How's the Parallel Computing Revolution Going?

Towards Parallel, Scalable VM Services

Kathryn S McKinley

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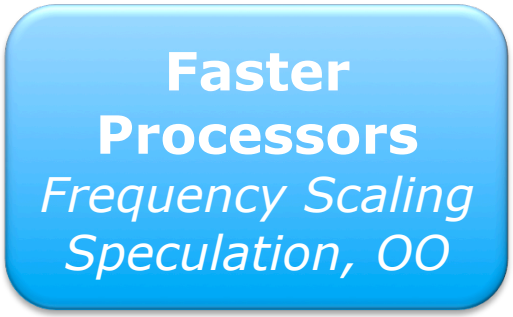
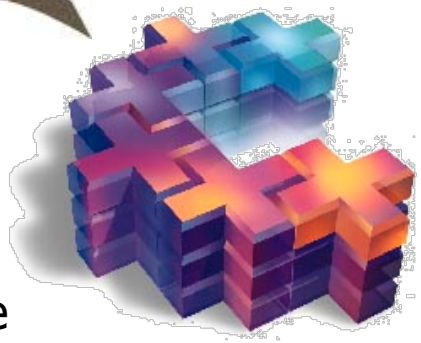
20th Century Simplistic Hardware View



programs do not change

they just run faster

Programming Language Evolution



Native Programming Languages

Managed Programming Languages

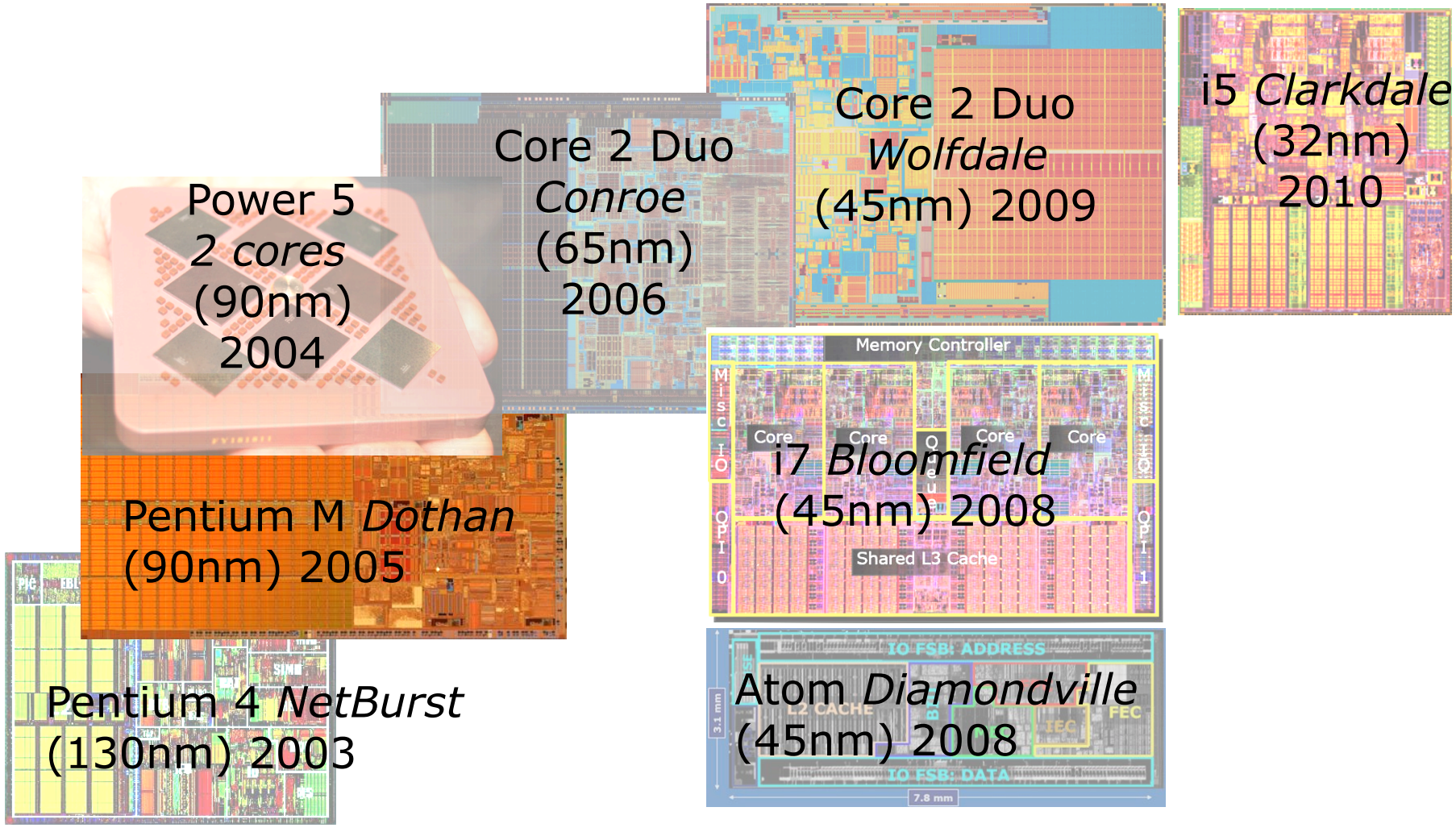
20th Century Simplistic Software View

Larger, More Capable Software
Managed Languages

hardware does not change

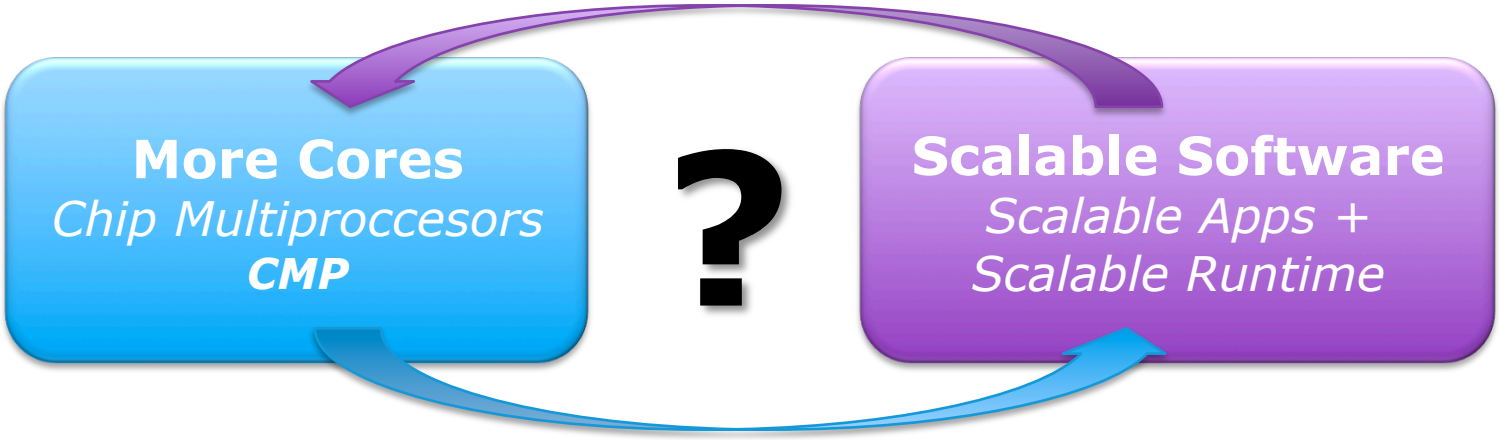
it just runs faster

Processor Technology Evolution



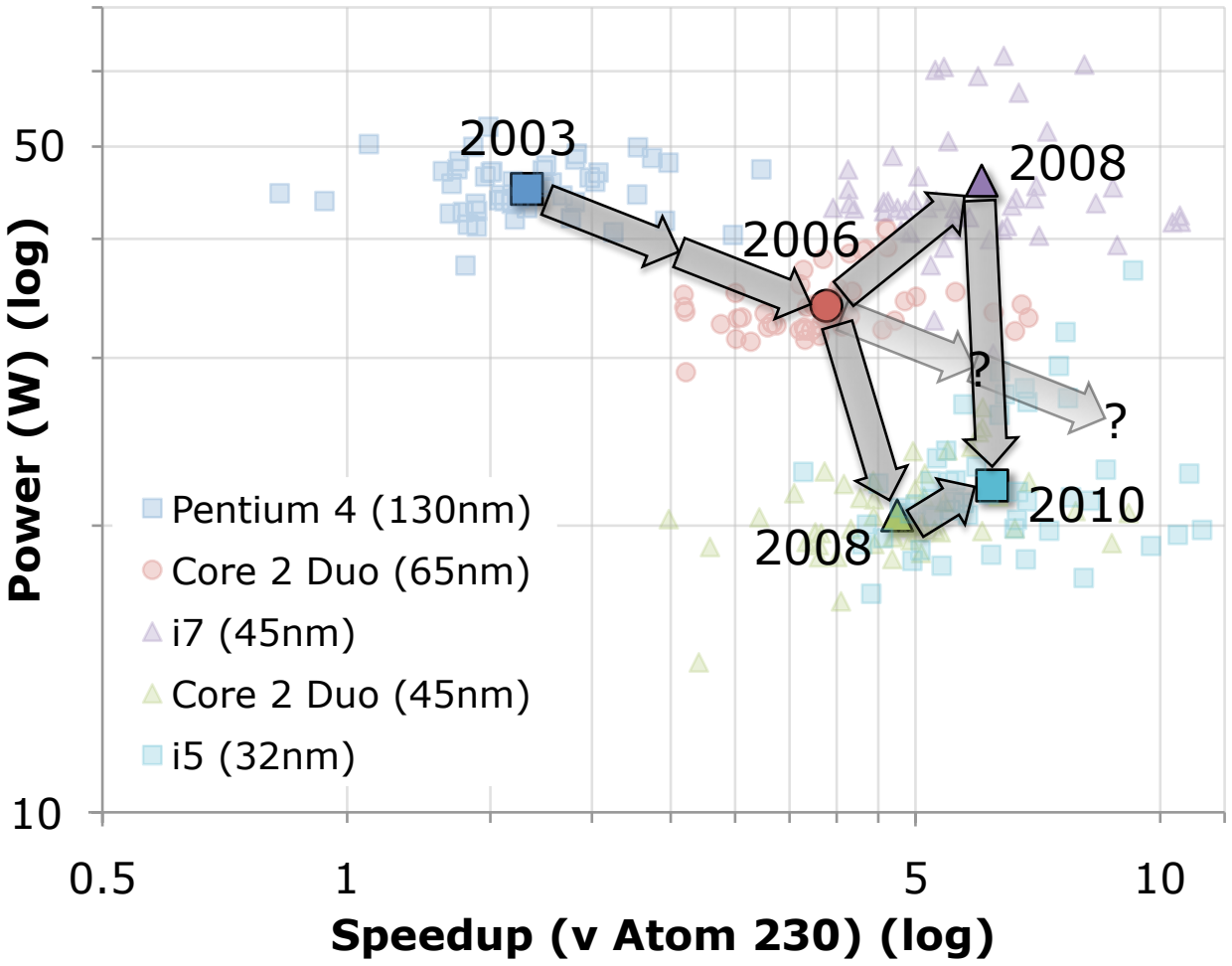
The 20th Century Virtuous Cycle

The 21st Century Virtuous Cycle?



How is this new virtuous cycle going?

