiment Scenarios

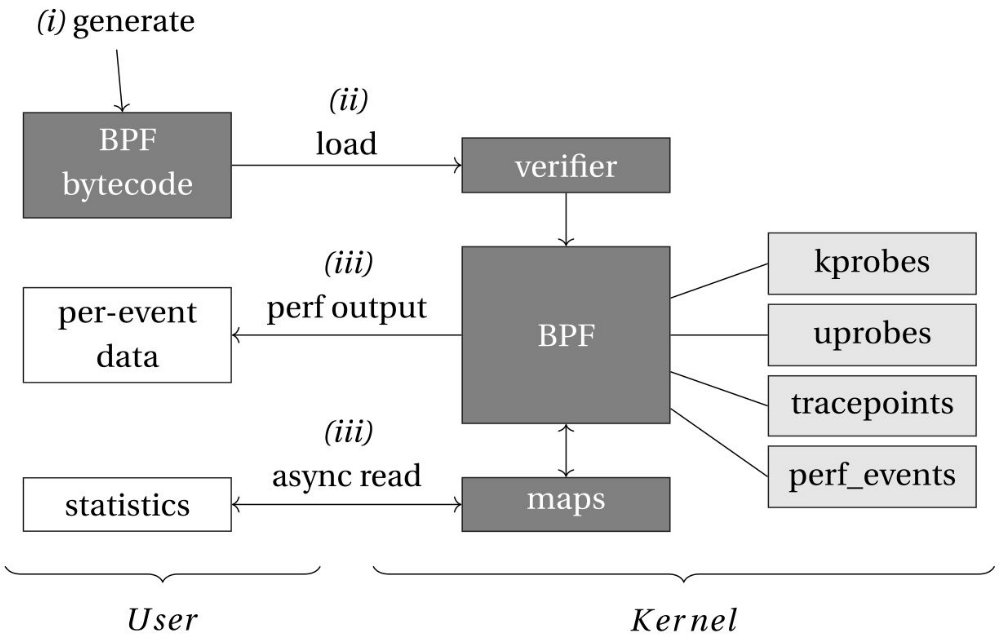
number	shortname	tenant a	tenant b
1	a_b	undercommited	
2	a_b	saturated	
3	a_b	overcommitted	
4	a_b	unrestricted	
5	$a_u b_u$	undercommitted	undercommitted
6	$a_u b_s$	undercommitted	saturated
7	$a_u b_o$	undercommitted	overcommitted
8	$a_u b_f$	undercommitted	unrestricted
9	$a_s b_u$	saturated	undercommitted
10	$a_s b_s$	saturated	saturated
11	$a_s b_o$	saturated	overcommitted
12	$a_s b_f$	saturated	unrestricted
13	$a_o b_u$	overcommitted	undercommitted
14	$a_o b_s$	overcommitted	saturated
15	$a_o b_o$	overcommitted	overcommitted
16	$a_o b_f$	overcommitted	unrestricted

- Scenario runtime ~30min
- 10 iterations per scenario
- Runtime per experiment ~ 35 hours
- 4 Experiments total (1 per resource)

