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Hybrid Profiling Support

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Project Motivation and Goal

- Hardware/Software interaction is increasingly complex
- Understanding dynamic program behavior
  - Key to extracting performance
- Profiling systems
  - Summarize execution behavior
  - Capture and characterize profile-guided optimization opportunities
  - Online profile collection
    - Enables dynamic optimization, specialization, and reconfiguration
    - Introduces overhead
    - Sample-based techniques reduce overhead at a cost in accuracy

- **Goal of our work**
  - Online profiling support for the **low-overhead** collection of **accurate** sample-based profiles

Current Approaches to Online Profiling

- Hardware
  - EX: performance counters, special add-ons, co-processor
  - + Low overhead
  - - Consume die-area and additional resources (e.g. power)
  - - Inflexible
  - - No software context

- Software
  - EX: sampling framework, dynamic instrumentation
  - + Flexible
  - + Arbitrary profiles including fine-grained
  - + Usually more accurate (can capture high-level program info)
  - - Added overhead (cycles, memory, ...)
  - - Indirect effect on performance

Our Work: Hybrid Profiling Support

- **Combine** H/W and S/W
  - General-purpose, low-area, efficient hardware
  - Flexible sample-based profiling interface
- To **Achieve**
  - Low profiling overhead
  - Flexible online management facility
  - Arbitrary instruction-based profile type collection
  - Minimal indirect effect
  - No static analysis and instrumentation for most profile types

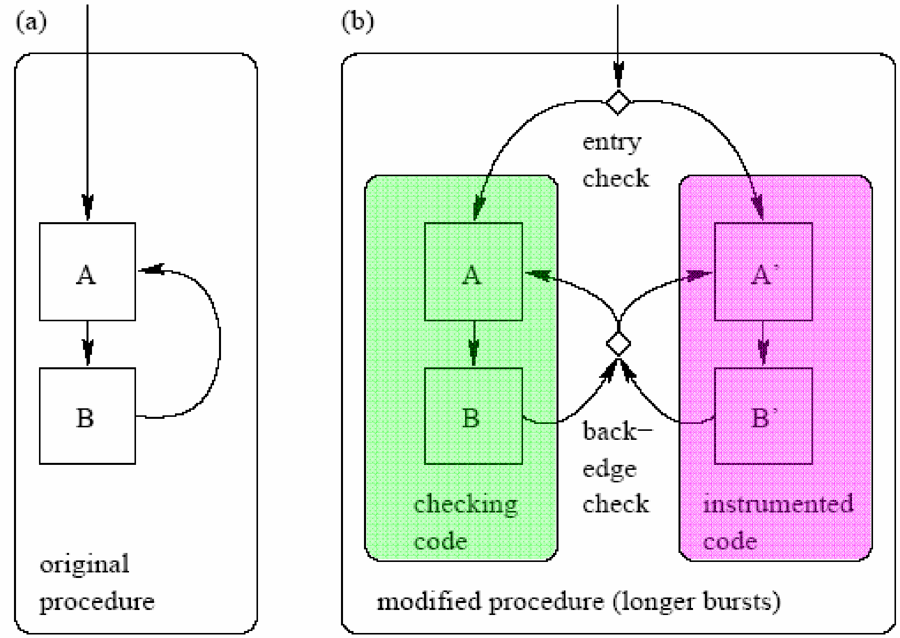
Outline

- Motivation and Overview
- Software Sampling
- Dynamic Instruction Stream Editing (DISE)
- Sample-based Profiling with DISE
- HPS Extensions to DISE
- Results
- Conclusion

Software Sampling Framework

Arnold and Ryder '01

- **Duplicate** code
  - instrumented & checking
  - Sample (switch to inst.) according to expired counter in checking code
    - Exec single pass of profiled code (until loop or call)

