LoopPoint Tools: Sampled Simulation of Complex Multi-threaded Workloads using Sniper and gem5

Alen Sabu[1], Changxi Liu[1], Akanksha Chaudhari[1], Harish Patil[2], Wim Heirman[2], Zhantong Qiu[3], Jason Lowe-Power[3], Trevor E. Carlson[1]

[1]National University of Singapore

[2]Intel Corporation

[3]University of California, Davis

International Symposium on High-Performance Computer Architecture, February 25th, 2023, Canada

Agenda

Time (Eastern)	Speaker	Topic
13.20 to 13.30	Trevor E. Carlson	Overview of the tutorial
13.30 to 14.20	Akanksha Chaudhari	Performance analysis, simulation, sampling
14.20 to 15.20	Harish Patil	Using tools: Pin, PinPlay, SDE, ELFies
15.20 to 15.40		Break
15.40 to 16.20	Alen Sabu	Multi-threaded sampling and LoopPoint
16.20 to 17.00	Changxi Liu	Sniper and LoopPoint demo
17.00 to 17.40	Zhantong Qiu	Using LoopPoint with gem5

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Performance Analysis, Simulation, Sampling

- Speaker: Akanksha Chaudhari
  - Research Assistant, National University of Singapore
- Topics Covered
  - Architectural exploration and evaluation
  - Simulation as a tool for performance estimation
  - Methods for fast estimation using simulation
  - State-of-the-art single-threaded sampled simulation techniques

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Using Tools: Pin, PinPlay, SDE, ELFies

- Speaker: Harish Patil
  - Principal Engineer, Intel Corporation
- Topics Covered
  - Binary instrumentation using Pin or writing Pintools
  - PinPlay kit and PinPlay-enabled tools
  - SDE build kit for microarchitecture emulation
  - Checkpointing threaded applications using PinPlay, SDE
  - Detailed discussion on ELFies including its generation and usage

Multi-threaded Sampling and LoopPoint

- Speaker: Alen Sabu
  - PhD Candidate, National University of Singapore
- Topics Covered
  - Sampled simulation of multi-threaded applications
  - Existing methodologies and their drawbacks
  - Detailed discussion on LoopPoint methodology
  - Experimental results of LoopPoint

Sniper and LoopPoint Demo

- Speaker: Changxi Liu
  - PhD Candidate, National University of Singapore
- Topics Covered
  - Overview of Sniper simulator
  - High-level structure of LoopPoint code
  - Demo on how to use LoopPoint tools
  - Sampling custom workloads using LoopPoint

Using LoopPoint with gem5

- Speaker: Zhantong Qiu
  - Undergraduate student, University of California, Davis
- Topics Covered
  - Overview of gem5 simulator
  - Structure of LoopPoint integration code
  - Demo on simulating LoopPoint regions on gem5
  - Running ELFies on gem5

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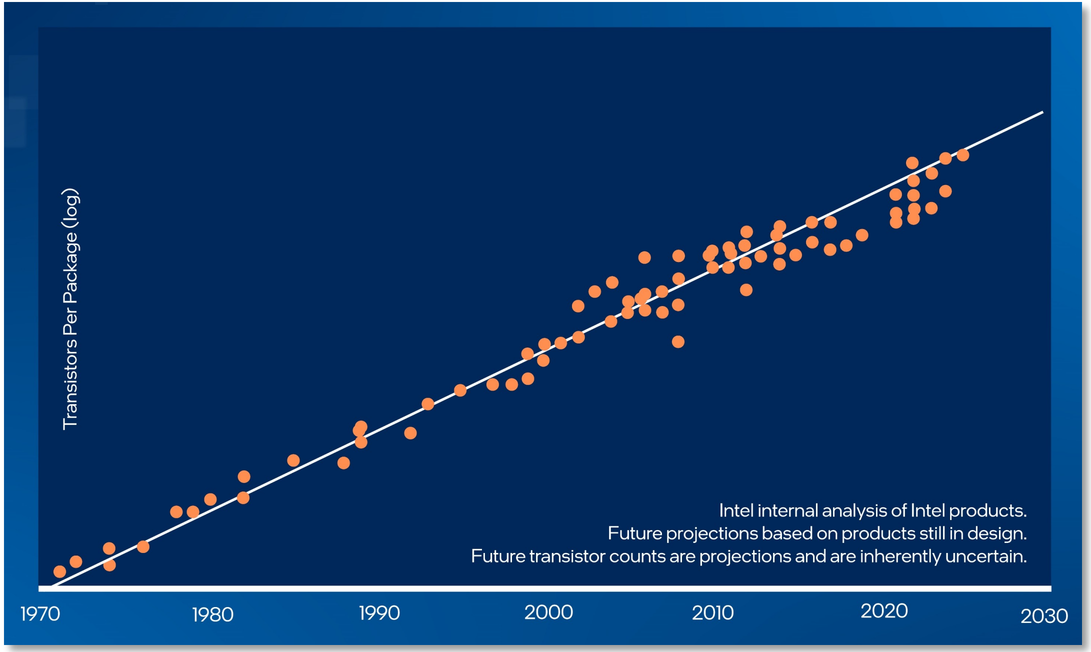
Session 1

Performance Analysis, Simulation, Sampling

AKANKSHA CHAUDHARI, RESEARCH ASSISTANT
NATIONAL UNIVERSITY OF SINGAPORE

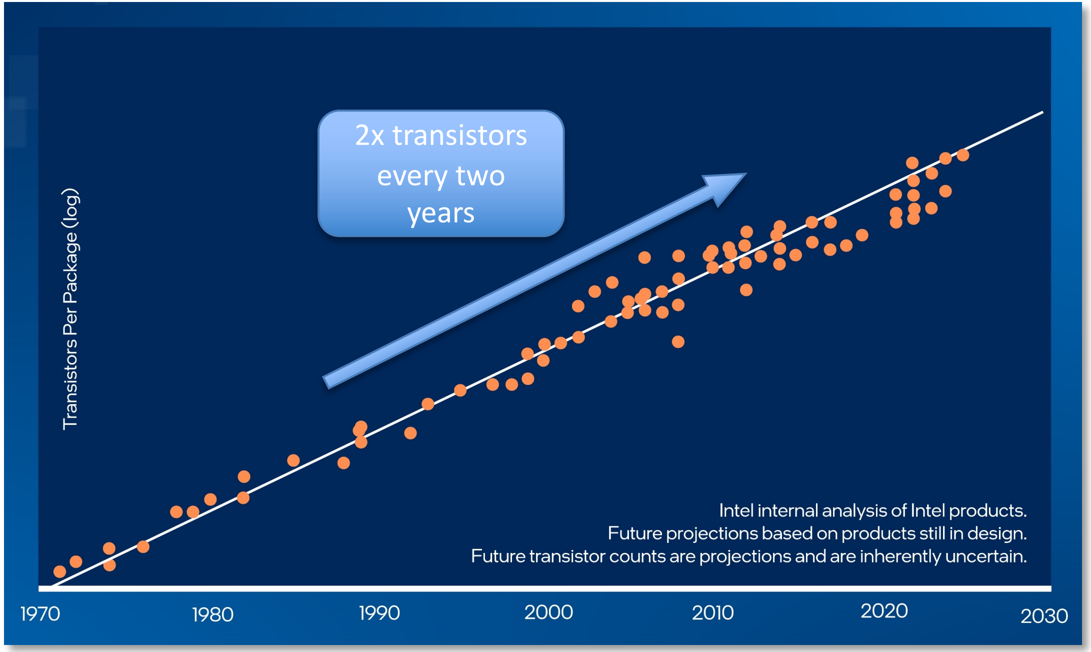
Architectural Trends in Processor Design



Moore Law number of transistor per device: past, present, future [Intel]

Source: https://www.intel.com

Architectural Trends in Processor Design



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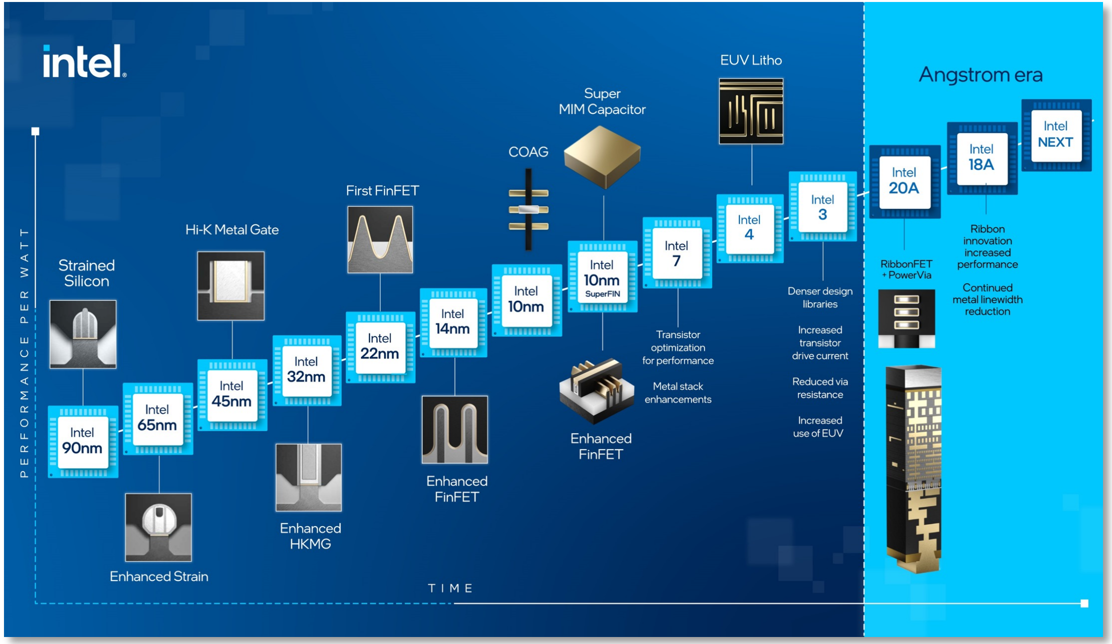

Transistor innovations over time

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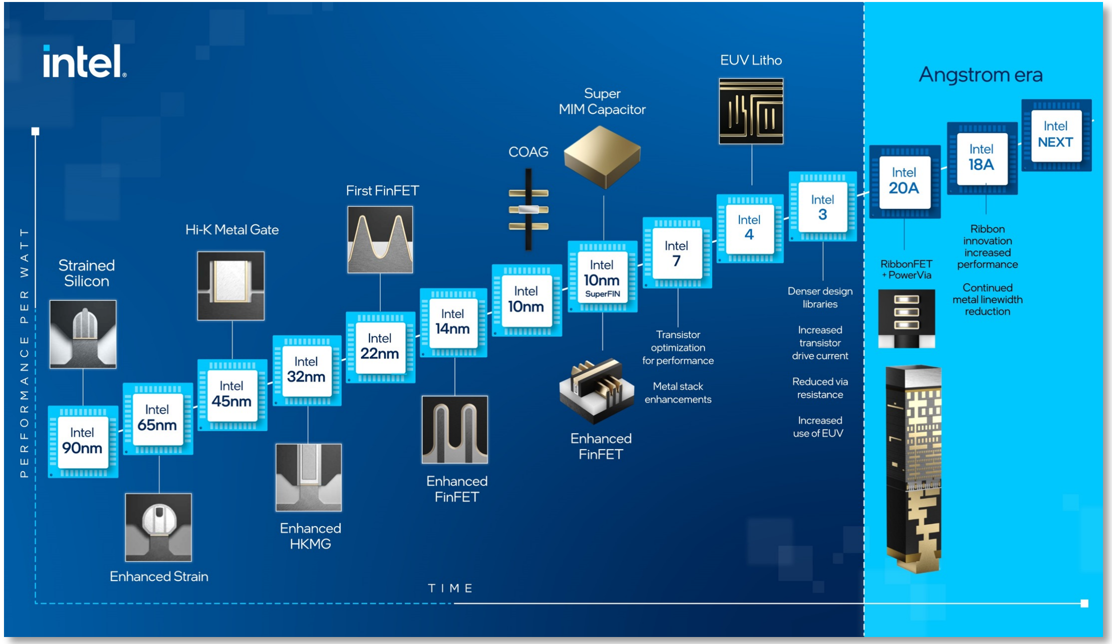

Transistor innovations over time

Higher performance

Reducing sizes

Source: https://www.intel.com/

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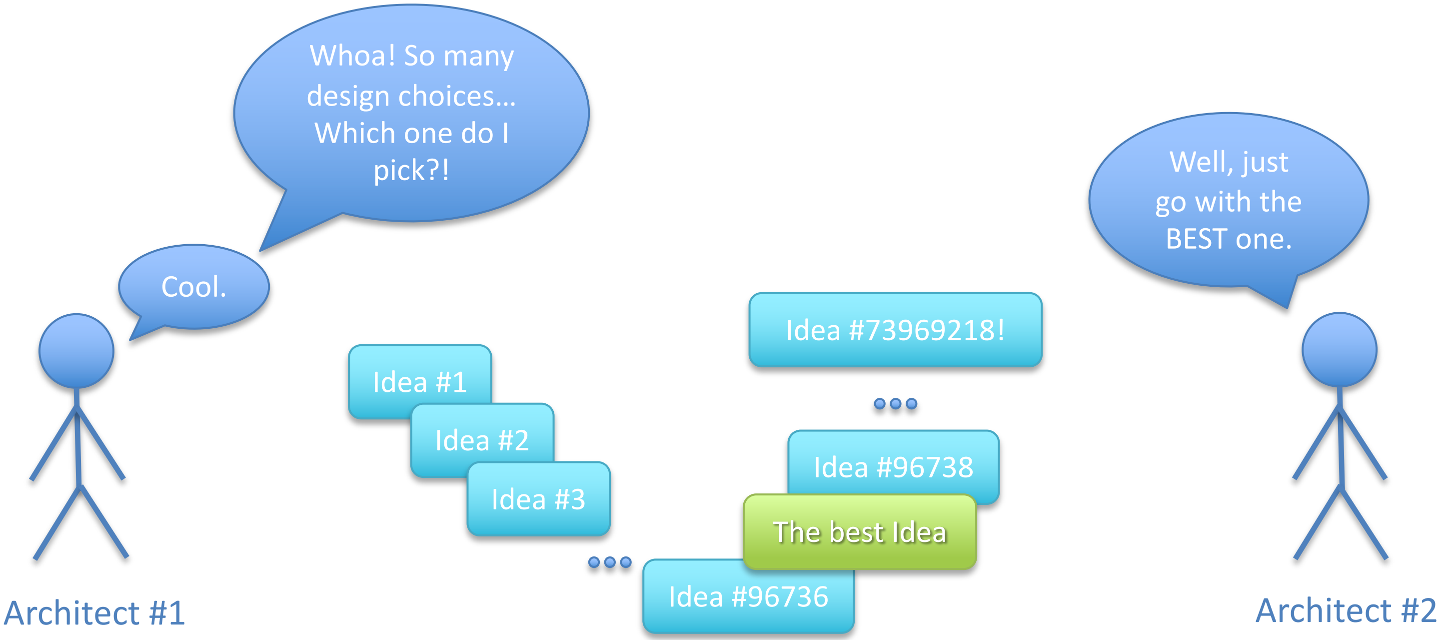
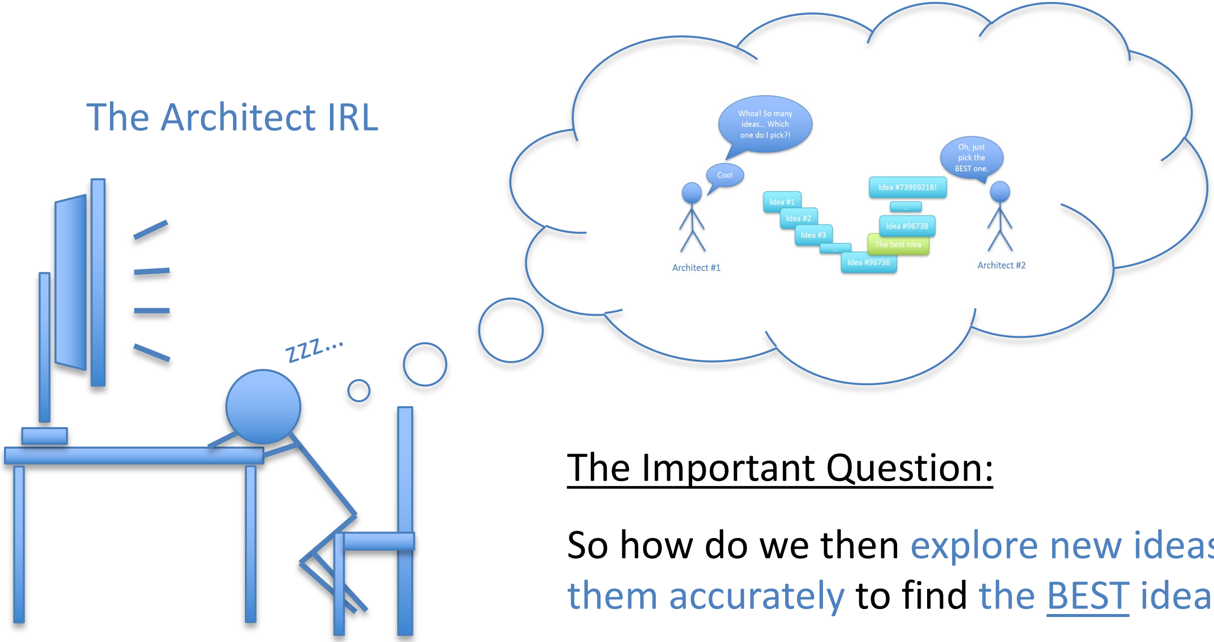
Exploration and Evaluation of New Ideas



Exploration and Evaluation of New Ideas

The Architect IRL

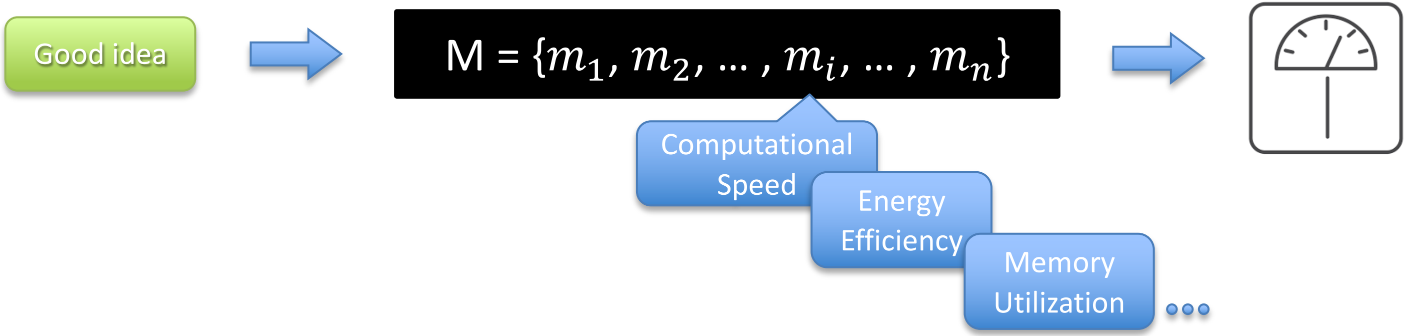


<u>The Important Question:</u>

So how do we then explore new ideas quickly and evaluate them accurately to find the <u>BEST</u> idea?

Exploration and Evaluation of New Ideas

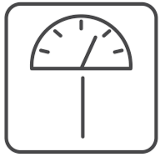
- A "good" idea optimizes a finite set of performance metrics:



Exploration and Evaluation of New Ideas

- A "good" idea optimizes a finite set of performance metrics:

Good idea → $M = \{m_1, m_2, \dots, m_i, \dots, m_n\}$ →



How to assess whether a given idea improves the target metrics?

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Exploration and Evaluation of New Ideas

Different evaluation methods:

- Theoretical proof
- Analytical modeling
- Simulation
- Prototyping
- Actual implementation

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An “Evaluation” of the Evaluation Methods

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Fairly complex for modern architectures

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Evaluating different workload profiles is difficult

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Evaluating different workload profiles is difficult → Worst-case estimates can be misleading

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Expensive!

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(Relatively) less expensive

An “Evaluation” of the Evaluation Methods

Different evaluation methods:

- Theoretical proof
- Analytical modelling
- Simulation
- Prototyping → (Relatively) less expensive
- Actual implementation

BUT limited by the capability of its components

An "Evaluation" of the Evaluation Methods

Different evaluation methods:

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- Prototyping
- Actual implementation

Not feasible for exploration of large design spaces!

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Allows for varying degrees of abstractions and accuracy

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Feasible exploration of large design spaces

An “Evaluation” of the Evaluation Methods

Different evaluation methods:

- Theoretical proof
- Analytical modelling
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- Prototyping
- Actual implementation

Most feasible way to explore and evaluate a large and complex design space in terms of time, cost and efficiency!

#1

Simulation: An Overview

- How does simulation work?
  - Mimics the key functional and/or timing behavior of a system to reflect its performance in terms of the target metrics.

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  - Allows verification, debugging, and optimization of existing systems.
  - Also enables evaluation and understanding of non-existent systems.

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  - Allows verification, debugging, and optimization of existing systems.
  - Also enables evaluation and understanding of non-existent systems.
- Caution: A simulator is only as good as the person who uses it.

Simulation: An Overview

- An ideal simulation technique:
  - High speed → For faster exploration.
  - High flexibility → For wider exploration.
  - High accuracy/low simulation error → For accurate evaluation.
- Practical simulation techniques involve trade-offs:
  - Speed vs. accuracy
  - Accuracy vs. flexibility
  - Flexibility vs. speed

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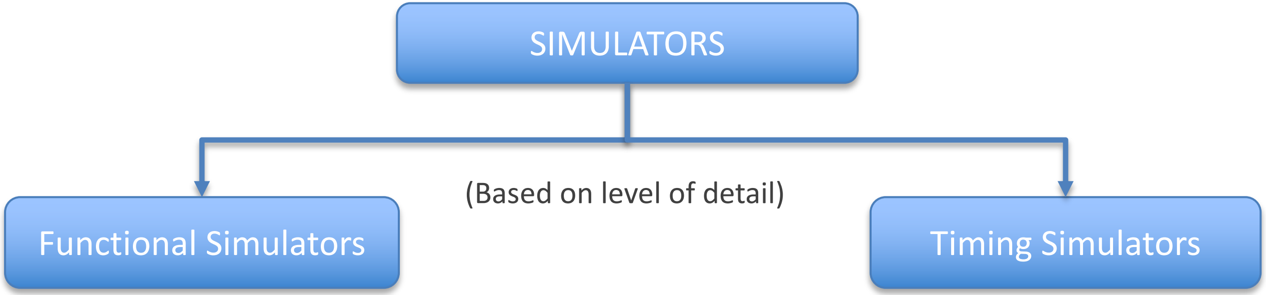
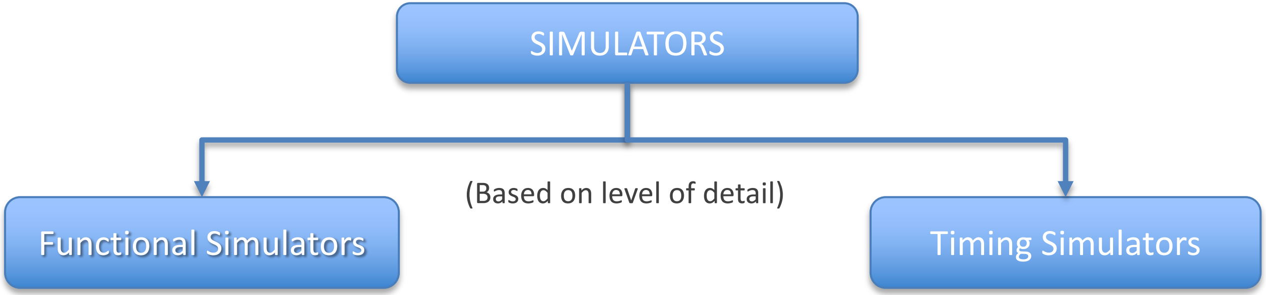
Different Simulation Techniques



Different Simulation Techniques



- Implement only architectural details and achieve same functionality as the modeled architecture.
- Tracks architectural stats (memory access locality, instruction count/mix).
- Faster, but cannot track detailed microarchitectural parameters.

Different Simulation Techniques

SIMULATORS

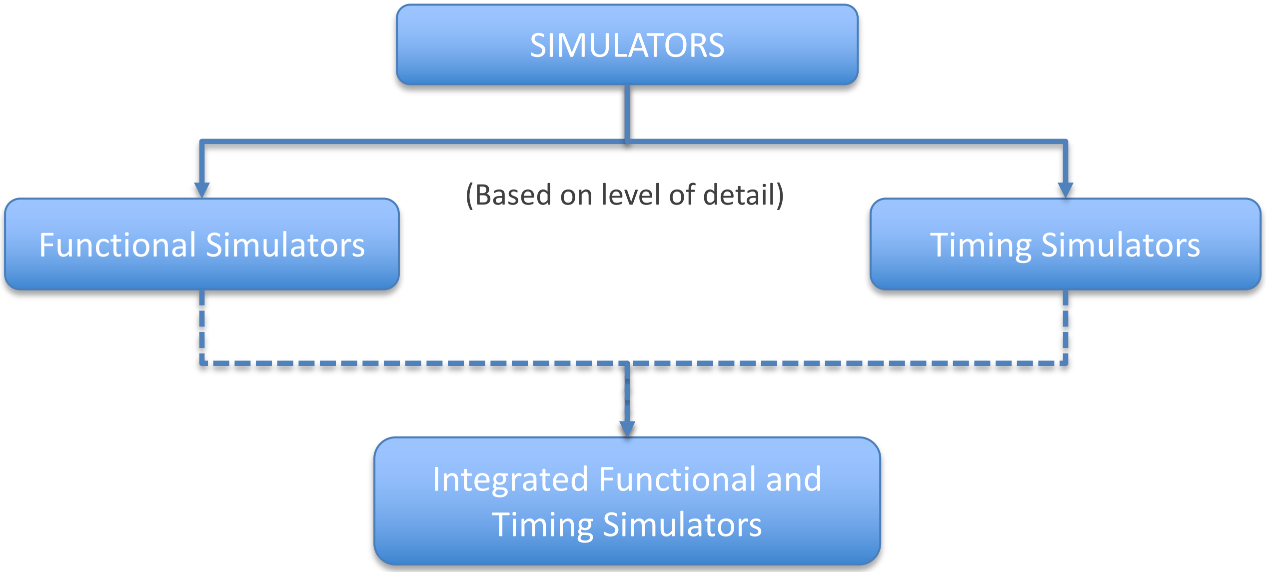
(Based on level of detail)

Functional Simulators

Timing Simulators

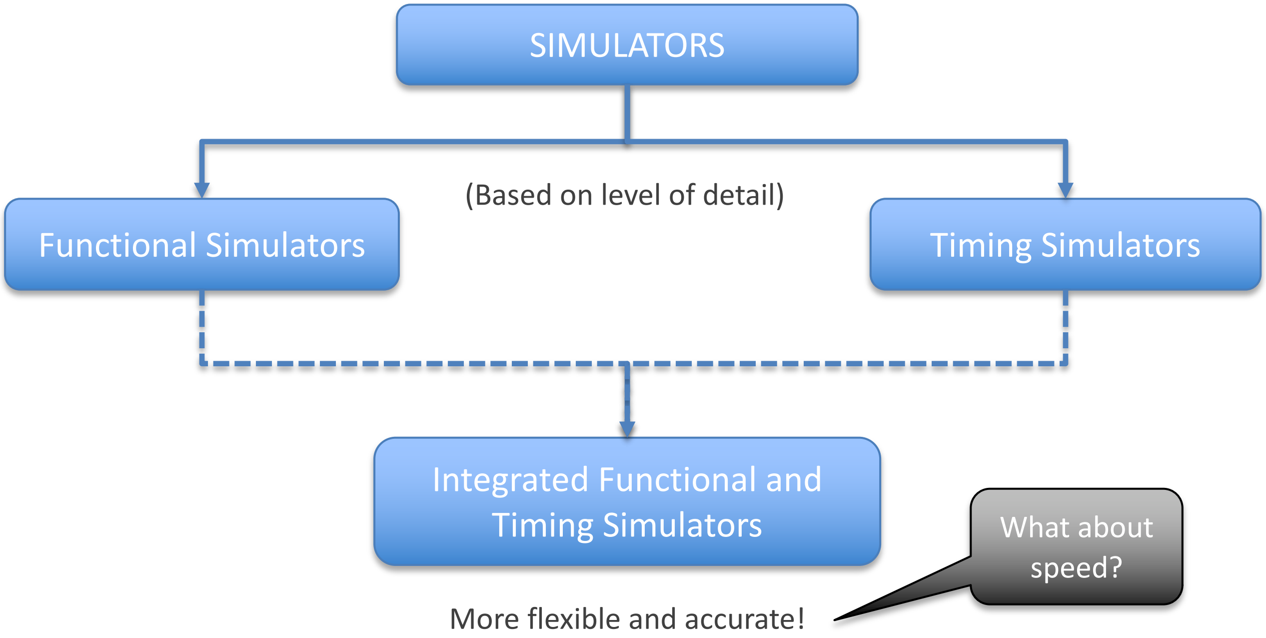
- Implement the microarchitecture.
- Produces detailed microarchitectural stats (IPC, runtime, memory performance).
- Do not have to emulate the functionality of the modeled architecture.

Different Simulation Techniques



More flexible and accurate!

Different Simulation Techniques



Techniques to Simulate Faster

- Partial simulation and extrapolation
  - Simulating the first 1 billion instructions in detail.

