Reducing Performance Non-determinism via Cache-aware Page Allocation Strategies

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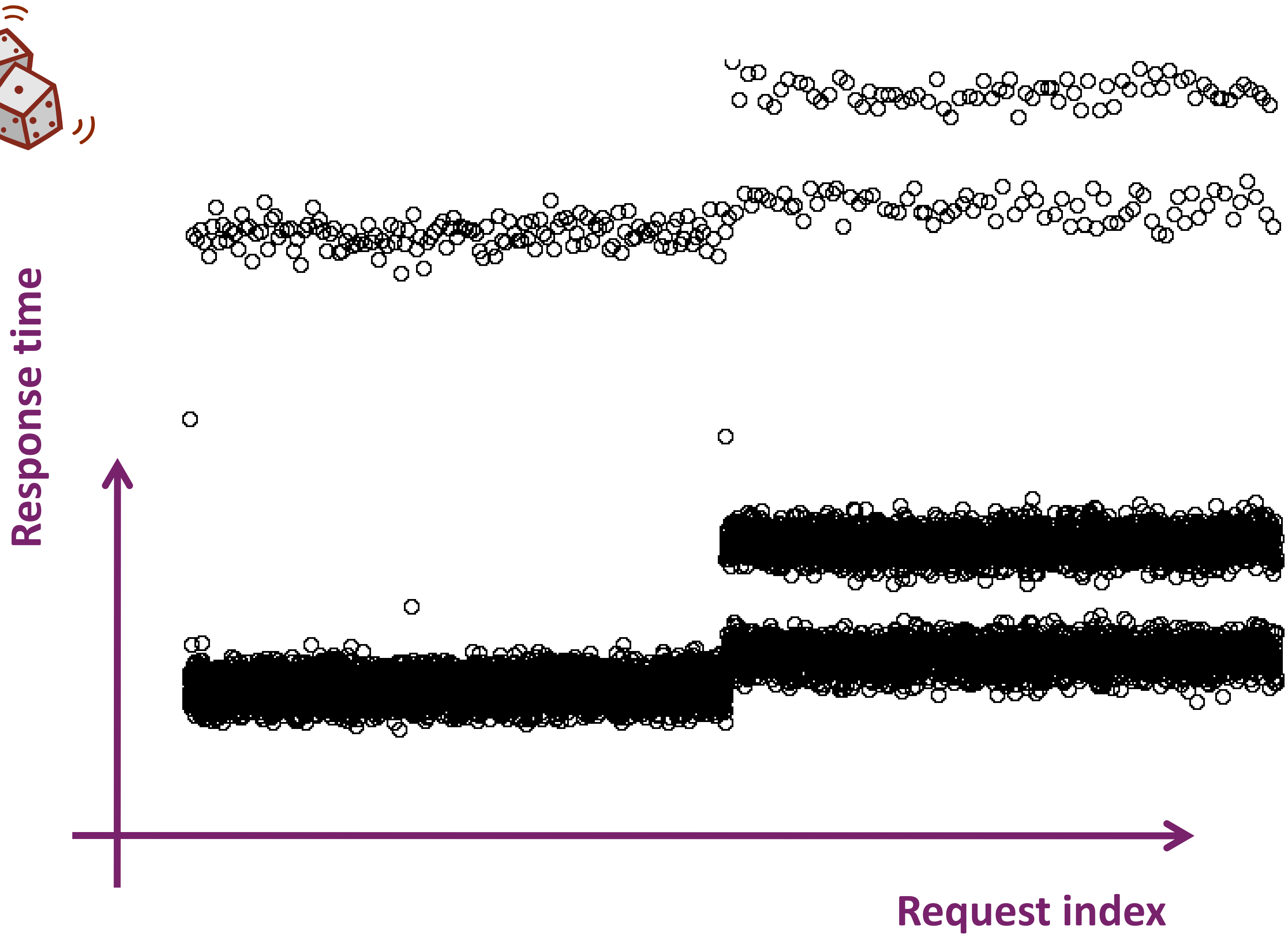
Performance Non-determinism