Measured Power vs Performance



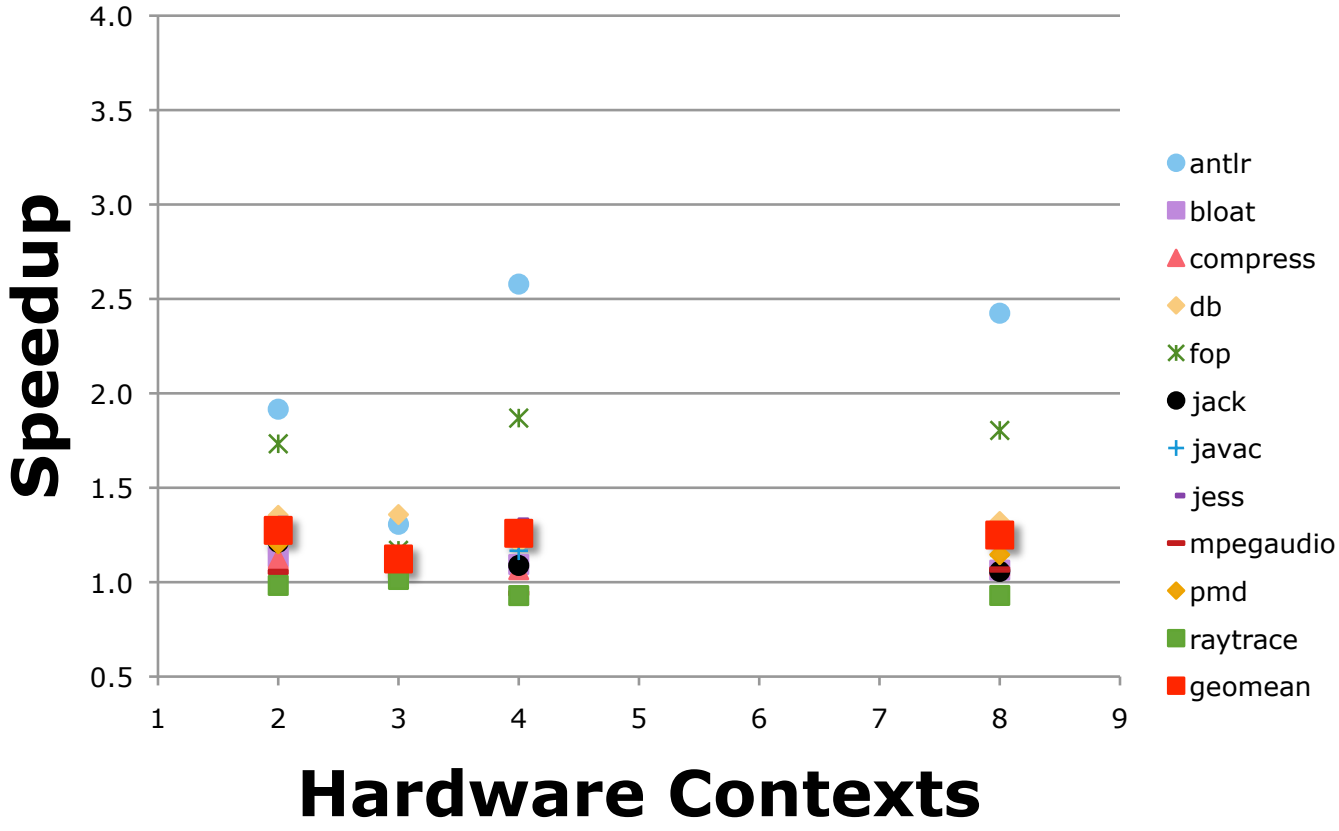
SPEC CPU 2006, DaCapo, SPEC jvm98

How is this new virtuous cycle going

for single threaded Java

Performance Scaling

Single Threaded Java Benchmarks
Core i7: 4 cores, 2 way SMT

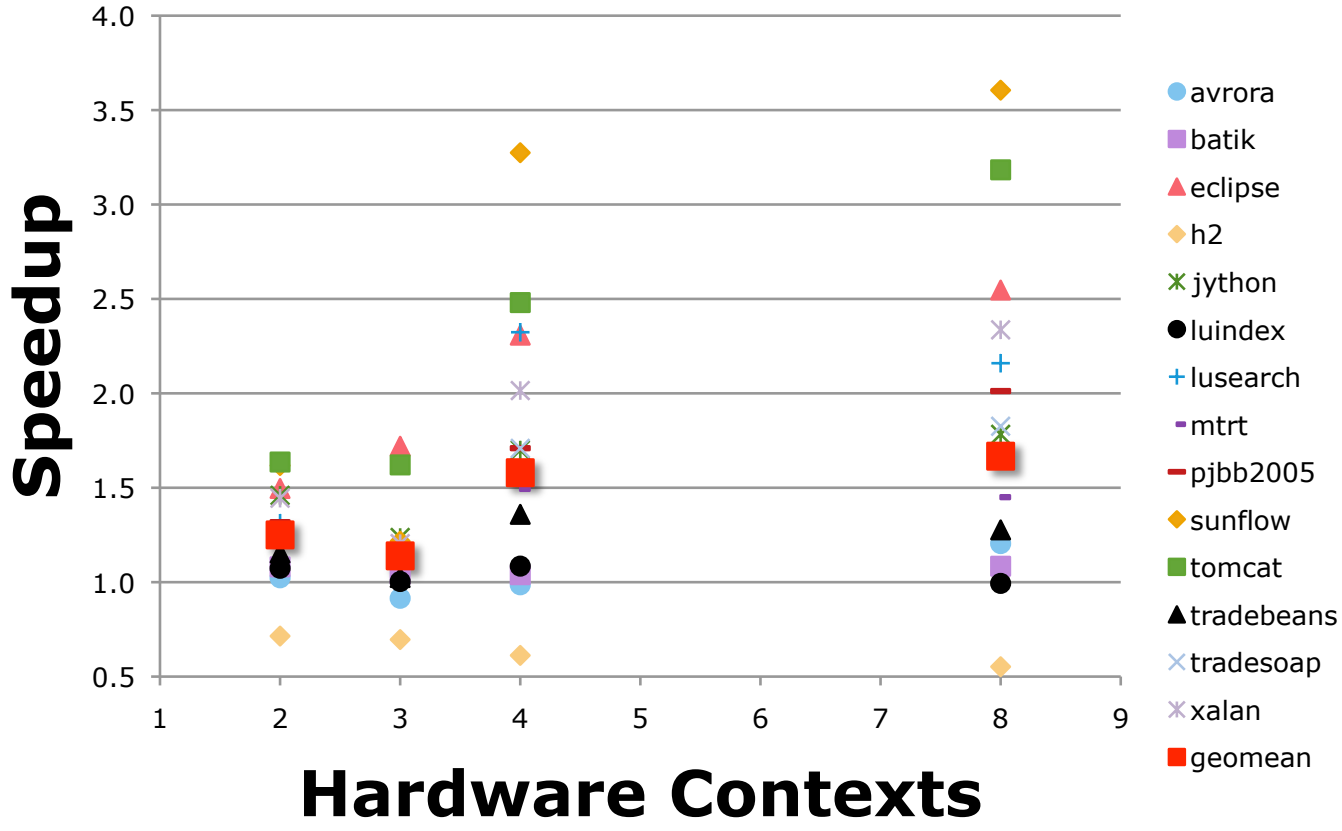


How is this new virtuous cycle going

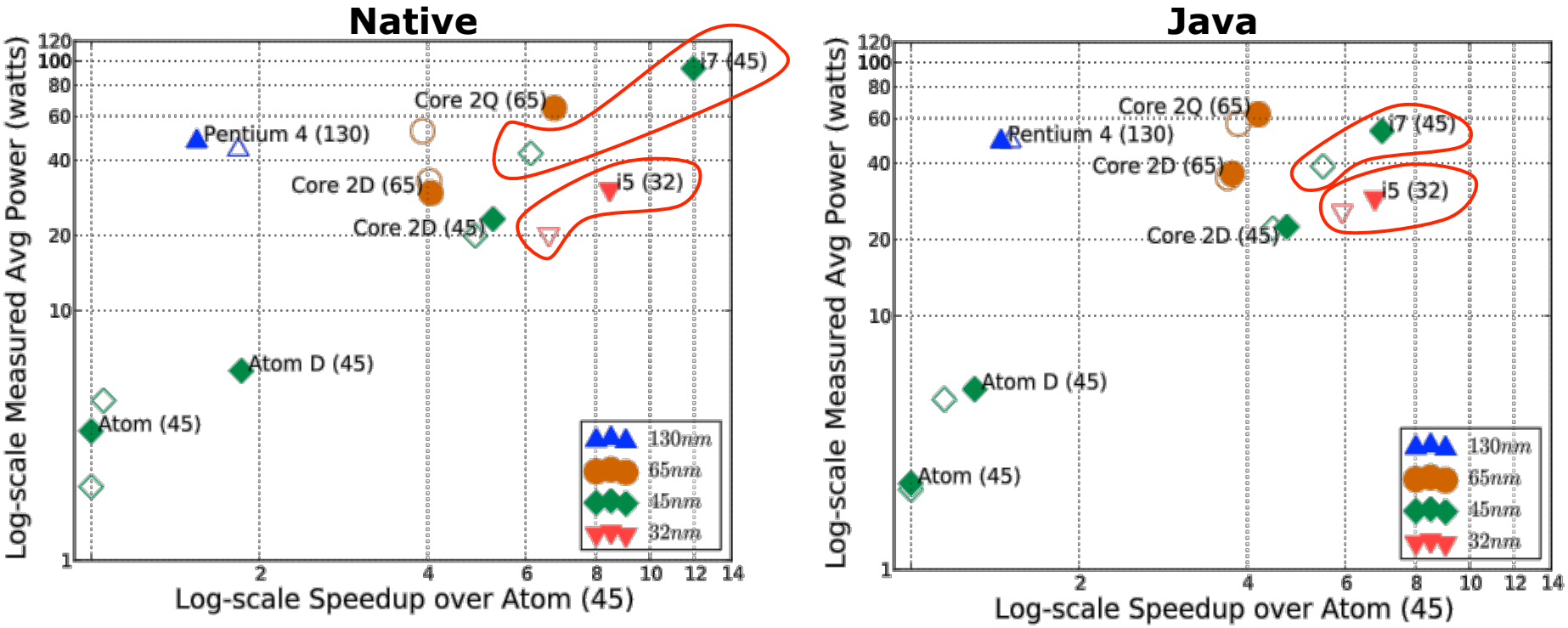
for multi-threaded Java

Performance Scaling

Multi-Threaded Java Benchmarks
Core i7: 4 cores, 2 way SMT



Power, Performance, and Concurrency



- **Single threaded hollow; multithreaded solid**
- Microarchitecture changes from Pentium 4 (130) to i5 (32) favored parallelism-no surprise
- Multithreaded performance incurs a significant power cost

Is there hope?