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  - Fast-forwarding, warming up μ-architectural state, and then simulating in detail.

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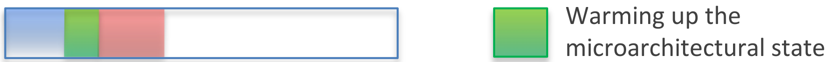

- Workload reduction: simulating for reduced input sets or loop counts.

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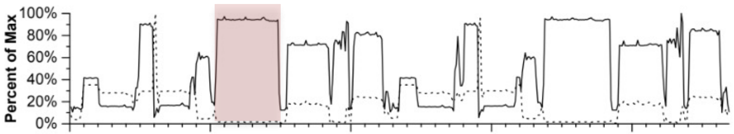
Techniques to Simulate Faster

- Problems with these techniques:
  - Partial simulation and extrapolation
    - Fails to capture global variations in program behavior and performance.



  - Workload reduction
    - Benchmark behavior may vary significantly across different input sizes.
    - Simulation with reduced input sets or loop counts does not reflect the actual performance.

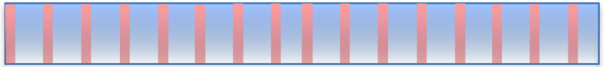
Source: Sherwood et al., “Automatically Characterizing Large Scale Program Behavior”, ASPLOS’02

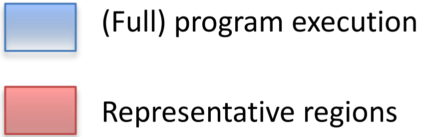
Sampled Simulation to the Rescue!

- Sampling enables the simulation of selective representative regions.
  - Subset of regions within a program execution that represent the behavior of the entire application when extrapolated.

- Selecting representative regions
  - Targeted sampling (like in SimPoint)

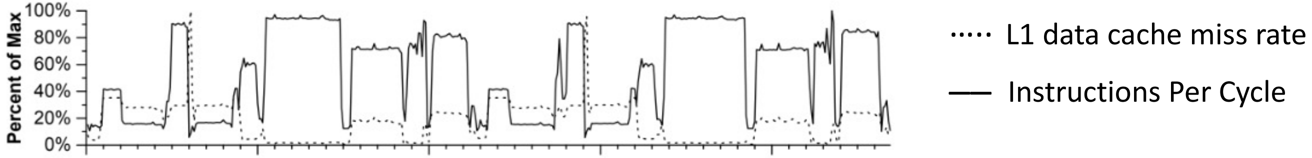
  - Statistical sampling (like in SMARTS)





Sampled Simulation Techniques: SimPoint

- Large-scale program behaviors vary significantly over their run times.



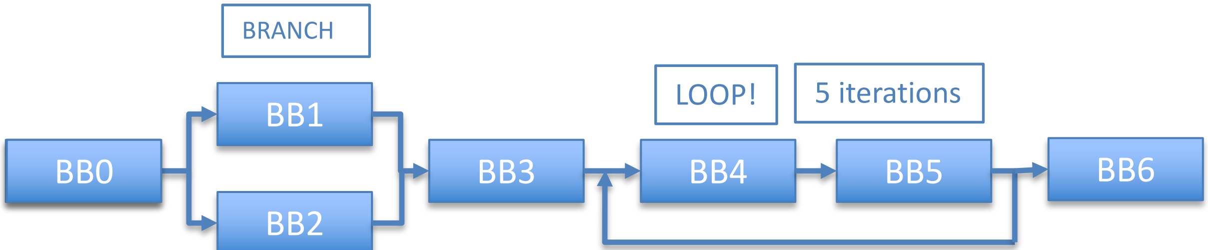
- Main goal: To automatically and efficiently analyze program behavior over the different phases of execution.
- SimPoint uses Basic Block Vectors (BBV) as a hardware-independent metric for characterizing the program behavior in different phases.

Source: Sherwood et al., "Automatically Characterizing Large Scale Program Behavior", ASPLOS'02

Sampled Simulation Techniques: SimPoint

Basic Block Vector (BBV) is a single-dimensional array that maintains a count of how many times each basic block was executed in each interval

Program execution:



Basic Block Vector:

0	1	2	3	4	5	6
1	1	0	1	5	5	1

← Indexed by Basic Block IDs

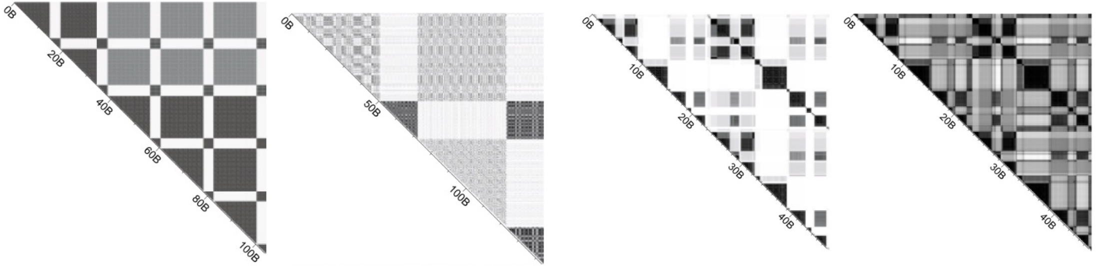
← Maintains the execution count for each Basic Block

Sampled Simulation Techniques: SimPoint

- Basic Block Similarity: Measured using Euclidean or Manhattan Distances.

$$EuclideanDist(a,b) = \sqrt{\sum_{i=1}^{D} (a_i - b_i)^2} \qquad ManhattanDist(a,b) = \sum_{i=1}^{D} |a_i - b_i|$$

- Depicted by Basic Block Similarity Matrices.



Using Manhattan distances   Using Euclidian distances

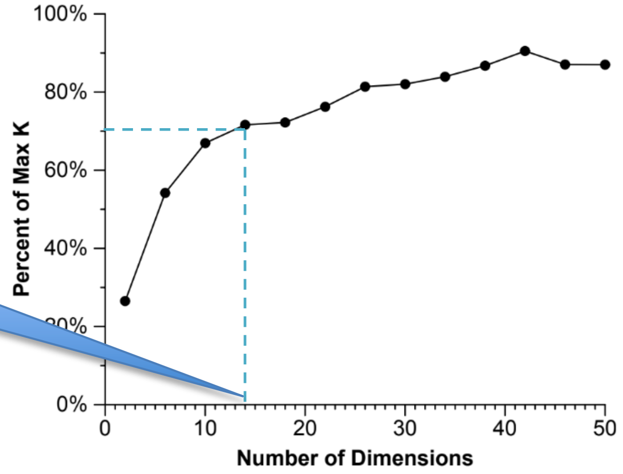
- Diagonal of the matrix → program execution
- Point (x, y) gives similarity index
- ↑ darkness → ↑ similarity

Source: Sherwood et al., "Automatically Characterizing Large Scale Program Behavior", ASPLOS'02

Sampled Simulation Techniques: SimPoint

- The BBVs obtained from the profiling step have a very large number of dimensions!
- “Curse of dimensionality”:
  - Hard to cluster the data.
  - Clustering time increases significantly.

Solution: Reduce number of dimensions using Random Linear Projections



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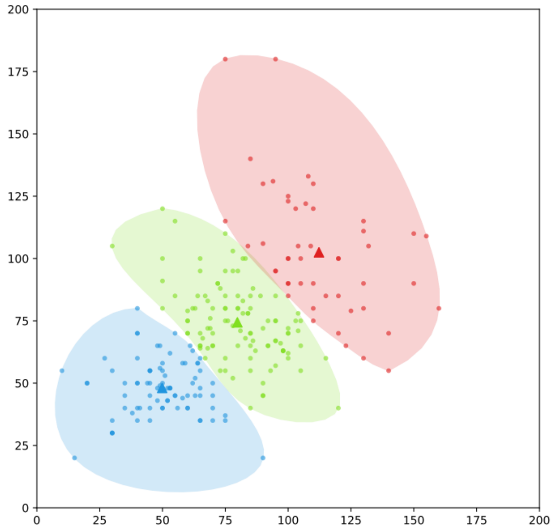
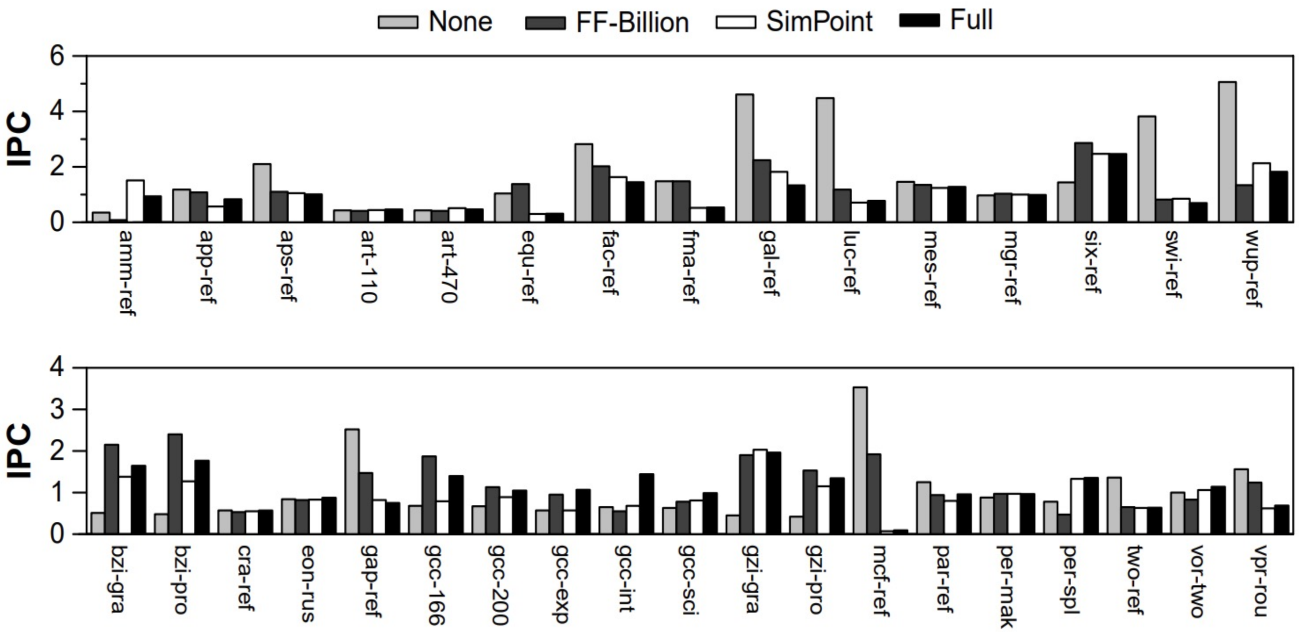
Sampled Simulation Techniques: SimPoint

K-means clustering:



- Representative region → single simulation point
  - BBV with the lowest distance from the centroid of all cluster centers.
- Representative regions → multiple simulation points
  - For each cluster, choose the BBV that is closest to the centroid of the cluster.

Sampled Simulation Techniques: SimPoint



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Sampled Simulation Techniques: SMARTS

- Main idea behind SMARTS:
  - Using systematic statistical sampling:
    - To identify a minimal representative sample from the population for simulation.
    - To establish a confidence level for the error on sample estimates.
  - Simulating using two modes :
    - Detailed simulation of sampled instructions.
    - Functional simulation of remaining instructions.

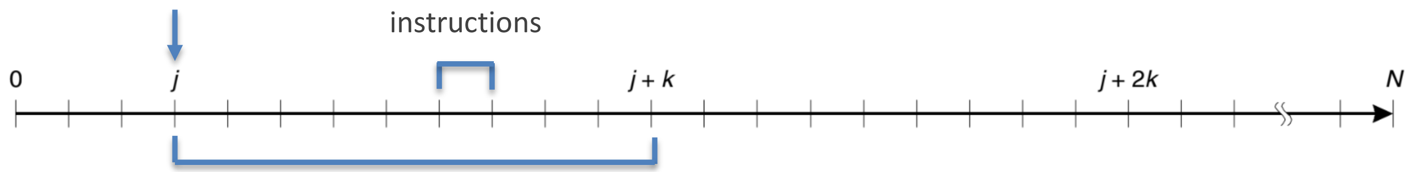
Sampled Simulation Techniques: SMARTS

- SMARTS uses Systematic Sampling:

Total sample size:
n = N/k units
OR
n x U instructions

Start sampling
at offset j

Each unit
consists of U
instructions

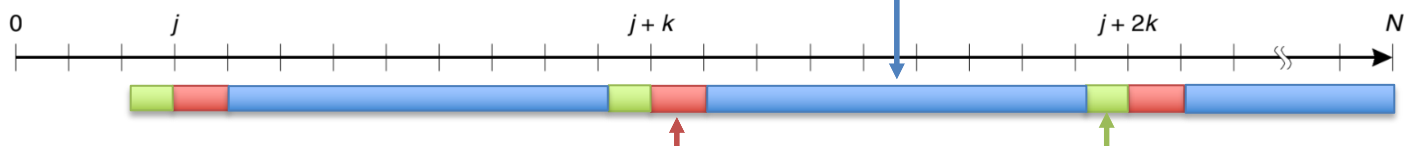


Sample at a fixed interval
of length k units or k x U
instructions, where
$k = N / n$

Sampled Simulation Techniques: SMARTS

- Simulation:

U(k -1) – W instructions are functionally simulated and large structures may be warmed



U instructions are measured as a sampling unit using detailed simulation

W instructions of detailed simulation warm state before each sampling unit

Values of U and W depend on workload characteristics

Sampled Simulation Techniques: SMARTS

- Evaluation results:
  - Average error:
    - 0.64% for CPI
    - 0.59% for EPI

    By simulating fewer than 50 million instructions in detail per benchmark.
  - Speedup over full-stream simulation:
    - 35x for 8-way out-of-order processors
    - 60x for 16-way out-of-order processors

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Session 2

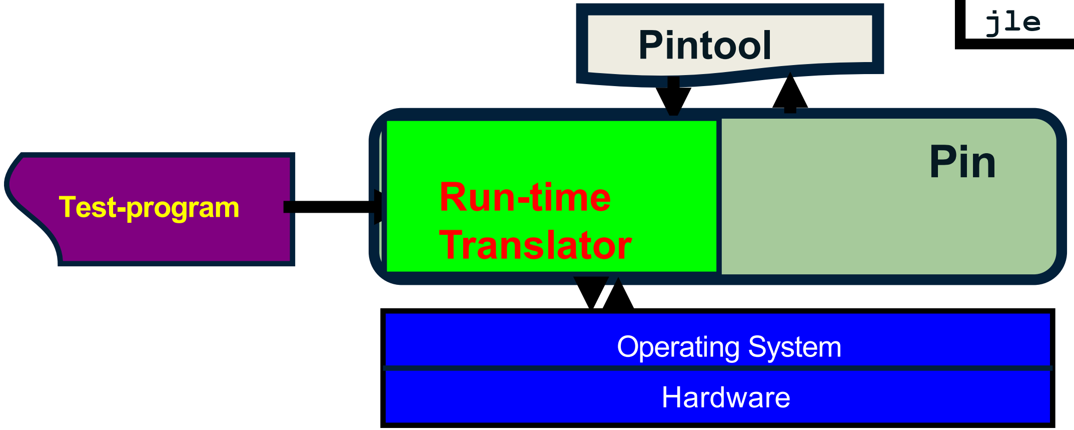
Using Tools: Pin, PinPlay, SDE, ELFies

HARISH PATIL, PRINCIPAL ENGINEER (DEVELOPMENT TOOLS SOFTWARE)
INTEL CORPORATION

Pin: A Tool for Writing Program Analysis Tools

```
sub     $0xff, %edx
movl    0x8(%ebp), %eax
jle     <L1>
```

```
counter++; print(IP)
sub     $0xff, %edx
counter++; print(EA)
movl  0x8(%ebp), %eax
counter++;print(br_taken)
jle     <L1>
```




```
$ pin –t pintool –- test-program
```

Normal output +
Analysis output

http://pintool.intel.com

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PinPlay: Software-based User-level Capture and Replay

Logger → **pinball** → Replayer + Pintool

Program/ Libraries

Input

License

No binaries/inputs

No application setup

No license checking

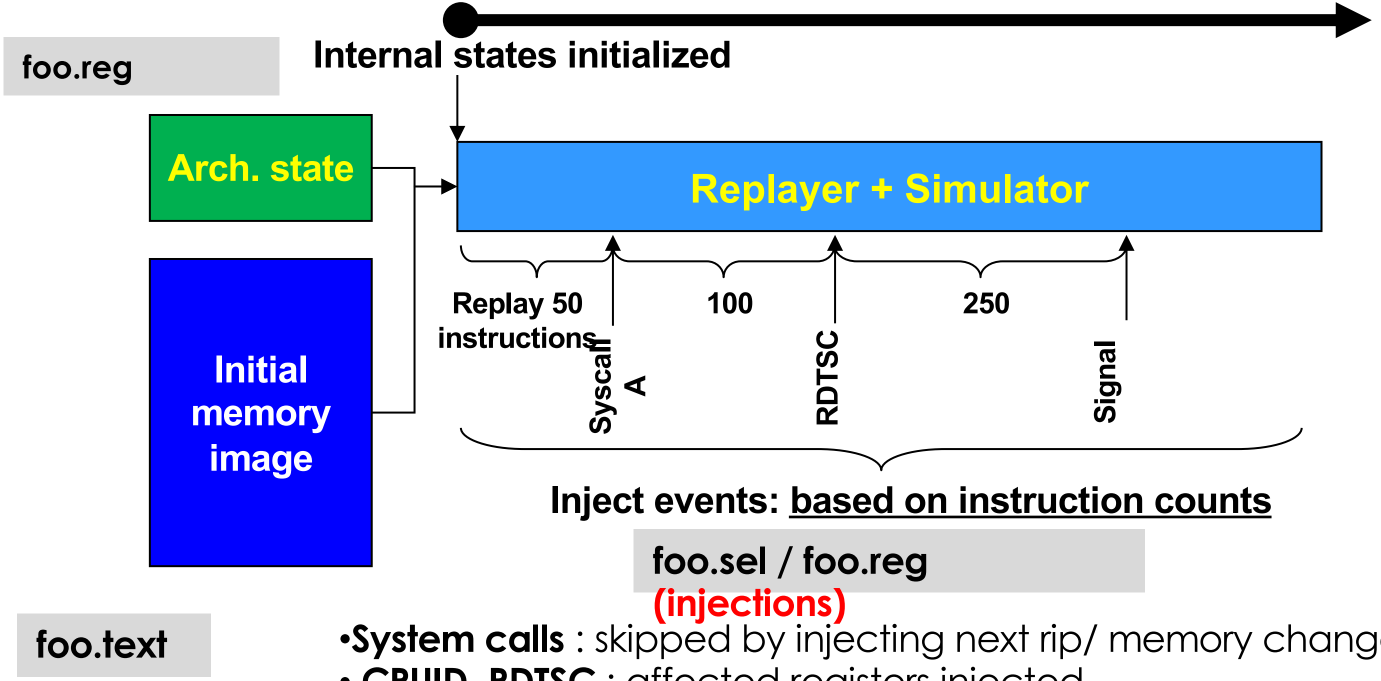
Platforms : Linux, Windows, MacOS

Upside : It works! Large OpenMP / MPI programs, Oracle

Downside : High run-time overhead: ~100-200X for capture ➔ Cannot be turned on all the time

http://pinplay.org

Pinball (single-threaded): Initial memory/register + injections



- **System calls** : skipped by injecting next rip/ memory changed
- **CPUID, RDTSC** : affected registers injected
- **Signals/Callbacks** : New register state injected

Pinball (multi-threaded): Pinball (single-threaded) + Thread-dependencies

foo.reg (per-thread)

Initial registers: T0

Initial registers: T1

Initial registers: T(n-1)

foo.text

Application Memory (common)

foo.reg (per-thread)

foo.sel (per-thread)

Event injection works only if same behavior (same instruction counts) is guaranteed during replay

[T1] 2 T2 2

[T1] 3 T2 3

[T2] 5 T4 1

Thread T2 cannot execute instruction 5 until T4 executes instruction 1

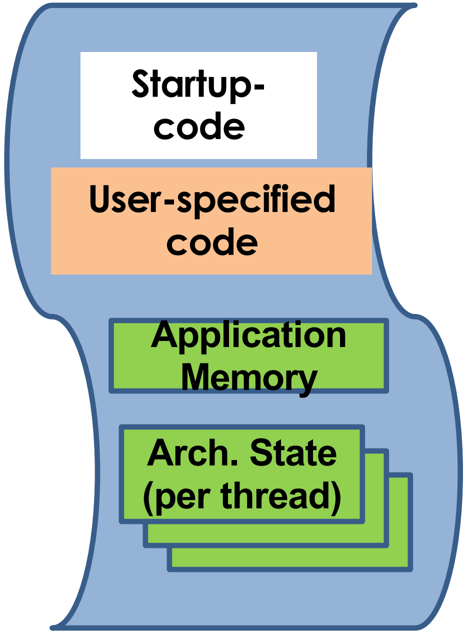
Thread T1 cannot execute instruction 2 until T2 executes instruction 2

foo.race (per-thread)

MT Pinball == race-files provide determinism

ELFie : An Executable Application Checkpoint

- **Checkpoint:** Memory + Registers
- **Application** : Only program state captured -- no OS or simulator states
- **Executable** : In the Executable Linkage Format commonly used on Linux



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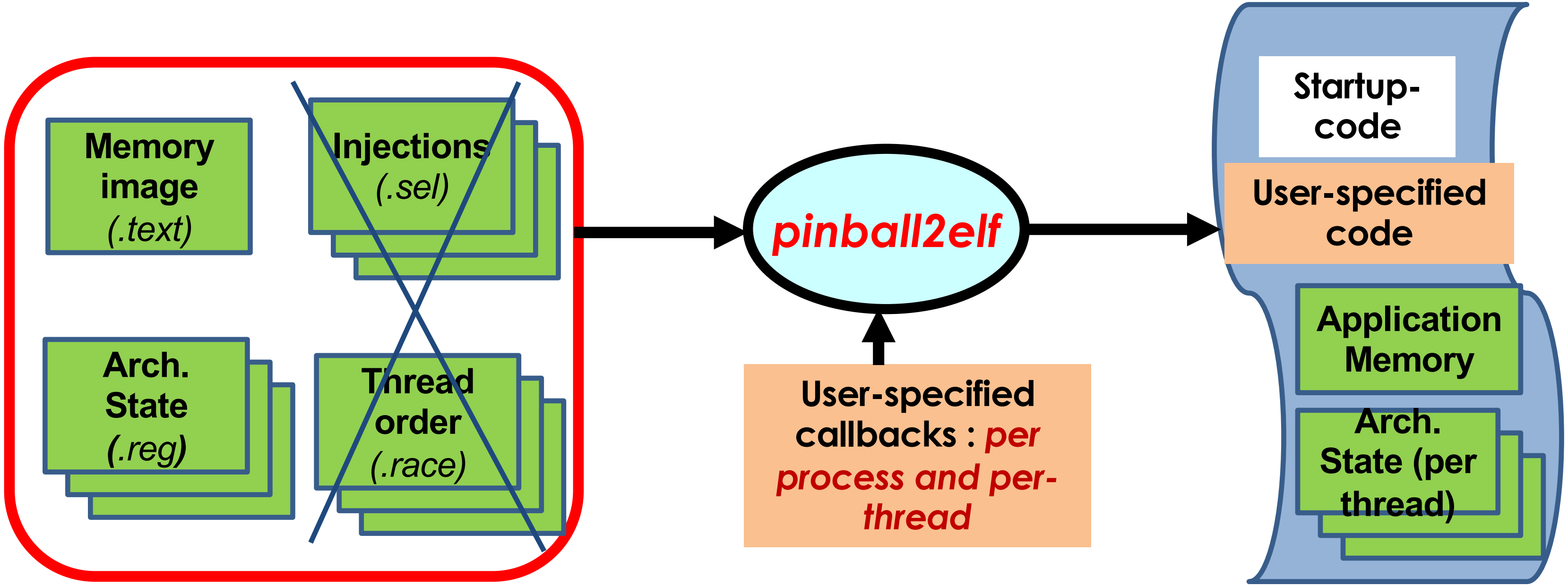
pinball2elf: Pinball converter to ELF



http://pinelfie.org

Getting started with *pinball2elf*

Prerequisite: '*perf*' installed on your Linux box (*perf stat /bin/ls* should work)

- Clone pinball2elf repository: *git clone https://github.com/intel/pinball2elf.git*
- *cd pinball2elf/src*
- *make all*
- *cd ../examples/ST*
- *./testST.sh*

Running ../../scripts//pinball2elf.basic.sh pinball.st/log_0

..

Running ../../scripts//pinball2elf.perf.sh pinball.st/log_0 st

export ELFIE_PERFLIST=0:0,0:1,1:1

…

hw_cpu_cycles:47272 hw_instructions:4951 sw_task_clock:224943

Tested : Ubuntu 20.04.4 LTS : gcc/g++ 7.5.0 and 9.4.0

and Ubuntu 18.04.6 LTS: gcc/g++ 7.5.0

ELFie types: basic, sim, perf

	basic	sim	perf
How to create	scripts/pinball2elf.basic.sh pinball	scripts/pinball2elf.sim.sh pinball	scripts/pinball2elf.perf.sh pinball perf.out
Exits gracefully?	NO, either hangs or dumps core	NO, either hangs or dumps core Simulator handles exit	YES, when retired instruction count reaches pinball icount
Environment variables used	NONE	ELFIE_VERBOSE=0/1 ELFIE_COREBASE=X Set affinity : thread 0 → core X, thread 1 → core x+1	"ELFIE_WARMUP" to decide whether to use warmup "ELFIE_PCCONT" to decide how to end warmup/simulation regions ELFIE_PERFLIST, enables performance counting

Optional: *Operating system state (SYSSTATE) per pinball: pintools/PinballSYSState [See CGO2021 ELFie paper]*

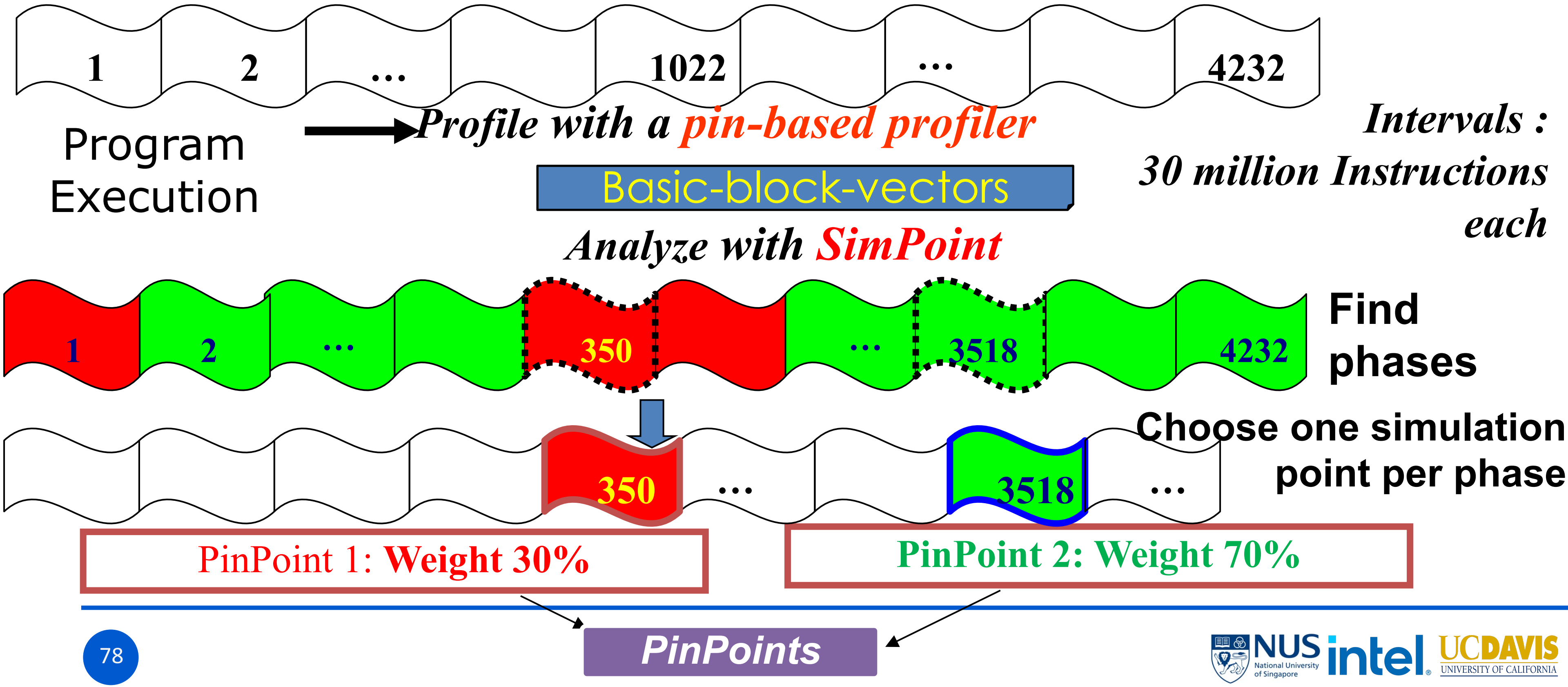
Example: ***ELFIE_PERFLIST*** **with a** ***perf ELFie***