Non-determinism in execution is particuarly bad for benchmarking

Sample Benchmark Structure

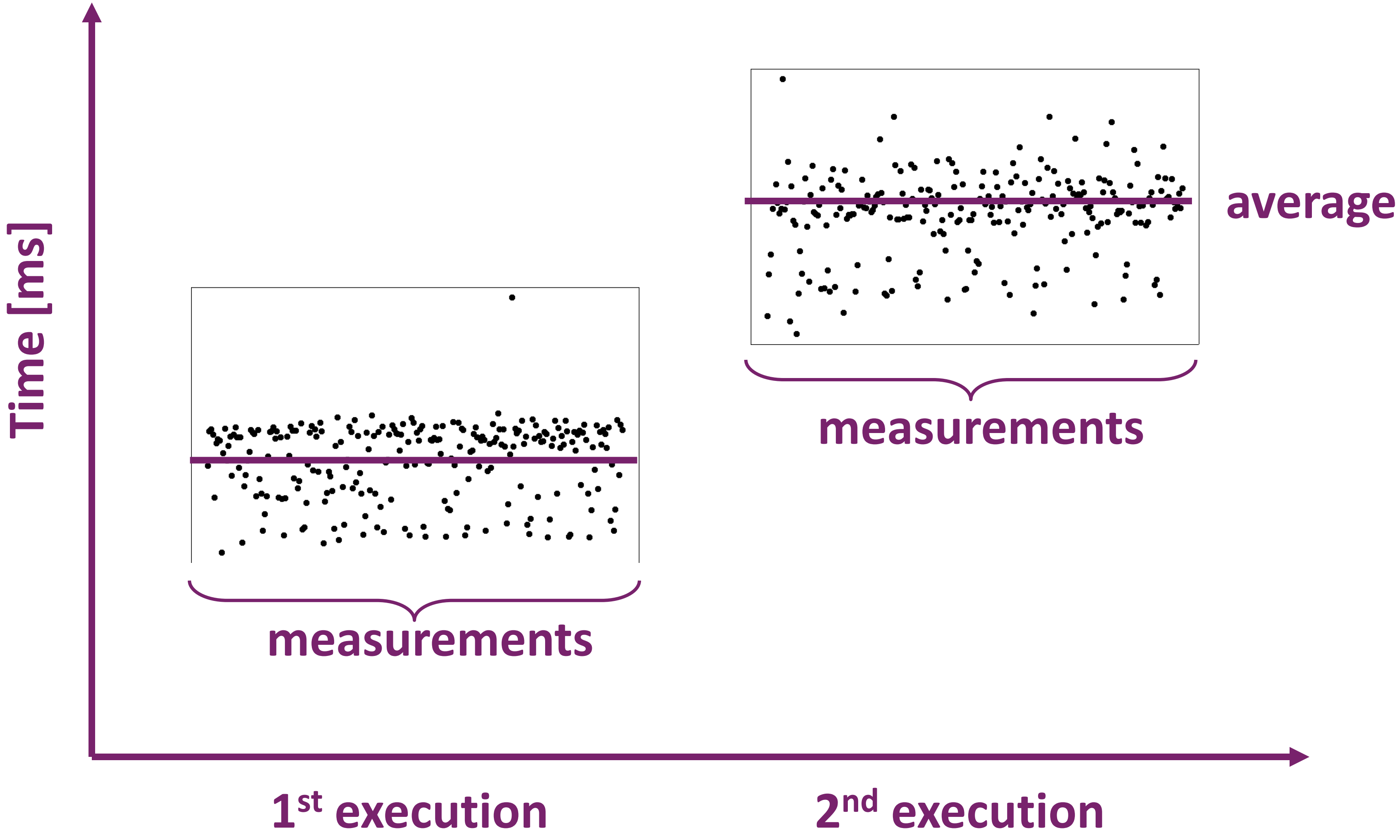
```
Main() {
  initialize();
  warm-up();

  for(i=0;i<nmeasurements, i++) {
    before = getCurrentTime();
    doOperation();
    after = getCurrentTime();

    results[i] = after - before;
  }

  print(results);
}
```