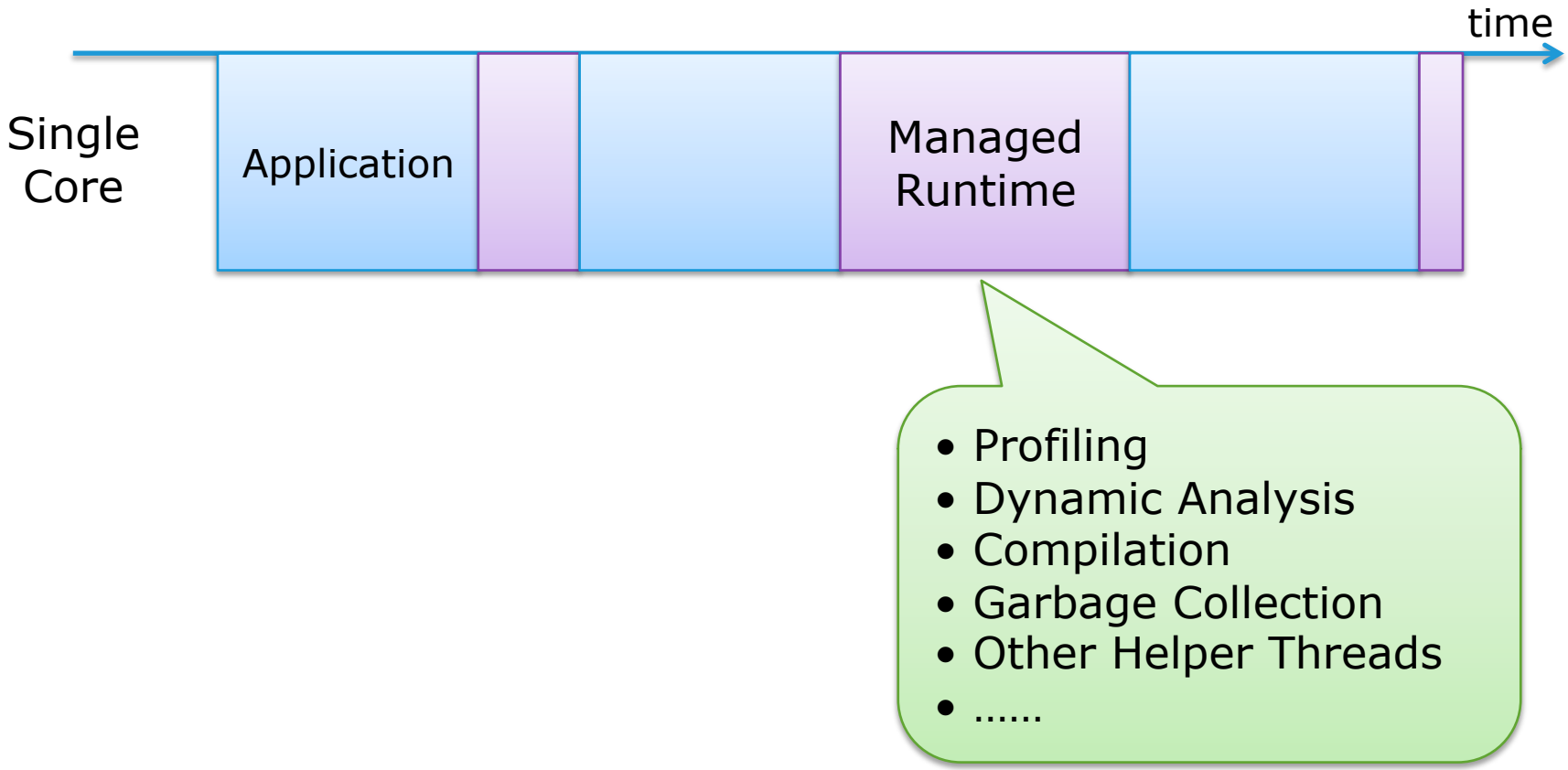
Managed Languages

Challenges & Opportunities

Must Start with a

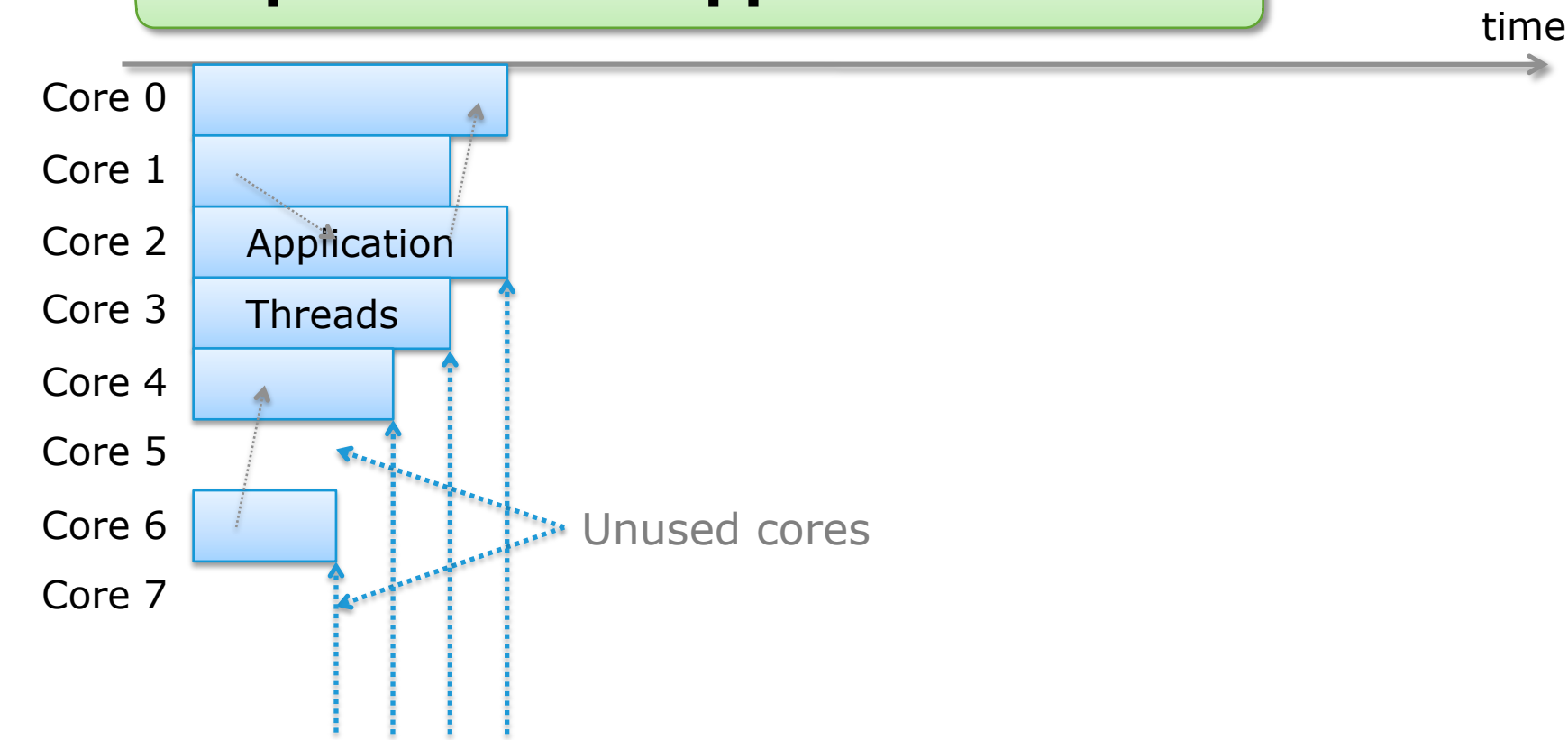
Scalable
Managed Runtime

Sequential Managed Programs



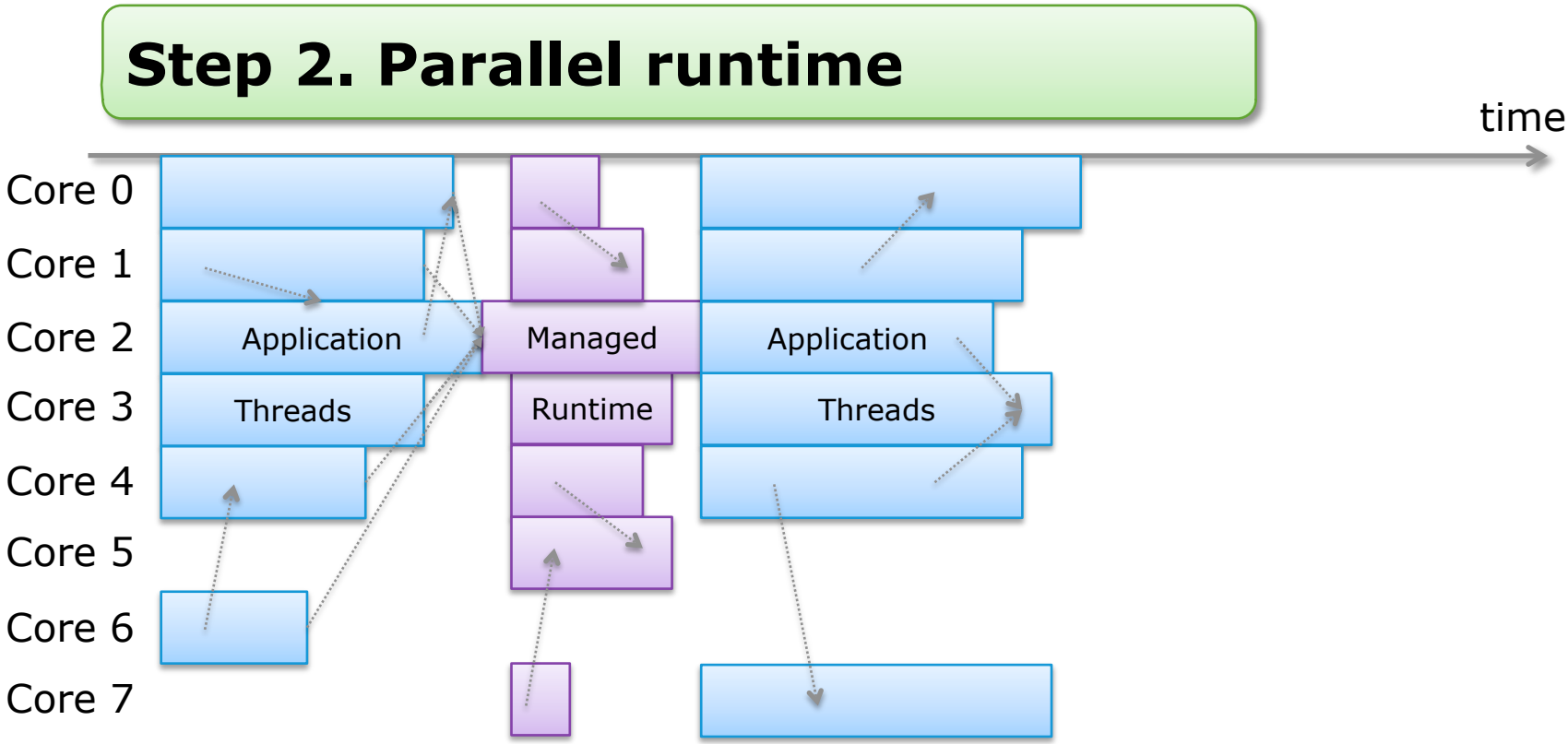
Steps towards scalability

Step 1. Parallel application



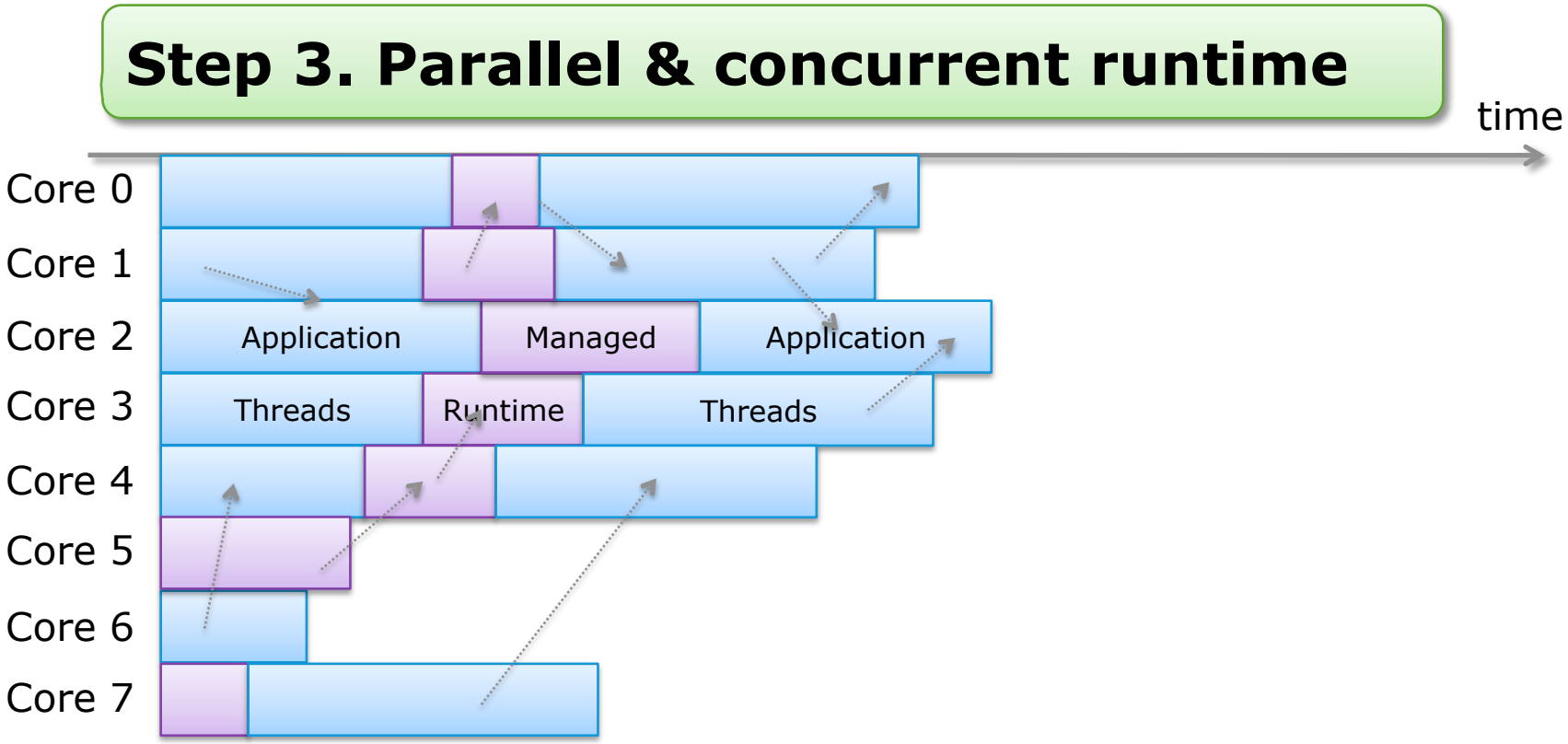
Each thread has different running time

Steps towards scalability



Runtime waits for all application threads to pause

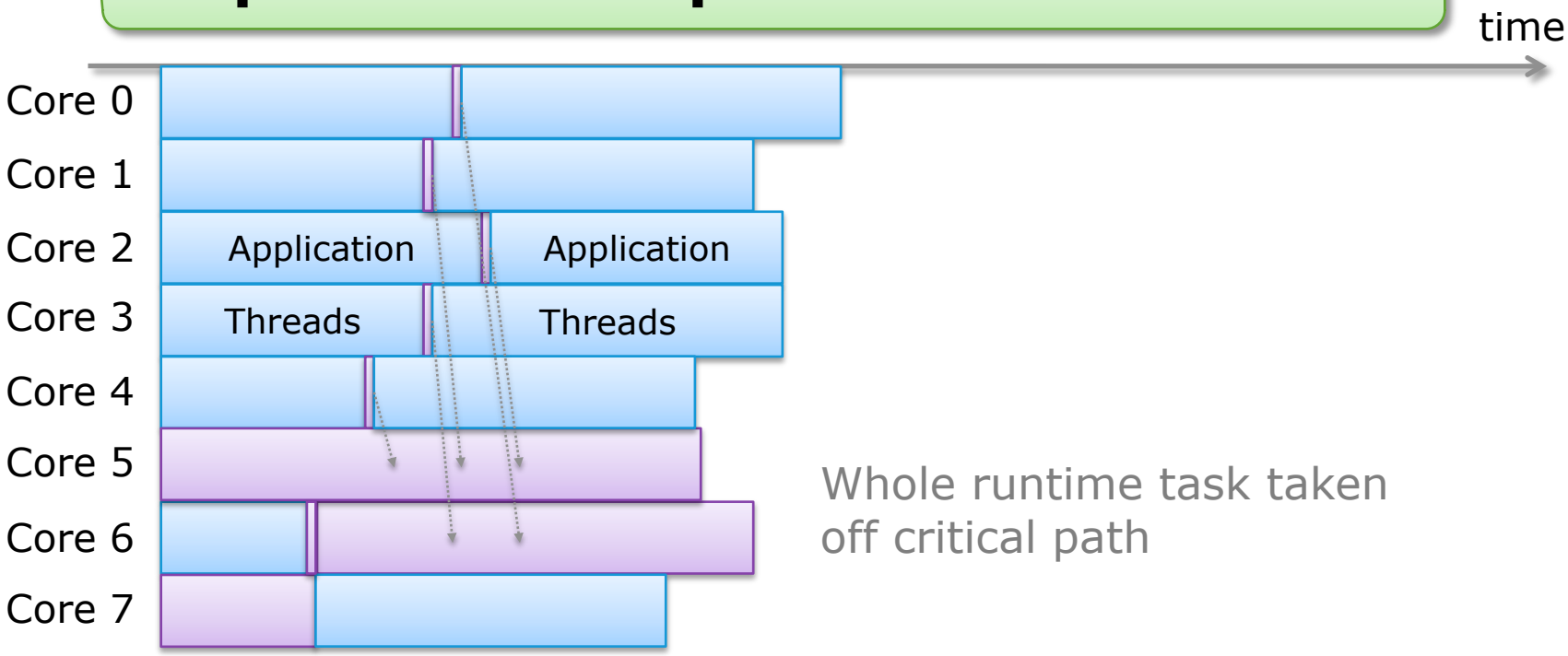
Steps towards scalability



Managed runtime on application's critical path may perturb its performance

Steps towards scalability
Ideal model

Step 4. Minimize perturbation

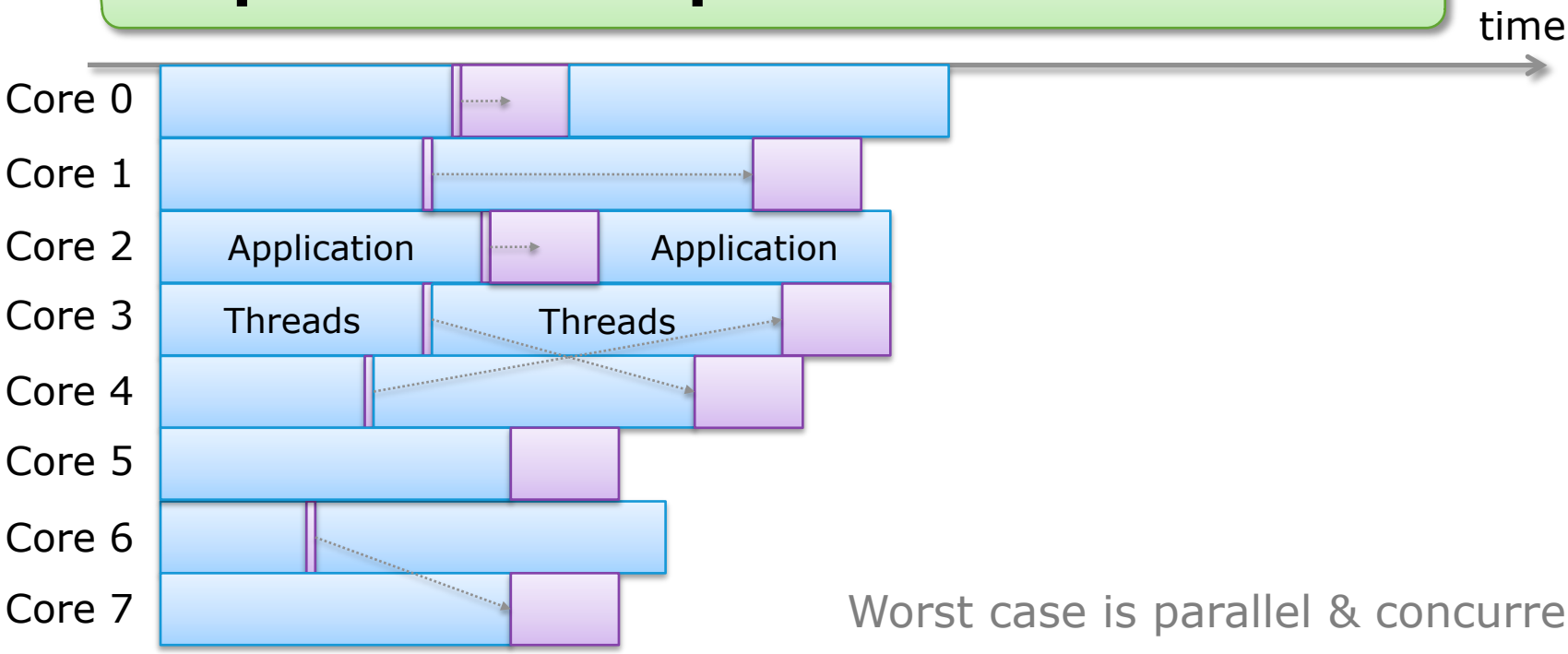


Whole runtime task taken off critical path

Application offloads work to concurrent runtime threads

Steps towards scalability
Ideal model

Step 4. Minimize perturbation



Worst case is parallel & concurrent

Vision

- **Scalable Runtimes**
  - Runtime & application parallelism & concurrency
  - CMP aware runtime improves application scalability
- **Communication**
  - Cache coherency is expensive and performance sensitive