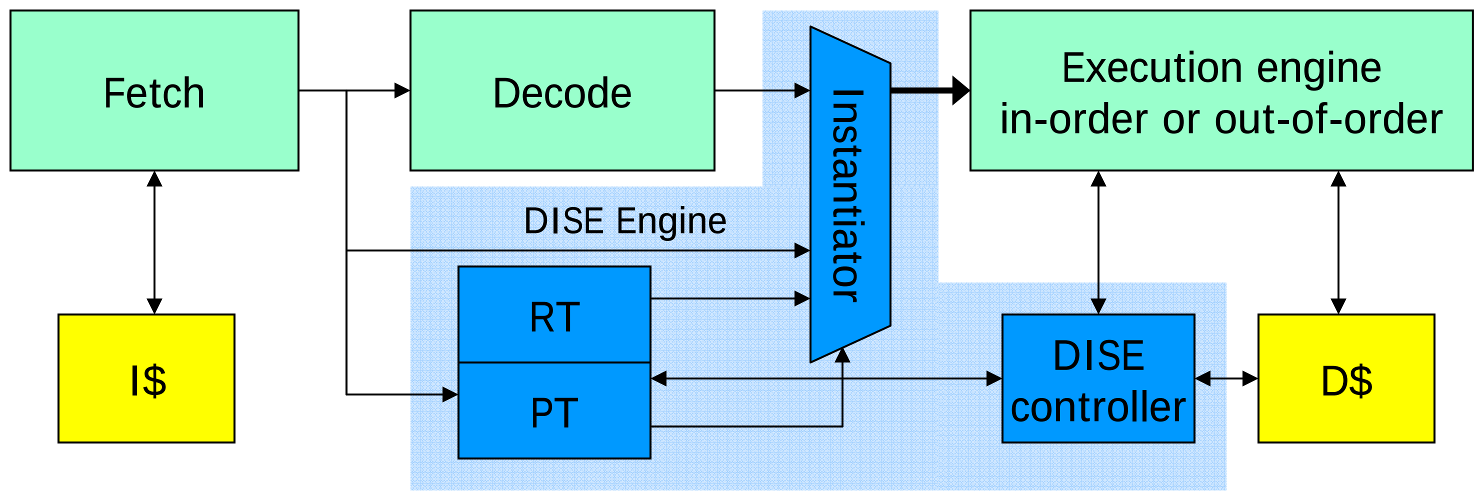


Source: Hirzel and Chillimbi '01

- **Bursty** extensions: Extend stays in the instrumented version
  - Requires additional counter(s) in profiled code

- **Basic Overhead:** 5%[1-9%] (VM), 16% [6-35%] (binary)