ELFIE_PERFLIST, enables performance counting
(based on /usr/include/linux/perf_event.h
perftype: 0 --> HW 1 --> SW
HW counter: 0 --> PERF_COUNT_HW_CPU_CYCLES
HW counter: 1 --> PERF_COUNT_HW_CPU_INSTRUCTIONS
SW counter: 0 --> PERF_COUNT_SW_CPU_CLOCK
... <see perf_event.h:'enum perf_hw_ids' and 'enum perf_sw_ids')

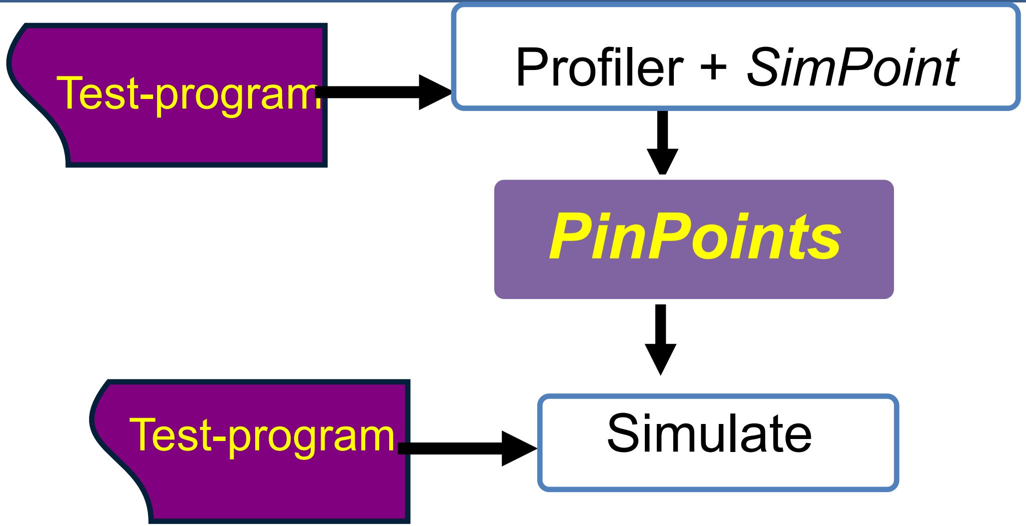
```
% cd examples/MT
% ../../scripts/pinball2elf.perf.sh pinball.mt/log_0 perf.out
% setenv ELFIE_PERFLIST "0:0,0:1,1:1“
% pinball.mt/log_0.perf.elfie
├── perf.out.0.perf.txt
├── perf.out.1.perf.txt
├── perf.out.2.perf.txt
```

```
ROI start: TSC 480511110586217756
Thread start: TSC 480511110623843452
-----------------------------------------------
Simulation end: TSC 480511110625045322
      Sim-end-icount 3436
hw_cpu_cycles:36148 hw_instructions:3476
sw_task_clock:141901
-----------------------------------------------
Thread end: TSC 480511110625366502
ROI end: TSC 480511110625959364
hw_cpu_cycles:40097 hw_instructions:4455
sw_task_clock:188637
```

PinPoints == Pin + SimPoint



PinPoints : The repeatability challenge

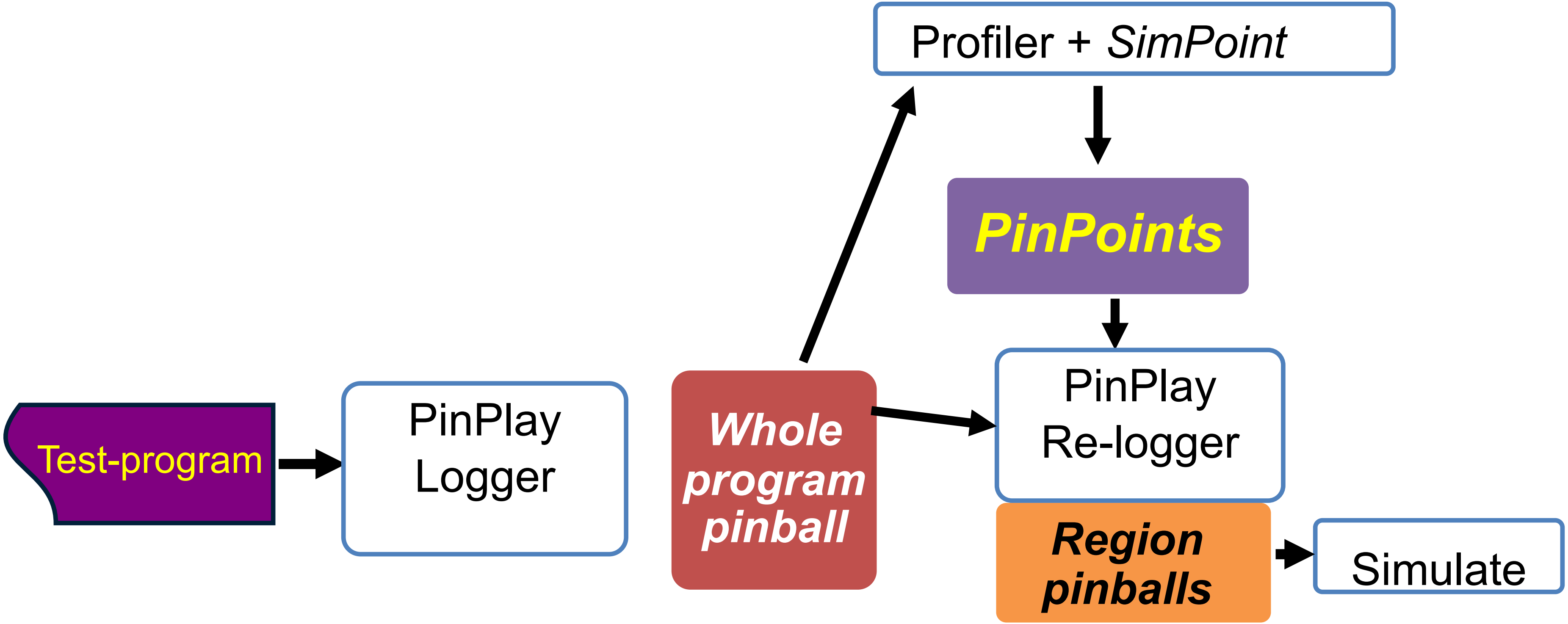


Problem: Two runs are not exactly same → PinPoints missed (PC marker based)

[*"PinPoints out of order"* *"PinPoint End seen before Start"*]

Found this for 25/54 SPEC2006 runs!

PinPlay provides repeatability



Single-threaded *PinPoints* → SPEC2006/2017 pinballs publicly available

1. University of California (San Diego), Intel Corporation, and Ghent University
   https://www.spec.org/cpu2006/research/simpoint.html
2. University of Texas at Austin
   https://www.spec.org/cpu2017/research/simpoint.html
3. Northwestern University
   Public Release and Validation of SPEC CPU2017 PinPoints

Simulation of multi-threaded Programs: The non-determinism challenge

- Runs across different configurations are non-deterministic [Alameldeen'03]
  - Locks are acquired in different order
  - Unprotected shared-memory accesses
- One can't compare two runs/simulations of the same benchmark directly

  →***Change in micro-architecture present/simulated or execution path taken?***

1.Alameldeen'03 Variability in Architectural Simulations of Multi-threaded Workloads (HPCA2003)

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Dealing with non-determinism

1. Run multiple simulations for each studied configuration [Alameldeen’03]
   - Needs random perturbation for each run
   - Average behavior per configuration
   - Cost: multiple runs

- 2. Force deterministic behavior so that one run in each configuration is performed [Pereira’08 @ Intel]
   - Same execution paths
   - Cost: loss in fidelity, thread behavior tied to tracing machine

- 3. Simulate the same “amount of work” [Alameldeen’06] : *LoopPoint* approach

A. Pereira’08: Reproducible Simulation of Multi-Threaded Workloads for Architecture Design Exploration, International Symposium on Workload Characterization (IISWC'08)

B. Alameldeen’06 IPC Considered Harmful for Multi-processors Workloads (IEEE-Micro-2006)

LoopPoint: Key idea 1: Filtering Synchronization Code during profiling

Why: Profiling should look only at 'real work'

What: Skip profiling of synchronization code

How?

- Automatically with Loop Analysis: Very hard

  "Spin Detection Hardware for Improved Management of Multithreaded Systems"
  Transactions on Parallel and Distributed Systems, 2006

  - **Look for loops that do not update architectural state**
  - Was implemented in Sniper(Pin-2) but many OpenMP spin loops maintain stats hence do update architecture state

✓ **Heuristic**

  - Filter synchronization library code: e.g. libiomp5.so, libpthread.so

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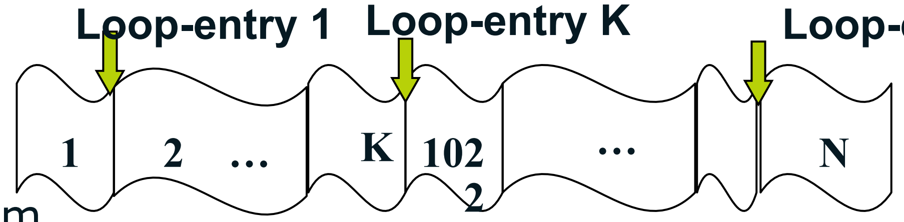
LoopPoint: Key idea 2: Loops as 'Units of work'

Why: Property of program/binary : independent of architecture

Profiling



Variable length intervals

Close to desired length : *-sliceSize S*

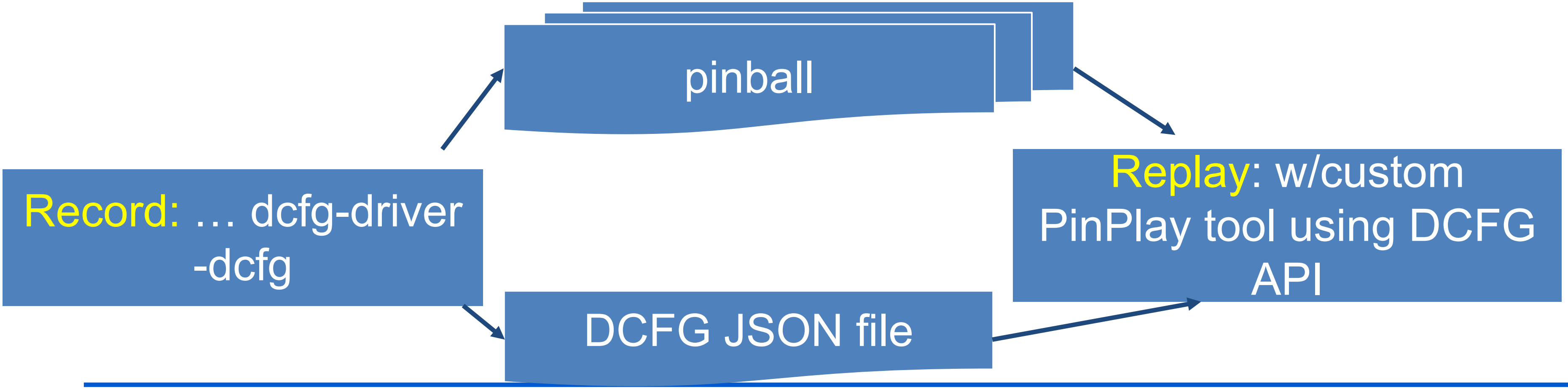
Program Execution → ***Profile with a SDE/DCFG-based profiler***

- Global counting of loop-entries
- Region start/stop : only in the main image
  - Stop when 'desired global instruction count' (SliceSize) is reached
  - Do not count instructions in synchronization library

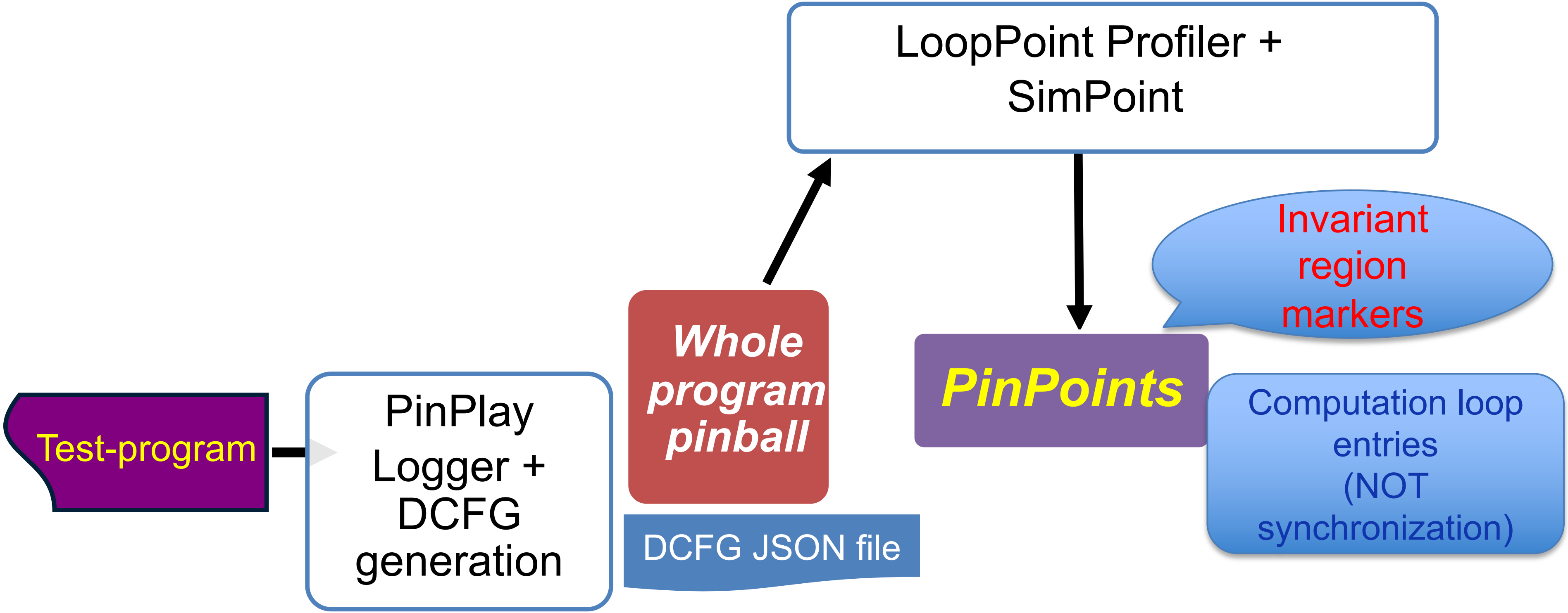
DCFG Generation with *PinPlay*

Dynamic Control-Flow Graph (DCFG)

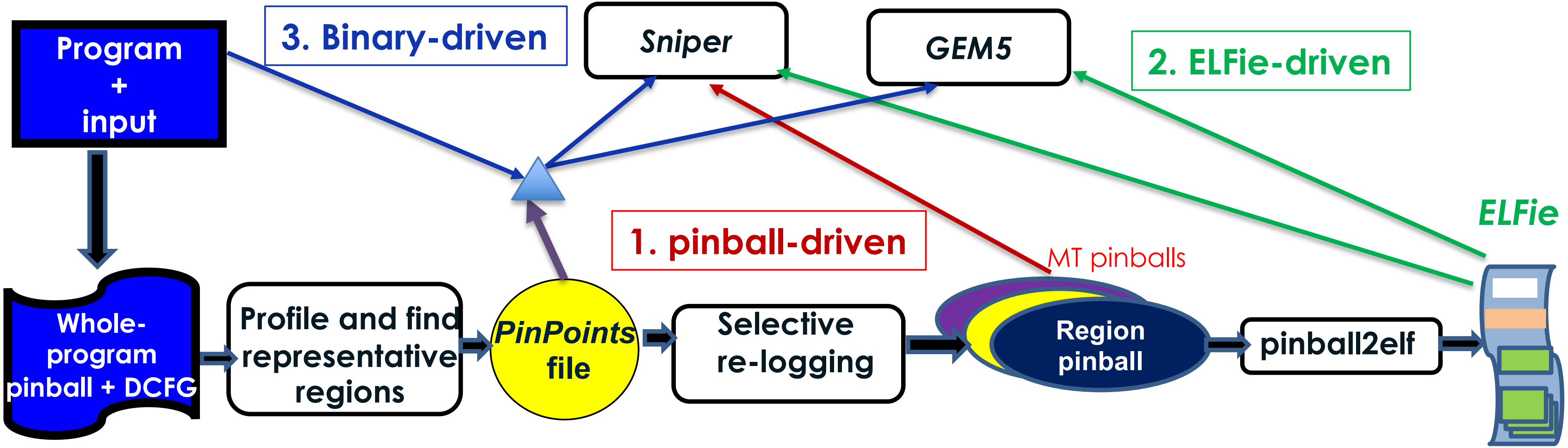
Directed graph extracted for a specific execution:
Nodes ➔ basic blocks
Edges ➔control-flow : augmented with per-thread execution counts



PinPlay + DCFG : Stronger Repeatability



LoopPoint: Simulation alternatives



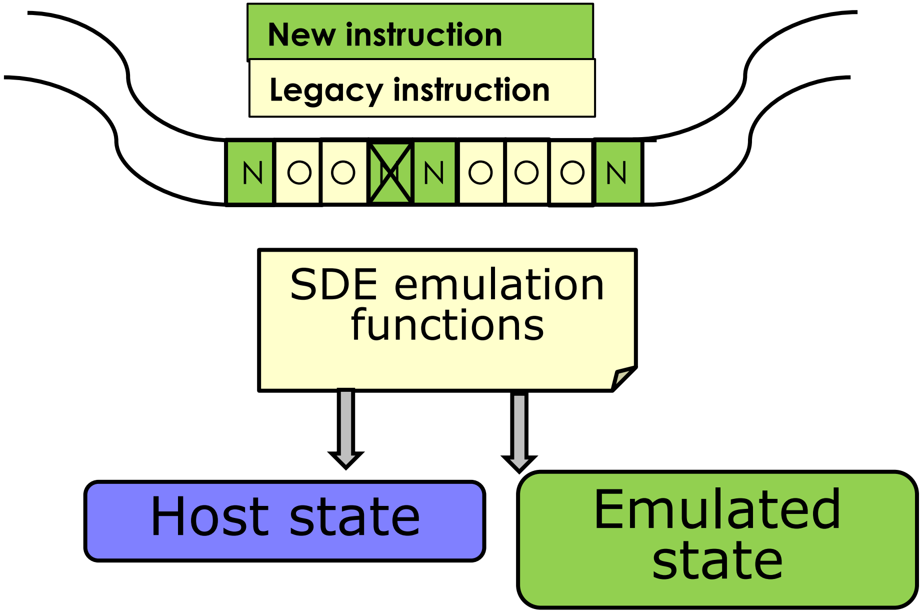
Requirement: Execution invariant region specification
(PC+count for compute loop entries)

Intel Software Development Emulator (*Intel SDE*)

- The Intel® Software Development Emulator is **a functional user-level (ring 3) emulator** for x86 (32b and 64b) new instructions built upon Pin and XED (X86 encoder/decoder)
- **Goal**: New instruction/register emulation between the time when they are designed and when the hardware is available.
- Used for compiler development, architecture and workload analysis, and tracing for architecture simulators
- No special compilation required
- Supported on Windows/Linux/Mac OS
- Runs only in user space (ring 3)

How *SDE* Works

- Based on Pin (http://pintool.intel.com) and XED decoder/encoder (https://github.com/intelxed/xed)
- Instrument new instructions
  - Add call to emulation routine
  - Delete original instruction
- Emulation routine:
  - Update native state with emulated state



http://www.intel.com/software/sde

Using *SDE* for *PinPoints* and *LoopPoint*

See later sessions of the tutorial

Summary: Simulation of Multi-threaded Programs: Tools & Methodologies

Where to simulate?

SDE + *LoopPoint*
Compute-loop iterations as
`Unit of work'

How to simulate?

1. **Pinball-driven**
2. **ELFie-driven**
3. **Binary-driven**

Are the regions representative?

1. Simulation (Sniper) -based
2.ELFie-based / Binary+*ROIPerf* (*not covered*)
Whole-program performance vs
Region-predicted performance

Agenda

Time (Eastern)	Speaker	Topic
13.20 to 13.30	Trevor E. Carlson	Overview of the tutorial
13.30 to 14.20	Akanksha Chaudhari	Performance analysis, simulation, sampling
14.20 to 15.20	Harish Patil	Using tools: Pin, PinPlay, SDE, ELFies
15.20 to 15.40	Break	
15.40 to 16.20	Alen Sabu	Multi-threaded sampling and LoopPoint
16.20 to 17.00	Changxi Liu	Sniper and LoopPoint demo
17.00 to 17.40	Zhantong Qiu	Using LoopPoint with gem5

LoopPoint Tools: Sampled Simulation of Complex Multi-threaded Workloads using Sniper and gem5

Alen Sabu[1], Changxi Liu[1], Akanksha Chaudhari[1], Harish Patil[2], Wim Heirman[2], Zhantong Qiu[3], Jason Lowe-Power[3], Trevor E. Carlson[1]

[1]National University of Singapore

[2]Intel Corporation

[3]University of California, Davis

International Symposium on High-Performance Computer Architecture, February 25th, 2023, Canada

Session 3

Multi-threaded Sampling and LoopPoint

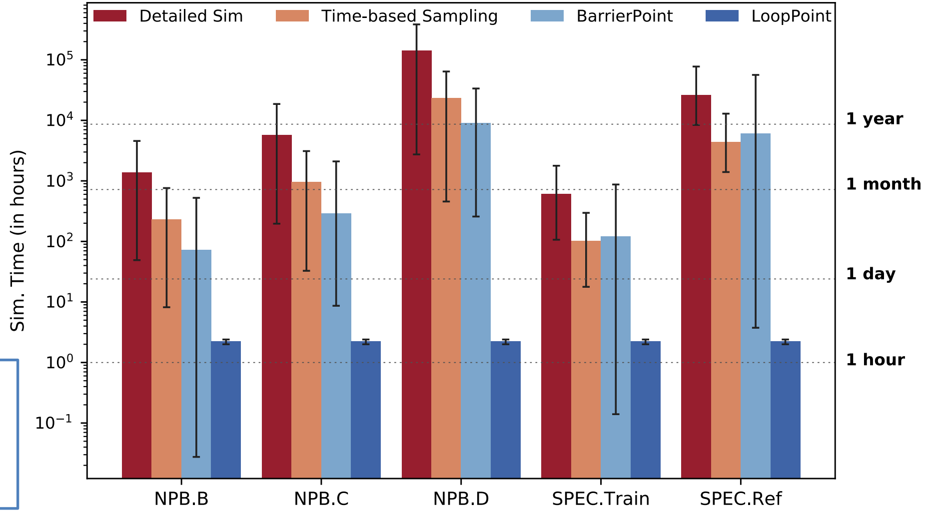
ALEN SABU, PHD CANDIDATE
NATIONAL UNIVERSITY OF SINGAPORE

Simulation in the Post-Dennard Era

Microarchitectural simulation is slow

Solution: Simulate regions of interest

Simulation in the Post-Dennard Era



Benchmarks with *8* threads, *static* schedule, *passive* wait-policy, simulated at *100 KIPS*.

Solution: Simulate regions of interest

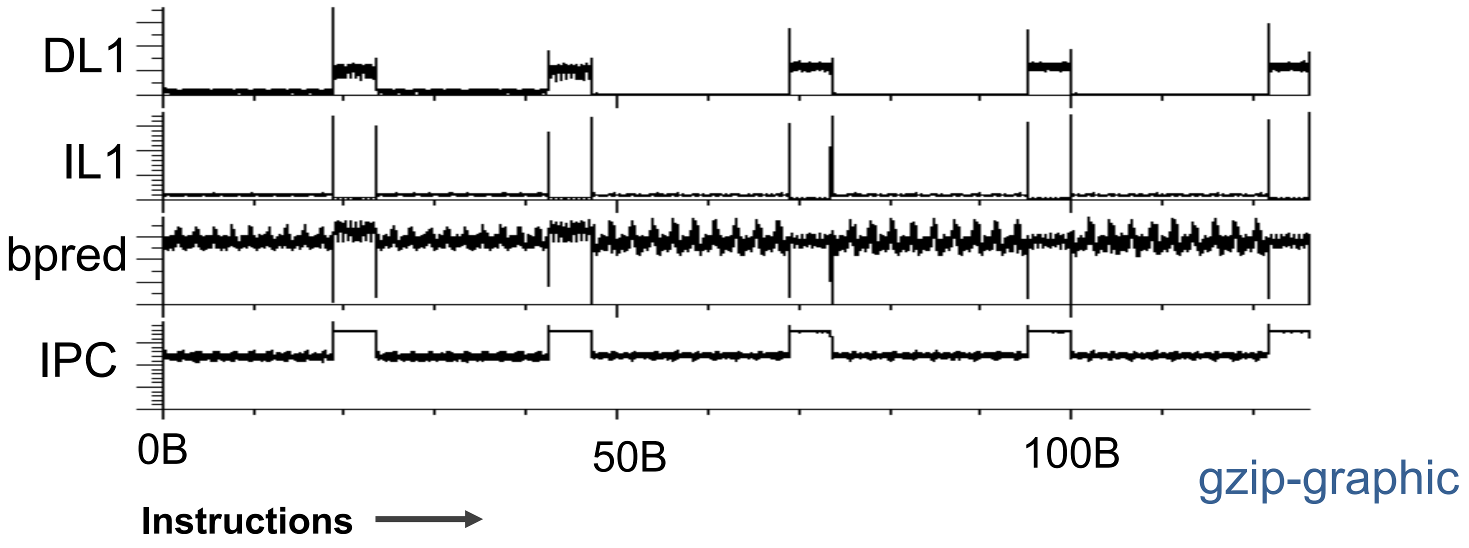
Microarchitectural simulation is slow

Selection of Regions of Interest

Program executions are structured as phases

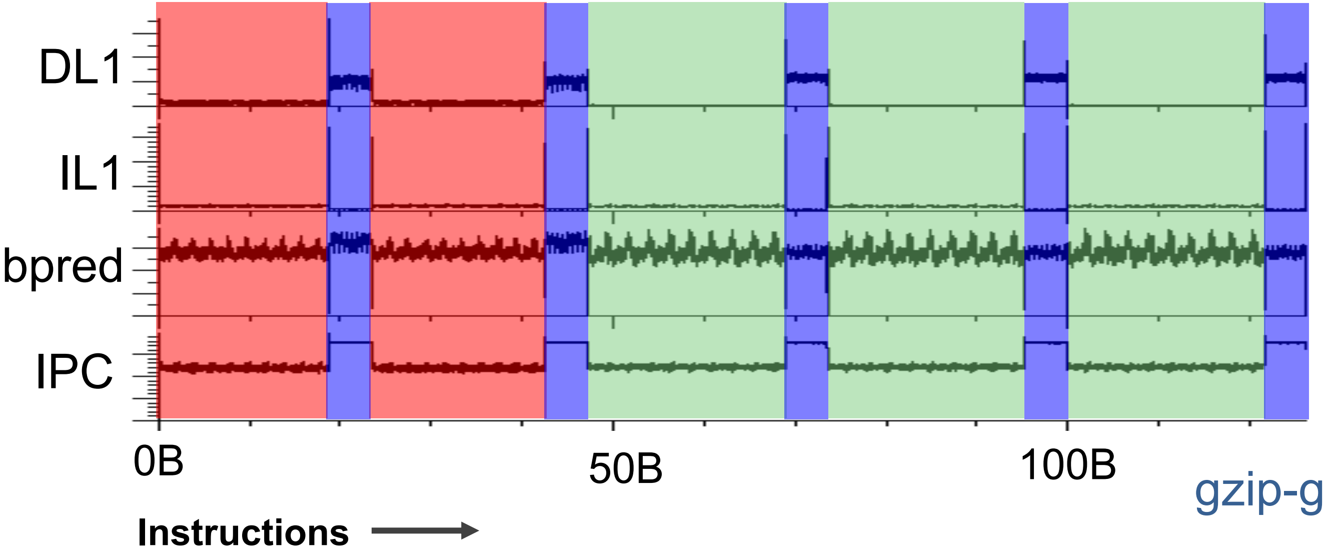
Selection of Regions of Interest

Program executions are structured as phases



Selection of Regions of Interest

Program executions are structured as phases



gzip-graphic

Source: Sherwood et al., “Automatically Characterizing Large Scale Program Behavior”, ASPLOS’02

