Benchmarking and Resource Measurement

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Benchmarking is Important

- Evaluation of new approaches
- Evaluation of tools
- Competitions
- Tool development (testing, optimizations)

Reliable, reproducible, and accurate results needed!

Benchmarking is Hard

- ~~Influence of I/O~~
- ~~Networking~~
- ~~Distributed tools~~
- ~~User input~~

Not relevant for
most verification tools

- Different hardware architectures
- Heterogeneity of tools
- Parallel benchmarks

Relevant!

Goals

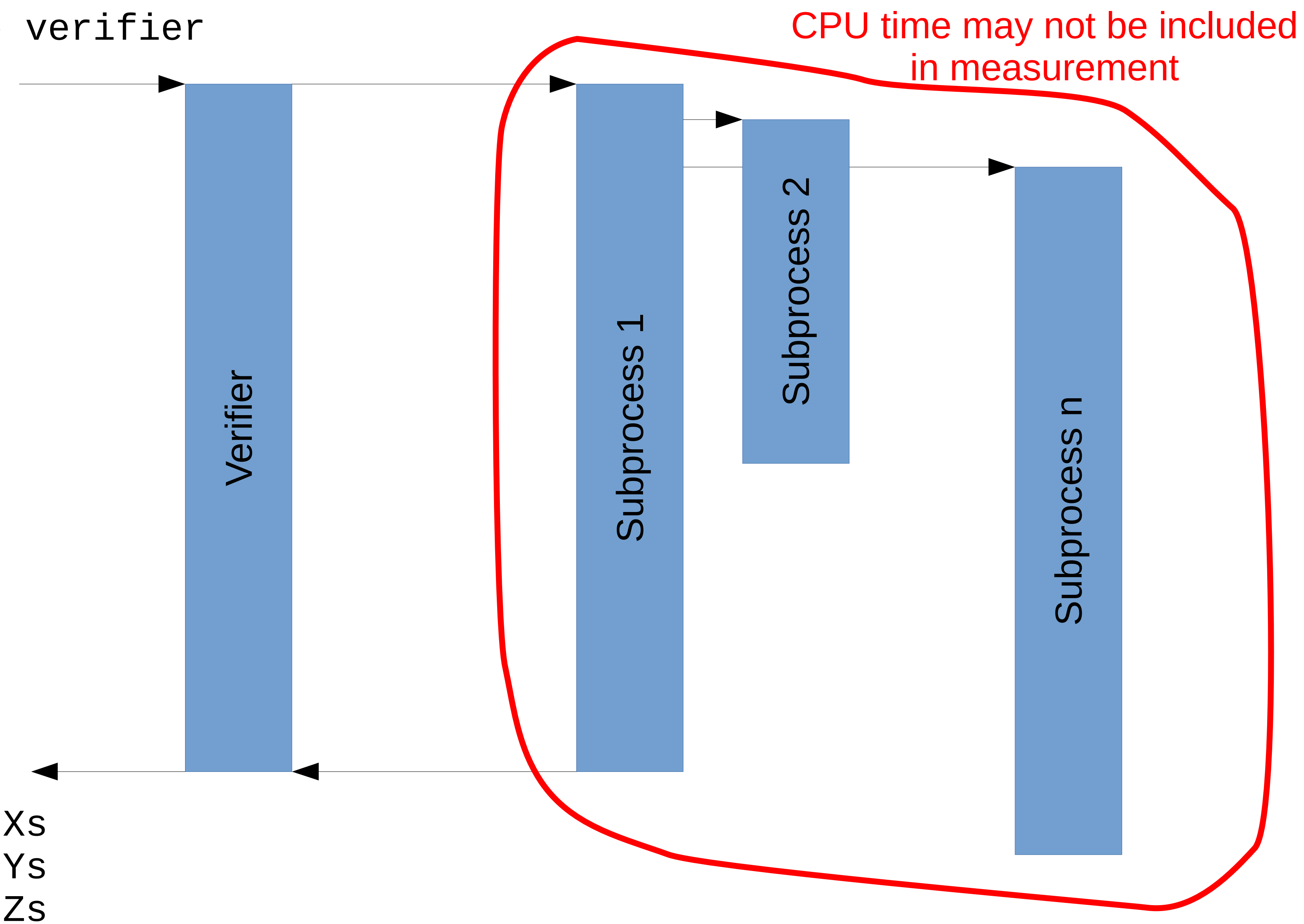
- Reproducibility
  - Avoid non-deterministic effects and interferences
  - Provide defined set of resources
- Accurate results
- For verification tools (and similar)
- On Linux