Dynamic Instruction Stream Editing



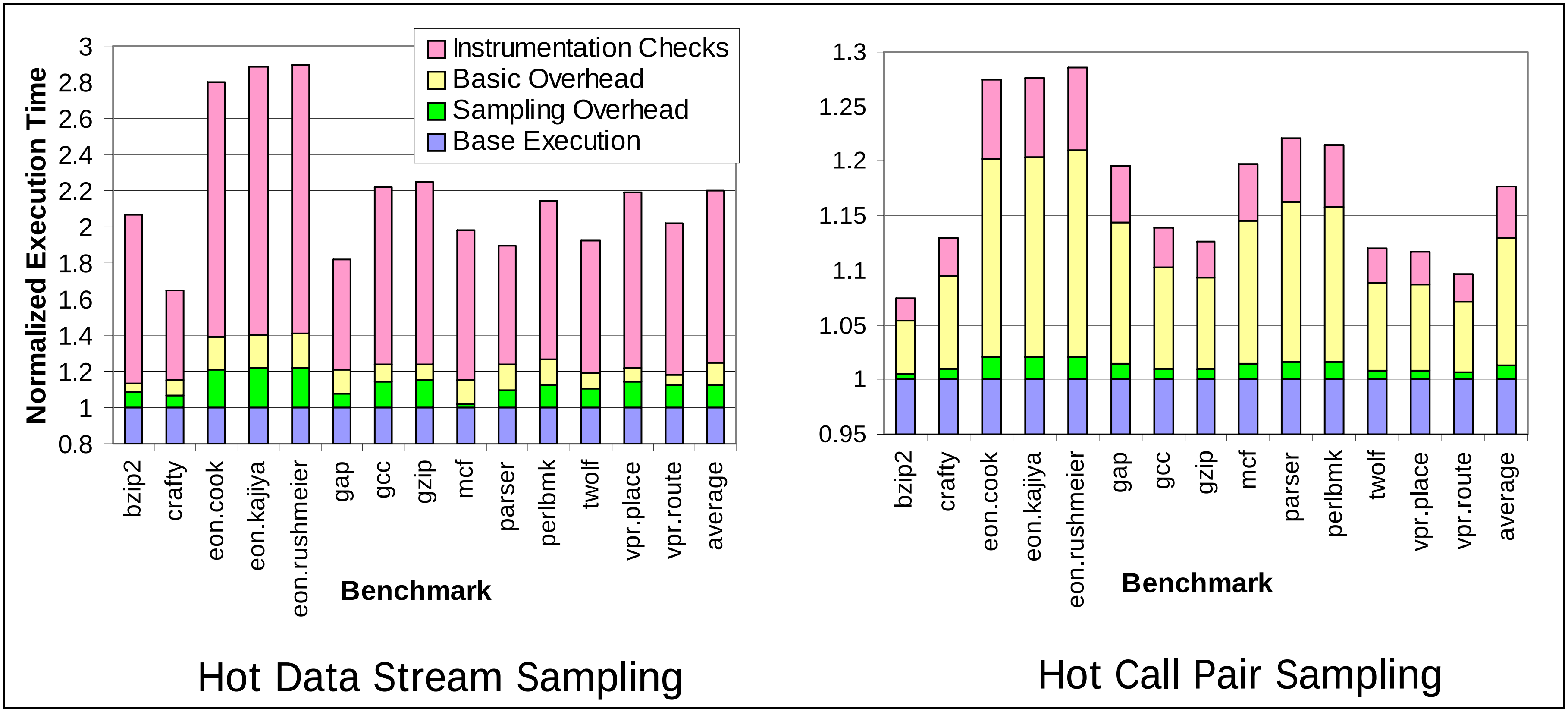
Source: Corliss'05

- Processor extension [Corliss'03]
  - Matches an instruction according to pattern (from PT)
  - Replace with alternate stream (from RT)
- User specifies patterns & replacements via specification language (DISE Productions).

Sampling Framework Using DISE

- Emulate code transitions via **Sampling Flag**
  - Eliminate code duplication
- Dynamic instrumentation in hardware
  - Eliminate static analysis and code modification
- DISE productions
  - @ Sampling boundaries => manage (toggle) flag
  - @ Profiled instruction => check flag and profile
- Drawback
  - **Overhead** from too many instrumentations