One measurement

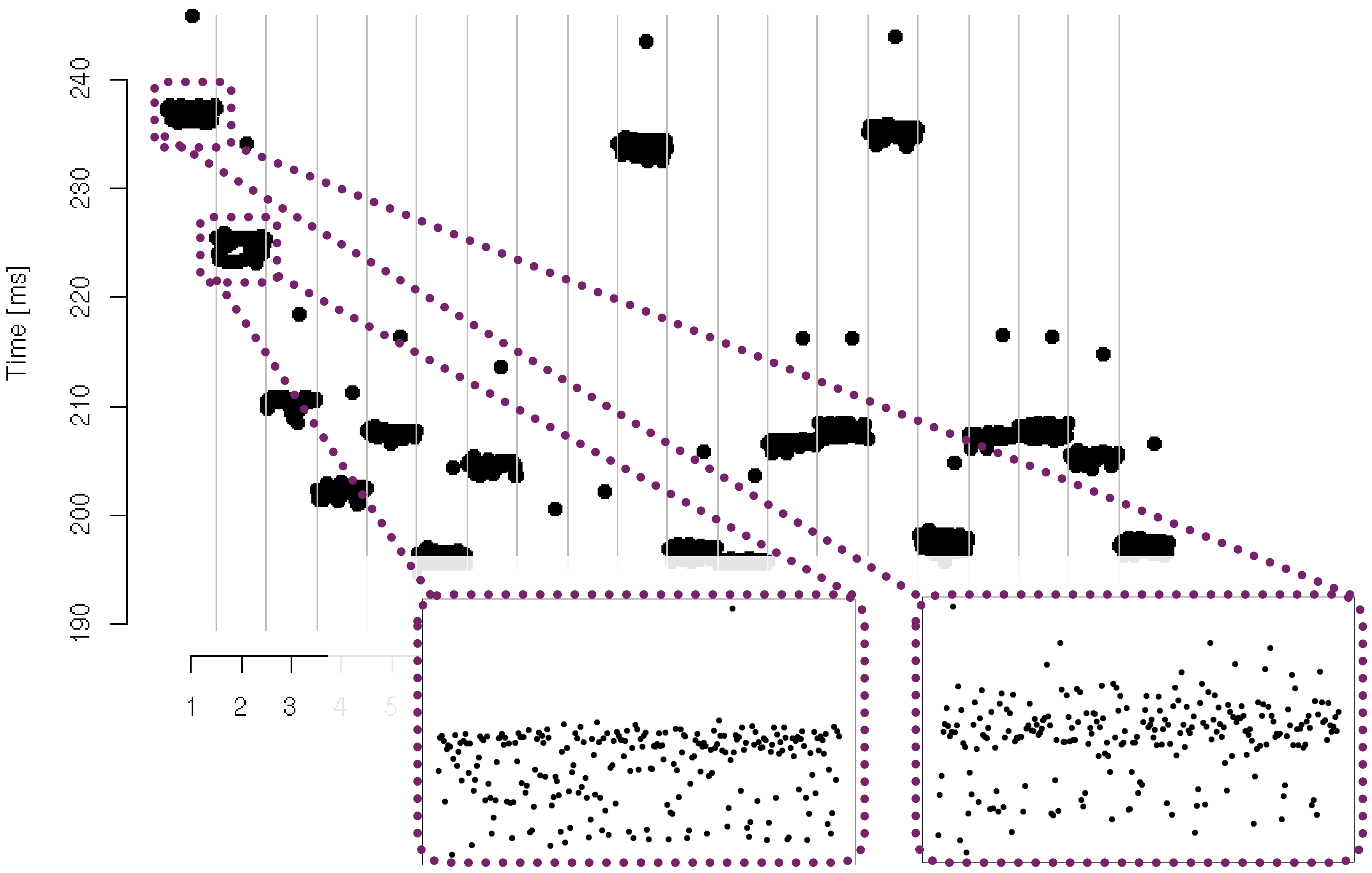
```
Cmd-line> ./benchmark
Cmd-line> ./benchmark
Cmd-line> ./benchmark
```