  - Memory bandwidth scaling is problematic
- **Heterogeneity**
  - Move non-critical path off power-hungry cores
  - Smarter, more aggressive analysis
- **Specialization?**
  - Tuned cores? Special purpose cores?

Approach

- **Profiling** (feedback directed optimization)
  - Concurrent analysis
  - More invasive analysis on low-power cores
- **GC**
  - High performance concurrent GC
  - High performance non-moving GC
  - Reduced synchronization overheads
  - Distributed & scratchpad GC
- **JIT**
  - Concurrent, parallel JIT
  - Cost-benefit shift as low-power cores used
- **Architecture**
  - Tuned and/or specialized cores for runtime services
  - Coherence tailed for restricted, common case of GC

Today

- **Profiling** (feedback directed optimization)
  - Concurrent analysis
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- **GC**
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A Concurrent Dynamic Analysis Framework For CMP Hardware

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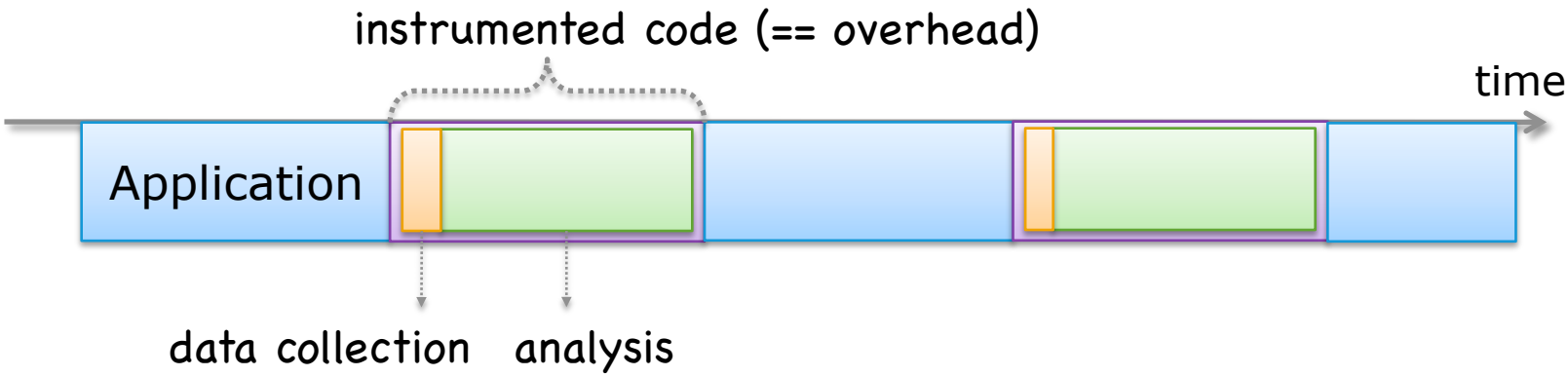
Australian National University

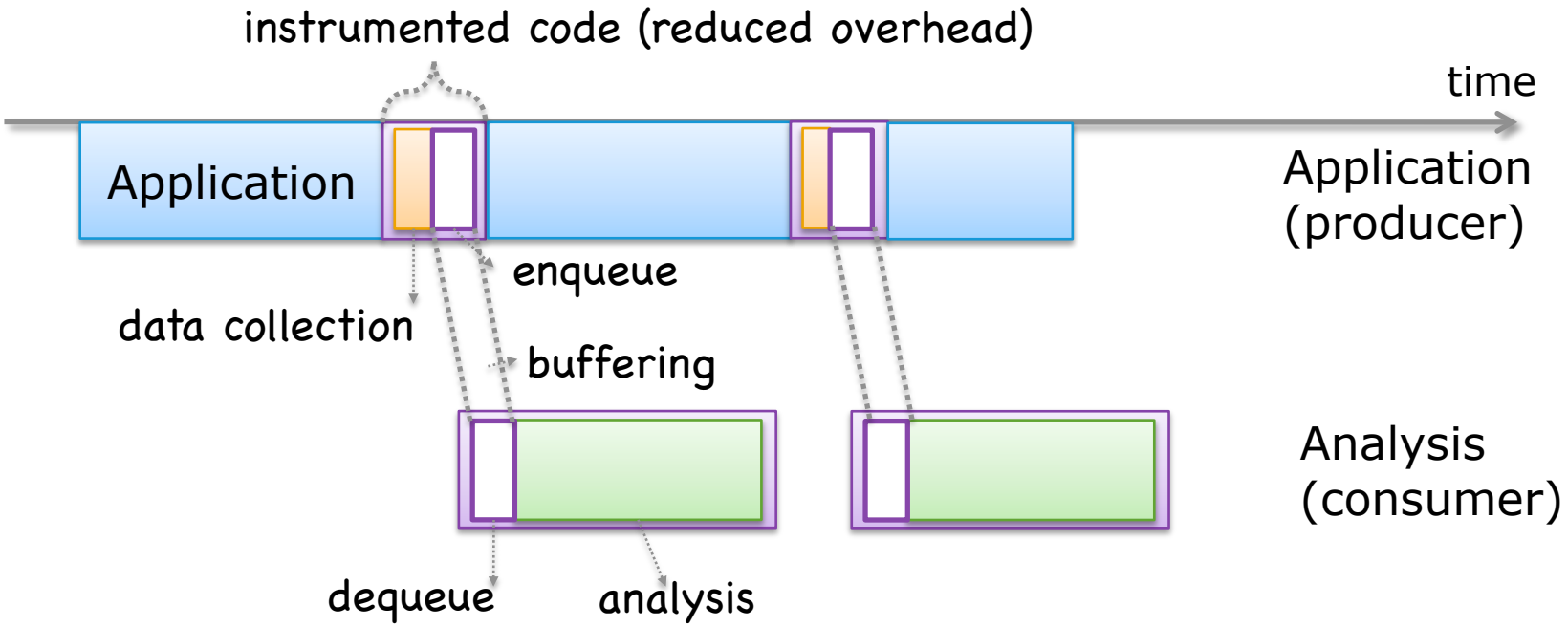
Kathryn S. McKinley
University of Texas at Austin