R2 Load Generation



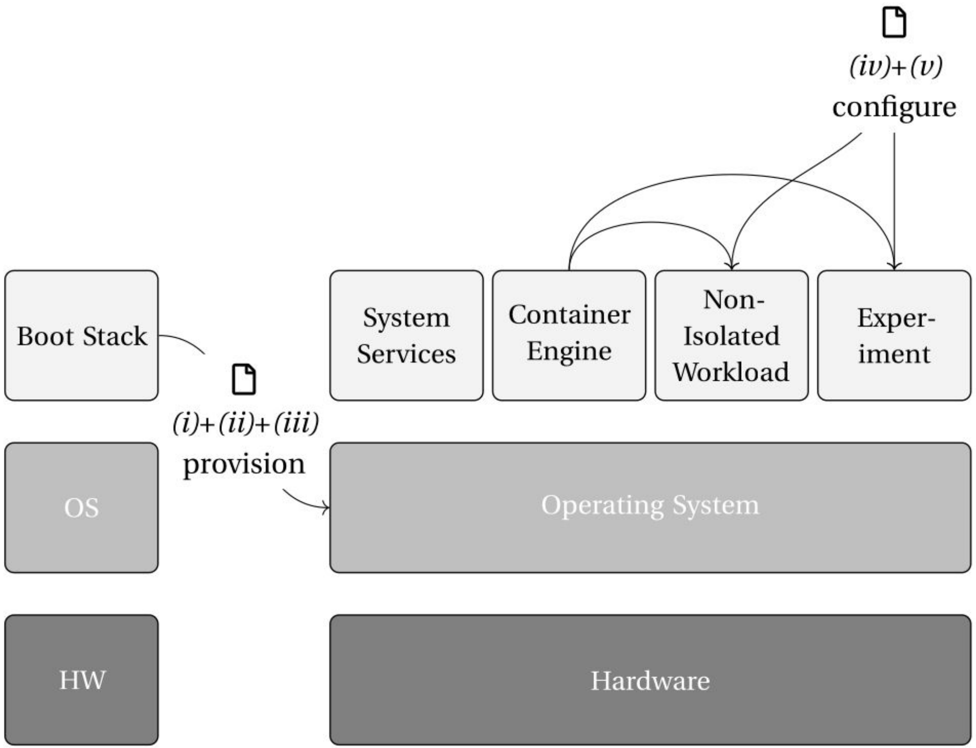
R3 Data Acquisition



[13] Brendan Gregg. 2020.Systems Performance: Enterprise and the Cloud. (Sec-ond ed.).Addison-Wesley Professional Computing Series. Addison-Wesley, Boston.isbn: 978-0-13-682015-4.