One execution

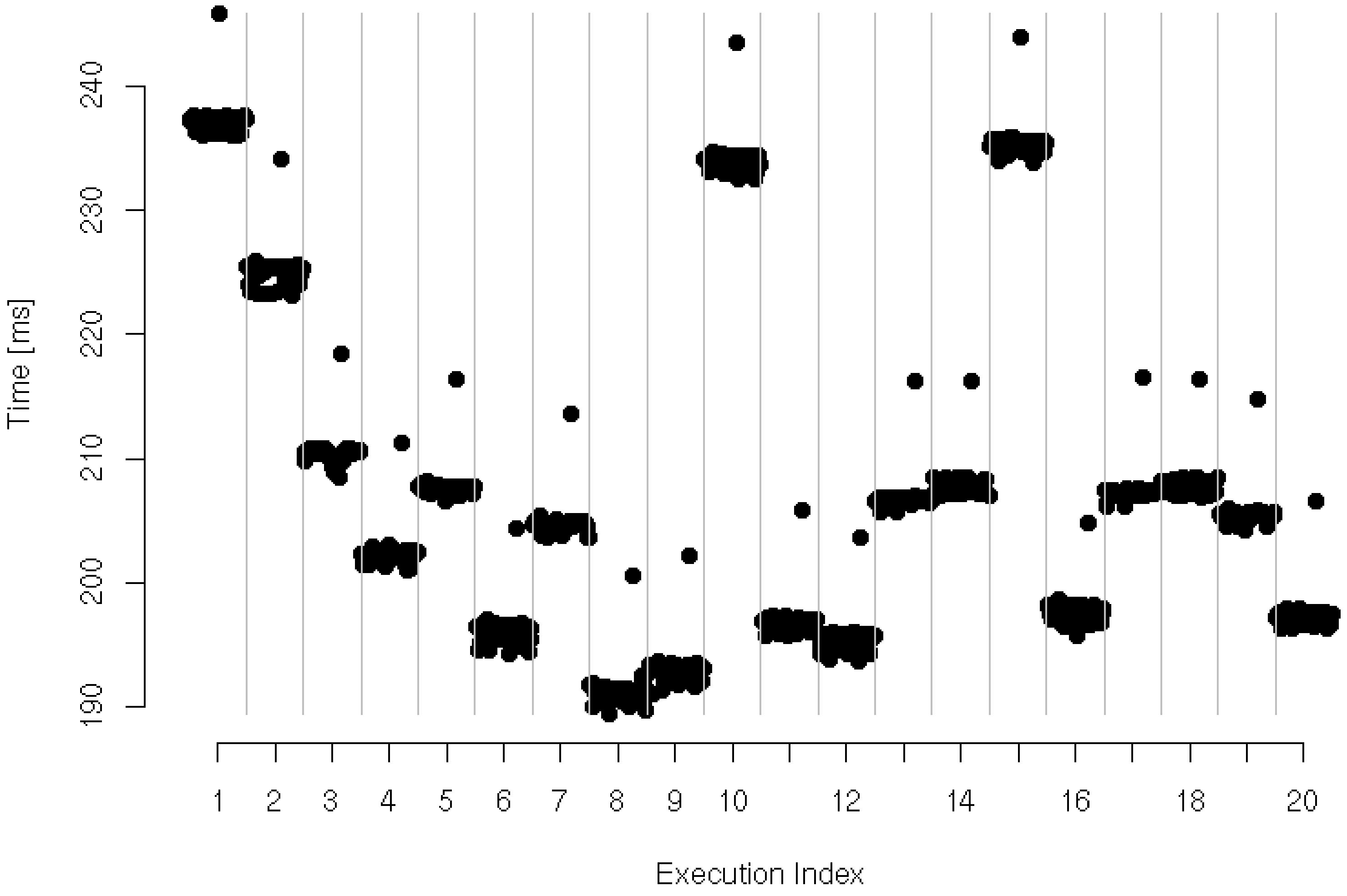
Non-Determinism in Measurement and Execution



Non-Determinism in Measurement and Execution



Non-Determinism in Measurement and Execution



Non-determinism in Execution is Costly

```
Main() {

  initialize();
  warm-up();

  for(i=0;i<nmeasurements, i++) {
    before = getCurrentTime();
    doOperation();
    after = getCurrentTime();

    results[i] = after - before;
  }

  print(results);
}
```