Selection of Regions of Interest

Sampling using ***SimPoint***

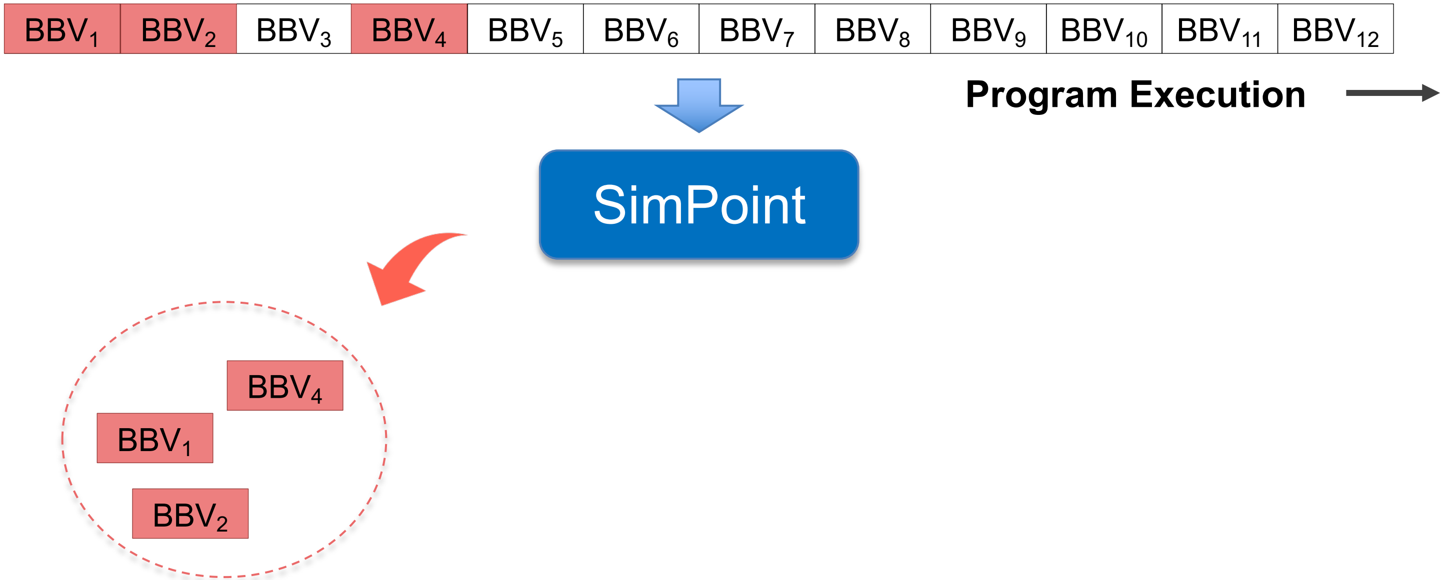
BBV_1	BBV_2	BBV_3	BBV_4	BBV_5	BBV_6	BBV_7	BBV_8	BBV_9	BBV_{10}	BBV_{11}	BBV_{12}

Program Execution →

SimPoint

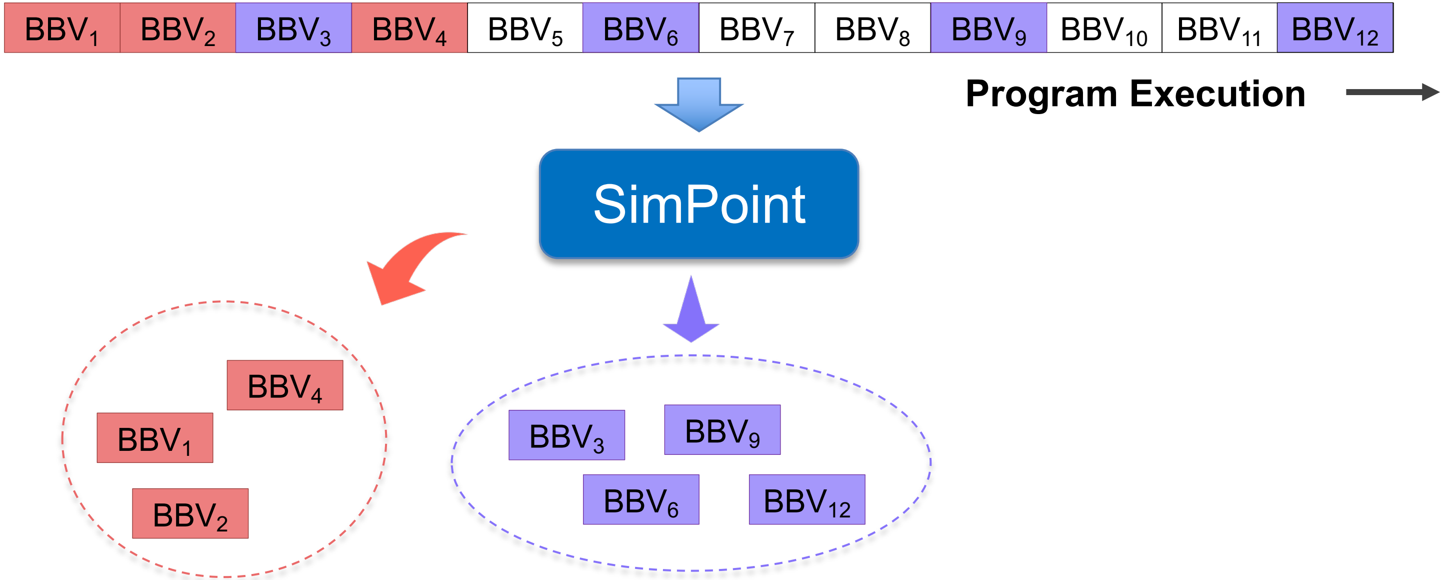
Selection of Regions of Interest

Sampling using ***SimPoint***



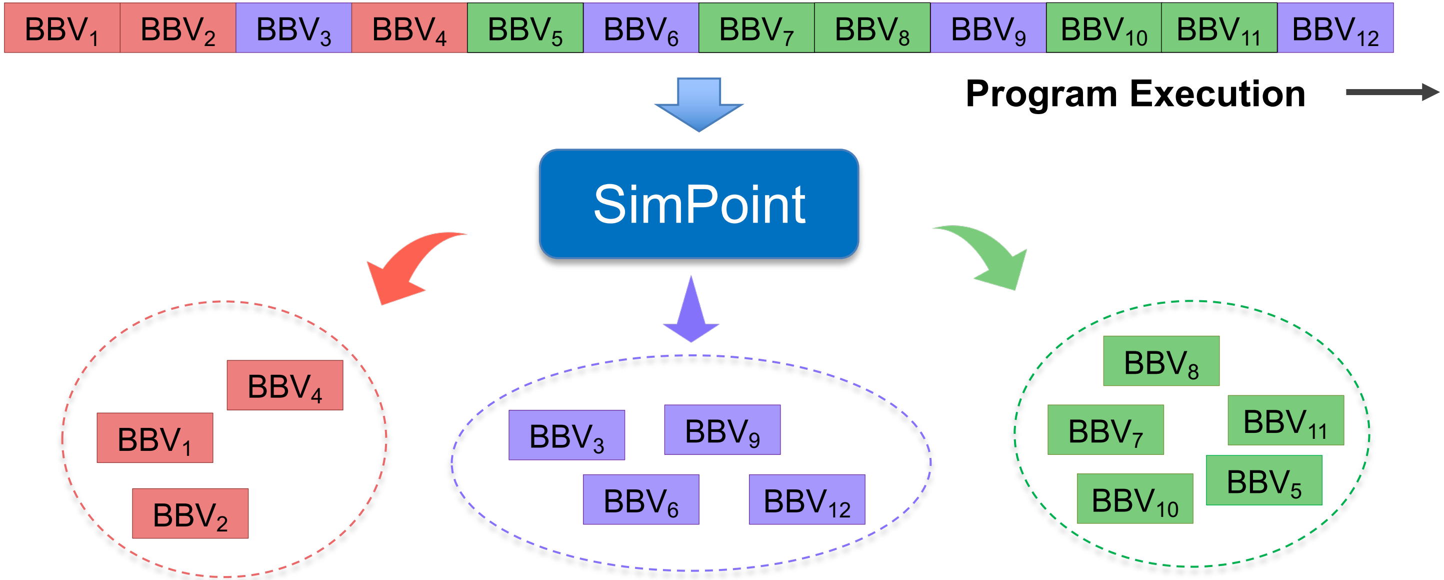
Selection of Regions of Interest

Sampling using *SimPoint*



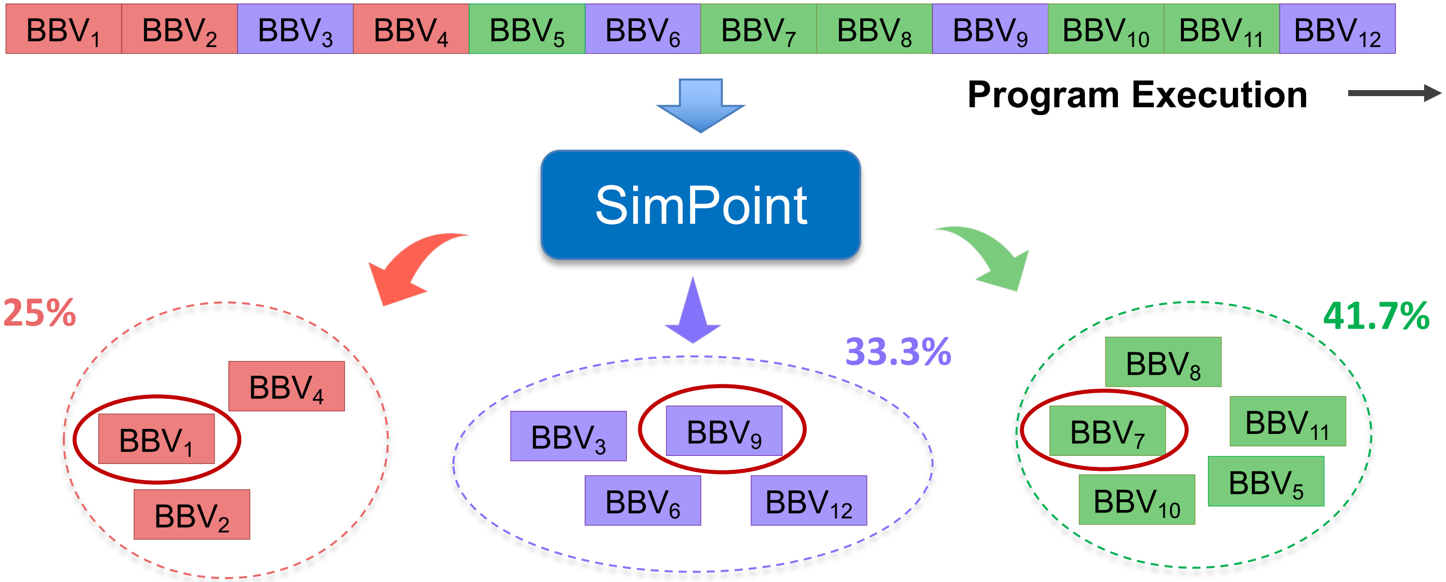
Selection of Regions of Interest

Sampling using ***SimPoint***



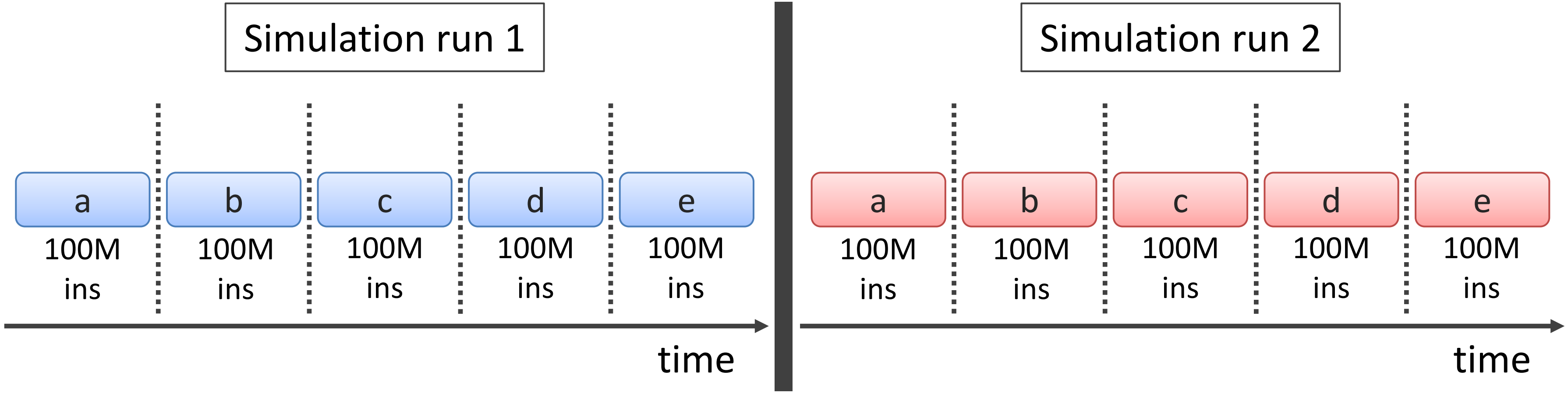
Selection of Regions of Interest

Sampling using ***SimPoint***



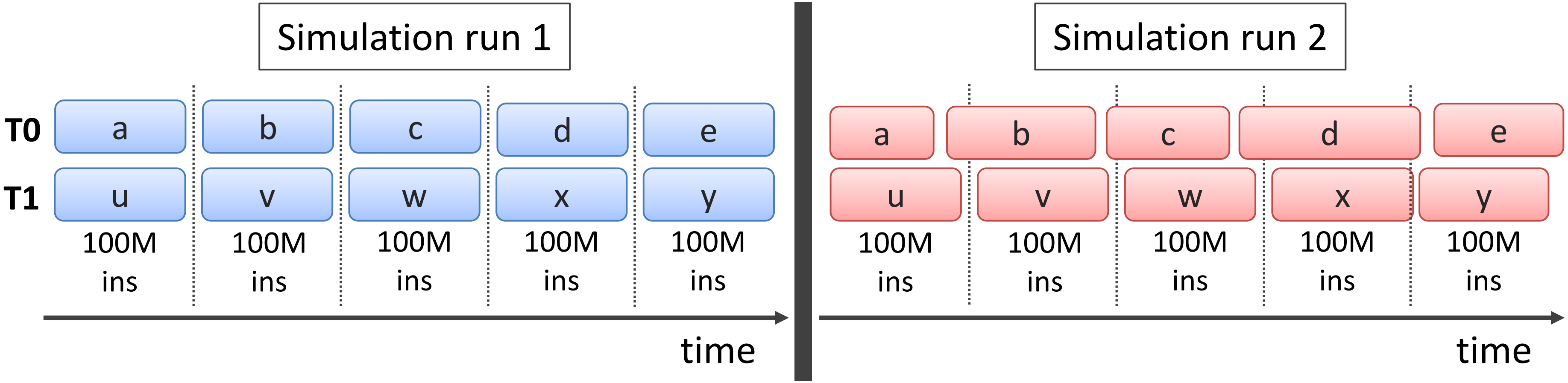
Extending Single-threaded Techniques

- SimPoint or SMARTS ➢ Instruction count-based techniques
  - Works well for single-threaded applications



Extending Single-threaded Techniques

- SimPoint or SMARTS ➢ Instruction count-based techniques
  - Inconsistent regions for multi-threaded applications



Multi-threaded Sampling is Complex

Instruction count-based techniques are unsuitable[1]

Threads progress differently due to load imbalance

Representing parallelism among threads

Differentiating thread waiting from real work

[1]Alameldeen et al., "IPC Considered Harmful for Multiprocessor Workloads", IEEE Micro 2006

Multi-threaded Sampling is Complex

Instruction count-based techniques are unsuitable[1]

Threads progress differently due to load imbalance

Identify a *unit of work* that is *invariant* across executions

Representing parallelism among threads

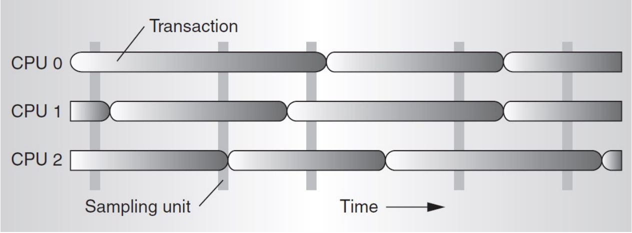
Differentiating thread waiting from real work

[1]Alameldeen et al., "IPC Considered Harmful for Multiprocessor Workloads", IEEE Micro 2006

Multi-threaded Sampling: Prior works

FlexPoints

- Designed for non-synchronizing throughput workloads
- Instruction count-based sampling
- Assumes no thread interaction
- Requires simulation of the full application

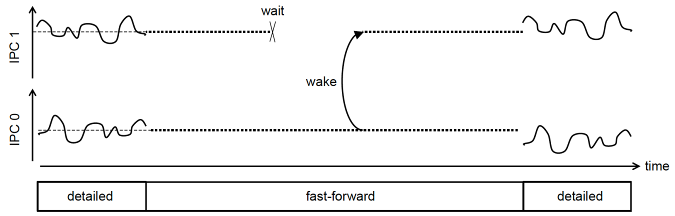


Wenisch et al., “SimFlex: statistical sampling of computer system simulation”, IEEE Micro’06

Multi-threaded Sampling: Prior works

Time-based Sampling

- Designed for synchronizing generic multi-threaded workloads
- Applies to generic multi-threaded workloads
- Extremely slow
- Requires simulation of the full application

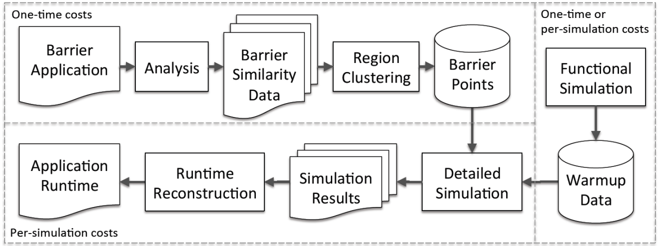


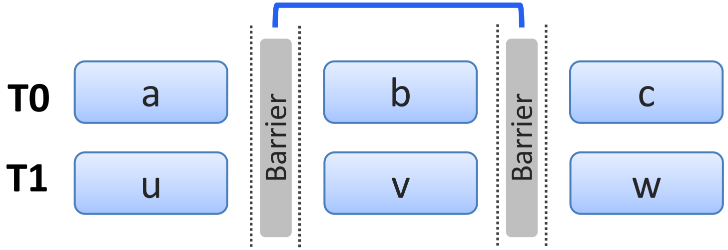
Carlson et al., "Sampled Simulation of Multithreaded Applications", ISPASS'13
Ardestani et al., "ESESC: A fast multicore simulator using time-based sampling." HPCA, 2013

Multi-threaded Sampling: Prior works

BarrierPoint

- Designed for barrier-synchronized multi-threaded workloads
- Scales well with number of barriers
- Slow when *inter-barrier regions* are large





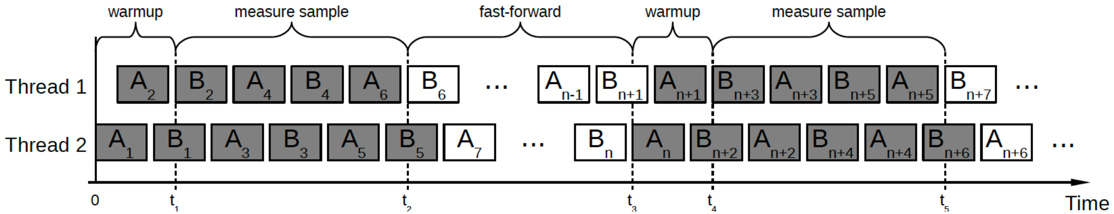
Carlson et al., "BarrierPoint: Sampled simulation of multi-threaded applications", ISPASS'14

Multi-threaded Sampling: Prior works

TaskPoint

- Designed for task-based workloads
- Uses analytical models to improve accuracy
- Works only for the particular workload type

```
#pragma omp task
    label(task type 1)
do_something();
```



Grass et al., "TaskPoint: Sampled simulation of task-based programs", ISPASS'16

The Unit of Work

Single-threaded Sampling

SimPoint[1]
SMARTS[2] → Instruction count

Multiprocessor Sampling

Flex Points[3] → Instruction count

Multi-threaded Sampling

Time-based sampling[4] → Time

Application-specific Sampling

BarrierPoint[5] → Inter-barrier regions
TaskPoint[6] → Task instances

[1]Sherwood et al., "Automatically Characterizing Large Scale Program Behavior", ASPLOS'02
[2]Wunderlich et al., "SMARTS: Accelerating Microarchitecture Simulation via Rigorous Statistical Sampling", ISCA'03
[3]Wenisch et al., "SimFlex: statistical sampling of computer system simulation", IEEE Micro'06

[4]Carlson et al., "Sampled Simulation of Multithreaded Applications", ISPASS'13
[5]Carlson et al., "BarrierPoint: Sampled simulation of multi-threaded applications", ISPASS'14
[6]Grass et al., "TaskPoint: Sampled simulation of task-based programs", ISPASS'16

The Unit of Work

Single-threaded Sampling

SimPoint[1]
SMARTS[2]
→ Instruction count

Time-based sampling[4] → Time

Multiprocessor Sampling

Flex Points[3] → Instruction count

BarrierPoint[5] → Inter-barrier regions

TaskPoint[6] → Task instances

We consider generic loop iterations as the unit of work

[1]Sherwood et al., "Automatically Characterizing Large Scale Program Behavior", ASPLOS'02
[2]Wunderlich et al., "SMARTS: Accelerating Microarchitecture Simulation via Rigorous Statistical Sampling", ISCA'03
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[5]Carlson et al., "BarrierPoint: Sampled simulation of multi-threaded applications", ISPASS'14
[6]Grass et al., "TaskPoint: Sampled simulation of task-based programs", ISPASS'16

