Accurate emulation of CPU performance

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Validation of distributed systems

Approaches:

- Theoretical approach (paper and pencil)
  - ☺ the most general results and understanding
  - ☹ very hard (leads to unsolvability results)
- Experimentation (real application on a real environment)
  - ☺ realistic context, credibility
  - ☹ difficulty of preparation and control, questionable reproducibility
- Simulation (modeled application inside modeled environment)
  - ☺ very simple and perfectly reproducible
  - ☹ experimental bias, possibly unrealistic
- Emulation (real application inside a modeled environment)
  - ☺ control over the experiment parameters
  - ☹ difficult

Emulation

The perfect emulated environment should emulate (independently):

- Network bandwidth, latency, topology
- Performance and number of CPUs
- Memory capabilities
- Background noise (network, CPU, faults)

Already implemented in **Wrekavoc** – a tool to define and control heterogeneity of the cluster (but not perfect yet!)

In this talk, however, we specifically concentrate on

Emulation

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Emulation of CPU

CPU emulation

Various elements of CPU architecture could be emulated:

- speed
- number of cores
- sizes and properties of caches (and topology thereof)
- memory access speed (especially for NUMA systems)

In this talk, we will talk about

CPU emulation

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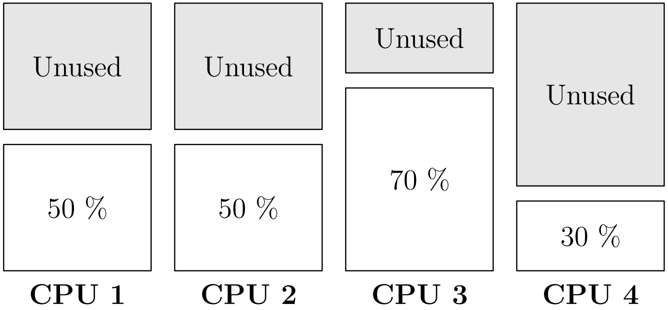
In this talk, we will talk about

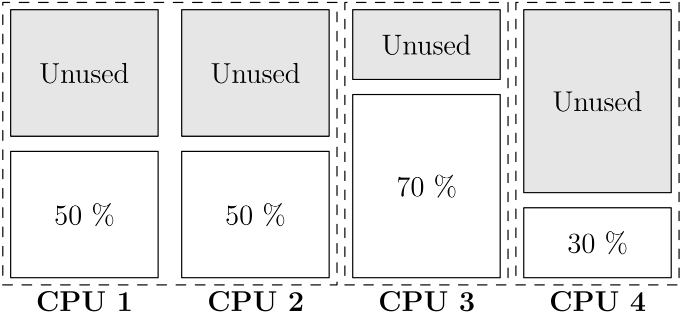
Degradation of CPU speed

An example



(1) controlling speed of each CPU/core independently

An example (continued)



(2) being able to create separated scheduling zones

Dynamic frequency scaling (CPU-Freq)

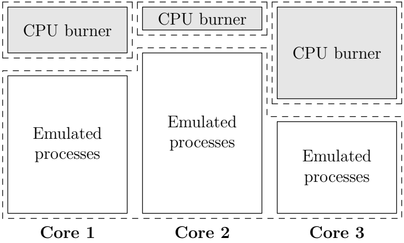
- AKA Intel Enhanced SpeedStep or AMD Cool'n'Quiet
- Hardware solution to reduce:
  - heat
  - noise
  - power usage
- For:
  - no overhead of emulation
  - completely unintrusive
  - meaningful CPU time measure
- Against:
  - only a finite set of different frequency levels

CPU-Lim

- Method available in Wrekavoc
- Algorithm:
  - if CPU usage ≥ threshold → send SIGSTOP to the process
  - if CPU usage < threshold → send SIGCONT to the process
- $CPU\ usage = \frac{CPU\ time\ of\ the\ process}{process\ lifetime}$
- For:
  - easy and almost POSIX-compliant
- Against:
  - intrusive and unscalable
  - decision based on one process instead of global CPU usage
  - sleeping is indistinguishable from preemption