DISE sampling overhead



Breakdown of overheads of sample-based hot data stream profiling using DISE

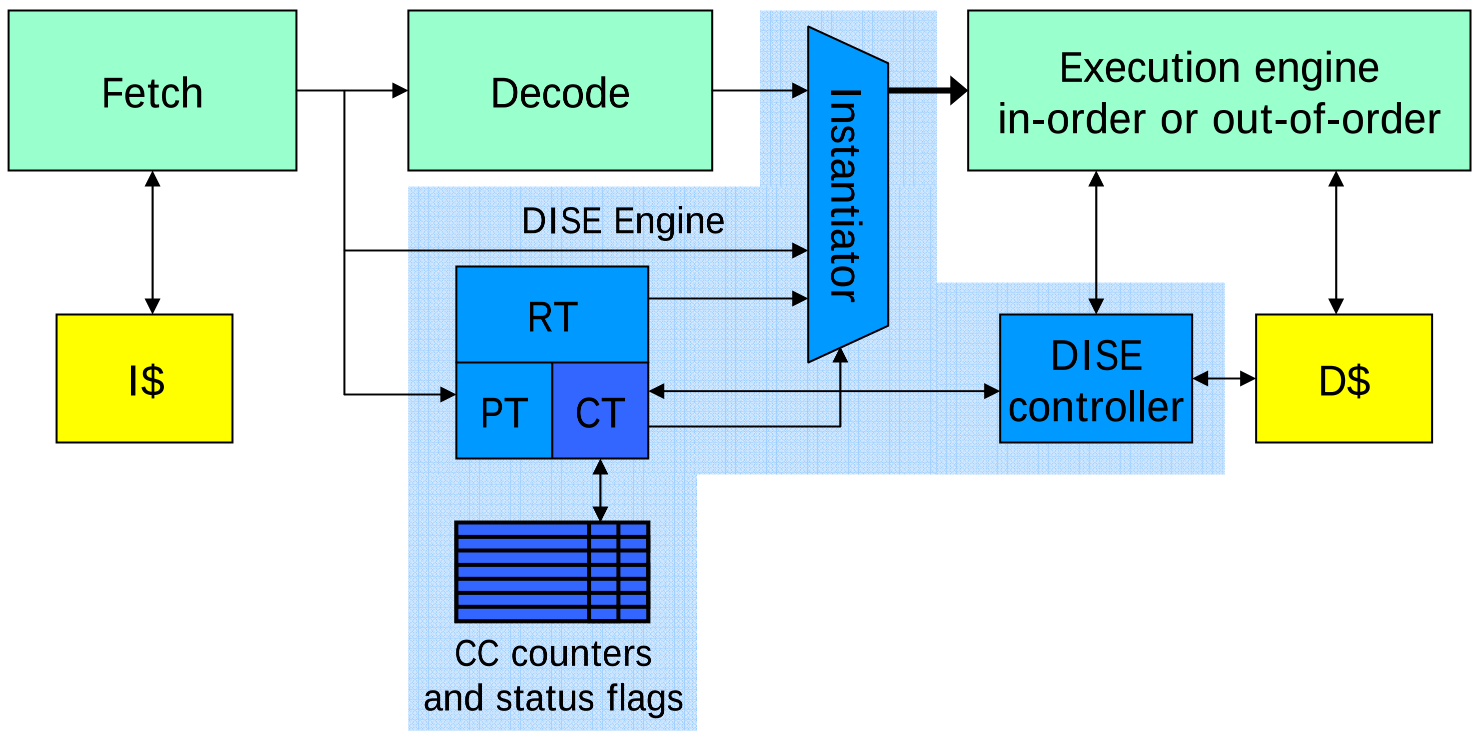
HPS: DISE extensions

- Basic overhead: simple counter manipulations and checks
- Instrumentation overhead: exclusively flag checking
- Our extension is H/W design + semantic definition for a ***conditional controller*** to
  - Manipulate counters and flags
  - Conditionally apply DISE productions

Original: DISE_Production ::= Instruction_Pattern
$\Rightarrow$ Replacement_Sequence

HPS extended: DISE_Production ::= Instruction_Pattern **&& Conditional**
$\Rightarrow$ (Replacement_Sequence**|null**) **&& (Conditional_Control|null**)

HPS: Architecture



HPS: Profiling Productions

Sampling Framework: **toggle profiling on/off**

\# We are not profiling, check for procedure call and backward branch
\# increment the sampling counter - CC1- and fail production

P1:T.OPCLASS == proc_call && !sample_flag ⇒ null, CC1
P2:T.OPCLASS == branch && T.PC < T.Target && !sample_flag
⇒ null, CC1

\# We are profiling, check for procedure call and backward branch,
\# increment the burst counter - CC2 - and fail production
P3:T.OPCLASS == proc_call && sample_flag && !burst_flag
⇒ null, CC2
P4:T.OPCLASS == branch && T.PC < T.Target
&& sample_flag && !burst_flag ⇒ null, CC2

\# We are done profiling because burst counter status (overflow_2)
\# has overflowed. reset counters (this unsets overflow_1 and
\# overflow_2) causing sampling to stop
P5:T.OPCLASS == proc_call && sample_flag && burst_flag
⇒ null, CC3
P6:T.OPCLASS == branch && T.PC < T.Target
&& sample_flag && burst_flag ⇒ null, CC3

CC1: inc_sample_counter;
CC2: inc_burst_counter;
CC3: set_sample_counter(sampleFreq);
set_burst_counter(burstLength);

Profile Type Productions: **Collect the profiling data**

Hot Data Stream Analysis
P1: T.OPCLASS == mem_op && sample_flag ⇒ R1, null
R1: call(DataStream_handler)
T.INSN

Hot Call Pair Analysis
P2: T.OPCLASS == proc_call && sample_flag ⇒ R2, null
R2: call(CallPair_handler)
T.INSN

Hot Method Analysis
P3: T.OPCLASS == proc_call
|| (T.OPCLASS ==branch && T.PC < T.Target)
&& sample_flag ⇒ R3, null
R3: call(HotMethod_handler)
T.INSN

HPS: Profiling Productions

Not Profiling

P1:T.OPCLASS == proc_call
&& !sample_flag
⇒ null, CC1
P2:T.OPCLASS == branch
&& T.PC < T.Target && !sample_flag
⇒ null, CC1
CC1: inc_sample_counter;

Sample_counter overflow →

Profiling

P3:T.OPCLASS == proc_call
&& sample_flag && !burst_flag
⇒ null, CC2
P4:T.OPCLASS == branch
&& T.PC < T.Target
&& sample_flag && !burst_flag
⇒ null, CC2
CC2: inc_burst_counter;