LoopPoint Methodology

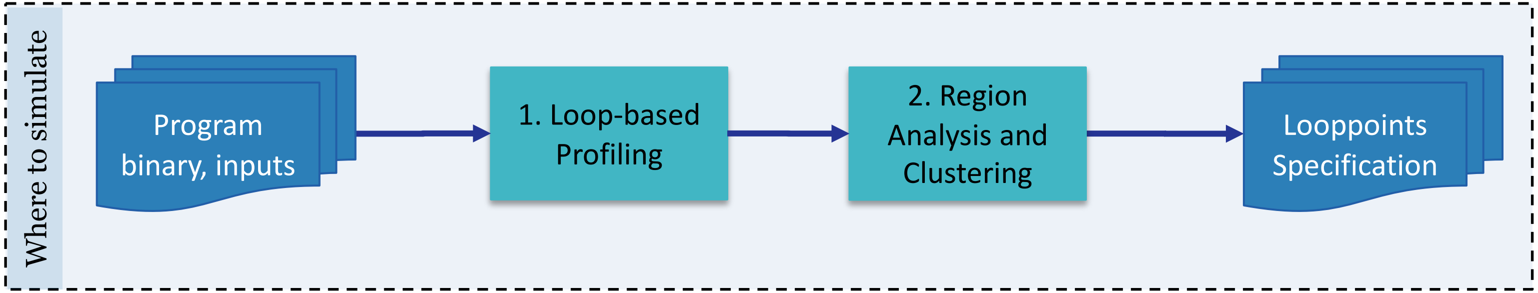
Where to simulate

How to simulate

LoopPoint Methodology

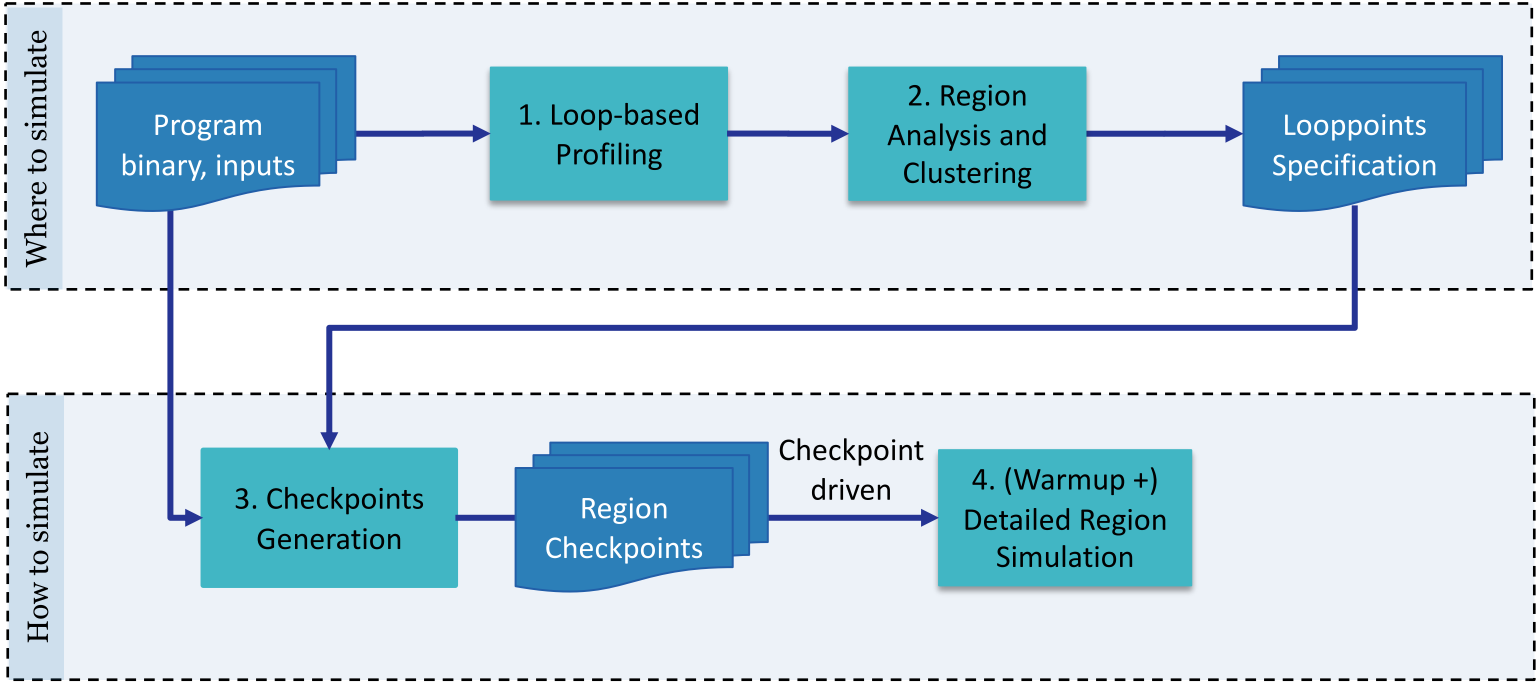
How to simulate

LoopPoint Methodology

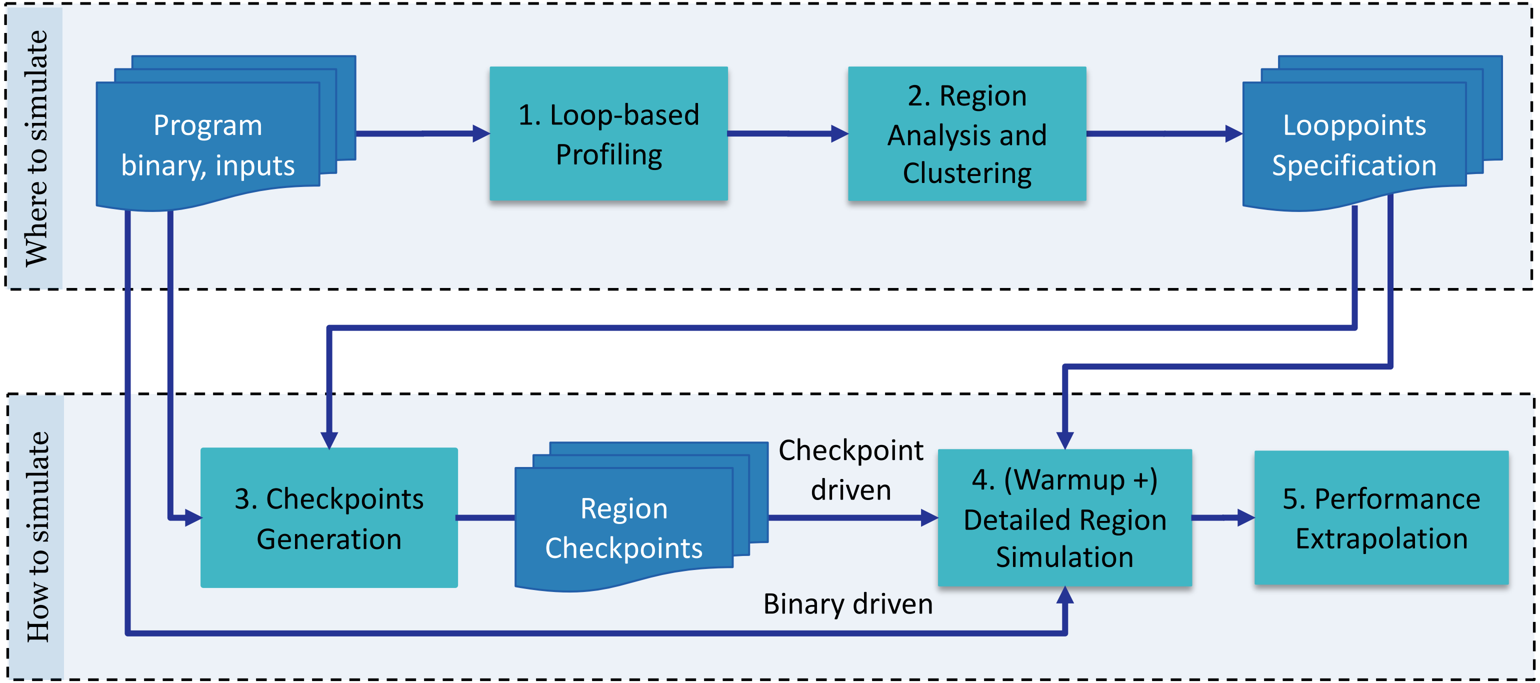


How to simulate

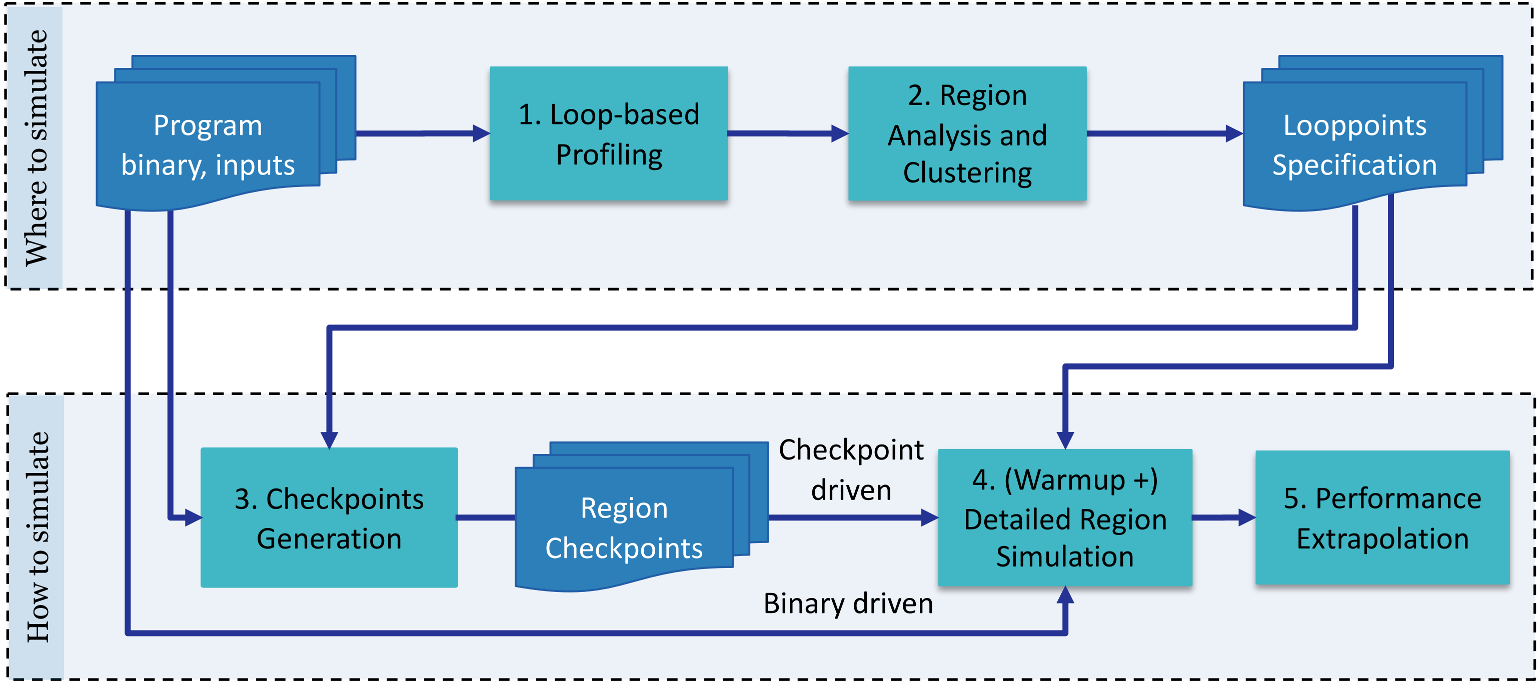
LoopPoint Methodology



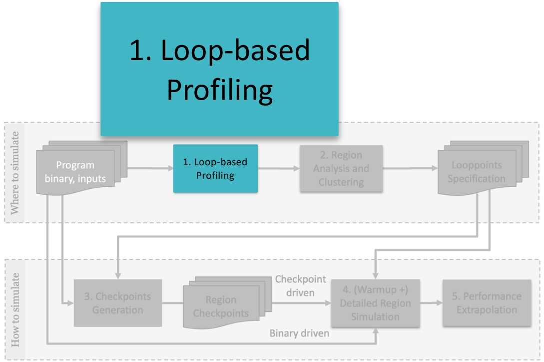
LoopPoint Methodology



Loop-based Profiling

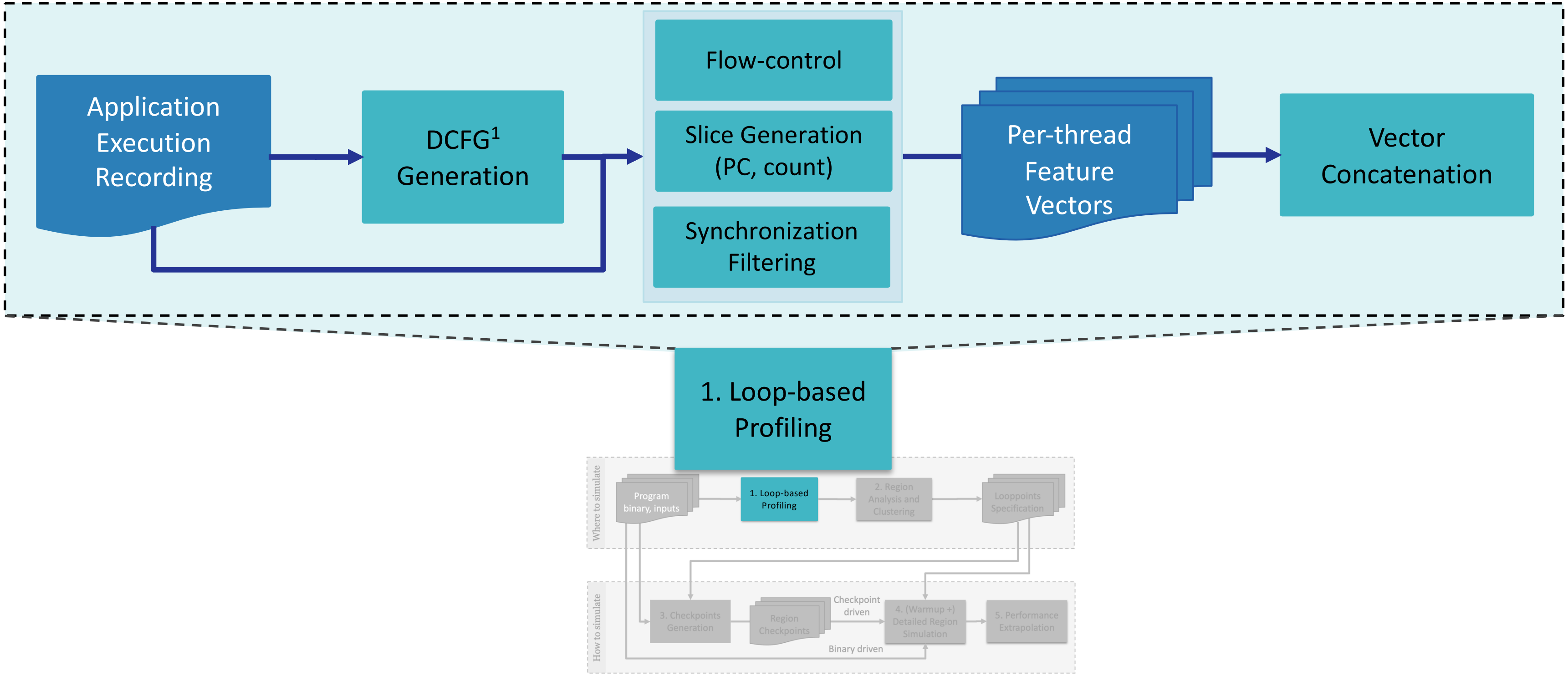


Loop-based Profiling



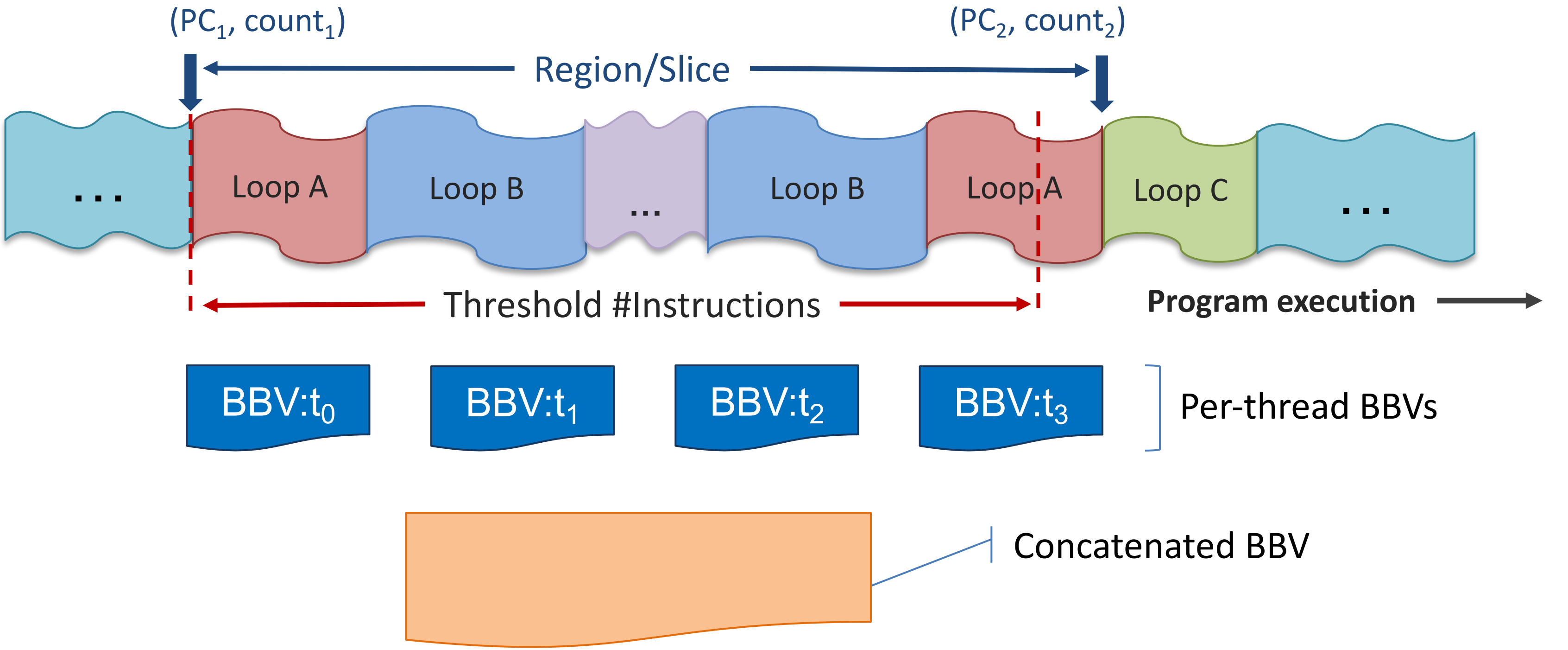
[1]DCFG: Dynamic Control-Flow Graph

Loop-based Profiling

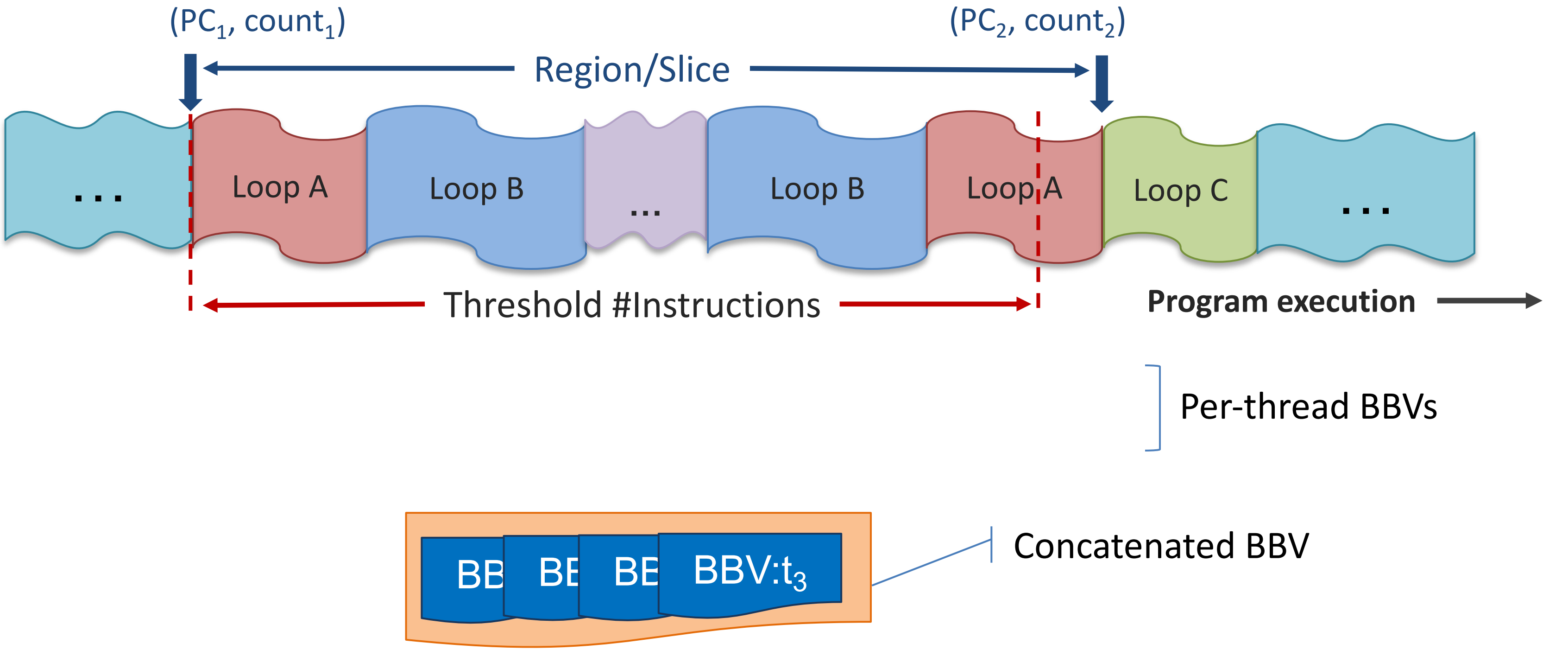


[1]DCFG: Dynamic Control-Flow Graph

Region Representation



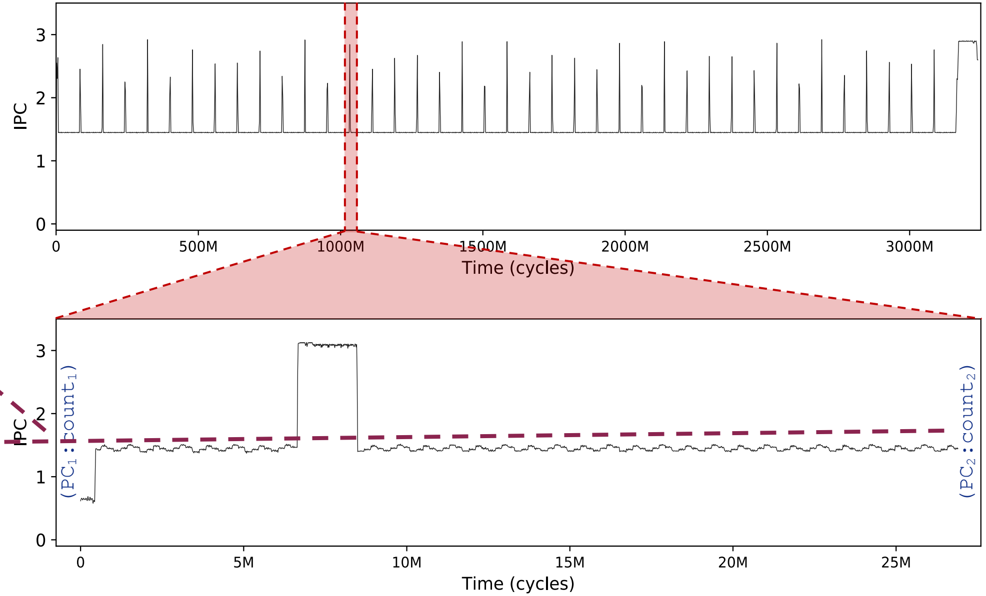
Region Representation



A LoopPoint Region

638.imagick_s/magick/morphology.c

```
#if defined(MAGICKCORE_OPENMP_SUPPORT)
  #pragma omp parallel for schedule(static,4) shared(progress,status) \
    magick_threads(image,result_image,image->rows,1)
#endif
  for (y=0; y < (ssize_t) image->rows; y++)
  {
     ……
     for (x=0; x < (ssize_t) image->columns; x++)
     {
        for (v=0; v < (ssize_t) kernel->height; v++) {
          for (u=0; u < (ssize_t) kernel->width; u++, k--) {
     ……
          } /* u */
     ……
        }  /* v */
     } /* x */
  } /* y */
         ……
```

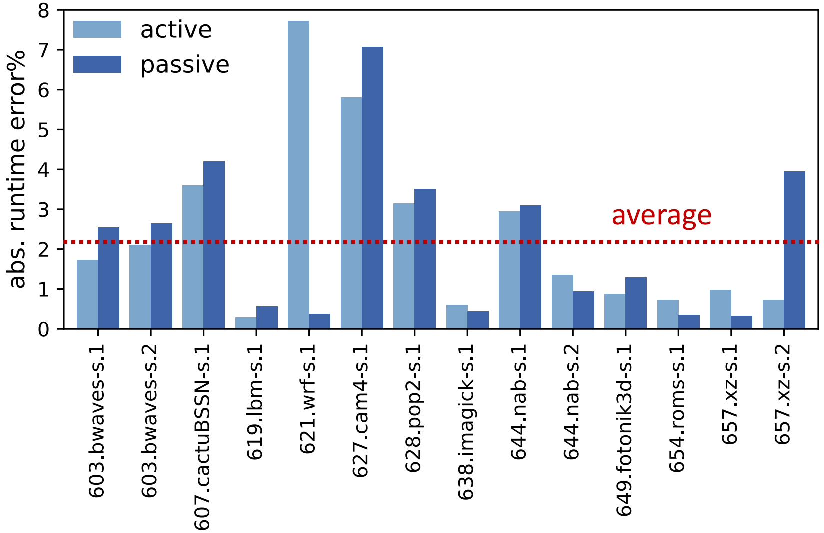


638.imagick_s, train input, 8 threads

Accuracy Results

Prediction error wrt. performance of whole application

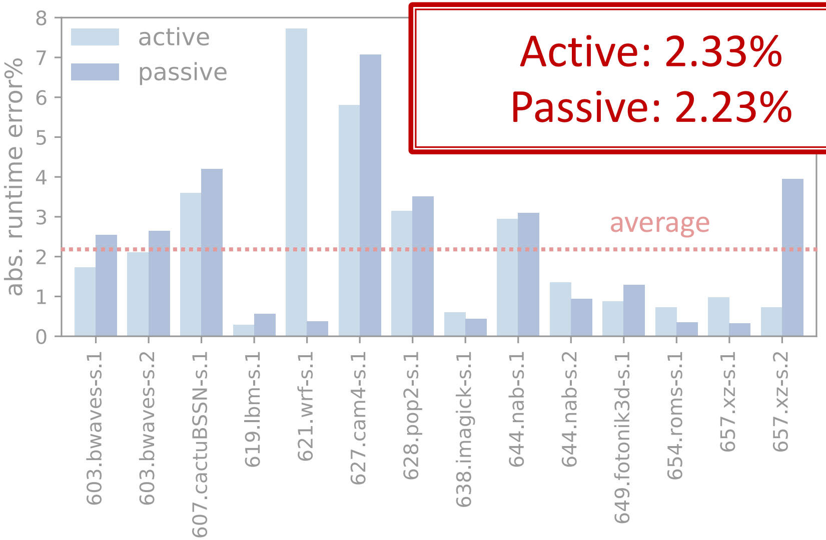
SPEC CPU2017 with train inputs, *8* threads



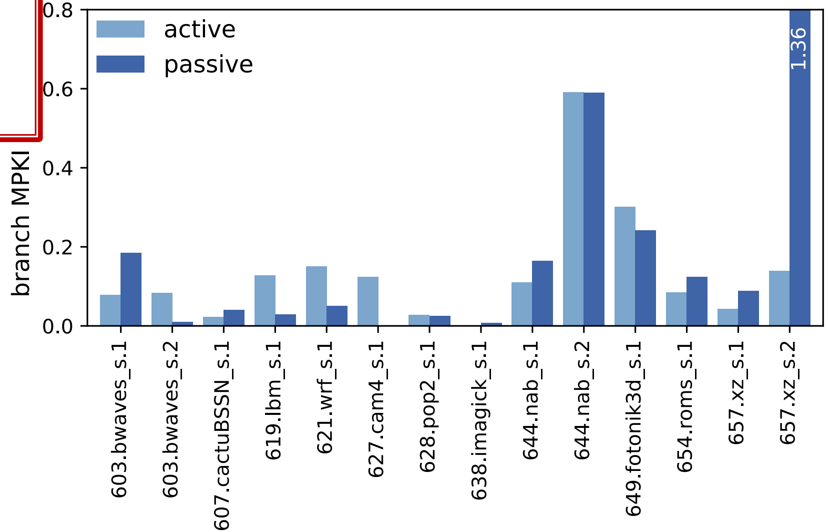
Accuracy Results

Prediction error wrt. performance of whole application

SPEC CPU2017 with train inputs, *8* threads



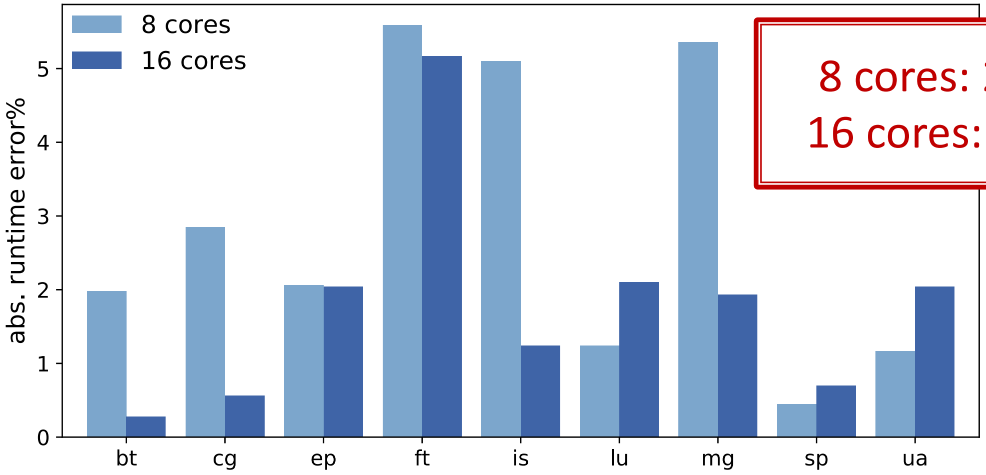
Active: 2.33%
Passive: 2.23%



Changing Thread Count

Runtime prediction error wrt. whole application runtime

NPB 3.3 with *Class C* inputs, *8* and 16 threads, *passive* wait-policy

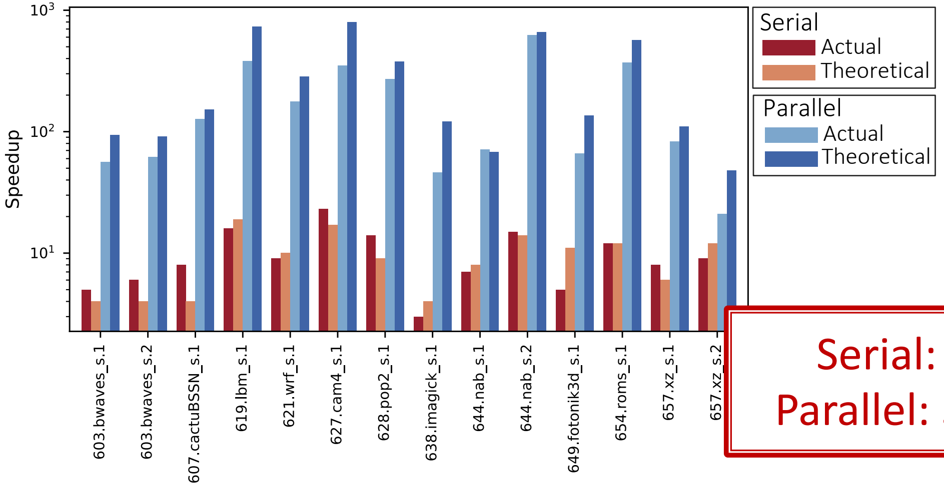


8 cores: 2.87%
16 cores: 1.78%

Speedup

Parallel and serial speedup achieved for LoopPoint

SPEC CPU2017 with *train* inputs, *8* threads, *active* wait-policy



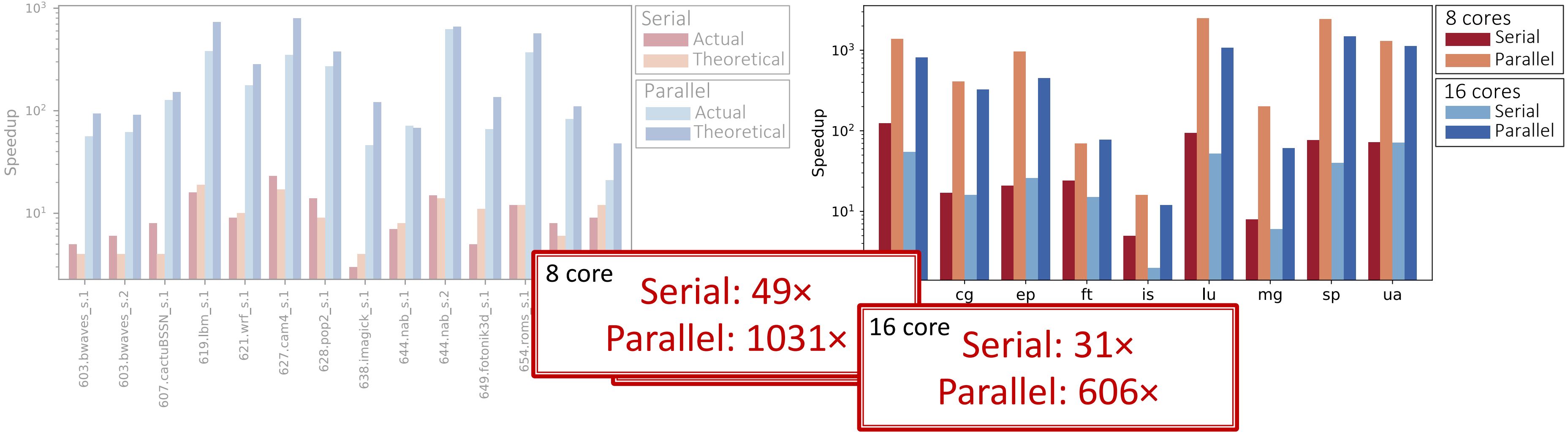
Serial: 9×
Parallel: 303×

Speedup

Parallel and serial speedup achieved for LoopPoint

SPEC CPU2017 with *train* inputs, *8* threads, *active* wait-policy

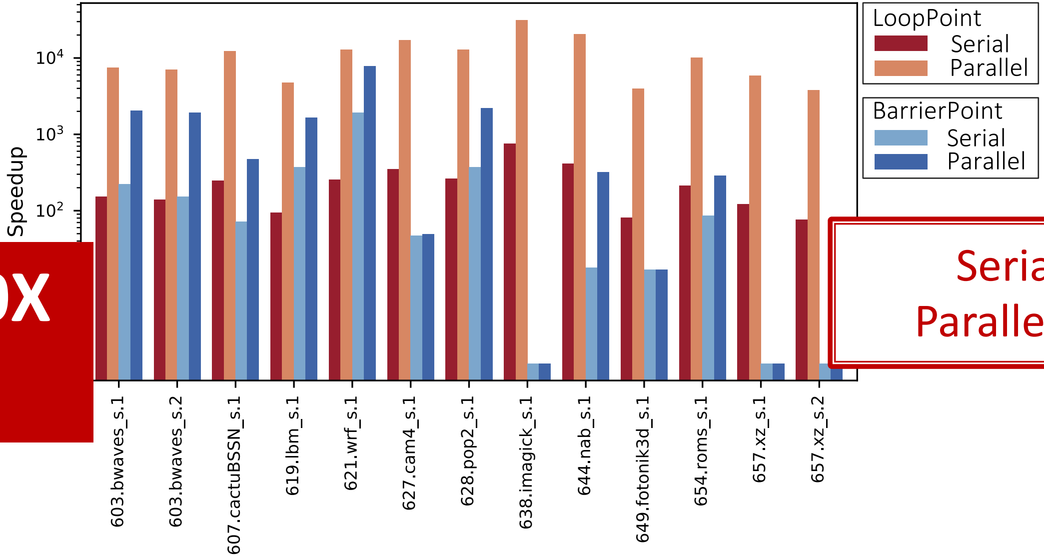
NPB with *Class C* inputs, *8 and 16* threads, *passive* wait-policy



Speedup

Theoretical Speedup comparison with BarrierPoint

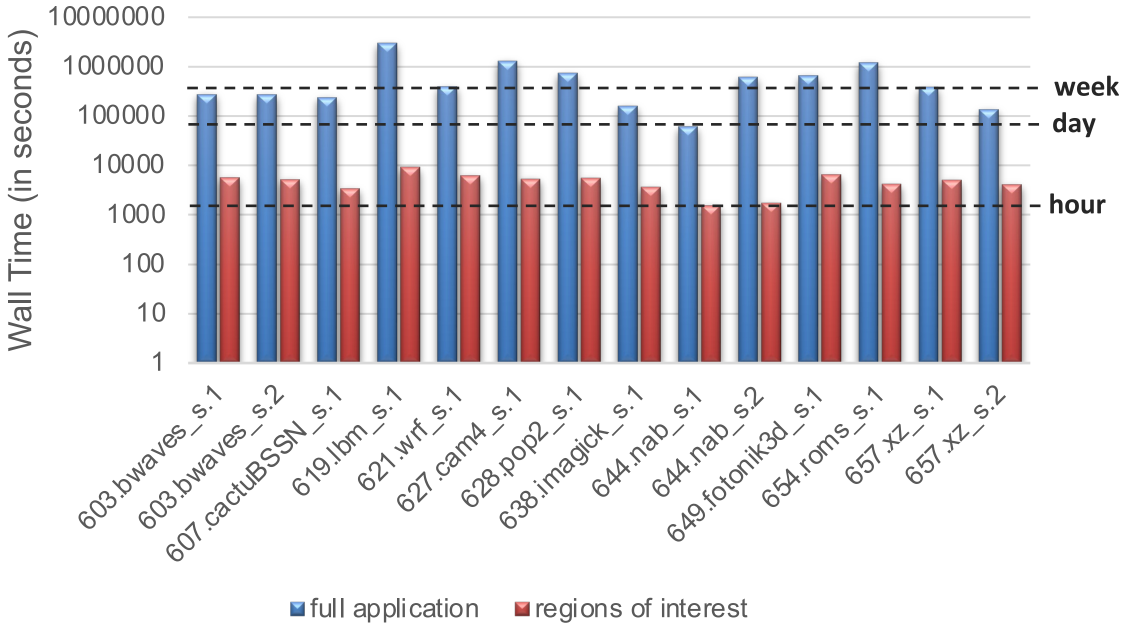
SPEC CPU2017 with *ref* inputs, *8* threads, *passive* wait-policy



Up to 31000X speedup!

