SuperPin: Parallelizing Dynamic Instrumentation for Real-Time Performance

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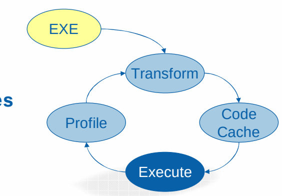
Dynamic Binary Instrumentation

Inserts user-defined instructions into executing binaries

- Easily
- Efficiently
- Transparently

Why?

- Detect inefficiencies
- Detect bugs
- Security checks
- Add features



Examples

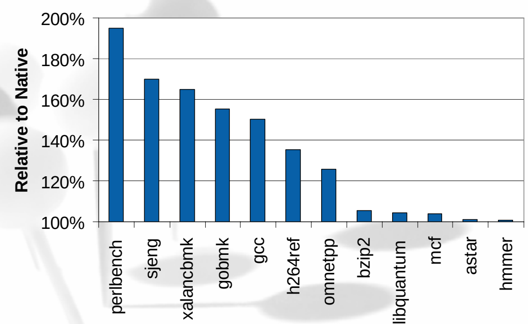
- Valgrind, DynamoRIO, Strata, HDTrans, Pin

Intel Pin

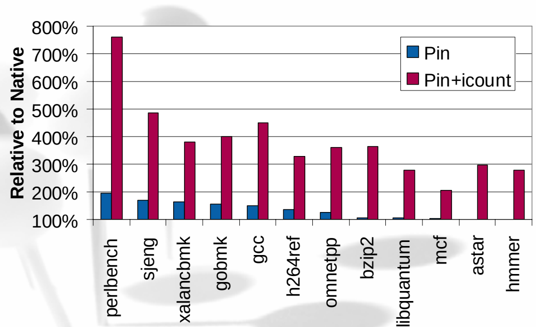
- **A dynamic binary instrumentation system**
- **Easy-to-use instrumentation interface**
- **Supports multiple platforms**
  - Four ISAs – IA32, Intel64, IPF, ARM
  - Four OSes – Linux, Windows, FreeBSD, MacOS
- **Robust and stable (Pin can run itself!)**
  - 12+ active developers
  - Nightly testing of 25000 binaries on 15 platforms
  - Large user base in academia and industry
  - Active mailing list (Pinheads)
- **11,500 downloads**

Our Goal: Improve Performance

The latest Pin overhead numbers …



Adding Instrumentation



Sources of Overhead

Internal

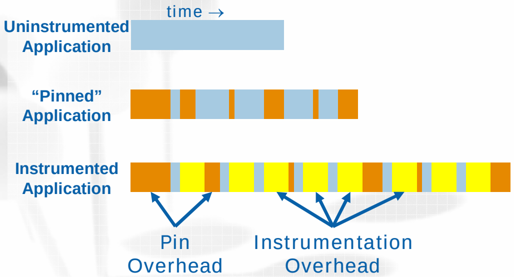
- **Compiling code & exit stubs (region detection, region formation, code generation)**
- **Managing code (eviction, linking)**
- **Managing directories and performing lookups**
- **Maintaining consistency (SMC, DLLs)**

External

- **User-inserted instrumentation**

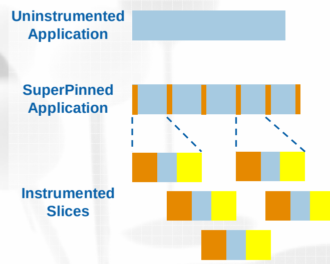
“Normal Pin” Execution Flow

Instrumentation is interleaved with application



“SuperPin” Execution Flow

SuperPin creates instrumented slices

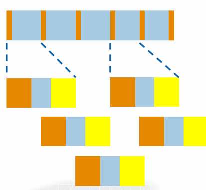


Issues and Design Decisions

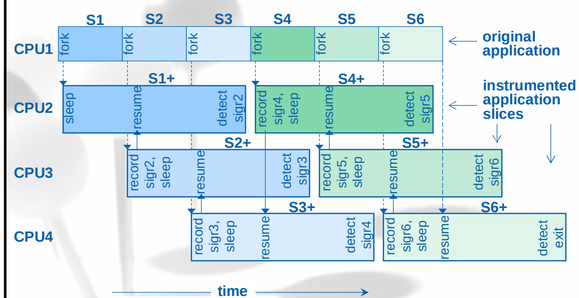
Creating slices
- How/when to **start** a slice
- How/when to **end** a slice