Fracas

- Based on idea from KRASH (load injection tool) idea
- Uses Linux Cgroups and Completely Fair Scheduler
- A predefined portion of the CPU is given to tasks burning CPU
- All other processes are given the remaining CPU time



Fracas

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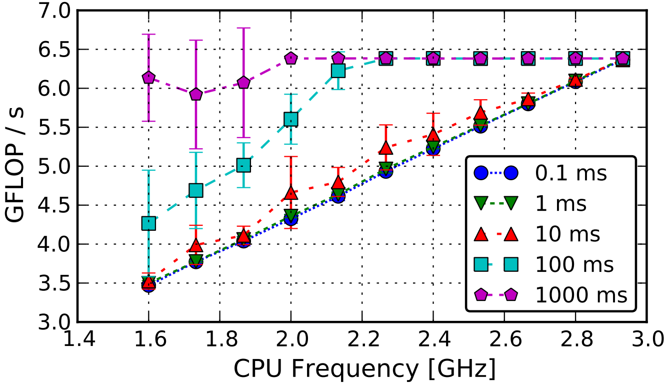
- For:
  - unintrusive
  - scalable
- Against:
  - unportable to other systems
  - sensitive to the configuration of the scheduler

Fracas and latency of the scheduler

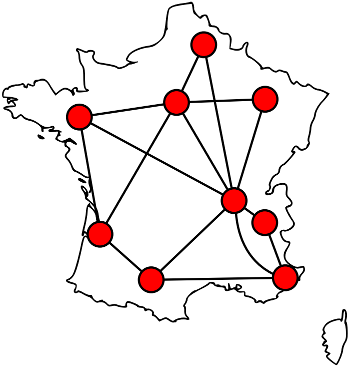


The smaller the latency, the better the emulation

Evaluation

- Based on different types of work:
  - CPU intensive (Linpack benchmark)
  - IO bound
  - multiprocessing
  - multithreading
  - memory speed (STREAM benchmark)
- X-axis – emulated frequency
- Y-axis – speed perceived by the benchmark
- each test repeated 10 times, results = average
  95% confidence interval using t-Student distribution
- Evaluation performed on Grid'5000 platform
  - nodes with two quad-core Intel Xeon X5570 processors
  - nodes with a pair of single-core AMD Opteron 252 processors

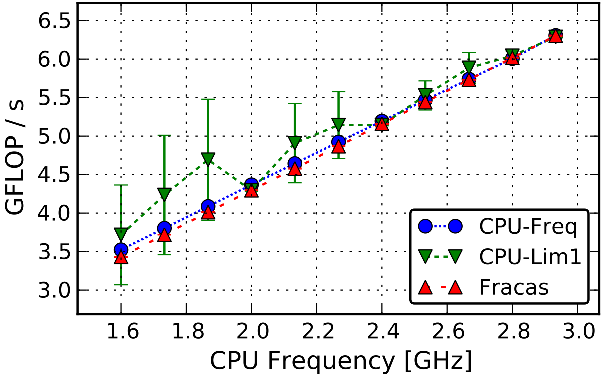
Grid'5000



- 9 sites, 1600 machines

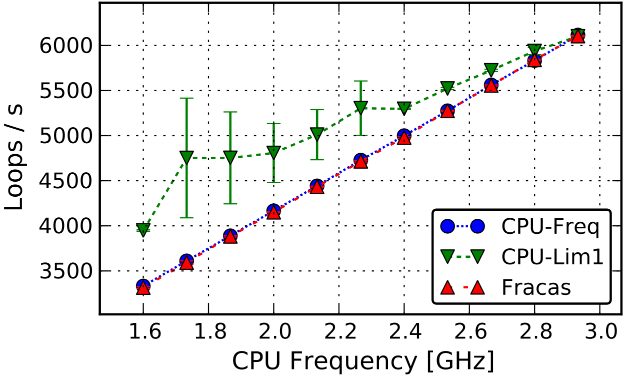
  Lille, Rennes, Orsay, Nancy, Bordeaux, Lyon, Grenoble, Toulouse, Sophia
- Dedicated to research on distributed systems and HPC