Serial: 244×
Parallel: 11587×

Full Applications Vs. Regions of Interest



A comparison of simulation wall times of SPEC CPU2017 benchmarks using train inputs and 8 threads on SDE-based IWPS (CLX)

Application	Train	Ref
603.bwaves_s.1	33.33	1.01
603.bwaves_s.2	32.79	1.03
607.cactuBSSN_s.1	26.81	0.45
619.lbm_s.1	4.86	0.65
621.wrf_s.1	9.28	0.47
627.cam4_s.1	4.78	0.23
628.pop2_s.1	6.27	0.46
638.imagick_s.1	25.93	0.13
644.nab_s.1	21.15	0.32
644.nab_s.2	9.74	–
649.fotonik3d_s.1	12.93	1.55
654.roms_s.1	3.98	0.71
657.xz_s.1	21.43	0.74
657.xz_s.2	42.55	1.26

Fraction of regions to be simulated in detail for SPEC CPU2017 benchmarks using 8 threads

More Information

- Links
  - SPEC2017 Looppoint-based checkpoints (ELFies[1])
    - 603.bwaves_s.1: https://mynbox.nus.edu.sg/u/lAblPcAG5X6GBuU-/9491eb22-b988-4bc5-9865-991a66d20944?l
    - 603.bwaves_s.2: https://mynbox.nus.edu.sg/u/8L13gqS9d8DivXeB/6d14af21-6c4e-413a-b046-3c6115a211fc?l
  - LoopPoint GitHub: https://github.com/nus-comparch/looppoint
  - ELFies GitHub: https://github.com/intel/pinball2elf
  - Web page: https://looppoint.github.io
  - Short talk: https://youtu.be/Tr6O9MkT42g
  - Questions: alen@u.nus.edu.sg, tcarlson@nus.edu.sg

[1]Representative checkpoints of SPEC CPU2017 benchmarks with 8 OpenMP threads, active wait-policy, static schedule, original binaries compiled with ICC (-O3) for Nehalem architecture.

Agenda

Time (Eastern)	Speaker	Topic
13.20 to 13.30	Trevor E. Carlson	Overview of the tutorial
13.30 to 14.20	Akanksha Chaudhari	Performance analysis, simulation, sampling
14.20 to 15.20	Harish Patil	Using tools: Pin, PinPlay, SDE, ELFies
15.20 to 15.40	Break	
15.40 to 16.20	Alen Sabu	Multi-threaded sampling and LoopPoint
16.20 to 17.00	Changxi Liu	Sniper and LoopPoint demo
17.00 to 17.40	Zhantong Qiu	Using LoopPoint with gem5

LoopPoint Tools: Sampled Simulation of Complex Multi-threaded Workloads using Sniper and gem5

Alen Sabu[1], Changxi Liu[1], Akanksha Chaudhari[1], Harish Patil[2], Wim Heirman[2], Zhantong Qiu[3], Jason Lowe-Power[3], Trevor E. Carlson[1]

[1]National University of Singapore

[2]Intel Corporation

[3]University of California, Davis

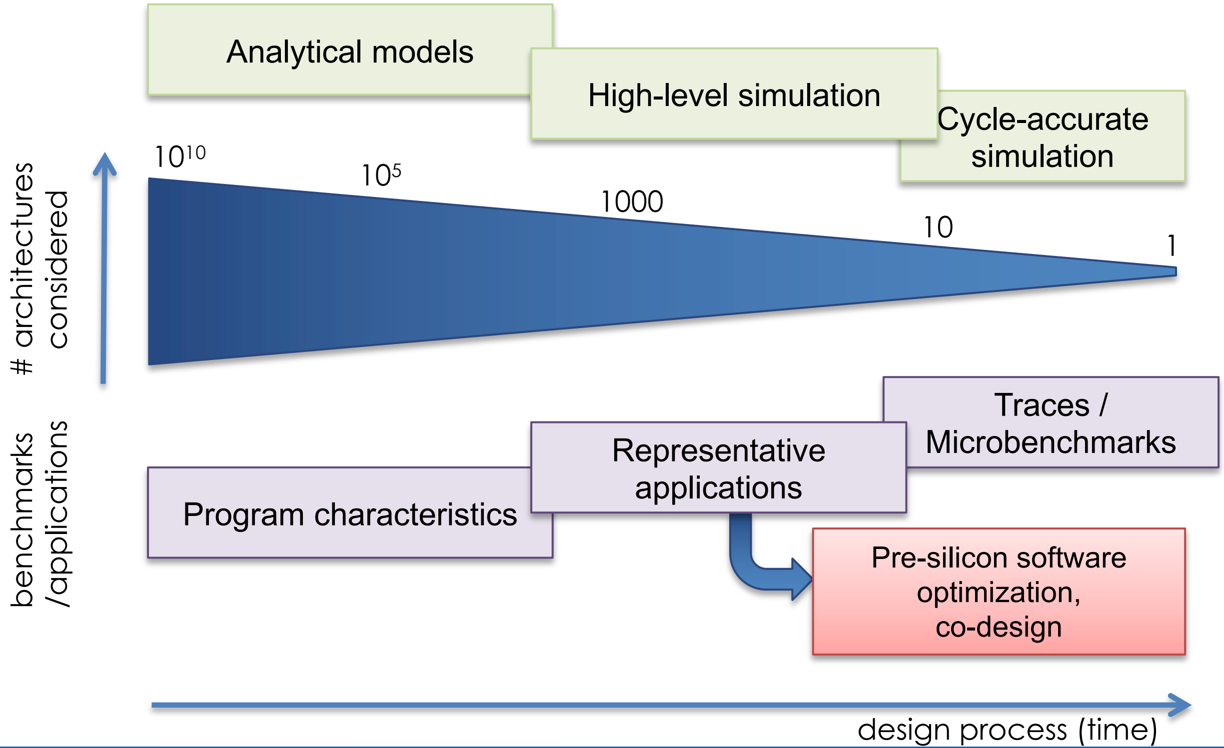
International Symposium on High-Performance Computer Architecture, February 25th, 2023, Canada

Session 4

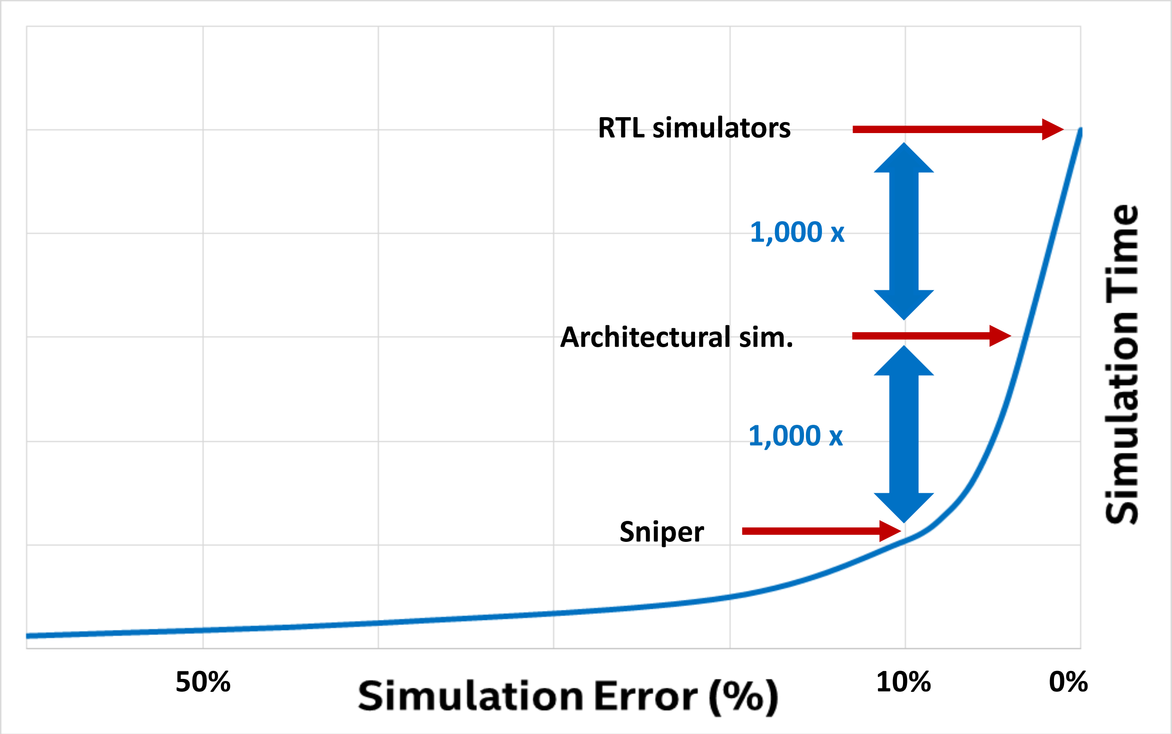
Sniper and LoopPoint Demo

CHANGXI LIU, PHD CANDIDATE
NATIONAL UNIVERSITY OF SINGAPORE

The Architect's Tools – Design Waterfall



Fast or accurate?

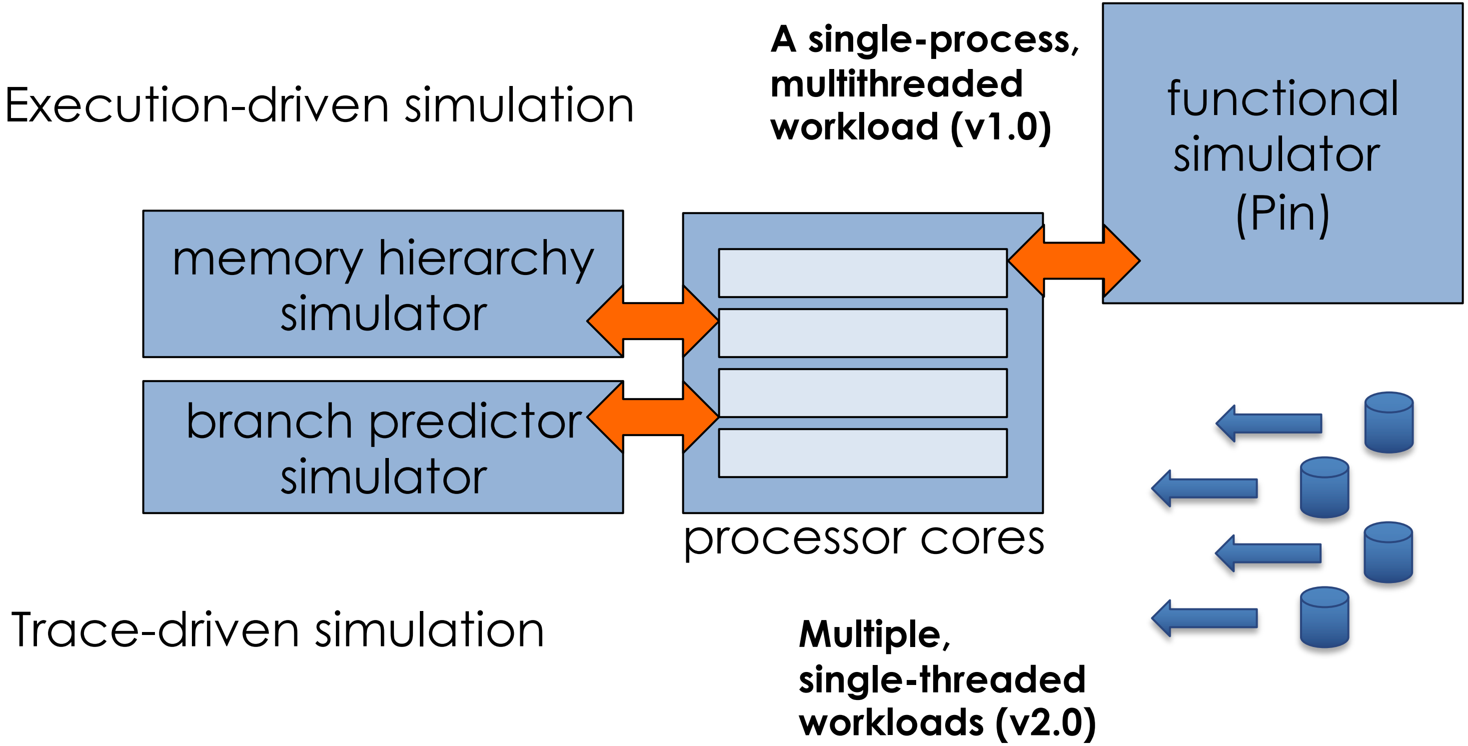


Sniper History

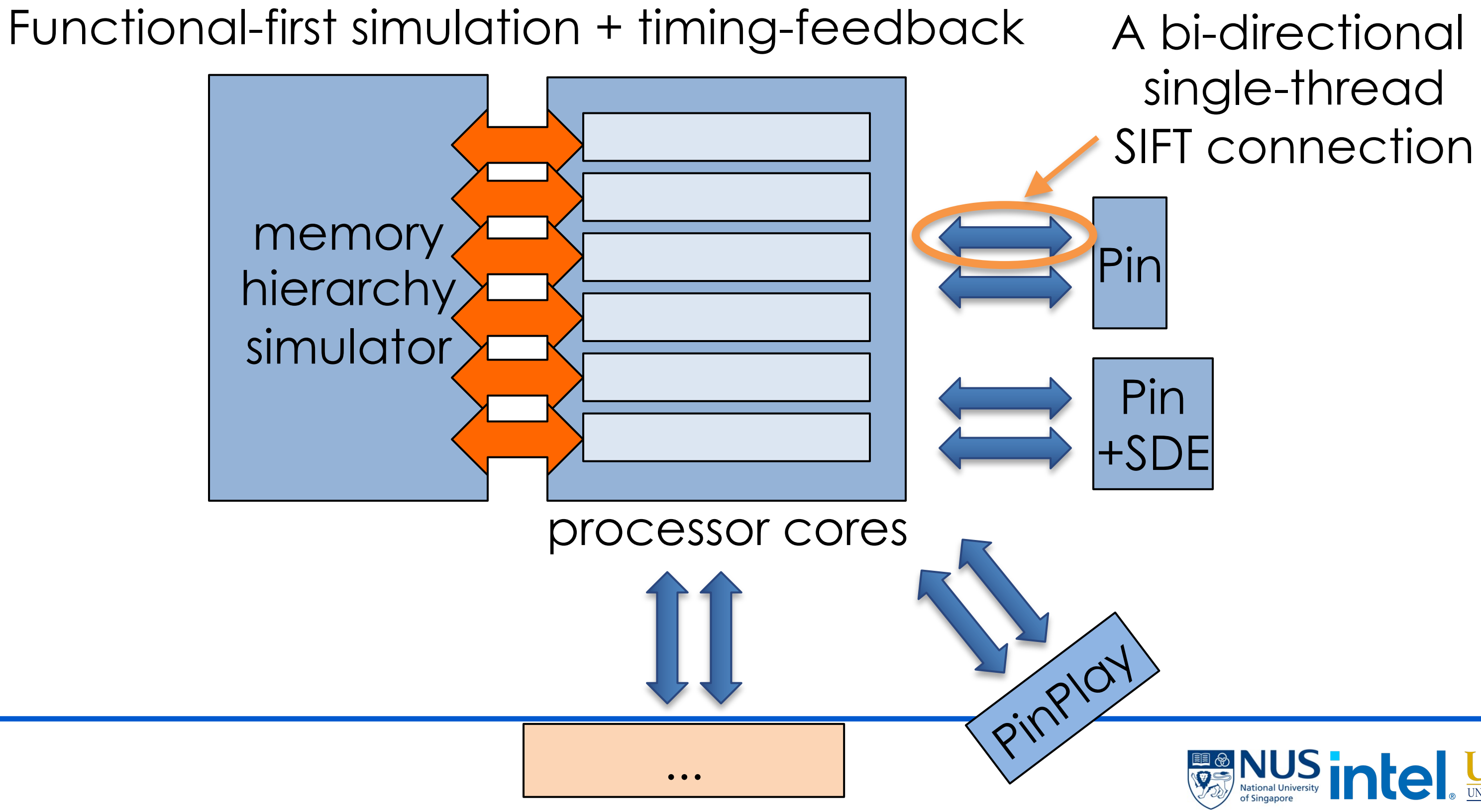
- August 2010: Sniper forked from MIT Graphite
- November 2011: SC'11 paper, first public release
- Today:
  - Interval and Instruction-window-centric core models
  - 7000+ downloads from 100+ countries
  - Active mailing list
  - 1200+ citations (SC'11 & TACO'12 papers)

snipersim.org downloads by quarter

Simulation in Sniper



Simulation in Sniper with SIFT



Running Sniper

Configuration Region of interest markers in code Workload command line

```
$ run-sniper -c gainestown --roi -- ./test/fft/fft -p2
[SNIPER] Start
[SNIPER] --------------------------------------------------------------------------------
[SNIPER] Sniper using Pin frontend
[SNIPER] Running pre-ROI region in  CACHE_ONLY mode
[SNIPER] Running application ROI in DETAILED mode
[SNIPER] Running post-ROI region in FAST_FORWARD mode
[SNIPER] --------------------------------------------------------------------------------

FFT with Blocking Transpose
   1024 Complex Doubles
   2 Processors

[SNIPER] Enabling performance models
[SNIPER] Setting instrumentation mode to DETAILED
[SNIPER] Disabling performance models
[SNIPER] Leaving ROI after 2.08 seconds
[SNIPER] Simulated 1.1M instructions, 0.9M cycles, 1.22 IPC
[SNIPER] Simulation speed 545.5 KIPS (272.8 KIPS / target core - 3666.2ns/instr)
[SNIPER] Setting instrumentation mode to FAST_FORWARD

                 PROCESS STATISTICS
...
[SNIPER] End
[SNIPER] Elapsed time: 5.97 seconds
```

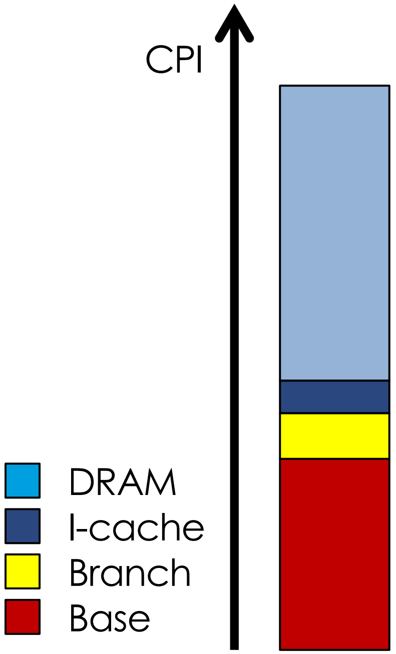
Simulation results

`sim.out`: Quick overview of basic performance results

```
                                      | Core 0     | Core 1
  Instructions                        |     506505 |     505562
  Cycles                              |     469101 |     468620
  Time (ns)                           |     176354 |     176173
Branch predictor stats                |            |
  num incorrect                       |       1280 |       1218
  misprediction rate                  |      7.70% |      7.42%
  mpki                                |       2.53 |       2.41
Cache Summary                         |            |
  Cache L1-I                          |            |
    num cache accesses                |      46642 |      46555
    num cache misses                  |        217 |        178
    miss rate                         |      0.47% |      0.38%
    mpki                              |       0.43 |       0.35
  Cache L1-D                          |            |
    num cache accesses                |     332771 |     332412
    num cache misses                  |        517 |        720
    miss rate                         |      0.16% |      0.22%
    mpki                              |       1.02 |       1.42
  Cache L2                            |            |
    num cache accesses                |        984 |       1090
    num cache misses                  |        459 |        853
```

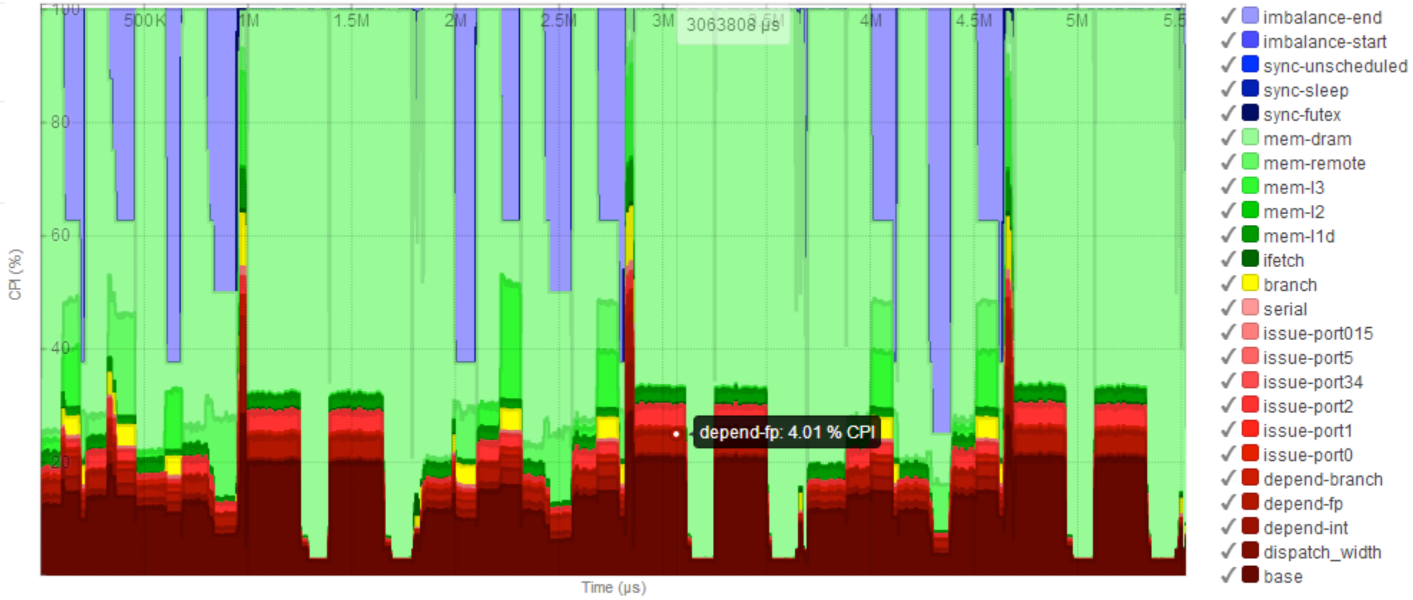
Cycle stacks

- Where did my cycles go?
  - Cycles/time per instruction
  - Broken up in components
    - Base: ideal execution, no bottlenecks
    - Add “lost” cycles do to each HW structure
  - Normalize by either
    - Number of instructions (CPI stack)
    - Execution time (time stack)
- *Different from miss rates*: cycle stacks directly quantify the effect on performance
- (Also: top-down analysis in VTune)



Advanced visualization

- Cycle stacks through time



Downloading Sniper 8.0

- Clone from https://github.com/snipersim/snipersim
- `export CC=gcc-9; export CXX=g++-9`
- `make`
- Set SNIPER_ROOT to point to the Sniper base directory
- All set to use Sniper 8.0!
- Testing:
  - `make -C test/fft`

Downloading LoopPoint

- Prerequisites
  - x86-based Linux machine
  - Require GCC 9
  - Python
  - Docker

Downloading LoopPoint

- Opensource code
  - https://github.com/nus-comparch/looppoint.git
  - Clone the repo

```
[redacted] $ git clone https://github.com/nus-comparch/looppoint.git
Cloning into 'looppoint'...
remote: Enumerating objects: 320, done.
remote: Counting objects: 100% (168/168), done.
remote: Compressing objects: 100% (141/141), done.
remote: Total 320 (delta 27), reused 148 (delta 21), pack-reused 152
Receiving objects: 100% (320/320), 15.74 MiB | 13.79 MiB/s, done.
Resolving deltas: 100% (56/56), done.
Checking connectivity... done.
[redacted] $ ls
looppoint
```

Building LoopPoint

- `make build`
  - Build docker image

```
  Created wheel for tabulate: filename=tabulate-0.8.9-py2-none-any.whl size=33171 sha256=c170d0c5148145e2deb57b20db0b76d241909980d4dcea24
278faa8f3e0a3136
  Stored in directory: /tmp/pip-ephem-wheel-cache-5zZe7v/wheels/0a/4b/e1/d0e504a346ed0882b93f971fe1122b9de64fabebd9b1d81b9f
Successfully built tabulate
Installing collected packages: tabulate
Successfully installed tabulate-0.8.9
Removing intermediate container f962cd7c7f48
 ---> fdccc13883e7
Step 11/11 : RUN pip3 install --no-cache-dir  --upgrade pip &&     pip3 install --no-cache-dir numpy
 ---> Running in 89fa1a2a269a
Collecting pip
  Downloading https://files.pythonhosted.org/packages/a4/6d/6463d49a933f547439d6b5b98b46af8742cc03ae83543e4d7688c2420f8b/pip-21.3.1-py3-n
one-any.whl (1.7MB)
Installing collected packages: pip
WARNING: Running pip as the 'root' user can result in broken permissions and conflicting behaviour with the system package manager. It is
 recommended to use a virtual environment instead: https://pip.pypa.io/warnings/venv
Successfully installed numpy-1.19.5
Removing intermediate container 89fa1a2a269a
 ---> b006ee297a64
[Warning] One or more build-args [TZ_ARG] were not consumed
Successfully built b006ee297a64
Successfully tagged ubuntu:18.04-looppoint
```


Successfully built b006ee297a64
Successfully tagged ubuntu:18.04-looppoint

Building LoopPoint

- `make build`
- `make`
  - Run the docker image

```
[redacted]looppoint (main)$ make
docker run --rm -it -v "[redacted]looppoint:[redacted]looppoint"
--user 2014:100 -w "[redacted]looppoint" ubuntu:18.04-looppoint
I have no name!@9b31dd16ef4e:[redacted]looppoint$ ls
Dockerfile-ubuntu-18.04  README.md  lplib.py    run-looppoint.py  tools
Makefile                 apps       preprocess  suites.py
I have no name!@9b31dd16ef4e:[redacted]looppoint$
```

Building LoopPoint

- `make build`
- `make`
- `make apps`
  - Build the demo applications
  - Source code of the apps
    - `apps/demo/matrix-omp`
    - `apps/demo/dotproduct-omp`

```
I have no name!@9b31dd16ef4e:[redacted]looppoint$ make apps
make -C apps/demo/matrix-omp
make[1]: Entering directory '[redacted]looppoint/apps/demo/matrix-omp'
g++ -g -O3 -fopenmp -o matrix-omp matrix-omp-init.cpp matrix-omp.cpp -static
/usr/lib/gcc/x86_64-linux-gnu/9/libgomp.a(target.o): In function `gomp_target_init':
(.text+0x358): warning: Using 'dlopen' in statically linked applications requires at
runtime the shared libraries from the glibc version used for linking
ln -s matrix-omp base.exe
make[1]: Leaving directory '[redacted]looppoint/apps/demo/matrix-omp'
make -C apps/demo/dotproduct-omp
make[1]: Entering directory '[redacted]looppoint/apps/demo/dotproduct-omp'
g++ -g -O3 -fopenmp -o dotproduct-omp dot_product_openmp.cpp
ln -s dotproduct-omp base.exe
make[1]: Leaving directory '[redacted]looppoint/apps/demo/dotproduct-omp'
I have no name!@9b31dd16ef4e:[redacted]looppoint$
```

Building LoopPoint

- `make build`
- `make`
- `make apps`
- `make tools`
  - Build Sniper and LoopPoint tools

Downloading Sniper

```
Downloading Sniper from https://github.com/snipersim/snipersim
make -C tools/sniper
make[1]: Entering directory '[redacted]looppoint/tools/sniper'
Using SDE kit
Building for x86 (intel64)
[DOWNLO] SDE 9.0.0
[DOWNLO] pinplay-scripts
[DOWNLO] Pin 3.18-98332
[DOWNLO] mbuild
[DOWNLO] xed
[INSTAL] xed
[PYTHON VERSION] 2.7.17
[GIT VERSION] v10.0-298-g2be2d28
[GCC VERSION] 9
        .
        .
        .
make[4]: Entering directory [redacted]looppoint/tools/sniper/sift/recorder'
make[4]: Leaving directory [redacted]looppoint/tools/sniper/sift/recorder'
make[3]: Leaving directory [redacted]looppoint/tools/sniper/sift/recorder'
make[2]: Leaving directory [redacted]looppoint/tools/sniper/sift'
make[2]: Entering directory [redacted]looppoint/tools/sniper/standalone'
[DEP    ] standalone/standalone.d
[DEP    ] standalone/exceptions.d
[CXX    ] standalone/exceptions.o
[CXX    ] standalone/standalone.o
[LD     ] lib/sniper
```

```
I have no name!@f3f87f6c10eb:[redacted]looppoint$ make tools
Downloading SDE kit
--2022-06-19 09:04:36--  https://downloadmirror.intel.com/684899/sde-external-9.0.0-2021-11-07-lin.tar.xz
Resolving downloadmirror.intel.com (downloadmirror.intel.com)... 13.33.88.124, 13.33.88.27, 13.33.88.68, ...
Connecting to downloadmirror.intel.com (downloadmirror.intel.com)|13.33.88.124|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 26240092 (25M) [binary/octet-stream]
Saving to: 'STDOUT'

-                      100%[=====================>]  25.02M  10.8MB/s    in 2.3s

2022-06-19 09:04:38 (10.8 MB/s) - written to stdout [26240092/26240092]
```