Generic Sequential Analysis



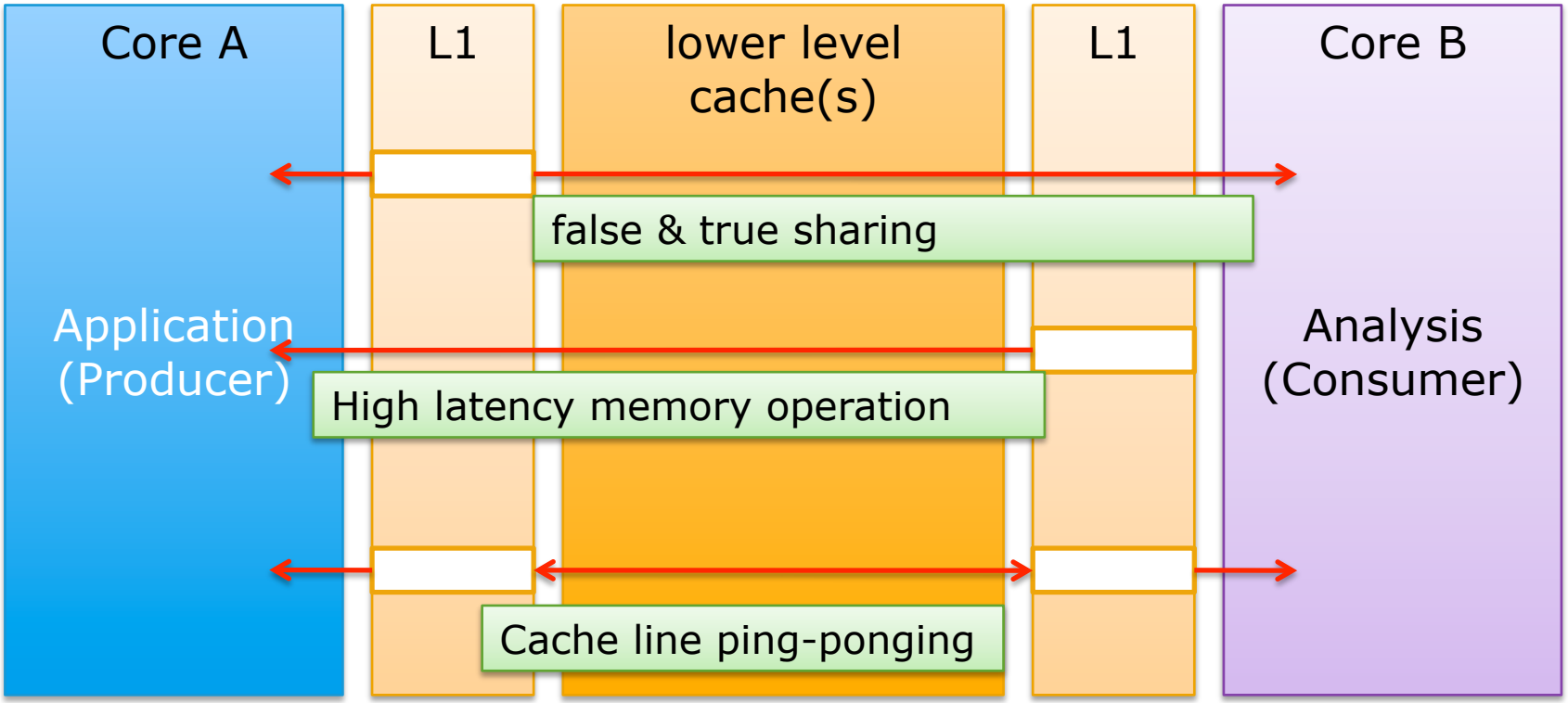
- Difficult to optimize instrumented code
- Trade accuracy for overhead (sampling)

Generic Concurrent Analysis



- Lower overhead & higher accuracy
- Must deal with microarchitectural side-effects

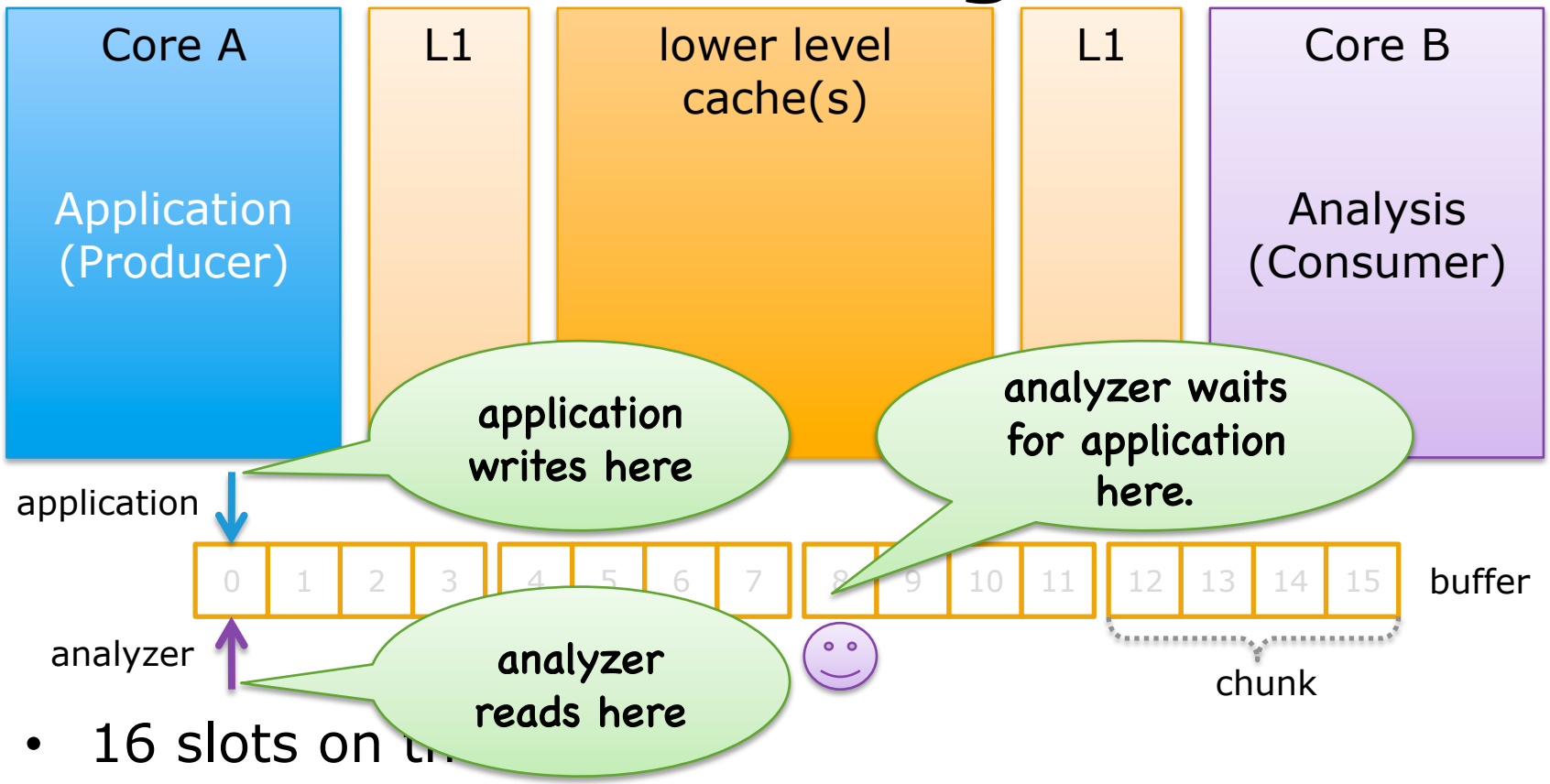
Side-effects to Avoid



Cache-friendly Asymmetric Buffering

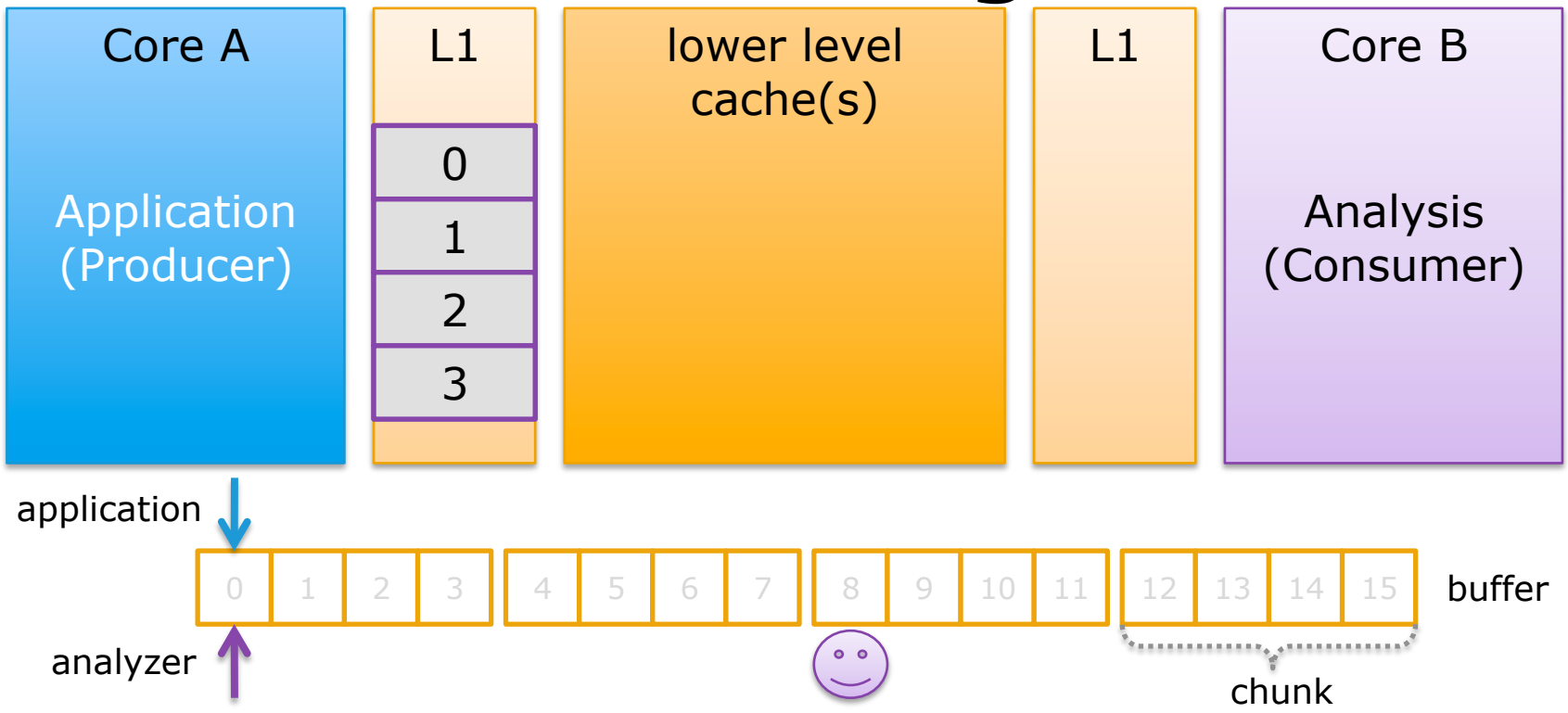
- **Lock-free** communication channel between application and analysis thread
- Cache-friendly asymmetric buffering
  - Actively avoids microarchitectural side-effects
  - **Enqueue**
    - light-weight instrumentation
    - produces one record at time
  - **Dequeue**
    - consumes one chunk (fraction of a buffer) at a time

Cache-friendly Asymmetric Buffering



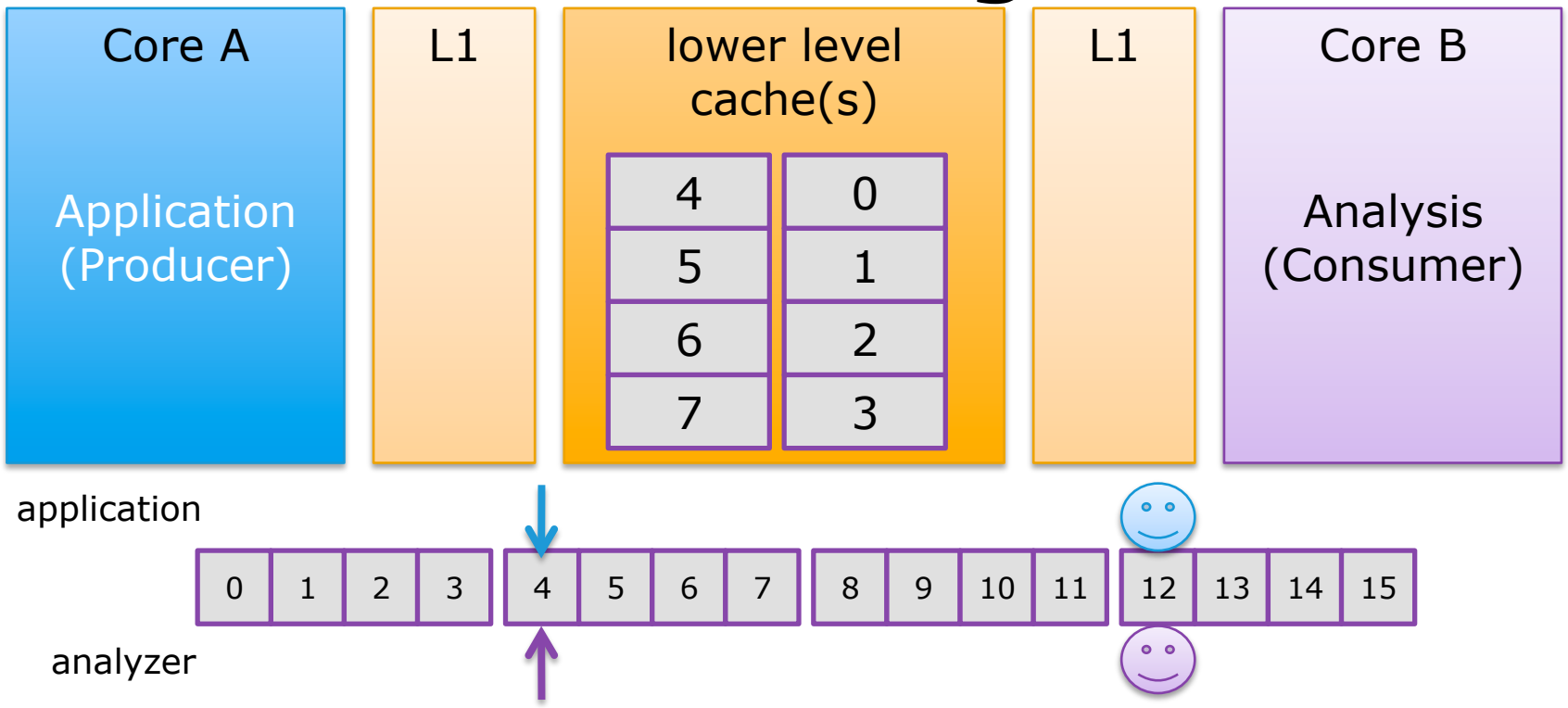
- 16 slots on t
- 4 chunks, 4 slot on each chunk
- L1 size == chunk size

Cache-friendly Asymmetric Buffering



- Delay consumer dequeue operation until cache line is flushed
  - 2 chunks away (smiley location)
- Analyzer operates one chunk at a time
  - chunk_size > L1 size
  - In practice, chunk_size >= 2 * L1 works well.