Burst_counter overflow →

P5:T.OPCLASS == proc_call
&& sample_flag && burst_flag
⇒ null, CC3
P6:T.OPCLASS == branch
&& T.PC < T.Target
&& sample_flag && burst_flag
⇒ null, CC3
CC3: set_sample_counter(sampleFreq);
set_burst_counter(burstLength);

Reset →

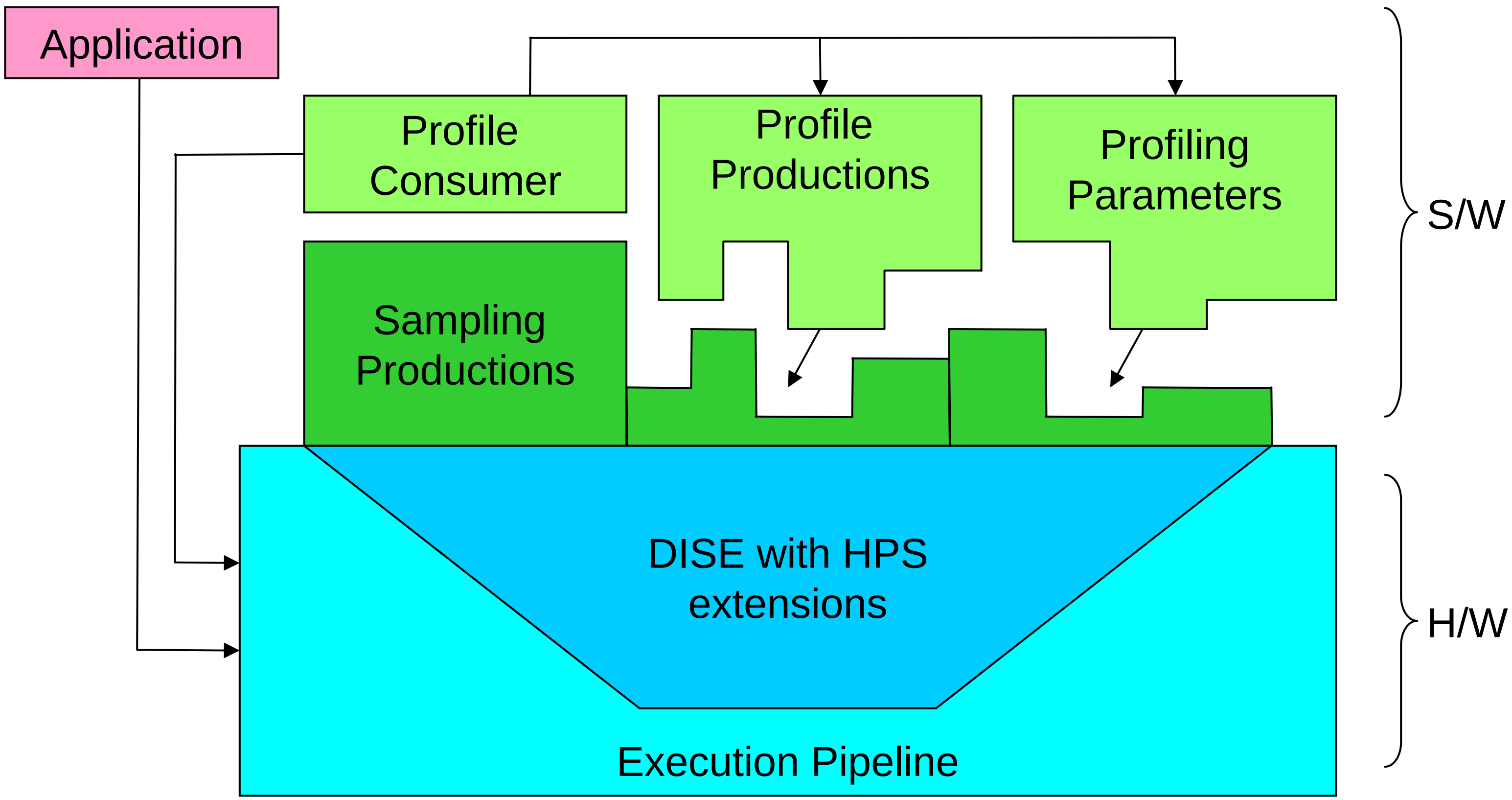
NOT Instrumented

<u>Hot Data Stream Analysis</u>
P1: T.OPCLASS == mem_op && sample_flag ⇒ R1, null
R1: call(DataStream_handler)
T.INSN