Checklist

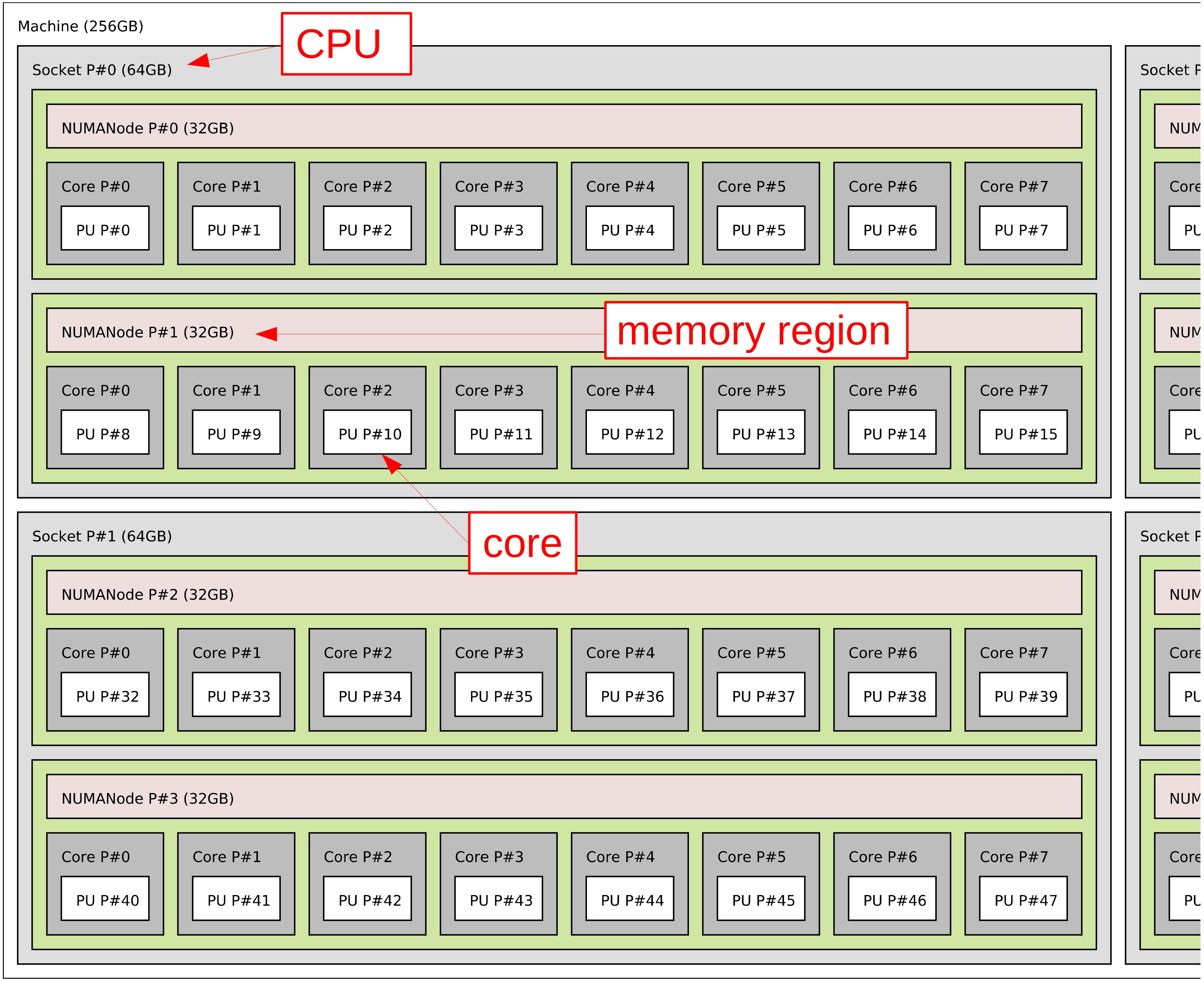
1. Measure and Limit Resources Accurately
   - Time
   - Memory
2. Terminate Processes Reliably
3. Assign Cores Deliberately
4. Respect Non-Uniform Memory Access
5. Avoid Swapping
6. Isolate Individual Runs
   - Communication
   - File system