System calls

Merging results



Execution Timeline



Starting Slices

How?
- **Master application process – ptrace**
- **Controlling process**
- **Child slices – fork**
  - Reserve memory for transparency
  - Each slice has its own code cache (for now)

When?
- **Timeouts**
  - Uses a special timer process
  - Tunable parameter
- **System calls**

Handling System Calls

Problem: **Don’t want to duplicate system calls in the main application/slices**

Solutions:
- **brk or anonymous mmap – duplication OK**
- **frequent calls – record and playback**
- **default – trigger new timeslice**

Duplicate	Record/Playback	End Slice
Instr A Instr B MMAP S1 Instr C Instr D	Instr A Instr B SysCallPlay S1 Instr C Instr D	Instr A Instr B S1 SysCall Instr C Instr D S2

Ending Slices

Each slice is responsible for detecting its own end-of-slice condition

S4+

record sig4, sleep

resume

detect sig5

Challenges:
- **Need to efficiently capture a point in time (signature)**
- **Need to efficiently detect when we've reached that point**

Signature Detection

End-of-slice conditions:
1. **System calls – easy to detect**
2. **Timeouts at arbitrary points – harder to detect**

Signature match:
- **Instruction pointer**
- **Architectural state**
- **Top of stack**

Implementing Signature Detection

Uses Pin's lightweight conditional analysis
- **INS_InsertIfCall** – lightweight inlined check
- **INS_InsertThenCall** – heavyweight (conditional) analysis routine

Instrument the end-of-slice instruction pointer
1. Lightweight check – two registers
2. Heavyweight check – full architectural state
3. Heavyweight check – top 100 words on the stack

- **Lightweight triggers heavyweight: ~2%**
- **Stack check fails: ~0%**

Performance Results

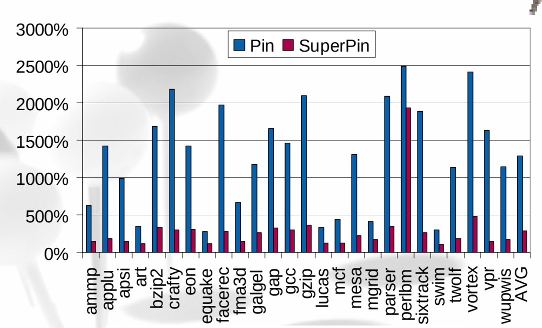
Icount1 – Instruments every instruction with count++

```
% pin –t icount1 -- ./hello
Hello CGO
Count: 496043
```

Icount2 – Instruments every basic block with count += bblength

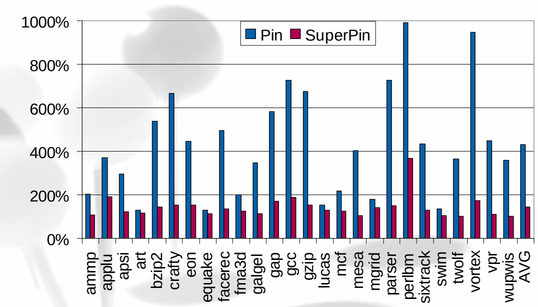
```
% pin –t icount2 -- ./hello
Hello CGO
Count: 496043
```