CPU intensive work



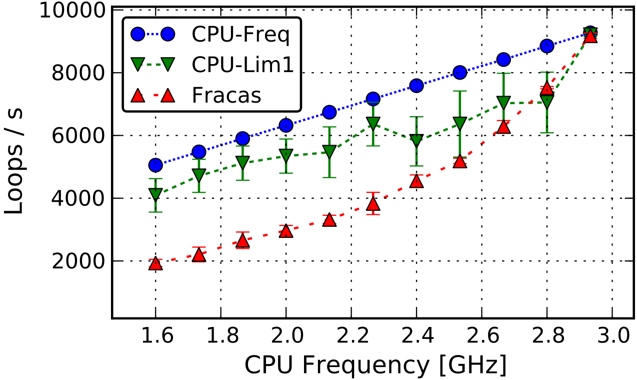
CPU-Lim is less predictable (the outcome has higher variance)

IO-bound work



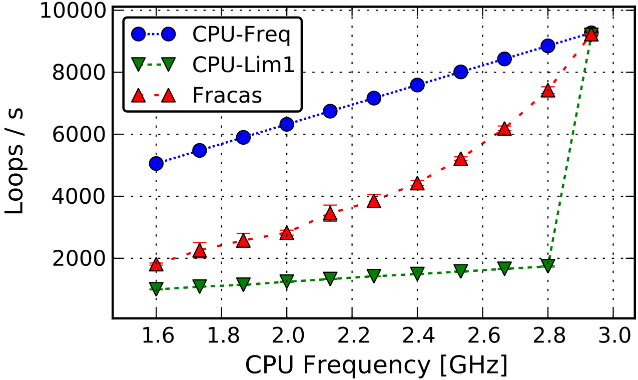
CPU-Lim gives (unfair) advantage to IO-bound tasks

Multiprocessing



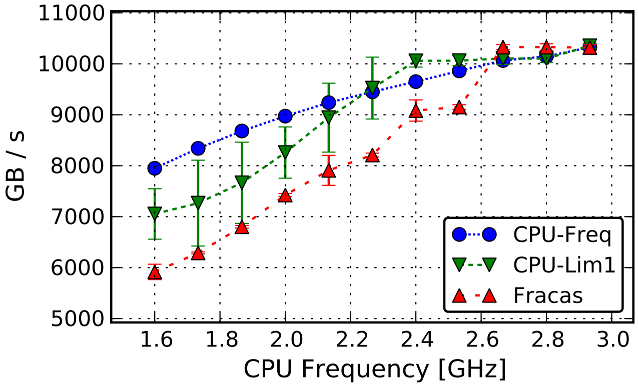
Fracas can't emulate CPU for multitask computation

Multithreading



CPU-Lim controls *processes* instead of scheduling entities

Memory speed



Memory speed is affected differently by each method

Summary of the evaluation

- CPU-Freq:
  - very good results
  - coarse granularity
- CPU-Lim:
  - not scalable due to implementation, intrusive
  - higher variance
  - controls processes, not threads
- Fracas:
  - good behavior for a single-task workload
  - scalable
  - bad behavior for multitask workload

Future work

- Explore other approaches
- Improve Fracas to cover multitasking
- Emulate memory bandwidth
- Emulate other aspects of CPU
- Integrate Fracas into Wrekavoc
- Take over the world :)

Conclusions

- Presented Fracas, a method for CPU performance emulation based on Linux cgroups
- Compared with CPU-Freq and CPU-Lim (Wrekavoc)
- Evaluated experimentally on Grid'5000
- None of the methods is perfect:
  - CPU-Freq: coarse grained
  - CPU-Lim: implementation problems, not scalable
  - Fracas: works perfectly in single thread/process case, needs work in multithread/process case

Questions?