Measuring CPU time with „`time`“

```
~$ time verifier
```



```
real    Xs
user    Ys
sys     Zs
```


Machine (256GB)
CPU
Socket P#0 (64GB)
NUMANode P#0 (32GB)
Core P#0
PU P#0
Core P#1
PU P#1
Core P#2
PU P#2
Core P#3
PU P#3
Core P#4
PU P#4
Core P#5
PU P#5
Core P#6
PU P#6
Core P#7
PU P#7
NUMANode P#1 (32GB)
memory region
Core P#0
PU P#8
Core P#1
PU P#9
Core P#2
PU P#10
Core P#3
PU P#11
Core P#4
PU P#12
Core P#5
PU P#13
Core P#6
PU P#14
Core P#7
PU P#15
core
Socket P#1 (64GB)
NUMANode P#2 (32GB)
Core P#0
PU P#32
Core P#1
PU P#33
Core P#2
PU P#34
Core P#3
PU P#35
Core P#4
PU P#36
Core P#5
PU P#37
Core P#6
PU P#38
Core P#7
PU P#39
NUMANode P#3 (32GB)
Core P#0
PU P#40
Core P#1
PU P#41
Core P#2
PU P#42
Core P#3
PU P#43
Core P#4
PU P#44
Core P#5
PU P#45
Core P#6
PU P#46
Core P#7
PU P#47

Isolate Individual Runs

- Excerpt of start script taken from some verifier in SV-COMP:

```
# … (tool started here)

killall z3 2> /dev/null
killall minisat 2> /dev/null
killall yices 2> /dev/null
```

- Thanks for thinking of cleanup
- But what if there are parallel runs?

Isolate Individual Runs

- Temp files with constant names like `/tmp/mytool.tmp` collide
- State stored in places like ~/.mytool hinders reproducibility
  - Sometimes even auto-generated
- Restrict changes to file system as far as possible