Performance – icount1



% pin –t icount1 -- <benchmark>

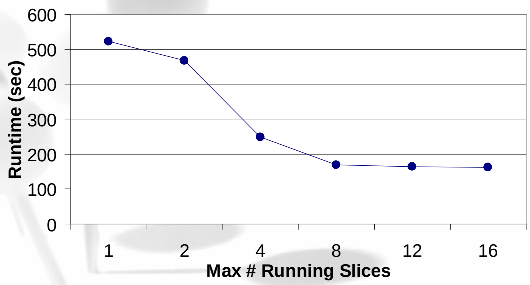
Performance – icount2



% pin –t icount2 -- <benchmark>

Performance Scalability

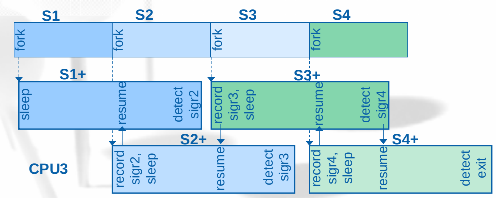
Running on an 8-processor HT-enabled machine (16 virtual processors)



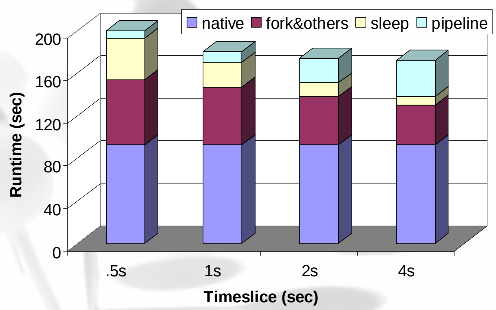
Overhead Categorization

Where is SuperPin spending its time?

- Executing the application
- Fork overheads
- Sleeping (waiting to start a slice)
- Pipeline delays



Overhead Categorization



The SuperPin API

You may write SuperPin-aware Pintools:

- SP_Init(fun)
- SP_AddSliceBeginFunction(fun,val)
- SP_AddSliceEndFunction(fun,val)
- SP_EndSlice()
- SP_CreateSharedArea(local,size,merge)

You may also control (via switches):

- Spmsec {value}: milliseconds per timeslice
- Spmp {value}: maximum slice count
- Spsysrecs {value}: maximum syscalls per slice

Pin Instrumentation API – icount2

```
VOID DoCount(INT32 c) { icount += c;}

VOID Trace(TRACE trace, VOID *v) {
for (BBL bbl=Head(trace); Valid(bbl); bbl=Next(bbl)) {
    INS_InsertCall(BBL_InsHead(bbl), IPOINT_BEFORE,
      (AFUNPTR)DoCount, IARG_INT32, BBL_NumIns(bbl),
      IARG_END);
  }
}

int main(INT32 argc, CHAR **argv) {
   PIN_Init(argc, argv);
   TRACE_AddInstrumentFunction(Trace);
   PIN_StartProgram();
   return 0;
}
```


SuperPin Version of Icount2

```
VOID DoCount(INT32 c) {//same as before}
VOID ToolReset(INT32 c) { icount = 0;}
VOID Merge(INT32 sliceNum) { *sharedData += icount;}
VOID Trace(TRACE trace, VOID *v) {//same as before}
int main(INT32 argc, CHAR **argv) {
  PIN_Init(argc, argv);
  SP_Init(ToolReset);
  sharedData = (UINT64*) SP_CreateSharedArea(&icount,
     sizeof(icount),0);
  SP_AddSliceEndFunction(Merge);
  TRACE_AddInstrumentFunction(Trace);
  PIN_StartProgram();
  return 0;
}
```

SuperPin Limitations

Not all instrumentation tasks are a good fit

Great fit – independent tasks
- Instruction profiling (counts, distributions)
- Trace generation

Requires massaging – dependent tasks
- Branch prediction
- Data cache simulation
  – Assume a starting state, resolve later

Stick with regular Pin – path modification
- Adaptive execution

Future (Rainy Day) Extensions

- **Adaptive parallelism detection**
  – Hardware feedback: adapts to available processors
  – OS feedback: adapts to present load
- **Adaptive slice timeouts**
- **Slice-shared code caches**
- **Multithreaded application support**

SuperPin Summary

Allows users to leverage available parallelism for certain instrumentation tasks

- **Hides the gory details**
- **Enables significant speedup (for the right tasks … on the right machines)**
- **Exposed as Pin API extensions**

➢ **Download it today!**
http://rogue.colorado.edu/pin