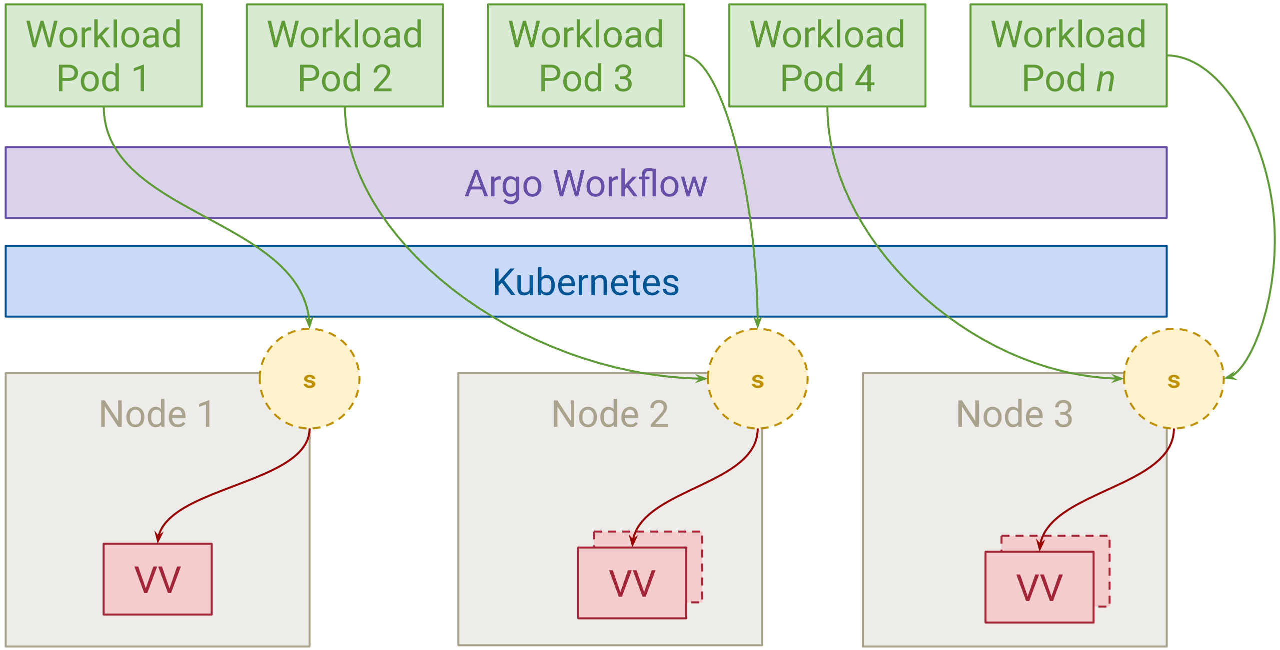
R4 Reproducibility

- Experiment as Code
- No Configuration Drift
- Immutability

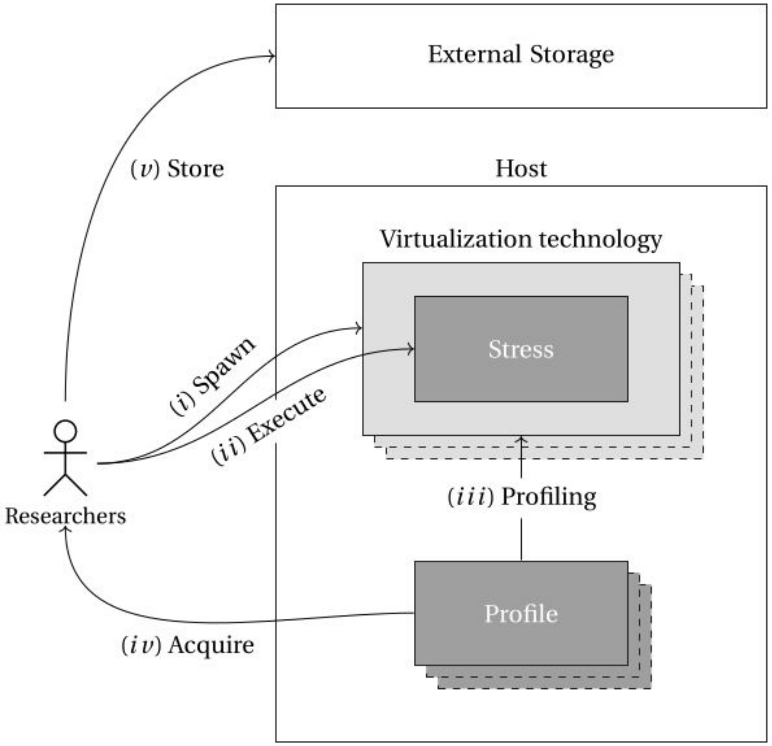


(i) Hardware
(ii) OS
(iii) OS Config
(iv) Experiment Runtime
(v) Experiment

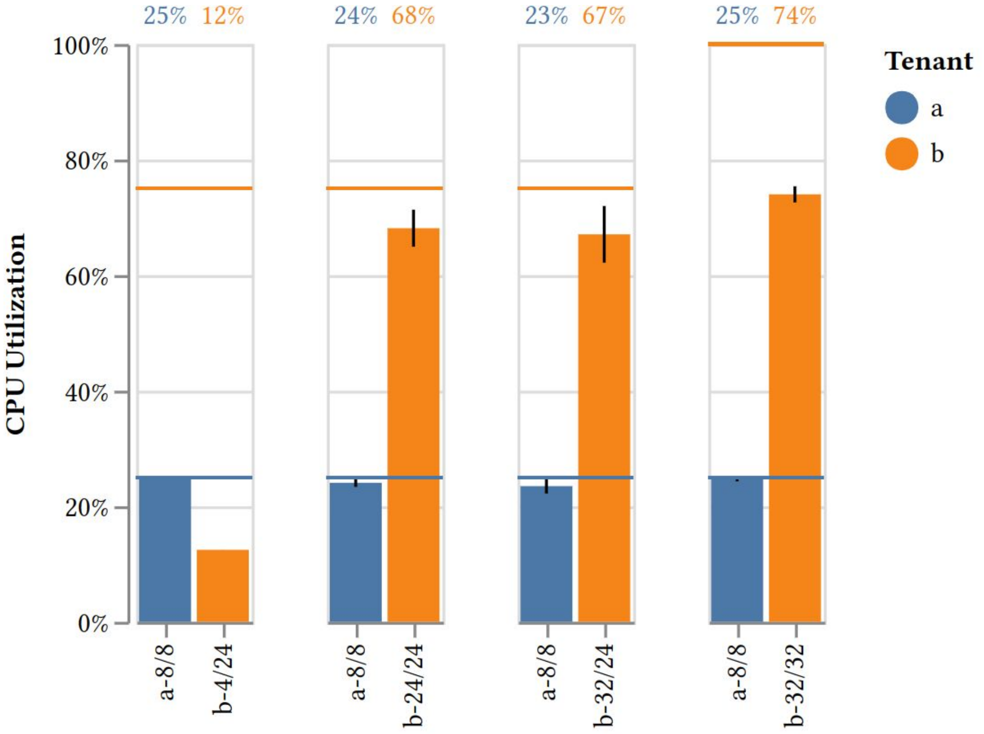
R5 Automation



Experiment Execution