Downloading Intel SDE

Sniper build completed

Building LoopPoint

- Opensource code
  - https://github.com/nus-comparch/looppoint.git
  - Clone the repo
- LoopPoint script
  - `make build`
    - Build docker image
  - `make`
    - Run docker image
  - `make apps`
    - Build the demo applications
  - `make tools`
    - Build Sniper and LoopPoint tools

Running LoopPoint

- Use LoopPoint driver script
  - `./run–looppoint.py –h`
  - Provides the information on how to run the tool

```
I have no name!@e7192c5315a6:[redacted]/looppoint$ ./run-looppoint.py -h
Benchmarks:
  demo:
    dotproduct matrix

The tool runs end-to-end LoopPoint sampling methodology targeting multi-threaded applications.
Usage:
    run-looppoint.py
    [-h | --help]: Help
    [-n | --ncores=<num of threads> (8)]
    [-i | --input-class=<input class> (test)]
    [-w | --wait-policy=<omp wait policy> (passive)]
    [-p | --program=<suite-application-input> (demo-matrix-1)]: Ex. demo-dotproduct-1,cpu2017-bwaves-1
    [-c | --custom-cfg=<cfg-file>]: Run a workload of interest using cfg-file in the current directory (See README.md for details)
    [--force]: Start a new set of end-to-end run
    [--reuse-profile]: Reuse the profiling data (used along with --force)
    [--reuse-fullsim]: Reuse the full program simulation (used along with --force)
    [--no-flowcontrol]: Disable thread flowcontrol during profiling
    [--use-pinplay]: Use PinPlay instead of SDE for profiling
    [--native]: Run the application natively (no sampling)
```

Running LoopPoint

- Example run command
  - `./run-looppoint.py -p demo-matrix-1 -n 8 --force`

```
I have no name!@e7192c5315a6:[redacted]looppoint$ ./run-looppoint.py -p demo-matrix-1 -n 8 --force
[LOOPPOINT] Generating fat pinball.
[PREPROCESS] matrix-omp
[PREPROCESS] apps/demo/matrix-omp/matrix-omp
[PREPROCESS] [redacted]looppoint/apps/demo/matrix-omp/matrix-omp
[PREPROCESS] symlinking matrix-omp /tmp/tmpVdu3HD/base.exe
[PREPROCESS] apps/demo/matrix-omp/test
[PREPROCESS] [redacted]looppoint/apps/demo/matrix-omp/test
[PREPROCESS] symlinking [redacted]looppoint/apps/demo/matrix-omp/test/matrix-omp.1.cfg /tmp/tmpVdu3HD/matrix-omp.1.cfg
[PREPROCESS] symlinking [redacted]looppoint/apps/demo/matrix-omp/test/matrix-omp.2.cfg /tmp/tmpVdu3HD/matrix-omp.2.cfg
[PREPROCESS] symlinking [redacted]looppoint/apps/demo/matrix-omp/test/matrix-omp.3.cfg /tmp/tmpVdu3HD/matrix-omp.3.cfg
[PREPROCESS] Done
***  TRACING: START  ***    February 27, 2023 03:56:22
Script version $Revision:1.128$
Script:                    sde_pinpoints.py
Script args:               --delete --mode mt --sdehome=[redacted]looppoint/tools/sde-external-9.14.0-2022-10-25-lin --cfg
[redacted]looppoint/apps/demo/matrix-omp/test/matrix-omp.1.cfg --log_options -start_address main -log:fat  -log:mp_atomic 0
 -log:mp_mode 0 -log:strace -log:basename [redacted]looppoint/results/demo-matrix-1-test-passive-8-20230227035621/whole_pro
gram.1/matrix.1 --replay_options=-replay:strace -l
```

Running LoopPoint

- The LoopPoint driver script
  - Profiling the application

Running LoopPoint

- The LoopPoint driver script
  - Profiling the application
    - `make_mt_pinball` : Generate whole-program pinball
    - `gen_dcfg` : Generate DCFG file to identify loop information
    - `gen_bbv` : Generate feature vector of each region
    - `gen_cluster` : Cluster regions

Fat Pinball

- Makes Pin-based analyses repeatable.
- Command:
  - `$SDE_KIT/pinplay-scripts/sde_pinpoints.py --mode mt --cfg=$CFGFILE --log_options="-start_address main -log:fat -log:basename $WPP_BASE” --replay_options="-replay:strace" -l`
- Generates a whole-program pinball for further profiling steps

DCFG Generation

- A dynamic control-flow graph (DCFG) is a specialized control-flow graph that adds data from a specific execution of a program
- C++ DCFG APIs available for accessing the data
  - `DCFG_LOOP_CONTAINER::get_loop_ids`
    - Get the set of loop IDs
  - `DCFG_LOOP`
    - `get_routine_id` : get the function that the loop belongs to
    - `get_parent_loop_id` : get the parent loop

DCFG Generation

- A dynamic control-flow graph (DCFG) is a specialized control-flow graph that adds data from a specific execution of a program
- C++ DCFG APIs available for accessing the data.
- More APIs can be found in
  - `tools/sde-external-9.14.0-2022-10-25-lin/pinkit/sde-example/include`
    - `dcfg_api.H`
    - `dcfg_pin_api.H`
    - `dcfg_trace_api.H`

DCFG Generation

- Collect Loop Information
- Command:
  - `$SDE_BUILD_KIT/pinplay-scripts/replay.py --pintool=sde-global-looppoint.so --pintool_options "-dcfg -replay:deadlock_timeout 0 -replay:strace -dcfg:out_base_name $DCFG_BASE $WPP_BASE"`
  - -dcfg : enable DCFG generation
  - DCFG_BASE : the basename of DCFG that is generated

BBV Generation

- Profiling the feature vector of each region
- Command:
  - `$SDE_BUILD_KIT/pinplay-scripts/sde_pinpoints.py --pintool="sde-global-looppoint.so" --global_regions --pccount_regions --cfg $CFG --whole_pgm_dir $WPP_DIR --mode mt -S $SLICESIZE -b --replay_options "-replay:deadlock_timeout 0 -global_profile -emit_vectors 0 -filter_exclude_lib libgomp.so.1 -filter_exclude_lib libiomp5.so -looppoint:global_profile -looppoint:dcfg-file $DCFG -looppoint:main_image_only 1 -looppoint:loop_info $PROGRAM.$INPUT.loop_info.txt -flowcontrol:verbose 1 -flowcontrol:quantum 1000000 -flowcontrol:maxthreads $NCORES”`
  - `-pccount_regions` : (PC, count)-based region information
  - `-S $SLICESIZE`: The *global* instruction count for each region
  - `-filter_exclude_lib`: Exclude libraries from profiling information

BBV Generation

- Profiling the feature vector of each region
- Command:
  - `$SDE_BUILD_KIT/pinplay-scripts/sde_pinpoints.py --pintool="sde-global-looppoint.so" --global_regions --pccount_regions --cfg $CFG --whole_pgm_dir $WPP_DIR --mode mt -S $SLICESIZE -b --replay_options "-replay:deadlock_timeout 0 -global_profile -emit_vectors 0 -filter_exclude_lib libgomp.so.1 -filter_exclude_lib libiomp5.so -looppoint:global_profile -looppoint:dcfg-file $DCFG -looppoint:main_image_only 1 -looppoint:loop_info $PROGRAM.$INPUT.loop_info.txt -flowcontrol:verbose 1 -flowcontrol:quantum 1000000 -flowcontrol:maxthreads $NCORES”`
  - `-looppoint:main_image_only`: Select only main image for choosing markers
  - `-looppoint:loop_info` : Utilize loop information as the marker of each region
  - `-flowcontrol:quantum` : synchronize each thread every 1000000 instructions

Clustering

- Cluster all regions into several groups.
  - SimPoint [1]
  - Utilize feature vectors of all threads
  - kmeans algorithm

[1] Sherwood et al., "Automatically Characterizing Large Scale Program Behavior", ASPLOS'02

Clustering

- Cluster all regions into several groups.
- Command
  - `$SDE_BUILD_KIT/pinplay-scripts/sde_pinpoints.py --pintool="sde-global-looppoint.so" --cfg $CFG --whole_pgm_dir $WPP_DIR -S $SLICESIZE --warmup_factor=2 --maxk=$MAXK --append_status -s --simpoint_options="-dim $DIM -coveragePct 1.0 -maxK $MAXK”`
  - DIM : The reduced dimension of the vector that BBVs are projected to
  - MAXK : Maximum number of clusters for kmeans

Running LoopPoint

- The LoopPoint driver script
  - Profiling Results:
    - `matrix.1_267851.global.pinpoints.csv`
    - `(start-pc, start-pc-count ), (end-pc, end-pc-count)`

```
# comment,thread-id,region-id,start-pc, start-image-name, start-image-offset, start-pc-count,end-pc, end-image-name, end-image-offset, end-pc-count,
end-pc-relative-count, region-length, region-weight, region-multiplier, region-type

# RegionId = 1 Slice = 78 Icount = 6240001076 Length = 80000040 Weight = 0.06977 Multiplier = 6.003 ClusterSlicecount = 6 ClusterIcount = 480234985
#Start: pc : 0x406528 image: matrix-omp offset: 0x6528 absolute_count: 611561136  source-info: matrix-omp.cpp:75
#End: pc : 0x406528 image: matrix-omp offset: 0x6528 absolute_count: 619549310  relative_count: 1046786.0 source-info: matrix-omp.cpp:75
cluster 0 from slice 78,global,1,0x406528,matrix-omp,0x6528,611561136,0x406528,matrix-omp,0x6528,619549310,1046786,80000040,0.06977,6.003,simulation
```

Running LoopPoint

- The LoopPoint driver script
  - Profiling Results:
    - `matrix.1_267851.global.pinpoints.csv`
    - `(start-pc, start-pc-count ), (end-pc, end-pc-count)`
    - Cluster group id

```
# comment,thread-id,region-id,start-pc, start-image-name, start-image-offset, start-pc-count,end-pc, end-image-name, end-image-offset, end-pc-count,
end-pc-relative-count, region-length, region-weight, region-multiplier, region-type

# RegionId = 1 Slice = 78 Icount = 6240001076 Length = 80000040 Weight = 0.06977 Multiplier = 6.003 ClusterSlicecount = 6 ClusterIcount = 480234985
#Start: pc : 0x406528 image: matrix-omp offset: 0x6528 absolute_count: 611561136  source-info: matrix-omp.cpp:75
#End: pc : 0x406528 image: matrix-omp offset: 0x6528 absolute_count: 619549310  relative_count: 1046786.0 source-info: matrix-omp.cpp:75
cluster 0 from slice 78,global,1,0x406528,matrix-omp,0x6528,611561136,0x406528,matrix-omp,0x6528,619549310,1046786,80000040,0.06977,6.003,simulation
```

Running LoopPoint

- The LoopPoint driver script
  - Profiling Results:
    - `matrix.1_267851.global.pinpoints.csv`
    - `(start-pc, start-pc-count ), (end-pc, end-pc-count)`
    - Cluster group id
    - Cluster multiplier

```
# comment,thread-id,region-id,start-pc, start-image-name, start-image-offset, start-pc-count,end-pc, end-image-name, end-image-offset, end-pc-count,
end-pc-relative-count, region-length, region-weight, region-multiplier, region-type

# RegionId = 1 Slice = 78 Icount = 6240001076 Length = 80000040 Weight = 0.06977 Multiplier = 6.003 ClusterSlicecount = 6 ClusterIcount = 480234985
#Start: pc : 0x406528 image: matrix-omp offset: 0x6528 absolute_count: 611561136  source-info: matrix-omp.cpp:75
#End: pc : 0x406528 image: matrix-omp offset: 0x6528 absolute_count: 619549310  relative_count: 1046786.0 source-info: matrix-omp.cpp:75
cluster 0 from slice 78,global,1,0x406528,matrix-omp,0x6528,611561136,0x406528,matrix-omp,0x6528,619549310,1046786,80000040,0.06977,6.003,simulation
```

Running LoopPoint

- The LoopPoint driver script
  - Profiling the application
    - `matrix.1_267851.global.pinpoints.csv`
    - Sampled Simulation : `(start-pc, start-pc-count ), (end-pc, end-pc-count), cluster group id`
    - Extrapolation : `cluster group id, cluster-multiplier`

Running LoopPoint

- The LoopPoint driver script
  - Profiling the application
  - Sampled simulation of selected regions

Simulation using Sniper

- LoopPoint support in Sniper 8.0
- Handle the beginning and ending of representative regions
    - Using PC-based markers
  - Sniper shifts simulation modes based on signals from Pin/SDE

Simulation using Sniper

- LoopPoint support in Sniper 8.0
  - Handle the beginning and ending of representative regions
  - `./run-sniper -n 8 -gscheduler/type=static -cgainestown -ssimuserroi --roi-script --trace-args=-pinplay:control start:address:<PC>:count<Count>:global --trace-args=-pinplay:control stop:address:<PC>:count<Count>:global -- <app cmd>`
  - Region start: `-control start:address:<PC>:count<Count>`
  - Region end: `-control end:address:<PC>:count<Count>`
  - *PC*, `Count` : LoopPoint region boundaries
  - Note: Use `-control` if SDE is used instead of Pin/Pinplay

Simulation using Sniper

Start PC and count

```
./run-sniper        -n 8        -v -sprogresstrace:10000000 -gtraceinput/timeout=2000 -gscheduler/type=static -
cgainestown --trace-args=-sniper:flow 1000 -ssimuserroi --roi-script --trace-args=-control start:address:
0x5555555553c0:count8095299:global --trace-args=-control stop:address:0x5555555553c0:count16984191:global -
gperf_model/fast_forward/oneipc/interval=100 -ggeneral/inst_mode_init=detailed -gperf_model/fast_forward/oneipc/
include_memory_latency=true -- ./base.exe
```

Application

End PC and count

Simulation using Sniper

Warmup ends

Fast-forwarding the rest

```
[PROGRESS] 700M instructions, 3198 KIPS, 2.37 IPC
[PROGRESS] 710M instructions, 6004 KIPS, 8.00 IPC
[PROGRESS] 720M instructions, 5526 KIPS, 8.00 IPC
[CONTROLLER] tid: 5 ip: 0x00005555555553e2 658579928 Start
[SNIPER] Enabling performance models
[PROGRESS] 730M instructions, 608 KIPS, 1.97 IPC
[PROGRESS] 740M instructions, 469 KIPS, 1.61 IPC
[PROGRESS] 750M instructions, 455 KIPS, 1.61 IPC
[PROGRESS] 760M instructions, 447 KIPS, 1.61 IPC
[PROGRESS] 770M instructions, 447 KIPS, 1.61 IPC
[PROGRESS] 780M instructions, 446 KIPS, 1.61 IPC
[PROGRESS] 790M instructions, 446 KIPS, 1.61 IPC
[PROGRESS] 800M instructions, 448 KIPS, 1.61 IPC
[CONTROLLER] tid: 4 ip: 0x00005555555553e2 669005339 Stop
[SNIPER] Disabling performance models
[SNIPER] Leaving ROI after 176.54 seconds
[SNIPER] Simulated 80.0M instructions, 708.4M cycles, 0.11 IPC
[SNIPER] Simulation speed 453.2 KIPS (56.6 KIPS / target core - 17654.0ns/instr)
[SNIPER] Sampling: executed 7.03% of simulated time in detailed mode
[SNIPER] Setting instrumentation mode to FAST_FORWARD
[PROGRESS] 810M instructions, 1918 KIPS, 4.23 IPC
```

Detailed simulation

Running LoopPoint

- The LoopPoint driver script
  - Profiling the application
  - Sampled simulation of selected regions
  - Extrapolation of performance results

Extrapolation of Performance Result

- Runtime of corresponding representative region : region_runtime
- Scaling factor : multiplier

```
for regionid, multiplier in region_mult.iteritems():
  region_runtime = 0
  try:
    region_runtime =  read_simstats(region_stats[regionid], region_config[regionid], 'runtime')
  except:
    print('[LOOPPOINT] Warning: Skipping r%s as the simulation results are not available' % regionid)
    continue
  cov_mult += multiplier
  extrapolated_runtime += region_runtime * multiplier
  if region_runtime > max_rep_runtime:
    max_rep_runtime = region_runtime
  sum_rep_runtime += region_runtime
```

Running LoopPoint

- The LoopPoint driver script
  - Profiling the application
  - Sampled simulation of selected regions
  - Extrapolation of performance results
    - Predicted runtime using sampled simulation

application	runtime actual (ns)	runtime predicted (ns)	error (%)	speedup (parallel)	speedup (serial)	coverage (%)
matrix-omp.1	211683500.0	217612143.3	-2.8	61.5	6.29	100.0

Running LoopPoint

- The LoopPoint driver script
  - Profiling the application
  - Sampled simulation of selected regions
  - Extrapolation of performance results
    - Predicted runtime using sampled simulation
    - The error rate of obtained using sampled simulation

application	runtime actual (ns)	runtime predicted (ns)	error (%)	speedup (parallel)	speedup (serial)	coverage (%)
matrix-omp.1	211683500.0	217612143.3	-2.8	61.5	6.29	100.0

Running Custom Workloads

- Create a config file in the application directory (format as below)

```
[Parameters]
program_name: bwaves-s
input_name: 1
command: ./speed_bwaves.icc18.0.g02avx bwaves_1 < bwaves_1.in
```

603.bwaves_s.1.cfg

- Run command:

Config file

```
$LOOPPOINT_ROOT/run-looppoint.py -c 603.bwaves_s.1.cfg -w active -n 8 --force
```

[LOOPPOINT] Collecting results for bwaves-s.1 using test input class and active OMP wait policy

application	runtime actual (ns)	runtime predicted (ns)	error (%)	speedup (parallel)	speedup (serial)	coverage (%)
bwaves-s.1	2108671000.0	2055671101.13	2.51	11.65	1.03	100.0

Agenda

Time (Eastern)	Speaker	Topic
13.20 to 13.30	Trevor E. Carlson	Overview of the tutorial
13.30 to 14.20	Akanksha Chaudhari	Performance analysis, simulation, sampling
14.20 to 15.20	Harish Patil	Using tools: Pin, PinPlay, SDE, ELFies
15.20 to 15.40	Break	
15.40 to 16.20	Alen Sabu	Multi-threaded sampling and LoopPoint
16.20 to 17.00	Changxi Liu	Sniper and LoopPoint demo
17.00 to 17.40	Zhantong Qiu	Using LoopPoint with gem5

LoopPoint Tools: Sampled Simulation of Complex Multi-threaded Workloads using Sniper and gem5

Alen Sabu[1], Changxi Liu[1], Akanksha Chaudhari[1], Harish Patil[2], Wim Heirman[2], Zhantong Qiu[3], Jason Lowe-Power[3], Trevor E. Carlson[1]

[1]National University of Singapore

[2]Intel Corporation

[3]University of California, Davis

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Session 5

Using LoopPoint with gem5

ZHANTONG QIU, UNDERGRADUATE STUDENT
UNIVERSITY OF CALIFORNIA, DAVIS

Quick background on gem5

Main difference between gem5 and Sniper?

gem5 is an execute-in-execute simulator

Two “modes:”

Full-system: boots a Linux kernel, requires disk image, etc.

Syscall emulation: “Fakes” the Linux system calls in gem5

We will be using **syscall emulation (SE) mode**

gem5 is a *python interpreter* which configures and controls simulation

We will show the python code needed to set up LoopPoints/ELFies

How to perform LoopPoint sampling in gem5?

- **Our implementation focuses on using the checkpoint methodology**
  - We take a checkpoint at the beginning of the selected region with a fast and simple architecture setup, and restore the checkpoints with the desired architecture.
- **The LoopPoint module in gem5 is designed to use with the gem5 standard library**
  - The gem5 standard library provides flexible and convenience modules for simulation setups.
- **In gem5, we use checkpoint to save the state of the simulation. It allows us to restore and simulate a particular region of the whole simulation with different architectures.**

A small example of what can and can not change when restoring a gem5 checkpoint

When taking checkpoints:

```
# When taking a checkpoint, the cache state is not saved, so the cache
# hierarchy can be changed completely when restoring from a checkpoint.
# By using NoCache() to take checkpoints, it can slightly improve the
# performance when running in atomic mode, and it will not put any restrictions
# on what people can do with the checkpoints.
cache_hierarchy = NoCache()

# Using simple memory to take checkpoints might slightly imporve the
# performance in atomic mode. The memory structure can be changed when
# restoring from a checkpoint, but the size of the memory must be maintained.
memory = SingleChannelDDR3_1600(size="2GB")
```

When restoring a checkpoint:

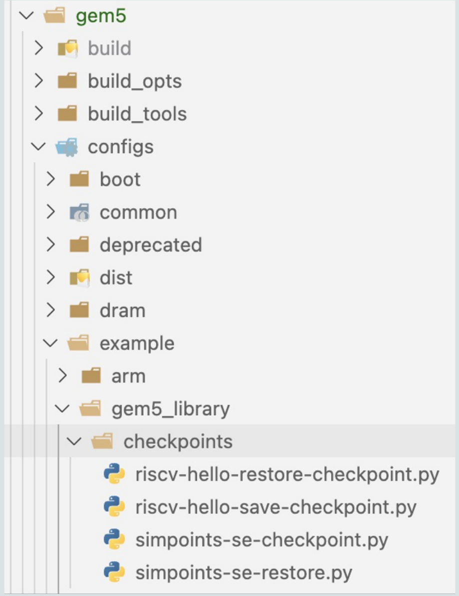
```
# The cache hierarchy can be different from the cache hierarchy used in taking
# the checkpoints
cache_hierarchy = PrivateL1PrivateL2CacheHierarchy(
    l1d_size="32kB",
    l1i_size="32kB",
    l2_size="256kB",
)

# The memory structure can be different from the memory structure used in
# taking the checkpoints, but the size of the memory must be maintained
memory = DualChannelDDR4_2400(size="2GB")
```

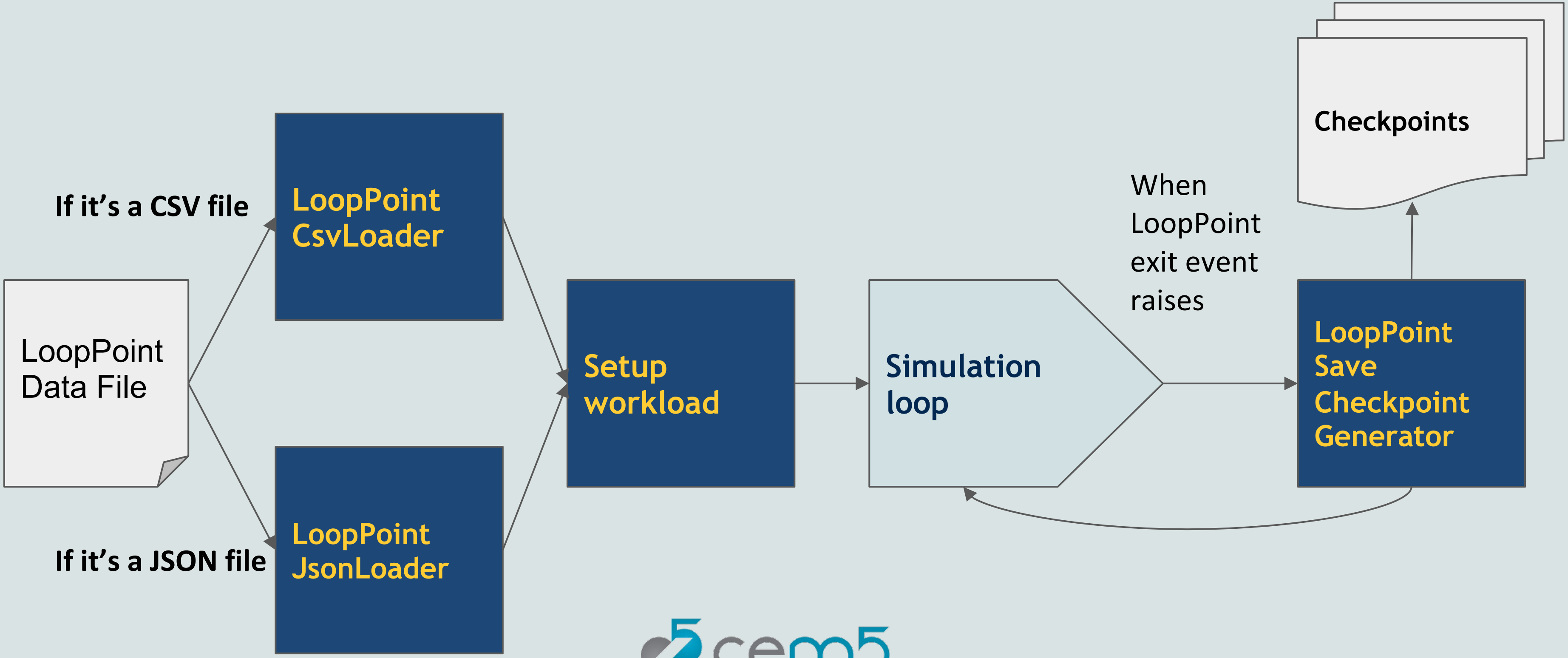
A tutorial on checkpointing in gem5 was given as a part of the gem5 2022 Bootcamp. A recording of this event can be found within this link:

https://gem5bootcamp.github.io/gem5-bootcamp-env/modules/extra%20topics/checkpointing-commmonitor

You can find example scripts of taking checkpoints in the gem5 directory:



How to take checkpoints for LoopPoint sampling?



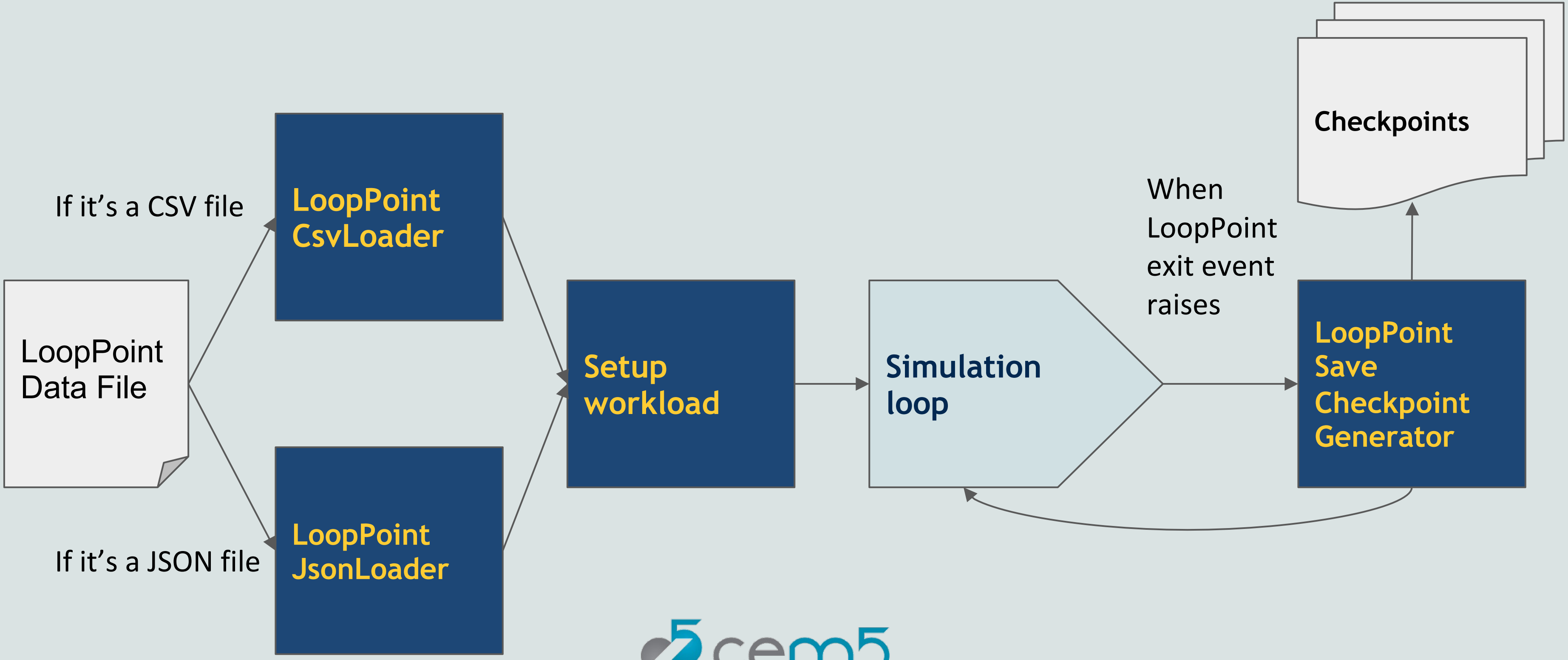
The LoopPoint JSON file

```
region id
    |___ simulation
    |       |___ start
    |       |       |___ pc
    |       |       |___ global
    |       |       |___ relative
    |       |___ end
    |               |___ pc
    |               |___ global
    |               |___ relative
    |___ warmup # optional to region
    |       |___ start
    |       |       |___ pc
    |       |       |___ global
    |       |       |___ relative
    |       |___ end
    |               |___ pc
    |               |___ global
    |               |___ relative
    |___ multiplier
```


```
"1": {
    "simulation": {
        "start": {
            "pc": 4221392,
            "global": 211076617,
            "relative": 15326617
        },
        "end": {
            "pc": 4221392,
            "global": 219060252,
            "relative": 23310252
        }
    },
    "multiplier": 4.0,
    "warmup": {
        "start": {
            "pc": 4221056,
            "count": 23520614
        },
        "end": {
            "pc": 4221392,
            "count": 211076617
        }
    }
},
```

```
"2": {
        "simulation": {
            "start": {
                "pc": 4206672,
                "global": 1
            },
            "end": {
                "pc": 4221392,
                "global": 6861604,
                "relative": 6861604
            }
        },
        "multiplier": 1.0
    }
```

How to take checkpoints for LoopPoint sampling?