Instrumented

<u>Hot Data Stream Analysis</u>
P1: T.OPCLASS == mem_op && sample_flag ⇒ R1, null
R1: call(DataStream_handler)
T.INSN

HPS: Big Picture

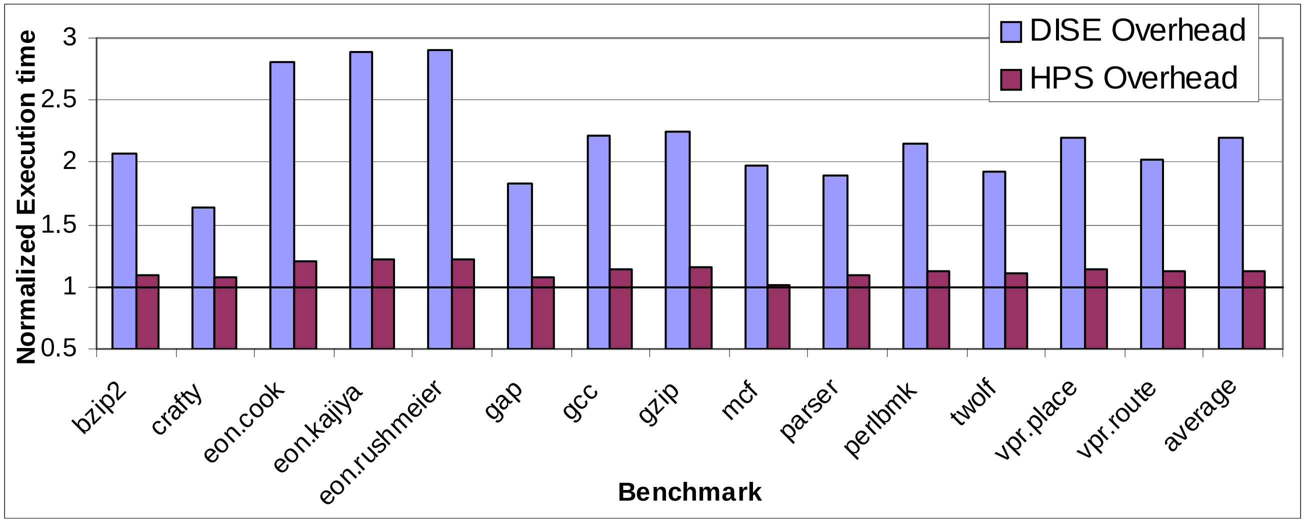


Experimental Methodology

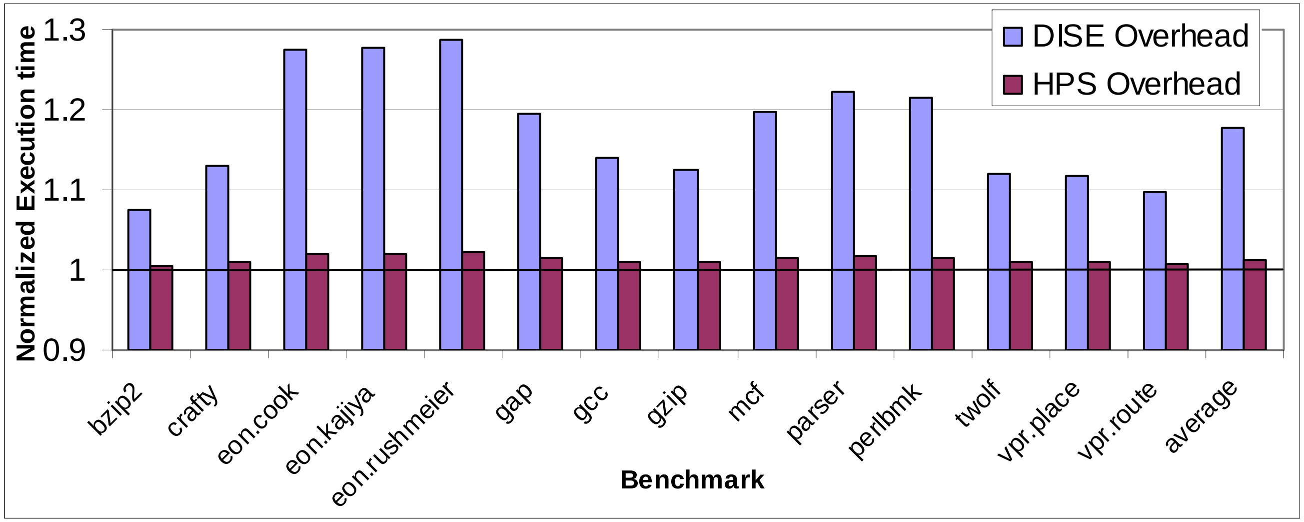
- Cycle accurate simulation (SimpleScalar for Alpha)
  - 4-way MIPS R10000, 12 stage pipeline
  - DISE: 32 entry PT, 2K entry RT, Conditional Controls
- Benchmarks
  - **SPECINT 2000** compiled for alpha EV6 with –O4
- Sampling rate
  - Frequencies from 1/100 to 1/10,000
- **Overhead** is increased execution time due to profiling
  - Baseline is execution time with no HPS instrumentation
- **Accuracy**: % overlap of sampled/exhaustive profile