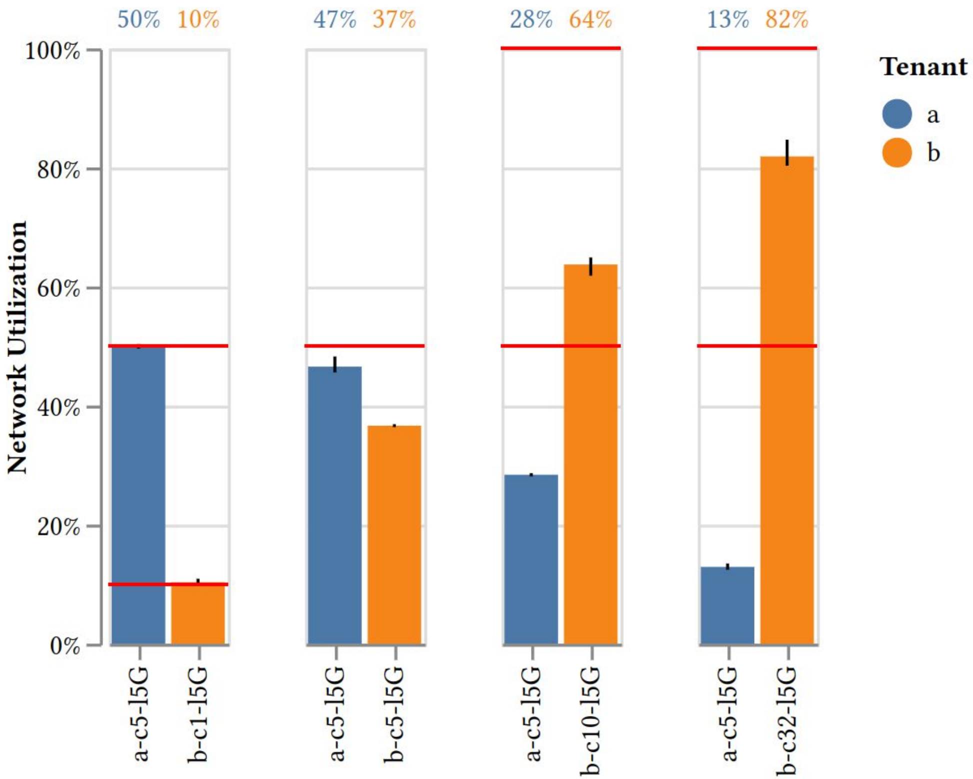


Selected Measurement - Podman CPU saturated



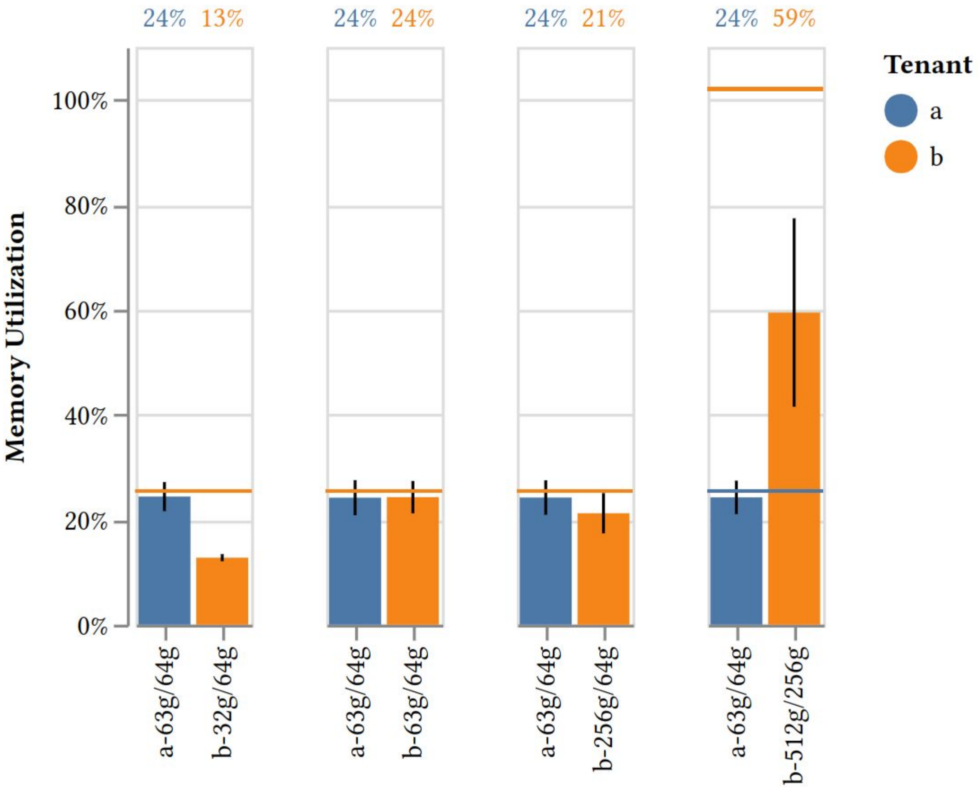
id	shortname	a cpu	a' cpu	I_{ulr}	I_{plr}
1	a_u	12.47			
2	a_s	25.00			
3	a_o	25.00			
4	a_f	98.92			
5	$a_u b_u$	12.47	12.48	0.00	0.06
6	$a_u b_s$	12.47	12.36	0.05	0.88
7	$a_u b_o$	12.47	12.35	0.06	1.03
8	$a_u b_f$	12.47	12.20	0.14	2.23
9	$a_s b_u$	25.00	24.91	0.05	0.37
10	$a_s b_s$	25.00	24.06	0.47	3.74
11	$a_s b_o$	25.00	23.48	0.76	6.07
12	$a_s b_f$	25.00	24.71	0.14	1.15
13	$a_o b_u$	25.00	25.00	0.00	0.01
14	$a_o b_s$	25.00	25.13	0.06	0.50
15	$a_o b_o$	25.00	25.08	0.04	0.30
16	$a_o b_f$	25.00	25.09	0.04	0.33