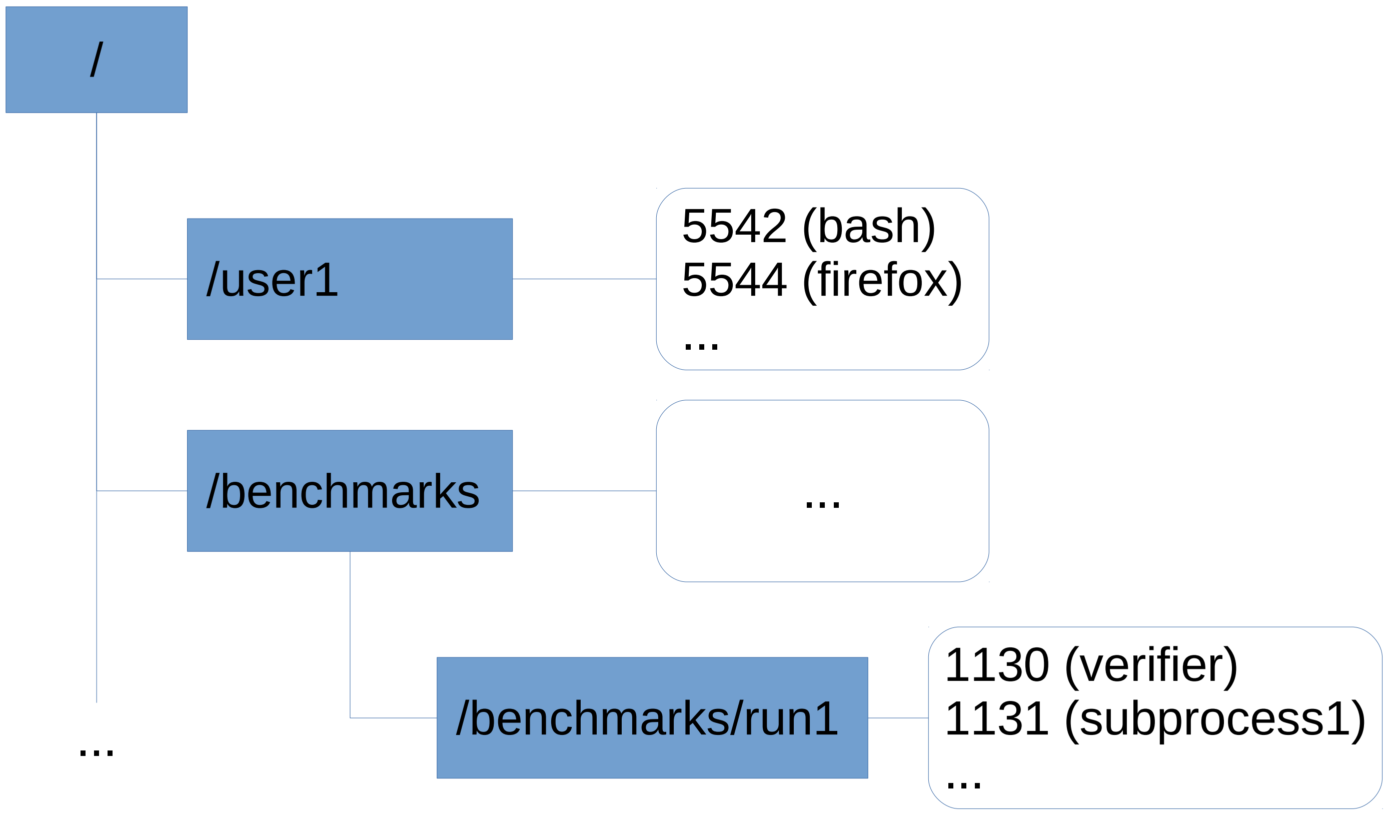
Cgroups

- Linux kernel „control groups“
- Reliable tracking of spawned processes
- Resource limits and measurements per cgroup
  - CPU time
  - Memory
  - I/O etc.

Only solution on Linux
for race-free handling of multiple processes!

Cgroups

- Hierarchical tree of sets of processes



Namespaces

- Light-weight virtualization
- Only one kernel running, no additional layers
- Change how processes see the system
- Identifiers like PIDs, paths, etc. can have different meanings in each namespace
  - PID 42 can be a different process in each namespace
  - Directory / can be a different directory in each namespace
  - …
- Can be used to build application containers without possibility to escape
- Usable without root access

Benchmarking Containers

- Encapsulate groups of processes
- Limited resources (memory, cores)
- Total resource consumption measurable
- All other processes hidden and no communication with them
- Disabled network access
- Adjusted file-system layout
  - Private `/tmp`
  - Writes redirected to temporary storage

BenchExec

- A Framework for Reliable Benchmarking and Resource Measurement
- Provides benchmarking containers based on cgroups and namespaces
- Allocates hardware resources appropriately
- Low system requirements (modern Linux kernel and cgroups access)

BenchExec

- Open source: Apache 2.0 License
- Written in Python 3
- https://github.com/sosy-lab/benchexec
- Used in International Competition on Software Verification (SV-COMP)
- Originally developed for software verification, but applicable to arbitrary tools

BenchExec Architecture

- `runexec`
  - Benchmarks a single run of a tool
  - Implements benchmarking container
  - Easy integration into other frameworks
- `benchexec`
  - Benchmarks multiple runs
    (e.g., a set of configurations against a set of files)
  - Allocates hardware resources
  - Can check whether tool result is as expected
- `table-generator`
  - Generates CSV and interactive HTML tables (with plots)
  - Computes result differences and regression counts

BenchExec Configuration

- Tool command line
- Expected result
- Resource limits
  - CPU time, wall time
  - Memory
- Container setup
  - Network access
  - File-system layout
- Where to put result files

Conclusion

Be careful when benchmarking!

Don't use time, ulimit etc.
Always use cgroups and namespaces!

BenchExec
https://github.com/sosy-lab/benchexec