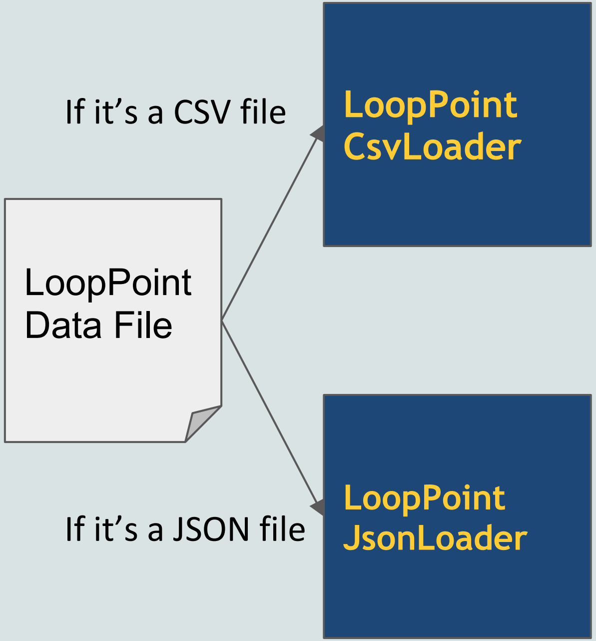
A config script with a simple architecture

```python
from gem5.simulate.exit_event import ExitEvent
from gem5.simulate.simulator import Simulator
from gem5.utils.requires import requires
from gem5.components.cachehierarchies.classic.no_cache import NoCache
from gem5.components.boards.simple_board import SimpleBoard
from gem5.components.memory.single_channel import SingleChannelDDR3_1600
from gem5.components.processors.simple_processor import SimpleProcessor
from gem5.components.processors.cpu_types import CPUTypes
from gem5.isas import ISA
from gem5.resources.resource import obtain_resource
from pathlib import Path

requires(isa_required=ISA.X86)
cache_hierarchy = NoCache()
memory = SingleChannelDDR3_1600(size="2GB")
processor = SimpleProcessor(
    cpu_type=CPUTypes.ATOMIC,
    isa=ISA.X86,
    num_cores=9,
)
```

```python
board = SimpleBoard(
    clk_freq="3GHz",
    processor=processor,
    memory=memory,
    cache_hierarchy=cache_hierarchy,
)
board.set_se_binary_workload(
    binary=obtain_resource("x86-matrix-multiply-omp"),
    # In here, we use the gem5 resource to obtain the binary
    # we can also input the local path to the binary, i.e.
    # binary=Path("path/to/binary")
    arguments=[100, 8]
)

simulator = Simulator(
    board=board
)
simulator.run()
```




```python
from gem5.resources.looppoint import LooppointCreatorCSV
```

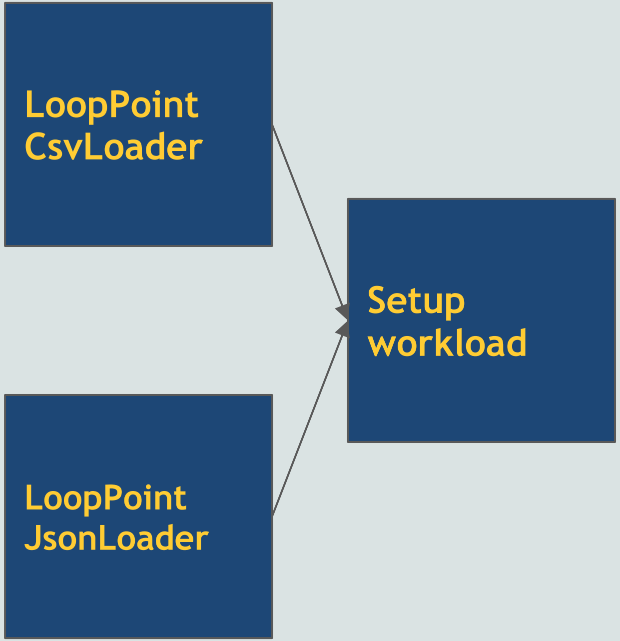
```python
looppoint = LooppointCreatorCSV(
    # Pass in the LoopPoint data file
    pinpoints_file=Path(
        obtain_resource(
            "x86-matrix-multiply-omp-100-8-global-pinpoints"
        ).get_local_path()
    )
)
```

OR

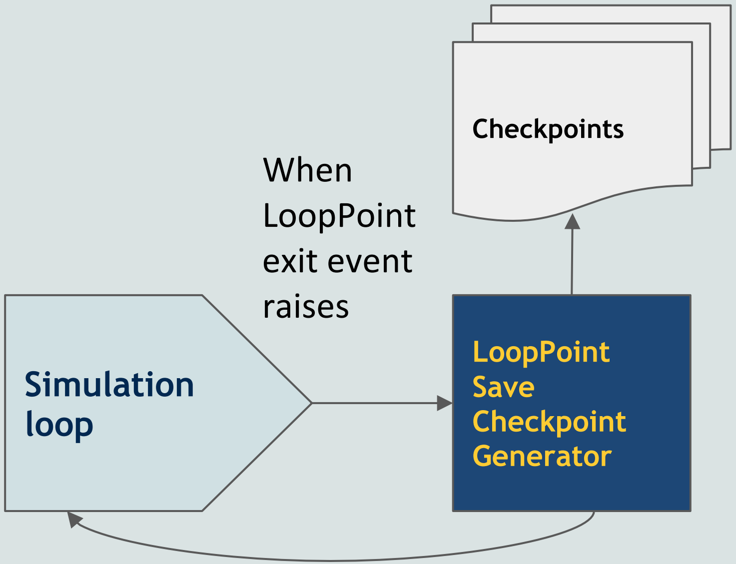
```python
from gem5.resources.looppoint import LooppointJsonLoader
```

```python
looppoint = LooppointJsonLoader(
    looppoint_file=Path(
        obtain_resource(
            "x86-matrix-multiply-omp-100-8-looppoint"
        ).get_local_path()
    )
)

```




```python
board.set_se_looppoint_workload(
    binary=obtain_resource("x86-matrix-multiply-omp"),
    arguments=[100, 8],
    # Pass LoopPoint module into the board
    looppoint=looppoint,
)
```




```python
from gem5.simulate.exit_event_generators import (
    looppoint_save_checkpoint_generator,
)
```

```python
# name the path of where the checkpoints should be saved
dir = Path("looppoint_checkpoints_folder")
dir.mkdir(exist_ok=True)

simulator = Simulator(
    board=board,
    on_exit_event={
        ExitEvent.SIMPOINT_BEGIN: looppoint_save_checkpoint_generator(
            checkpoint_dir=dir,
            looppoint=looppoint,
            # True if the relative PC count pairs should be updated during the
            # simulation. Default as True.
            update_relatives=True,
            # True if the simulation loop should exit after all the PC count
            # pairs in the LoopPoint data file have been encountered. Default
            # as True.
            exit_when_empty=True,
        )
    },
)
```

```python
simulator.run()

# Output the JSON file
looppoint.output_json_file()
```

```python
from gem5.simulate.exit_event import ExitEvent
from gem5.simulate.simulator import Simulator
from gem5.utils.requires import requires
from gem5.components.cachehierarchies.classic.no_cache import NoCache
from gem5.components.boards.simple_board import SimpleBoard
from gem5.components.memory.single_channel import SingleChannelDDR3_1600
from gem5.components.processors.simple_processor import SimpleProcessor
from gem5.components.processors.cpu_types import CPUTypes
from gem5.isas import ISA
from gem5.resources.resource import obtain_resource
from pathlib import Path
from gem5.simulate.exit_event_generators import (
    looppoint_save_checkpoint_generator,
)
from gem5.resources.looppoint import LooppointCreatorCSV

requires(isa_required=ISA.X86)

cache_hierarchy = NoCache()
memory = SingleChannelDDR3_1600(size="2GB")
processor = SimpleProcessor(
    cpu_type=CPUTypes.ATOMIC,
    isa=ISA.X86,
    num_cores=9,
)

looppoint = LooppointCreatorCSV(
    # Pass in the LoopPoint data file
    pinpoints_file=Path(
        obtain_resource(
            "x86-matrix-multiply-omp-100-8-global-pinpoints"
        ).get_local_path()
    )
)

board = SimpleBoard(
    clk_freq="3GHz",
    processor=processor,
    memory=memory,
    cache_hierarchy=cache_hierarchy,
```


```python
board = SimpleBoard(
    clk_freq="3GHz",
    processor=processor,
    memory=memory,
    cache_hierarchy=cache_hierarchy,
```


```python
)

board.set_se_looppoint_workload(
    binary=obtain_resource("x86-matrix-multiply-omp"),
    arguments=[100, 8],
    # Pass LoopPoint module into the board
    looppoint=looppoint,
)

# name the path of where the checkpoints should be saved
dir = Path("looppoint_checkpoints_folder")
dir.mkdir(exist_ok=True)

simulator = Simulator(
    board=board,
    on_exit_event={
        ExitEvent.SIMPOINT_BEGIN: looppoint_save_checkpoint_generator(
            checkpoint_dir=dir,
            looppoint=looppoint,
            # True if the relative PC count pairs should be updated during the
            # simulation. Default as True.
            update_relatives=True,
            # True if the simulation loop should exit after all the PC count
            # pairs in the LoopPoint data file have been encountered. Default
            # as True.
            exit_when_empty=True,
        )
    },
)

simulator.run()

# Output the JSON file
looppoint.output_json_file()
```

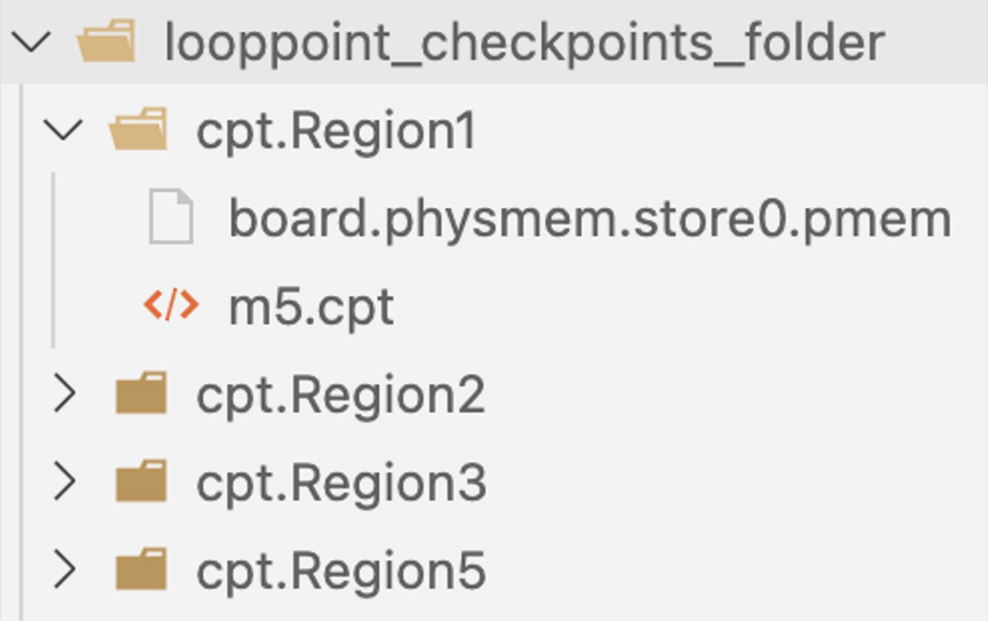
Example command to run the checkpoint script:

```
build/X86/gem5.opt create-checkpoints.py
```

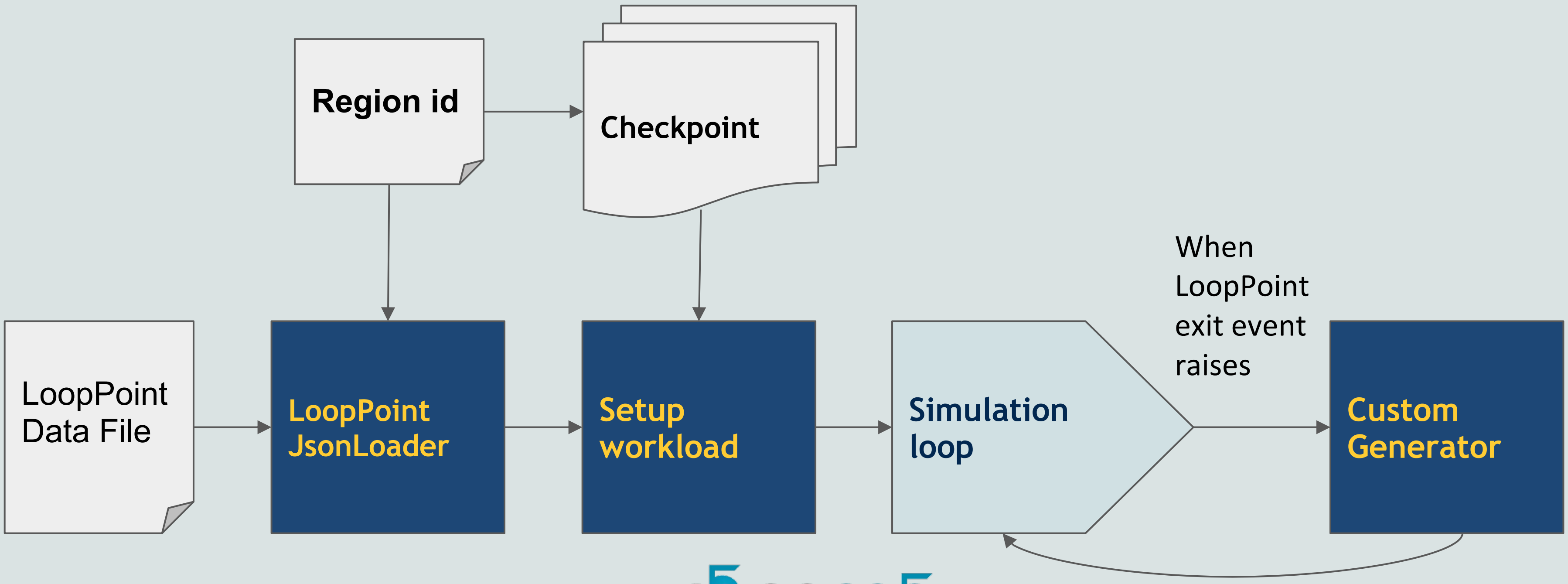
Example output

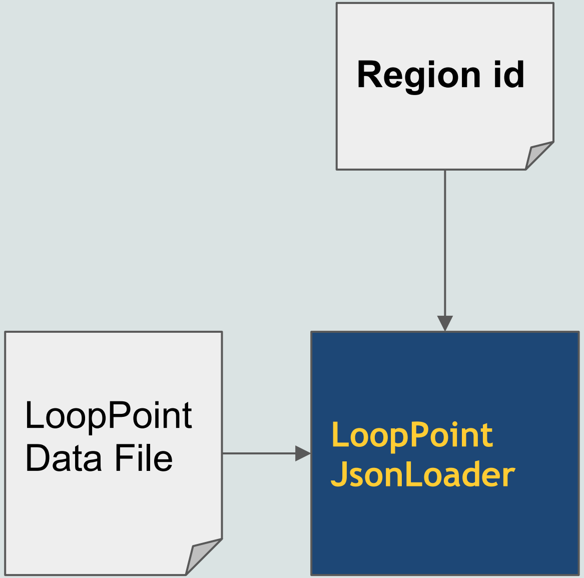
```
Writing checkpoint
build/X86/sim/simulate.cc:195: info: Entering event queue @ 138524528475.  Starting simulation...
build/X86/sim/simulate.cc:195: info: Entering event queue @ 154979540325.  Starting simulation...
build/X86/sim/simulate.cc:195: info: Entering event queue @ 163287976905.  Starting simulation...
build/X86/sim/simulate.cc:195: info: Entering event queue @ 171528530436.  Starting simulation...
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
Writing checkpoint
build/X86/sim/simulate.cc:195: info: Entering event queue @ 171528531102.  Starting simulation...
build/X86/sim/simulate.cc:195: info: Entering event queue @ 187980745752.  Starting simulation...
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
build/X86/sim/process.cc:382: warn: Checkpoints for pipes, device drivers and sockets do not work.
```

Example checkpoints:



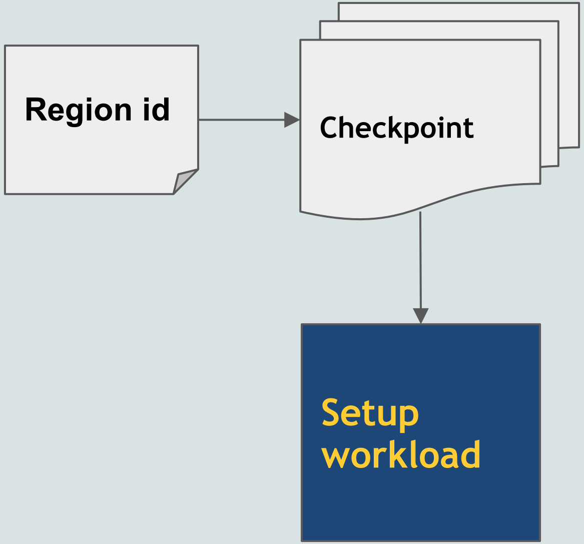
The process is similar for restoring a checkpoint



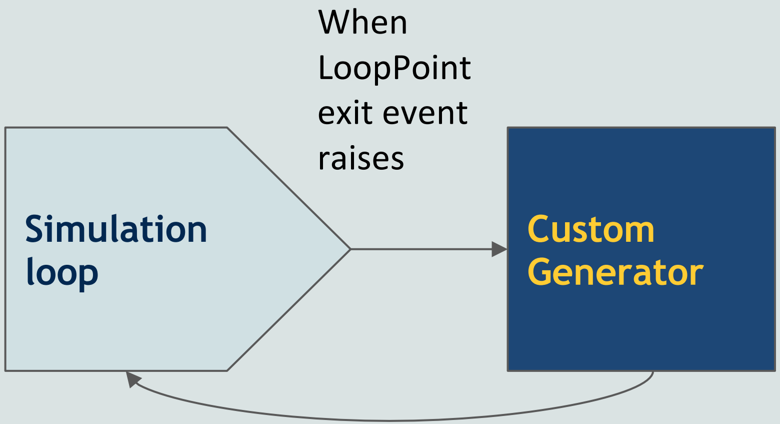



```python
from gem5.resources.looppoint import LooppointJsonLoader
```

```python
looppoint = LooppointJsonLoader(
    looppoint_file=Path(
        obtain_resource(
            "x86-matrix-multiply-omp-100-8-looppoint"
        ).get_local_path()
    ),
    # pass in the id of the region you want to restore
    # i.e. region_id=1
    region_id=args.checkpoint_region,
)
```



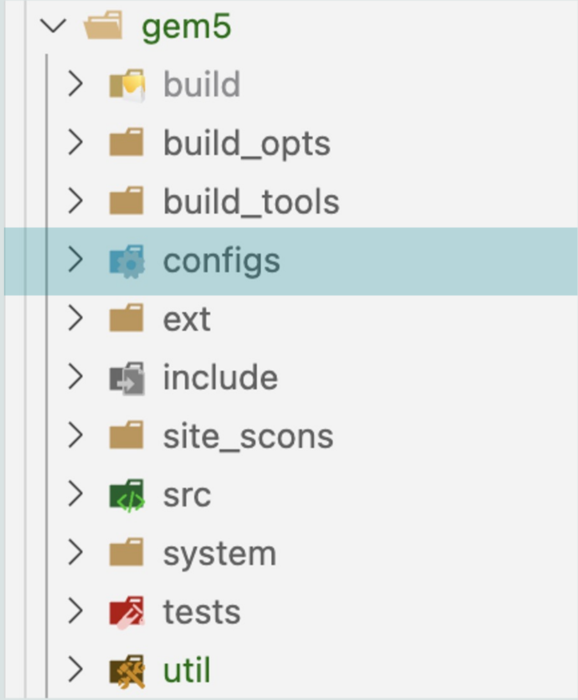

```python
board.set_se_looppoint_workload(
    binary=obtain_resource("x86-matrix-multiply-omp"),
    looppoint=looppoint,
    # Pass in the path to the checkpoint you want to restore
    # Each simualtion can only restore one checkpoint
    # i.e. checkpoint_path=Path("looppoint_checkpoints_folder/cpt.Region1")
    checkpoint=obtain_resource(
        f"x86-matrix-multiply-omp-100-8-looppoint-checkpoint-region-{args.checkpoint_region}"
    ).get_local_path()
)
```

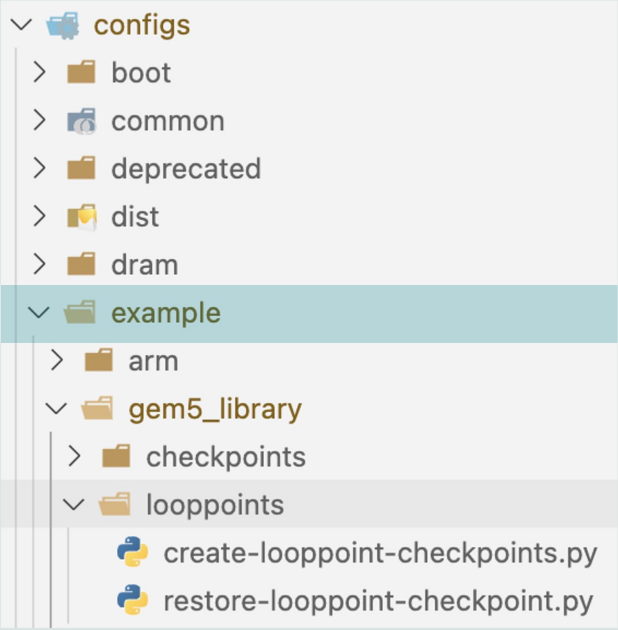



```python
# This generator will dump the stats and exit the simulation loop when the
# simulation region reaches its end. In the case there is a warmup interval,
# the simulation stats are reset after the warmup is complete.
def reset_and_dump():
    if len(looppoint.get_targets()) > 1:
        print("Warmup region ended. Resetting stats.")
        reset()
        yield False
    print("Region ended. Dumping stats.")
    dump()
    yield True
```

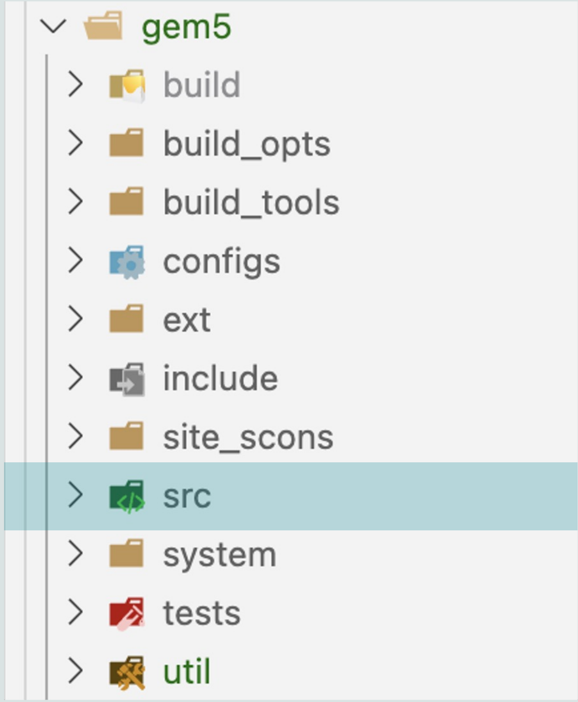
```python
simulator = Simulator(
    board=board,
    on_exit_event={ExitEvent.SIMPOINT_BEGIN: reset_and_dump()},
)
```

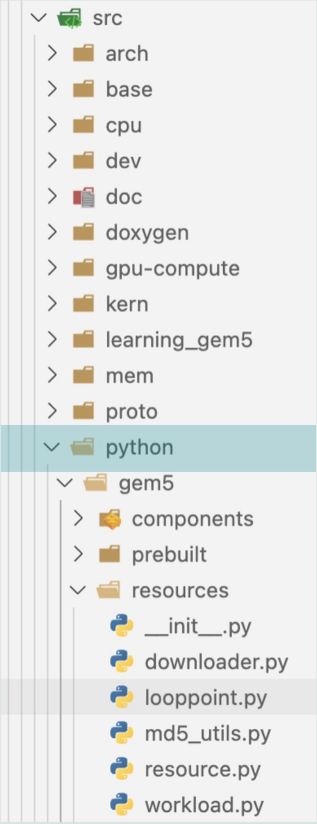
Where to find the LoopPoint related files?



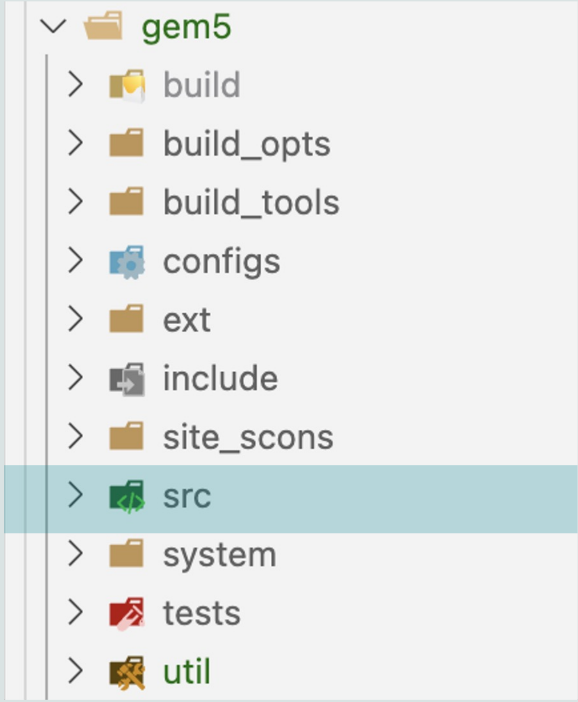


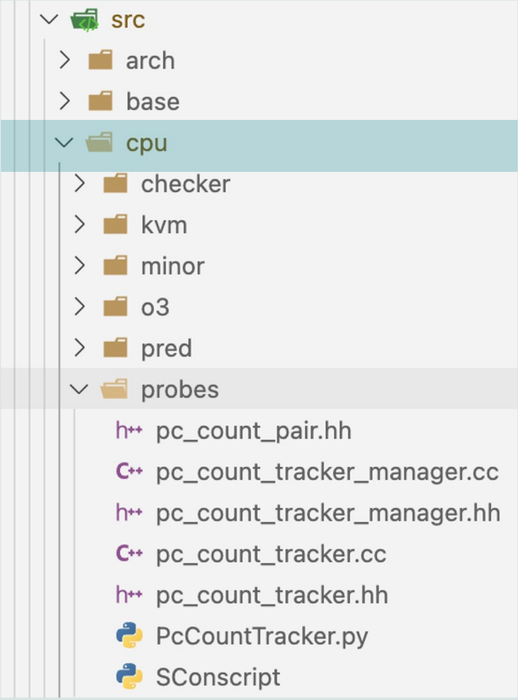
Where to find the LoopPoint related files?





Where to find the LoopPoint related files?





gem5

Debug Flag

The debug flag is activated by passing the option in the command line. For example:

```
build/X86/gem5.opt --debug-flags=PcCountTracker example-script.py
```

It shows all the PCs and PC Count pairs that the simulation is tracking.

```
      0: board.processor.cores0.core.probeListener.ptmanager: total 3 PCs in counter
      0: board.processor.cores0.core.probeListener.ptmanager: all targets:
(4221392,603516434)
(4221392,156028351)
(4221392,179989993)
(4221392,250145350)
```

It also shows the PC Count pair that’s struggling the exit event and the remaining pairs that haven’t been encountered.

```
682559042715: board.processor.cores0.core.probeListener.ptmanager: pc:(4221392,642586697) encountered
682559042715: board.processor.cores0.core.probeListener.ptmanager: There are 0 targets remained
682559042715: board.processor.cores0.core.probeListener.ptmanager: all targets are encountered.
```

Useful gem5 tutorials

Link to gem5 standard library tutorial:

https://www.gem5.org/documentation/gem5-stdlib/overview

Link to gem5 2022 bootcamp website:

https://gem5bootcamp.github.io/gem5-bootcamp-env/

Thank you!

LoopPoint Tools: Sampled Simulation of Complex Multi-threaded Workloads using Sniper and gem5

Alen Sabu[1], Changxi Liu[1], Akanksha Chaudhari[1], Harish Patil[2], Wim Heirman[2], Zhantong Qiu[3], Jason Lowe-Power[3], Trevor E. Carlson[1]

[1]National University of Singapore

[2]Intel Corporation

[3]University of California, Davis

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