Selected Measurement - Podman Network saturated



id	shortname	a network	a' network	I_{ulr}	I_{plr}
1	a_u	10.00			
2	a_s	50.12			
3	a_o	88.71			
4	a_f	93.29			
5	$a_u b_u$	10.00	10.05	0.05	0.50
6	$a_u b_s$	10.00	10.00	0.00	0.01
7	$a_u b_o$	10.00	8.29	1.71	17.08
8	$a_u b_f$	10.00	2.37	7.63	76.32
9	$a_s b_u$	50.12	49.99	0.13	0.25
10	$a_s b_s$	50.12	46.54	3.58	7.14
11	$a_s b_o$	50.12	28.38	21.74	43.37
12	$a_s b_f$	50.12	12.89	37.23	74.27
13	$a_o b_u$	88.71	79.20	9.52	10.73
14	$a_o b_s$	88.71	61.13	27.59	31.10
15	$a_o b_o$	88.71	51.99	36.72	41.39
16	$a_o b_f$	88.71	19.02	69.69	78.56

Selected Measurement - Podman Memory saturated



id	shortname	a memory	a' memory	I_{ulr}	I_{plr}
1	a_u	12.80			
2	a_s	24.14			
3	a_o	21.24			
4	a_f	71.94			
5	$a_u b_u$	12.80	12.74	0.06	0.48
6	$a_u b_s$	12.80	12.68	0.12	0.91
7	$a_u b_o$	12.80	12.74	0.06	0.44
8	$a_u b_f$	12.80	12.64	0.16	1.26
9	$a_s b_u$	24.14	24.39	0.25	1.02
10	$a_s b_s$	24.14	24.18	0.04	0.16
11	$a_s b_o$	24.14	24.20	0.06	0.27
12	$a_s b_f$	24.14	24.24	0.10	0.40
13	$a_o b_u$	21.24	21.29	0.05	0.25
14	$a_o b_s$	21.24	21.21	0.03	0.13
15	$a_o b_o$	21.24	21.72	0.49	2.30
16	$a_o b_f$	21.24	21.14	0.10	0.46

R3 Summary

- An evaluation methodology for the multidimensional evaluation of isolation capabilities and performance degradation.
  Addressing typical different types of hardware resources while being open regarding workload generation and further tooling
- A proof-of-concept implementation of the methodology as a benchmark-based evaluation framework.
  With a strict focus on aspects such as reproducibility, automation, and fine grained profiling.
- A validation of the proof-of-concept implementation of the methodology
  measuring the isolation capabilities of podman representing a container-based virtualisation technology

R3 Future Work

- Extend the system model to measure more resources
- Measure more virtualization technologies
- More complex benchmarks compared to micro-benchmarks
- Investigation and possibly compare further isolation models
- Release of the framework

Questions?