Cache-friendly Asymmetric Buffering



- application blocks only when buffer is full
  - waiting until two more chunks are available

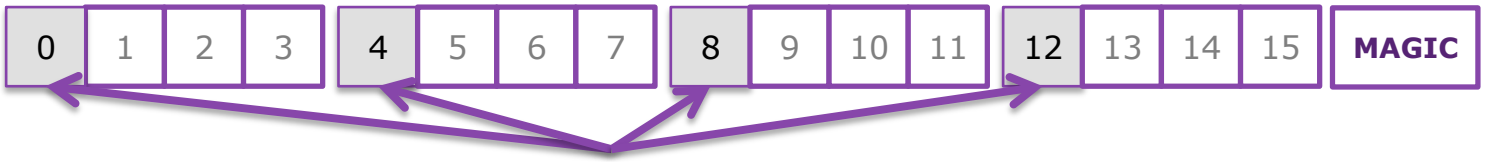
Cache-friendly Asymmetric Buffering

Producer (sees buffer)

```
while (*bufptr != 0) {
    if (*bufptr == MAGIC)
      bufptr = buffer;
    if (*bufptr != 0)
      block();
}
*bufptr++ = data;
```

Consumer (sees chunk)

```
while (app_is_running) {
    index = index_of(chunk_num+2);
    while (buffer[index] == 0)
          spin_or_sleep(); consume
    (chunk_num);
    chunk_num = NEXT(chunk_num);
}
```



Consumer only spins here

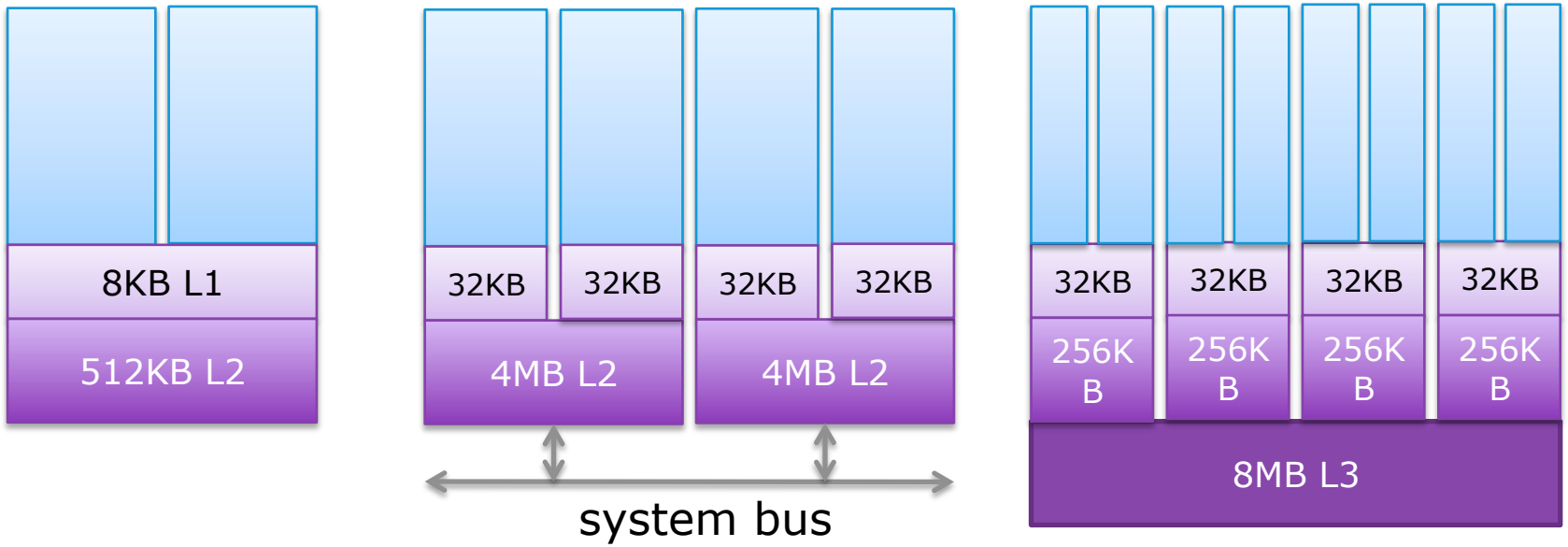
- producer may spin on *bufptr*, while consumer may spin on buffer
- Producer code common case is 6 instructions in x86.

Framework Provides …

- Cache-friendly Asymmetric Buffering (CAB)
  - Minimizes microarchitectural side-effects
  - Quickly offloads event data from application's critical path
- Configurable parameters for optimization
  - buffer size & chunk size
- Various collection mode
  - Exhaustive mode
  - Sampling mode
- Works on various threading model
  - N:M (green) threading model
  - native threading model

Evaluation

- 3 different CMP processors



Pentium 4 w/ hyperthreading

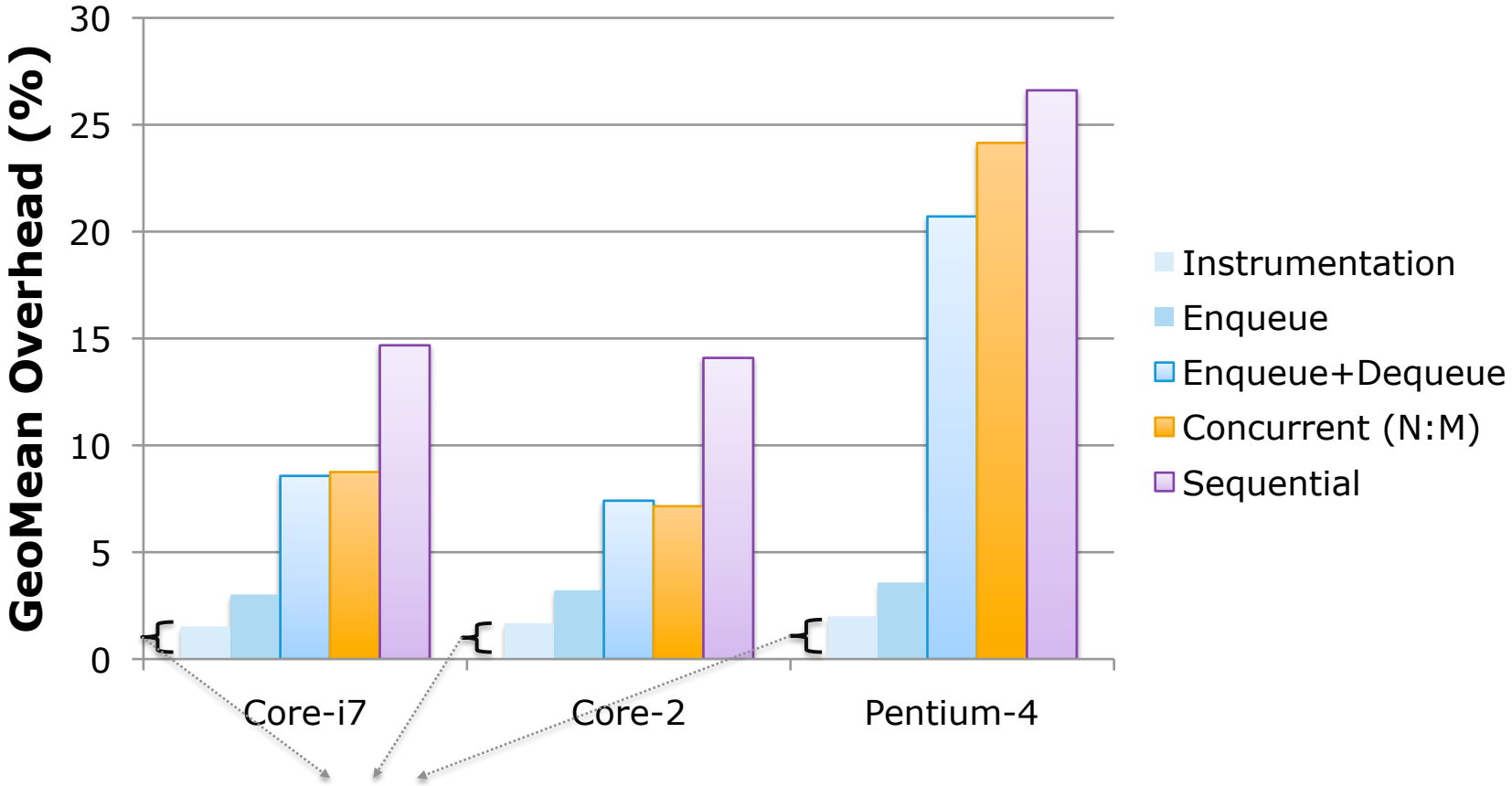
Core 2 Quad

Core i7

Evaluation

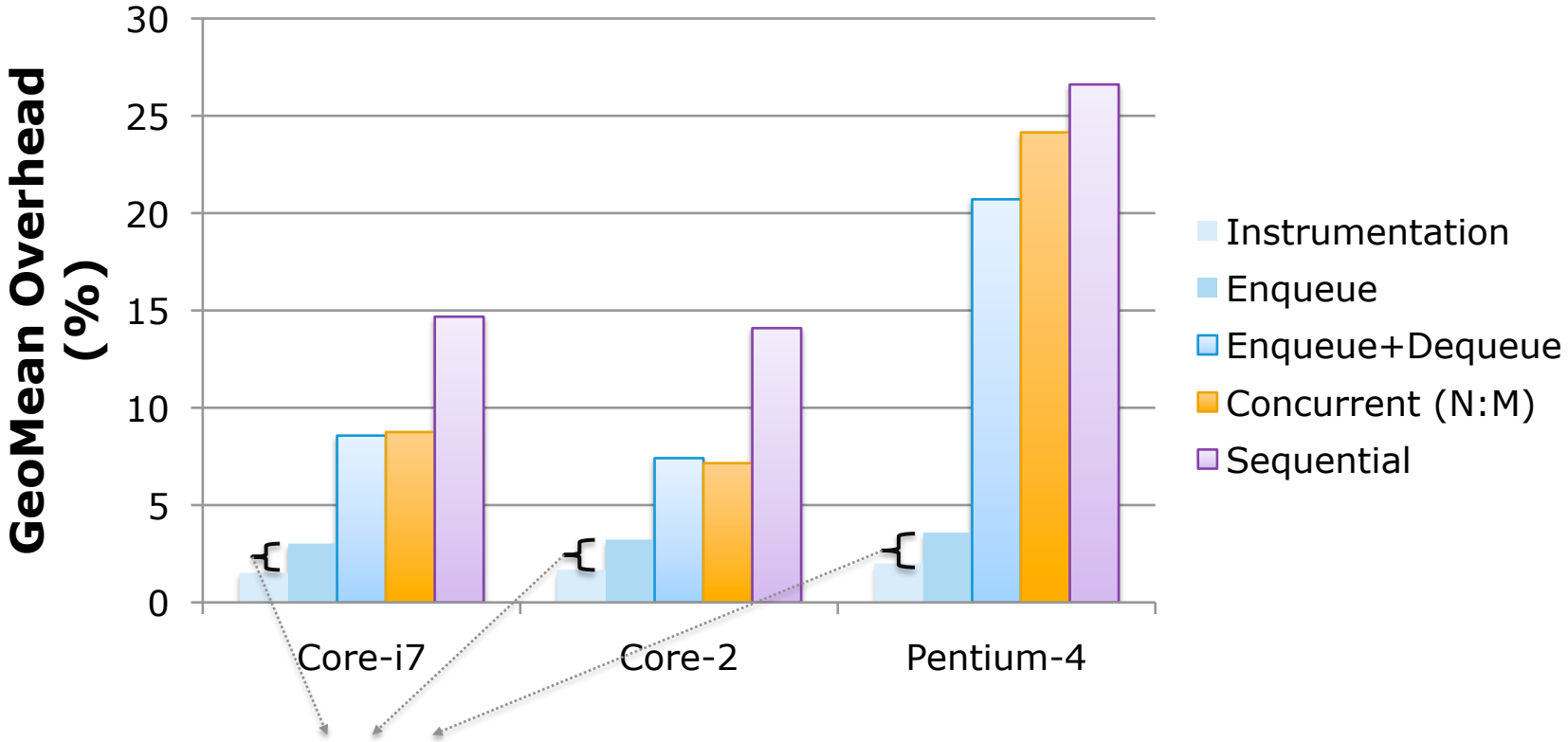
- Jikes RVM (2 different threading models)
  - N:M threading (Jikes RVM 2.9.2)
  - Native threading (Jikes RVM 3.0.1)
- Reference Dynamic Analysis Implementation
  - Method counting
  - Call graph
  - Call tree profiling
  - Path profiling
  - Cache simulator using load/store events
- Benchmarks
  - DaCapo, SPEC JVM 98 benchmark suites
- Parameters
  - buffer size = 2MB, chunk size = 128KB