Repeated with every execution

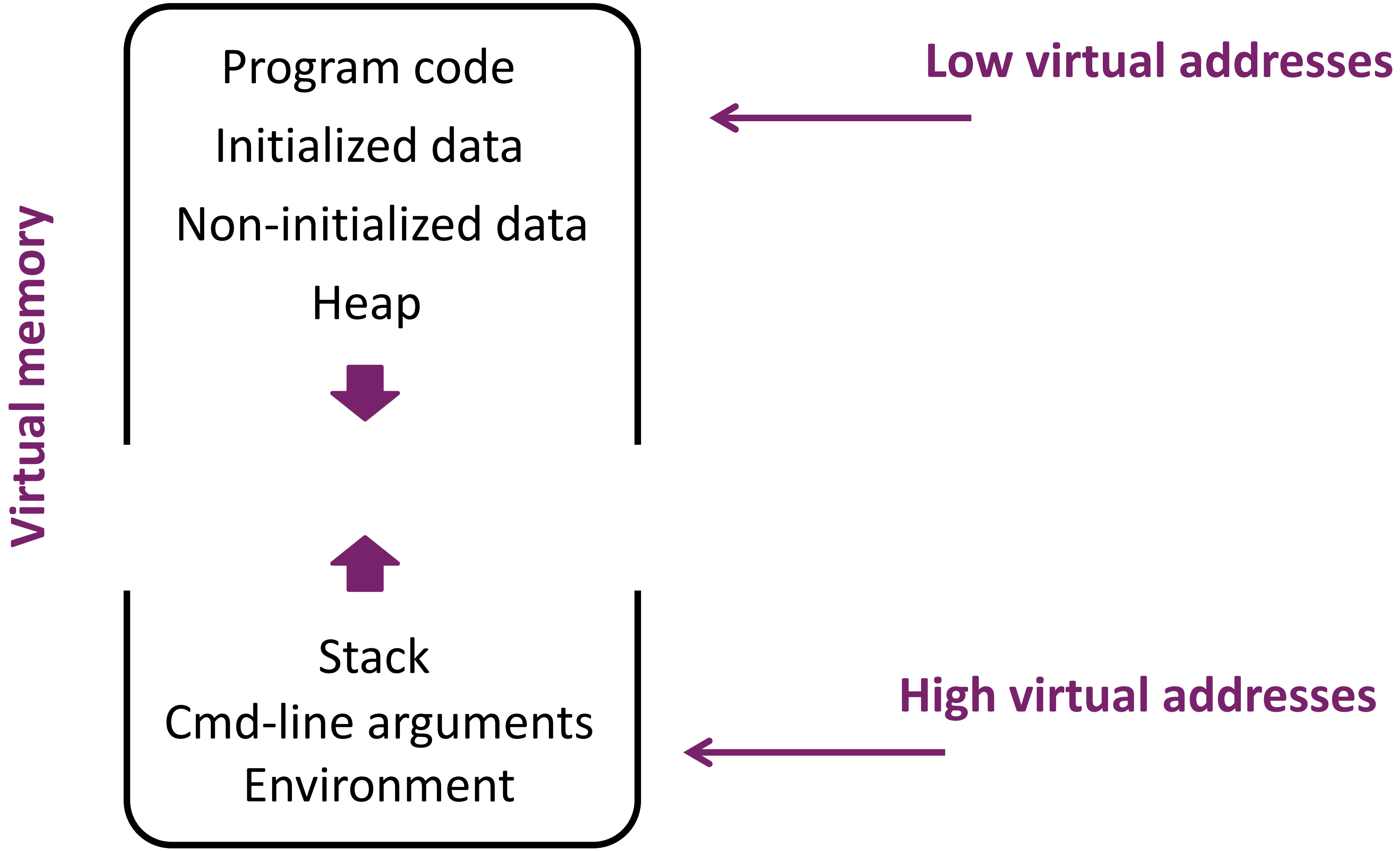
One measurement

```
Cmd-line> ./benchmark
Cmd-line> ./benchmark
Cmd-line> ./benchmark
```