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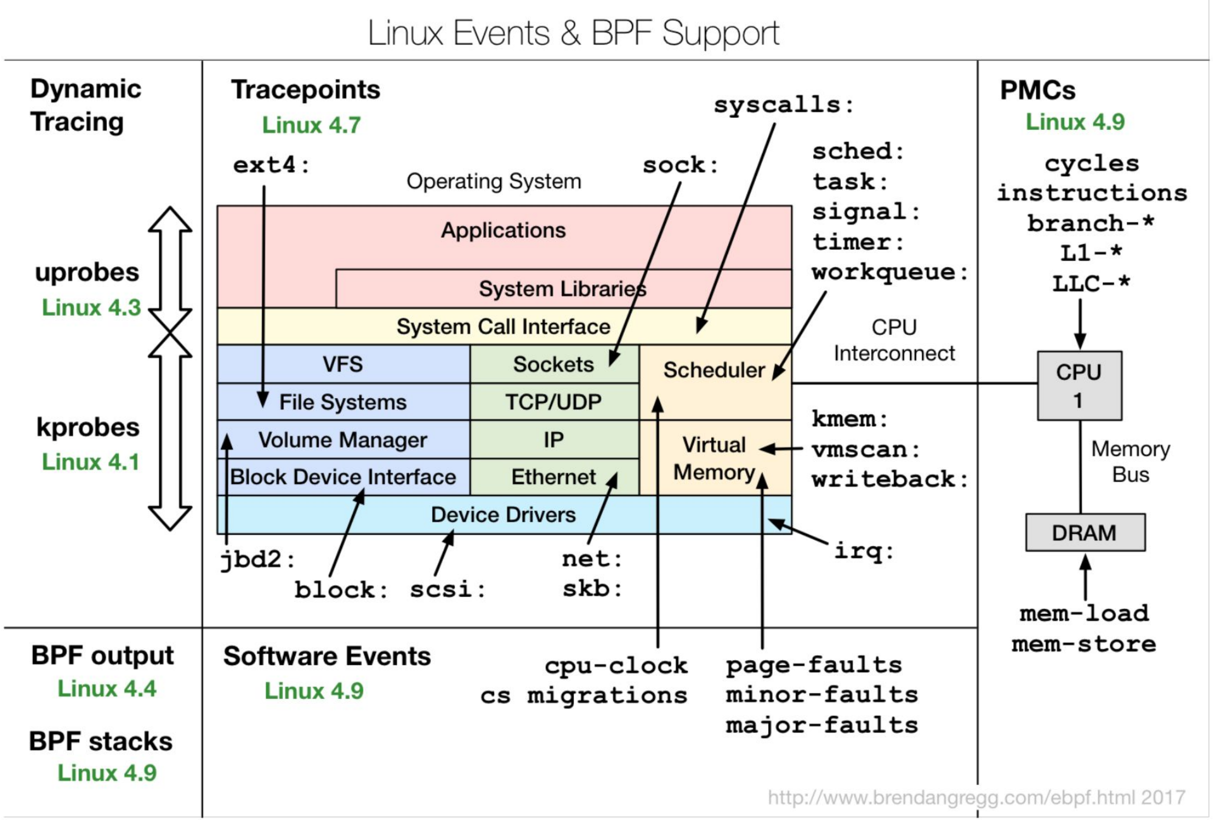
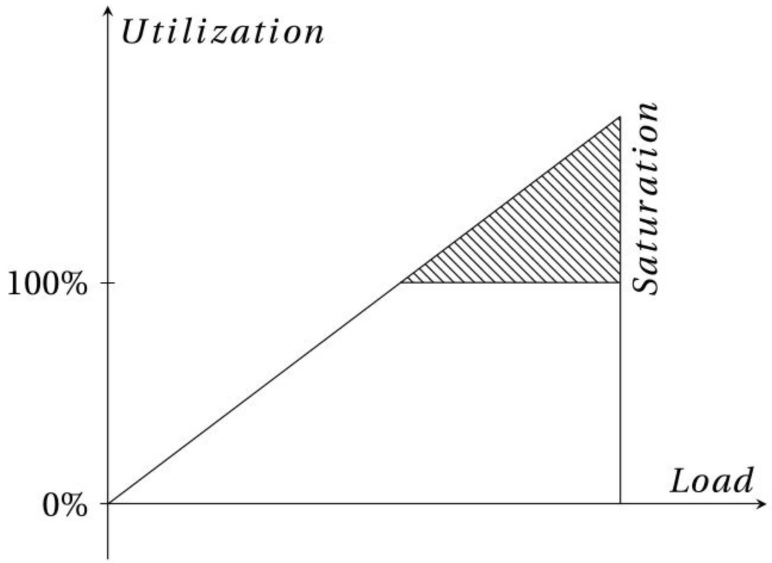
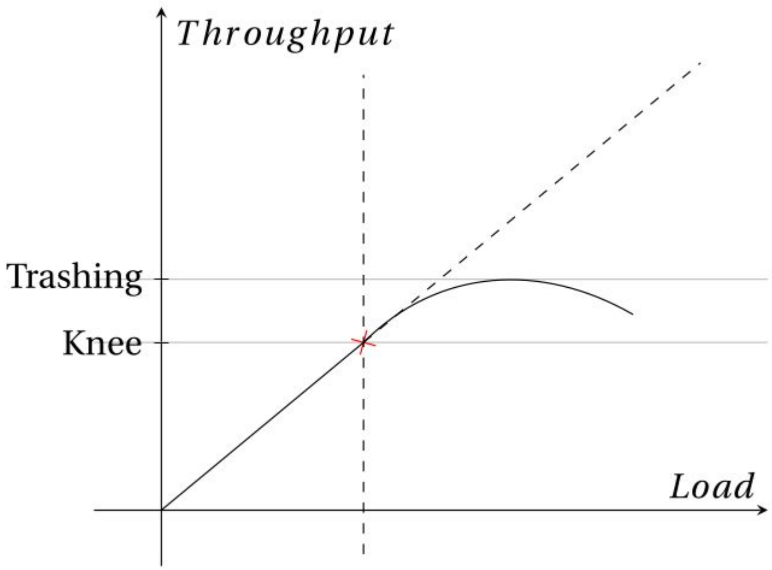
eBPF Landscape