Call Graph Profiling



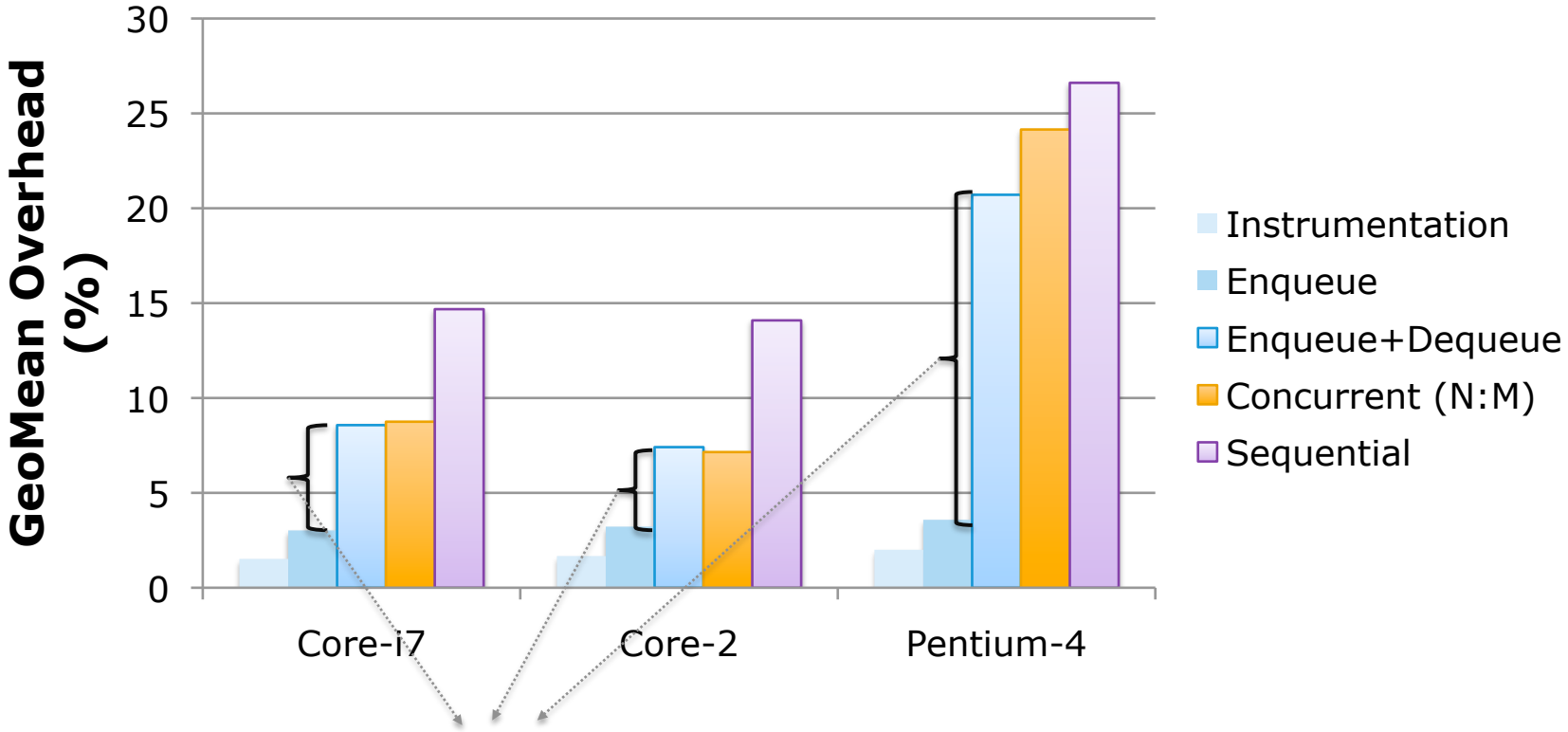
- **Instrumentation Overhead** – *Bar 1*
- Bar1 – Collect event data and write into a single word. No analysis thread

Call Graph Profiling



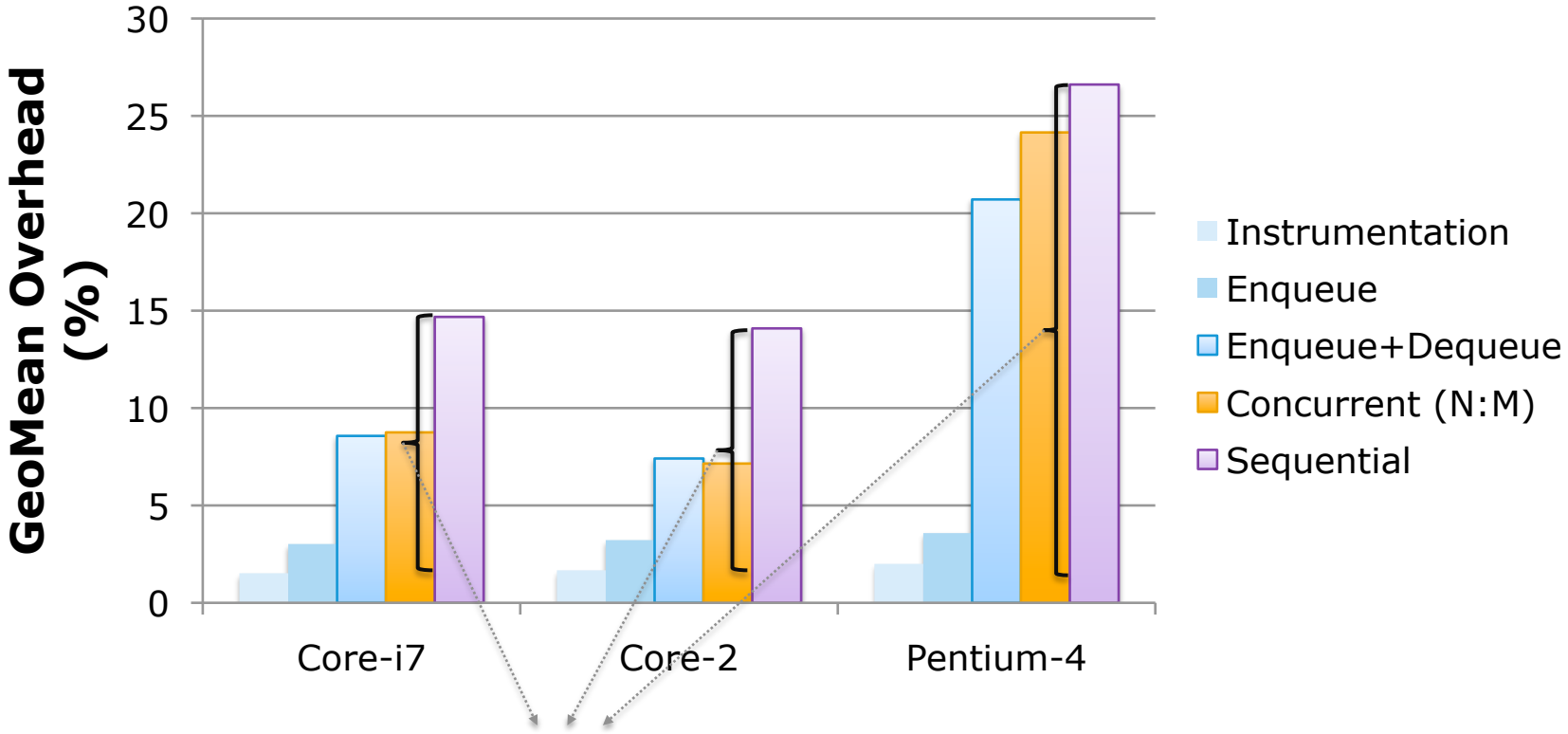
- **Enqueueing Overhead** – *(Bar2 - Bar 1)*
- Bar2 – Collect event data and write into the buffer. No analysis thread

Call Graph Profiling



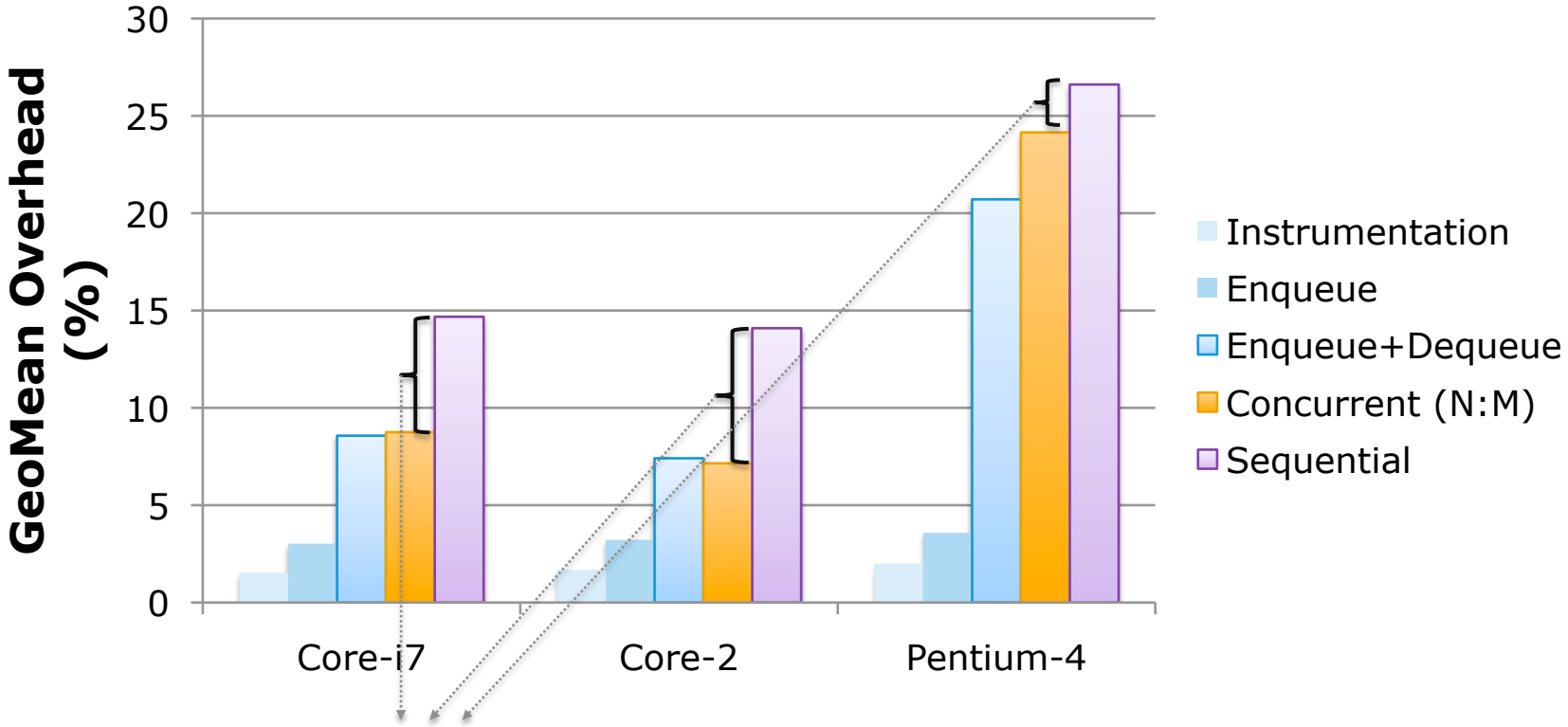
- **Communication Overhead** – *(Bar3 – Bar 2)*
- Bar3 – Analysis thread dequeues and write it into a single word.