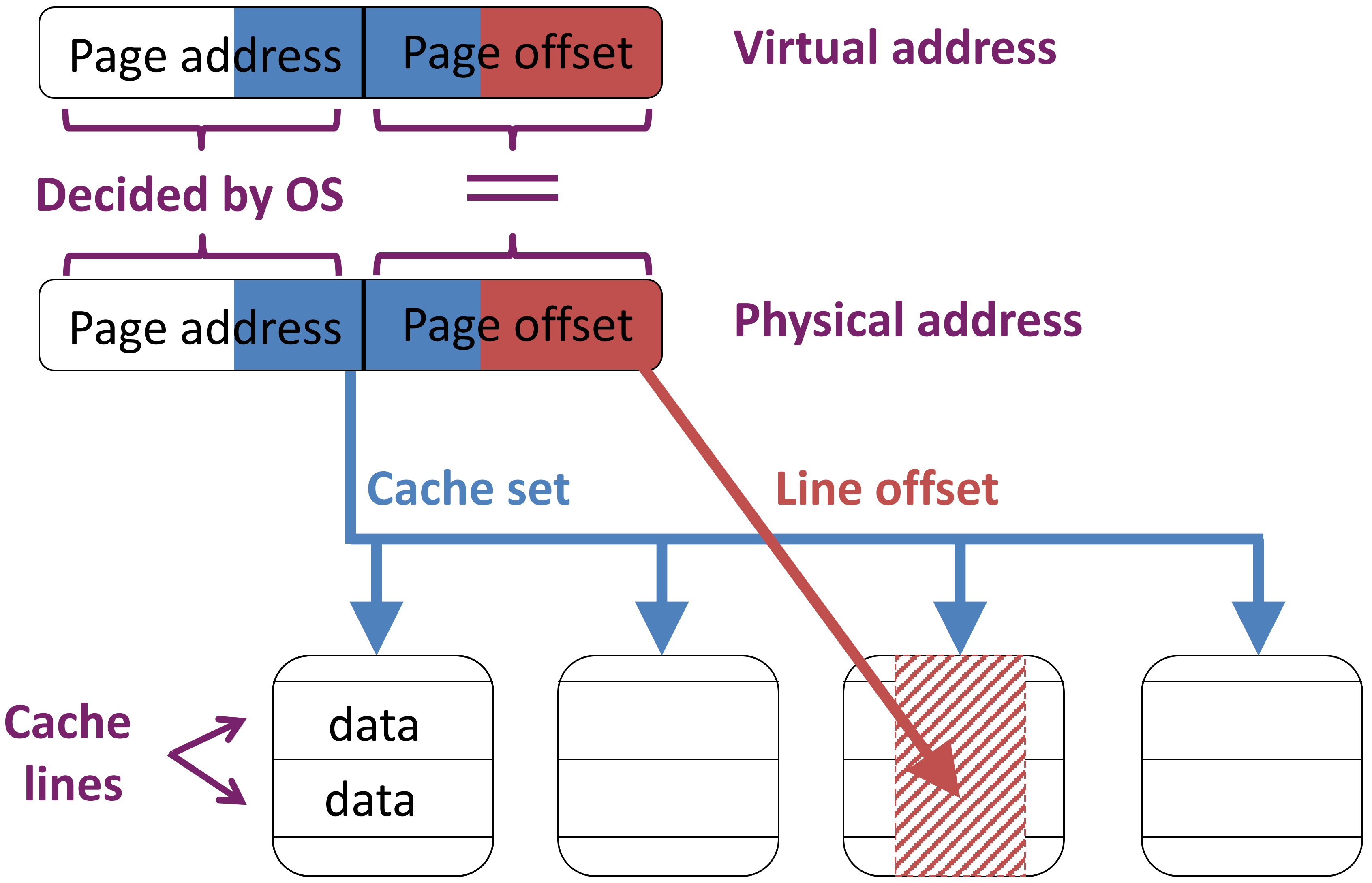
One execution

Non-determinism in execution is caused by cache & virtual memory

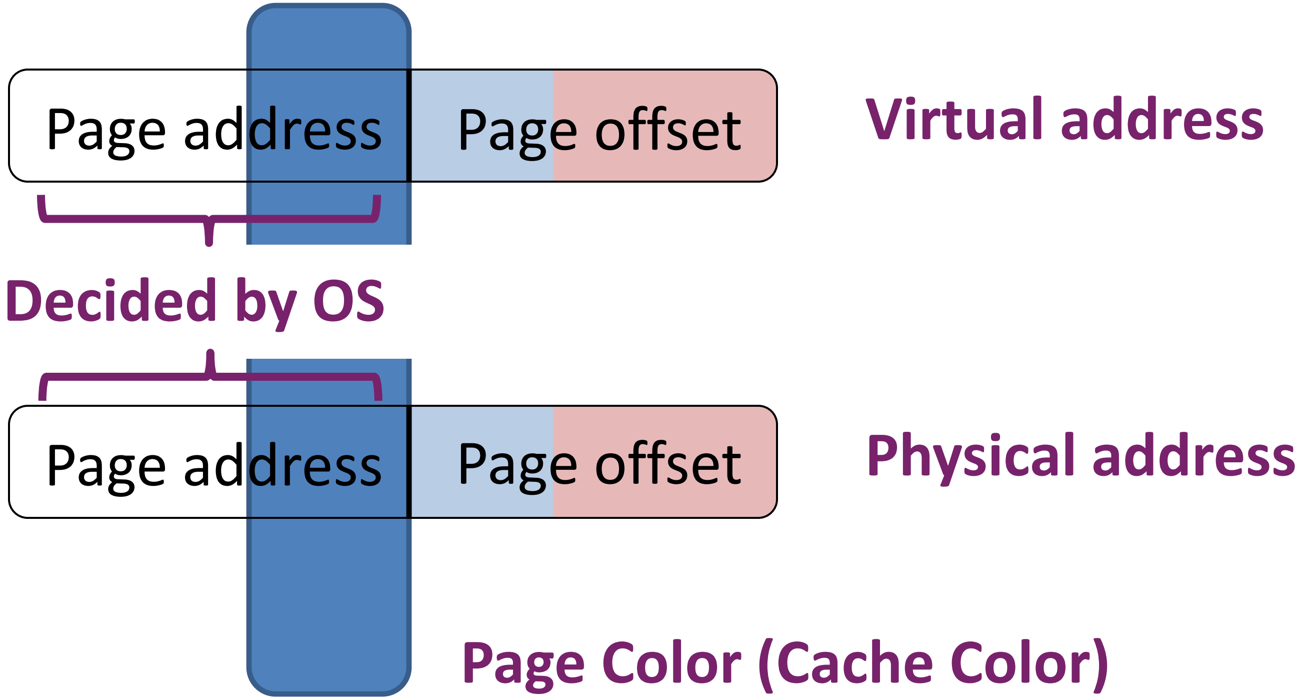
Application Memory Layout (Linux)



Cache and Addressing on Typical System



Page/Cache Color



- Operating system assigns colors to pages
- Data from pages of different colors do not collide in the cache

Could a cache-aware strategy for selecting page colors reduce non-determinism in execution ?

Good Old Cache-aware Strategies

- Page Coloring
  - Heuristic for “spatial locality”
  - Adjacent pages have different color – do not collide
  - Solaris, Windows, Free BSD
- Bin Hopping
  - Heuristic for “temporal locality”
  - Pages first accessed in sequence have different color
  - Digital Unix
- No Support in Linux

Our Contribution

- Linux Kernel extension for strategies
  - Supports bin hopping and page coloring as modules
  - Supports more: other strategies, application layer control, etc
- Large empirical study in Linux
  - 4500 benchmark experiments
  - Evaluation based on statistical methods