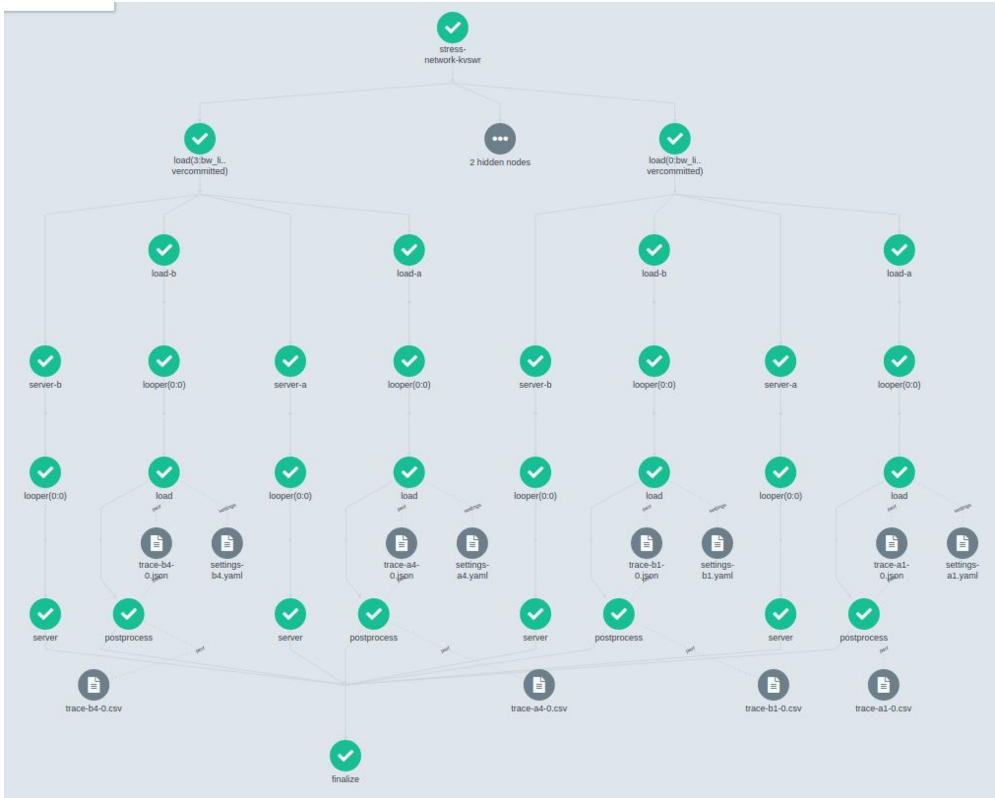


R2 System Model - Utilization & Saturation

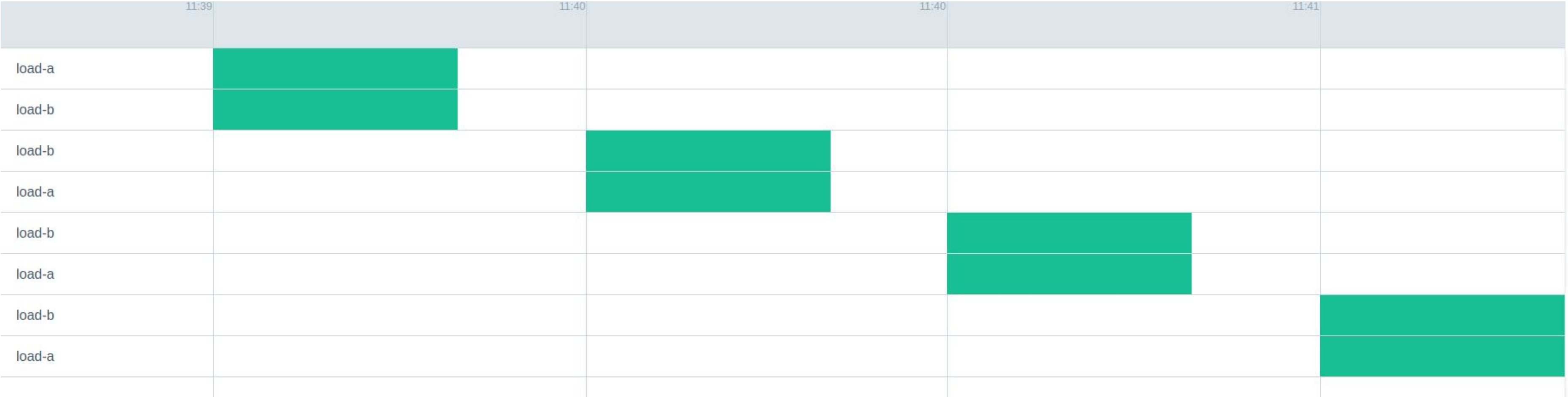




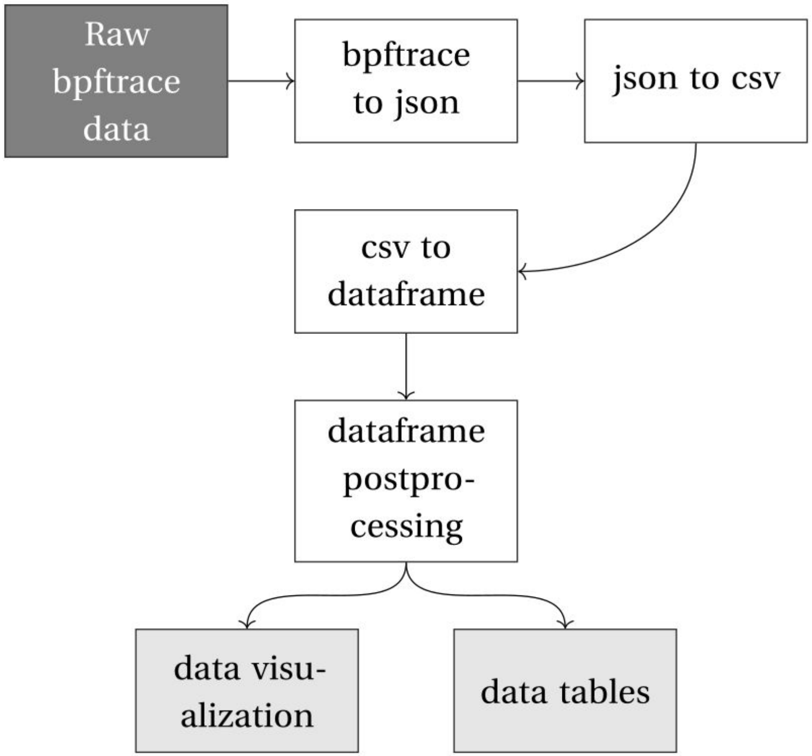
Automation - Argo Workflow Tree



Automation - Argo Workflow Process



Data Processing



Bpftrace Memory RSS Example

```
#!/usr/local/bin/bpftrace
#include <linux/sched.h>
#include <linux/mm.h>
BEGIN {
  @start = nsecs;
  print("timestamp,pid,mtype,bytes");
}
interval:ms:$SAMPLEMS
{
  $ts = (nsecs - @start)/1000;
  printf("%u",$ts);
  print(@);
}
tracepoint:kmem:rss_stat
/curtask->parent->parent->parent->pid == $ROOTPID/
{
  @[pid, args->member] = args->size;
}
END {
  clear(@);
  clear(@start);
}
```

Memory allocation over time