Call Graph Profiling



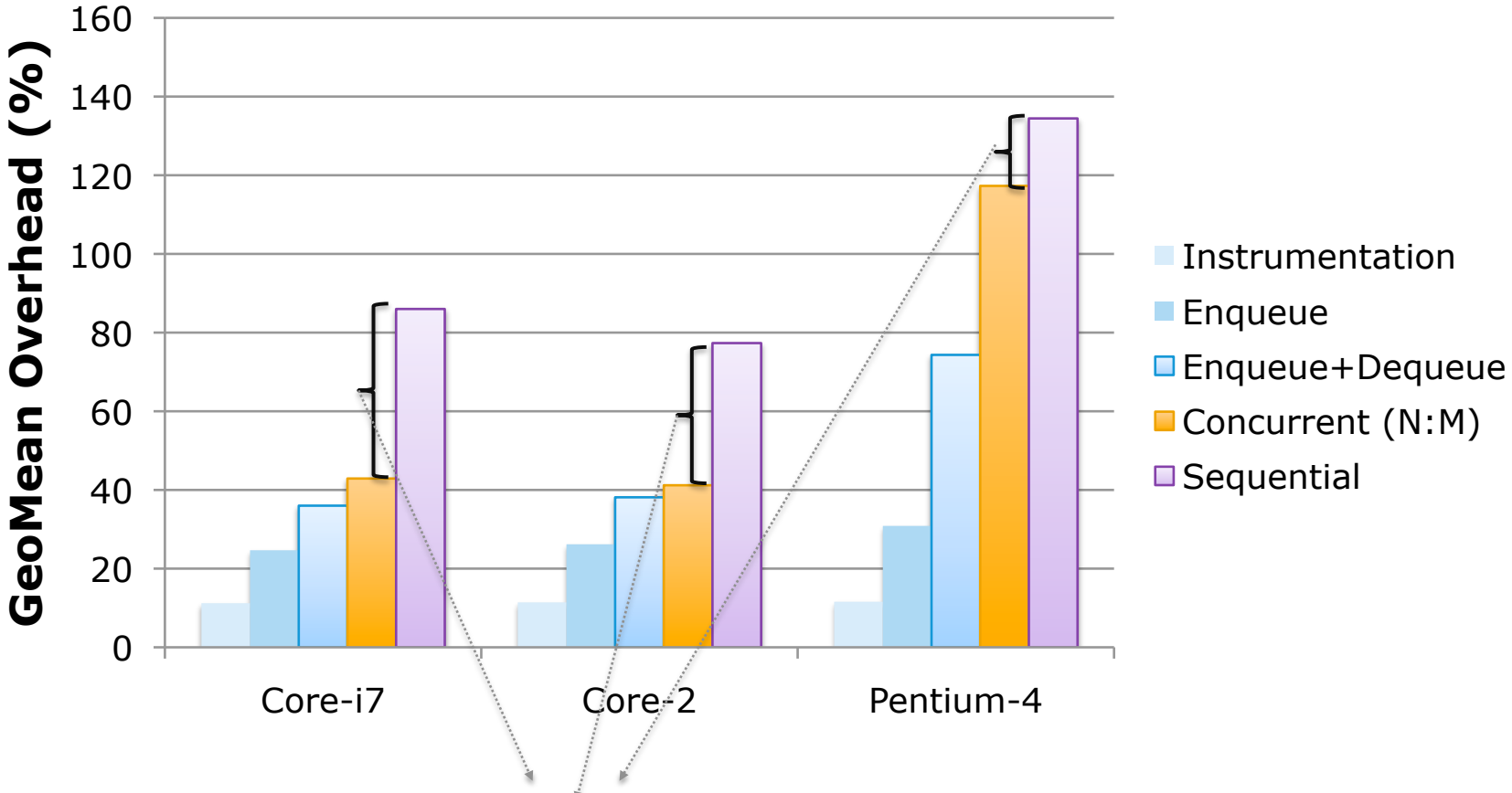
- **Analysis (data processing) Overhead** – *(Bar 5 – Bar 1)*
- Bar4 – Concurrent Analysis
- Bar5 – Sequential Analysis

Call Graph Profiling



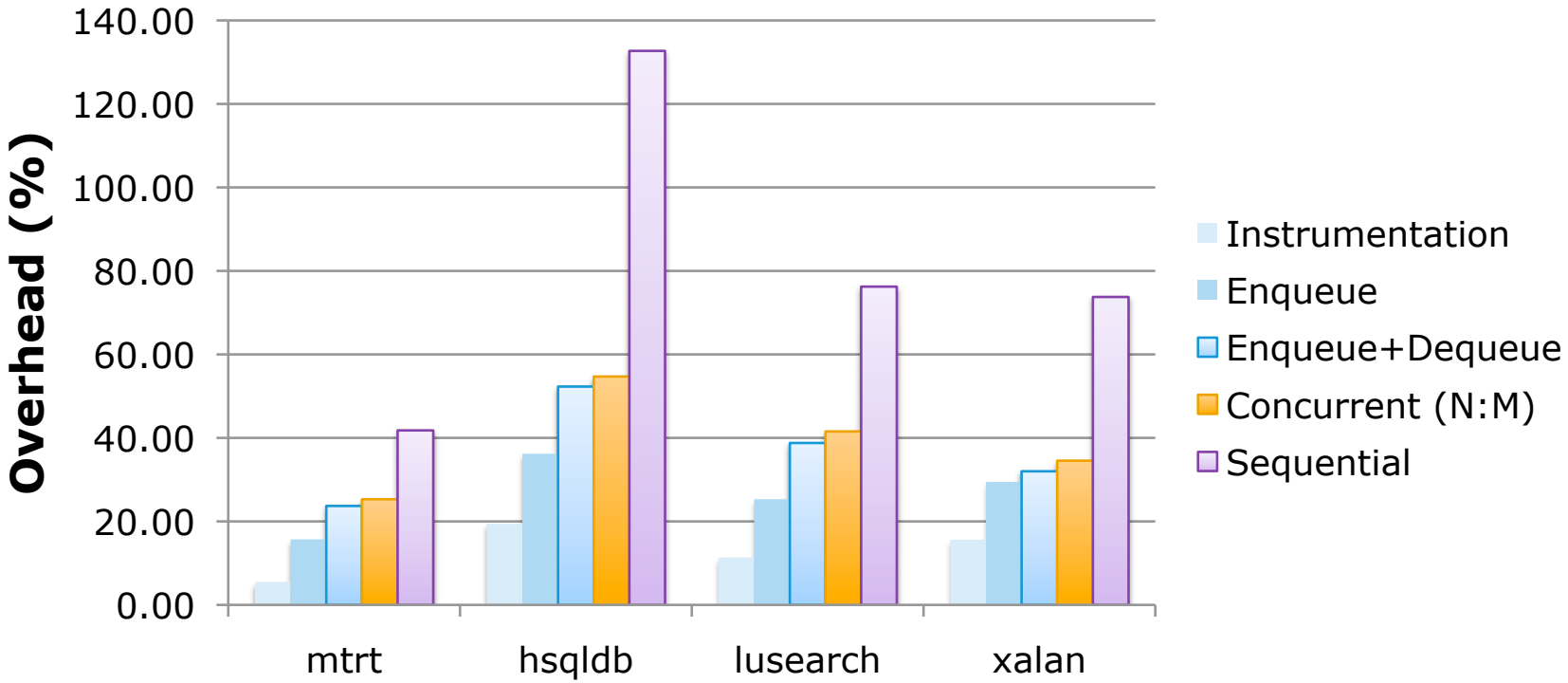
- **Overhead reduction with Concurrent Analysis** – *(Bar 5 – Bar 4)*
- Bar4 – Concurrent Analysis
- Bar5 – Sequential Analysis

Path Profiling



- **Overhead reduction with Concurrent Analysis** – *(Bar 5 – Bar 4)*
- More data & computation than call graph

Path Profiling Multithreaded Benchmarks



- Core 2
- Multi-threaded benchmarks

Concurrent Dynamic Analysis Framework

Conclusions

- Framework eases implementation of many client analyses
- CAB efficiently transfers application data to analysis thread avoiding microarchitectural side-effects
- Framework efficiently utilizes extra cycles to perform dynamic analysis concurrently

Related Work

- Concurrent Lock-free Queue
  - FastForward – single-producer & single-consumer [Giacomoni et al. 09]
- Concurrent analysis for specific clients
  - PiPA – cache simulator [Zhao et al. 08]
- Shadow process approach
  - Shadow profiling [Moseley et al. 07]
  - SuperPin [Wallace et al. 07]

Are we finished with CMP efficient buffering?

Are we finished with CMP efficient buffering?

Not yet

Are we finished with CMP efficient buffering?

Not yet

parallel analysis

memory scalable

self-tuning parameters

There is some hope

but we need many such base mechanisms

Software Challenges and Opportunities

Communication (efficient coherency)

Analysis (off critical path, new analyses)

GC (concurrent, parallel, high throughput)

JIT (concurrent, parallel, more aggressive)

Heterogeneity (exploit it)

Memory (PCM, bandwidth limits)

Hardware Challenges and Opportunities

Heterogeneity

- Tune cores to ubiquitous loads?
- Specialize for ubiquitous loads?

Coherence

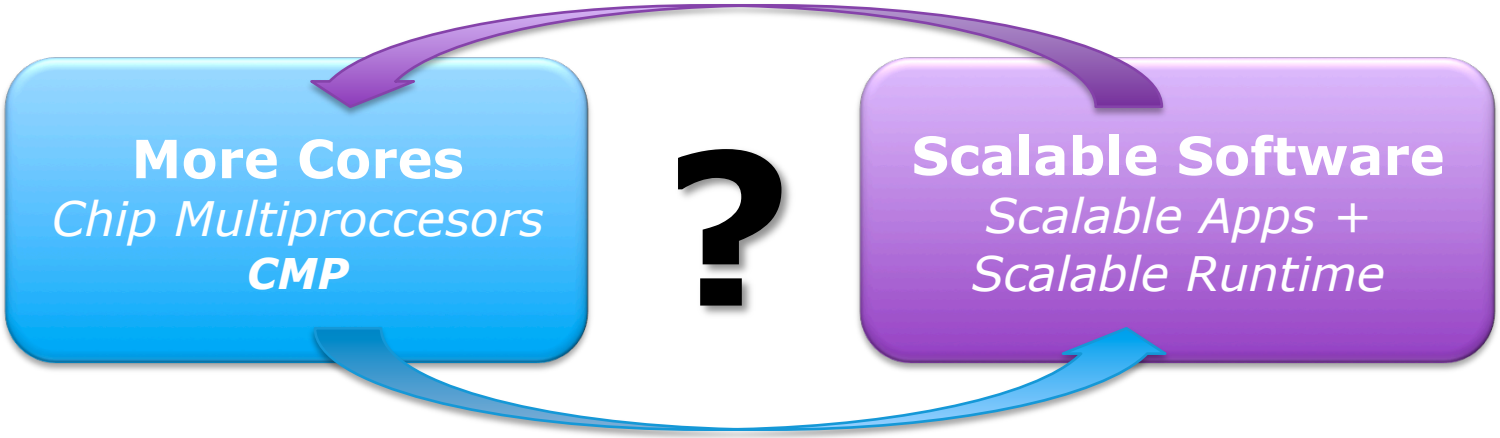
- SMT coherency does not scale
- software guarantees for simplified protocols?

Memory/Cache

- Exploit access behavior of managed languages

The 21st Century Virtuous Cycle?

Questions?



I love my job

- Because when I fail, I get better

Failures

- Rejected: jobs (all)
- Failed: my Rice PhD qualifying exam
- Rejected: jobs (8 of 11)
- Rejected: my first three grant applications
- Bad teaching evaluations
- Rejected **2 times**: my most cited paper
- Rejected: jobs (some)
- Rejected: papers, grants, papers, grants, …

Processor Technologies and Power

Processor	μArch	μProcessor	Process nm	# of Cores	# of Threads	Clock GHz	LLC MB	TDP W	Release Date
Pentium 4	NetBurst	Northwood	130	1	2	2.40	0.5	66.2	May '03
Core 2 Duo E6600	Core	Conroe	65	2	2	2.40	4.0	65.0	Jul '06
Core 2 Quad Q6600	Core	Kentsfield	65	4	4	2.40	8.0	105.0	Jan '07
Core i7 920	Nehalem	Bloomfield	45	4	8	2.66	8.0	130.0	Nov '08
Atom 230	Atom	Diamondville	45	1	2	1.66	0.5	4.0	Jun '08
Core 2 Duo E7600	Core	Wolfdale	45	2	2	3.06	3.0	65.0	May '09
Atom D510	Atom	Pineview	45	2	4	1.66	1.0	13.0	Dec '09
Core i5 670	Nehalem	Clarkdale	32	2	4	3.40	4.0	73.0	Jan '10

- Thermal Design Power (TDP) or chip power budget
  - The amount of power consumed without exceeding the maximum junction temperature
- Power measurement
  - Hall effect current sensor on 12V line driving the chip
  - Sampling rate 50Hz

Native and Java Benchmarks

- 61 benchmarks from six suites
- Native (Fortran/C/C++) single-threaded (**NST**)
  - SPEC CINT2006 (12)
  - SPEC CFP2006 (15)
- Native multithreaded benchmark (**NMT**)
  - PARSEC (11)
- Java single-threaded benchmarks (**JST**)
  - SPEC JVM98 (6)
  - DaCapo-2006-10-MR2 (2)
  - DaCapo-9.12 (2)
- Java multithreaded benchmarks (**JMT**)
  - SPEC JVM98 (1)
  - DaCapo-9.12 (11)
  - PJBB2005 (1)

Compiler, JVMs, OS, and Performance

- Intel compiler v11.1 with -O3 for NST
- Gnu gcc compiler v4.4.1 with -O3 for NMT
- Java virtual machines
  - Sun (Oracle) HotSpot build 16.3-b01
  - Oracle JRockit build R28.0.0-679-130297
  - IBM J9 build pxi3260sr8
  - We measure and report the 5th iteration
- Operating system
  - 32-bit Ubuntu 9.10 Karmic
  - Linux kernel version 2.6.31
- Performance
  - Normalized execution time to Atom *Diamondville* (45nm)
  - Java with HotSpot default