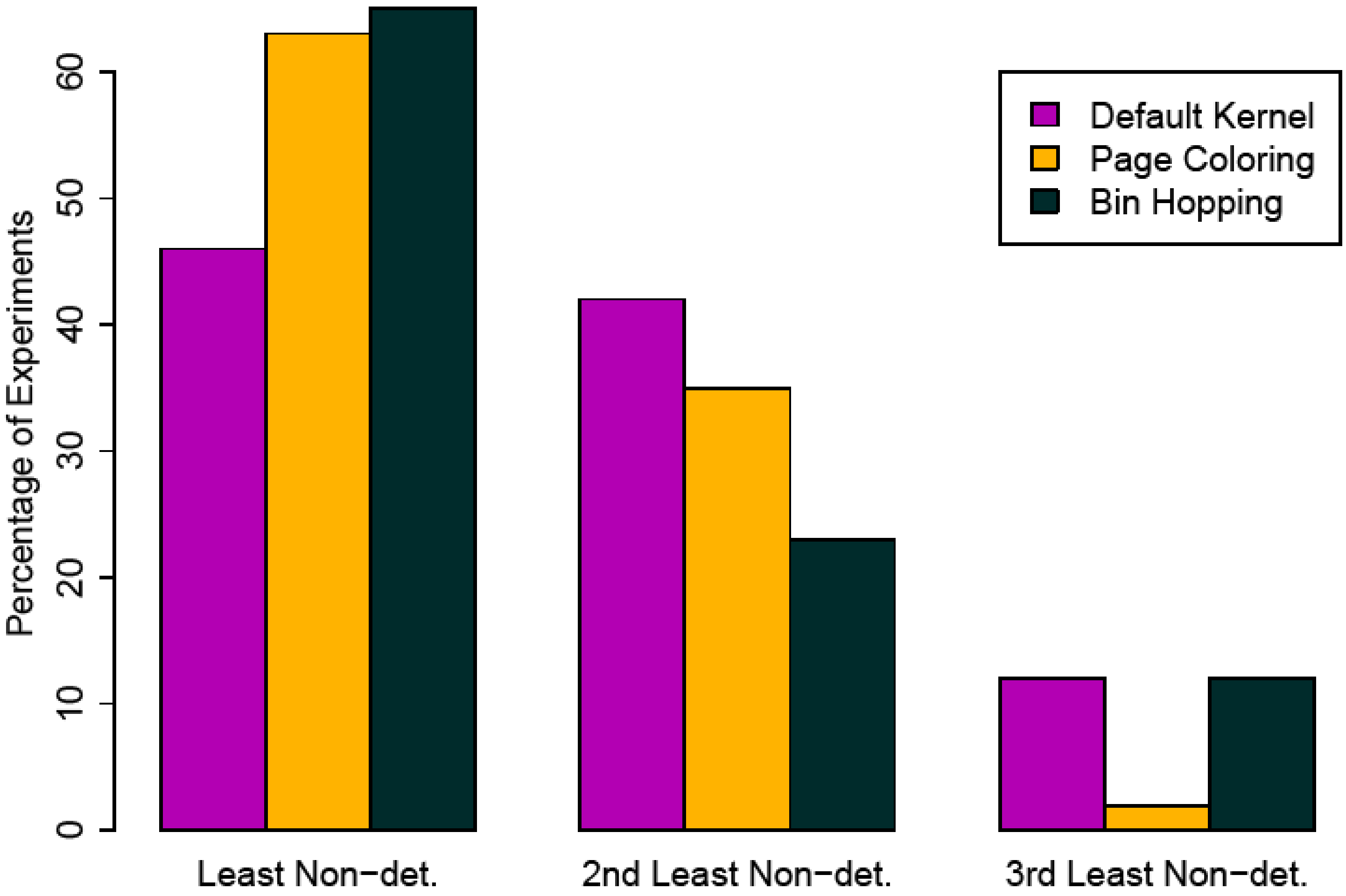
Benchmarks

- Mono (C#)
  - SciMark2 – FFT (numerical)
  - TCP/HTTP Ping (remote communication)
  - Rijndael (cryptography)
- SciMark2 (C, numerical)
  - FFT, Matrix Factorization, Monte Carlo, …
- Csibe (C/C++)
  - JPEG (multimedia compression)
  - GZIP, BZIP2, PNG (lossless compression)
  - Lexical analysis, abstract machine simulator, …

Evaluation Methodology

- Executed about 4500 experiments
- Question for evaluation:
  - *“Does page coloring or bin hopping provide lower response time/non-determinism than the default kernel strategy ?”*
- Metrics
  - Mean response time, impact factor of non-determinism
- Quantitative Summary
- Qualitative Summary

Non-det. in Execution: Quantitative Summary



Summary

- Response time
  - Cache-aware strategies don’t help
  - Page coloring performs like default, bin hopping is sometimes slightly slower
- Non-determinism
  - Cache-aware strategies reduce non-determinism
  - Bin hopping sometimes reduces a bit more than page coloring
- Our kernel extension allows to select a strategy on application basis