HPS Overhead

Hot data stream sampling

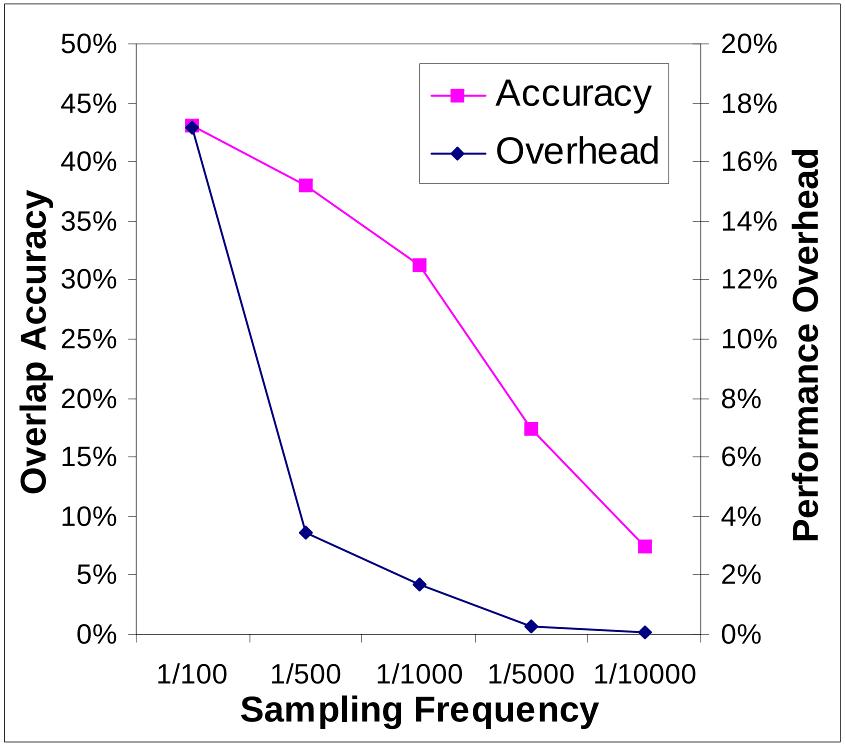


Hot call pair sampling

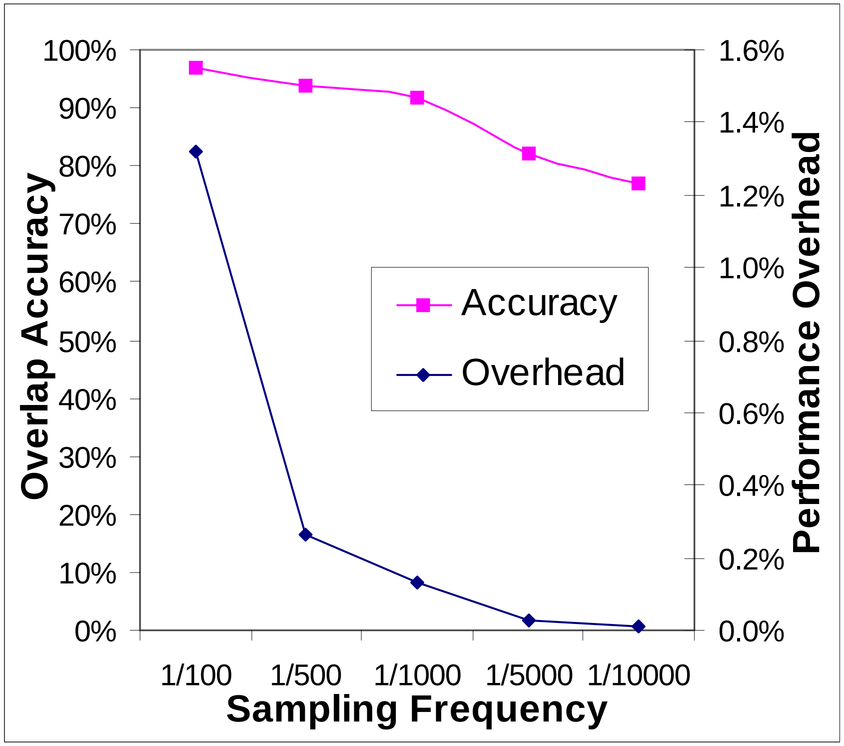


Sampling frequency = 1/100

HPS Overhead/Accuracy Tradeoffs

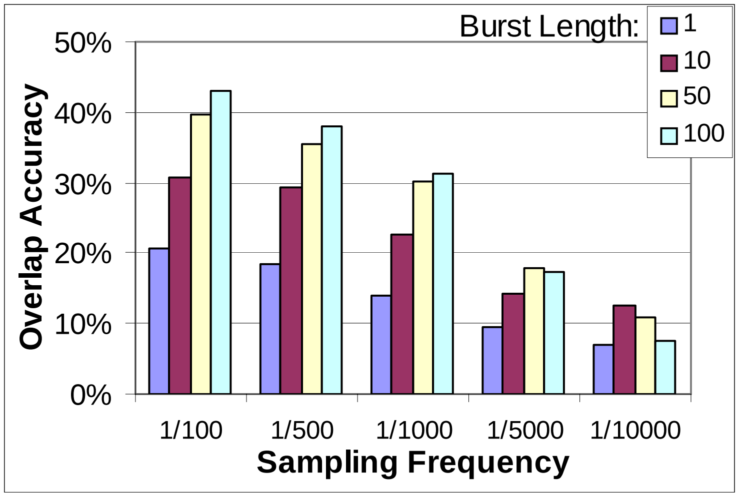


Hot data
stream sampling

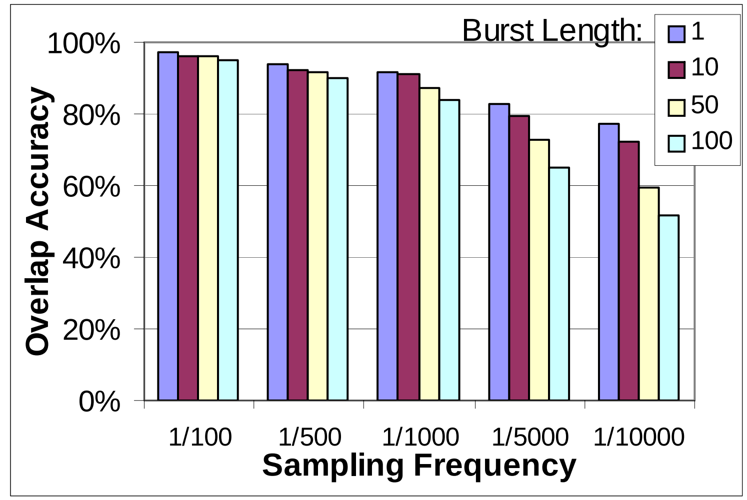


Hot call
pair sampling

Impact of Burst Length



Hot Data Stream Sampling



Hot Call Pair Sampling

- Impact of longer sampling burst varies across:
  - Profile types
  - Effective sampling frequency
  - Benchmark

Conclusions

- Hybrid Profiling Support
  - Manage sampling flag entirely in H/W
  - Insert profiling instruction via H/W instrumentation

- Primary contributions
  - “Pay as you go” profiling
    - Eliminate basic and instrumentation overhead
  - Efficient dynamic toggling
  - Flexible usage scenarios
    - Support arbitrary instruction-based profile types
  - 16-106% reduced overhead over direct DISE