Pin Optimizations

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Adapted from prior 6.823 offerings, and Intel’s Tutorial at CGO 2010
From the last tutorial...

What is Instrumentation?

- Instrumentation is a technique that inserts extra code into a program to collect runtime information.

- PIN does dynamic binary instrumentation.

<table>
<thead>
<tr>
<th>Runtime</th>
<th>No need to re-compile or re-link</th>
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Instrumentation: Instruction Count

Analysis routine

Instrumentation routine

counter++;  
sub $0xff, %edx  
counter++;  
cmp %esi, %edx  
counter++;  
jle <L1>  
counter++;  
mov $0x1, %edi  
counter++;  
add $0x10, %eax

Let’s increment counter by one before every instruction!
Instrumentation vs. Analysis

• **Instrumentation routines** define where instrumentation is inserted
  
  – ☕ Occurs immediately before an instruction is executed for the first time.

• **Analysis routines** define what to do when instrumentation is activated
  
  – ☕ Occurs *every time* an instruction is executed
How to Write Efficient Pintools
Reducing Instrumentation Overhead

Total Overhead = Pin’s Overhead + Pintool’s Overhead

- The job of Pin developers to minimize this
- ~5% for SPECfp and ~20% for SPECint

- Pintool writers can help minimize this!
Reducing Pintool’s Overhead

Pintool’s Overhead

Instrumentation Routines Overhead + Analysis Routines Overhead

Frequency of calling an Analysis Routine \times \text{Work required in the Analysis Routine}
Reducing Pintool’s Overhead

Pintool’s Overhead

Instrumentation Routines Overhead + Analysis Routines Overhead

Frequency of calling an Analysis Routine $\times$ Work required in the Analysis Routine
Instrumentation Granularity

• Instrumentation with Pin can be done at 3 different granularities:
  – Instruction
  – Basic block
    • A sequence of instructions terminated at a (conditional or unconditional) control-flow changing instruction
    • Single entrance, single exit
  – Trace
    • A sequence of basic blocks terminated at an unconditional control-flow changing instruction
    • Single entrance, multiple exits
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```
sub $0xff, %edx
cmp %esi, %edx
jle <L1>
mov $0x1, %edi
add $0x10, %eax
jmp <L2>
```
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6 insts

\[
\begin{align*}
\text{sub} & \quad $0x\text{ff}, \%edx \\
\text{cmp} & \quad %esi, %edx \\
\text{jle} & \quad <\text{L1}> \\
\text{mov} & \quad $0x1, \%edi \\
\text{add} & \quad $0x10, \%eax \\
\text{jmp} & \quad <\text{L2}>
\end{align*}
\]
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6 insts, 2 basic blocks

- sub $0xff, %edx
- cmp %esi, %edx
- jle <L1>
- mov $0x1, %edi
- add $0x10, %eax
- jmp <L2>
Instrumentation Granularity

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Recap of Pintool: Instruction Count

counter++
sub $0xff, %edx
counter++;
cmp %esi, %edx
counter++;
jle <L1>
counter++;
mov $0x1, %edi
counter++;
add $0x10, %eax
Recap of Pintool: Instruction Count

- Straightforward, but the counting can be more efficient

```asm
sub $0xff, %edx

counter++;
mov $0x1, %edi
counter++;
add $0x10, %eax
```
Faster Instruction Count

counter += 3
sub $0xff, %edx

cmp %esi, %edx

jle <L1>

counter += 2
mov $0x1, %edi

add $0x10, %eax

basic blocks (bbl)
```c
#include <stdio.h>
#include "pin.H"

UINT64 icount = 0;

void docount(INT32 c) { icount += c; }
void Trace(TRACE trace, void *v) {
    for (BBL bbl = TRACE_BblHead(trace);
         BBL_Valid(bbl); bbl = BBL_Next(bbl)) {
        BBL_InsertCall(bbl, IPOINT_BEFORE, (AFUNPTR)docount,
                       IARG_UINT32, BBL_NumIns(bbl), IARG_END);
    }
}

void Fini(INT32 code, void *v) {
    fprintf(stderr, "Count %lld\n", icount);
}

int main(int argc, char * argv[]) {
    PIN_Init(argc, argv);
    TRACE_AddInstrumentFunction(Trace, 0);
    PIN_AddFiniFunction(Fini, 0);
    PIN_StartProgram();
    return 0;
}
```

**analysis routine**

**instrumentation routine**
Reducing Frequency of Calling Analysis Routines

• Key:
  – Instrument at the largest granularity whenever possible:
    • Trace > Basic Block > Instruction
Reducing Pintool’s Overhead

Pintool’s Overhead

Instrumentation Routines Overhead + Analysis Routines Overhead

Frequency of calling an Analysis Routine x Work required in the Analysis Routine
Reducing Pintool’s Overhead

Pintool’s Overhead

Instrumentation Routines Overhead + Analysis Routines Overhead

Frequency of calling an Analysis Routine \( \times \) Work required in the Analysis Routine

Work required for transiting to Analysis Routine + Work done inside Analysis Routine
Example: Counting Control Flow Edges

L1: jne <L2>
    ...
    jmp <L3>

L2: call <L4>
    ...

L3: jne <L1>
    ...

L4: ...
    ret

How often is each branch taken?
Example: Counting Control Flow Edges

How often is each branch taken?
void docount2(ADDRINT src, ADDRINT dst, INT32 taken) {
    COUNTER *pedg = Lookup(src, dst);
    pedg->count += taken;
}

void Instruction(INS ins, void *v) {
    if (INS_IsBranchOrCall(ins)) {
        INS_InsertCall(ins, IPOINT_BEFORE, (AFUNPTR) docount2,
                       IARG_INST_PTR, IARG_BRANCH_TARGET_ADDR,
                       IARG_BRANCH_TAKEN, IARG_END);
    }
}

1 if taken, 0 if not taken
Inefficiency in Program

• About every 5th instruction executed in a typical application is a branch.
• Lookup will be called whenever these instruction are executed
  – significant application slowdown

• Direct vs. Indirect Branches
  – Branch Address in instruction vs. Branch Address in Register
  – Static vs. Dynamic
void docount(COUNTER* pedge, INT32 taken) {
    pedg->count += taken;
}

void docount2(ADDRINT src, ADDRINT dst, INT32 taken) {
    COUNTER *pedg = Lookup(src, dst);
    pedg->count += taken;
}

void Instruction(INS ins, void *v) {
    if (INS_IsDirectBranchOrCall(ins)) {
        COUNTER *pedg = Lookup(INS_Address(ins),
                                INS_DirectBranchOrCallTargetAddress(ins));
        INS_InsertCall(ins, IPOINT_BEFORE, (AFUNPTR) docount,
                       IARG_ADDRINT, pedg, IARG_BRANCH_TAKEN, IARG_END);
    } else
        INS_InsertCall(ins, IPOINT_BEFORE, (AFUNPTR) docount2,
                       IARG_INST_PTR, IARG_BRANCH_TARGET_ADDR,
                       IARG_BRANCH_TAKEN, IARG_END);
}
Eliminating Control Flow

```c
void docount(COUNTER* pedge, INT32 taken) {
    if (!taken)
        return;
    pedg->count++;
}
```

**VS.**

```c
void docount(COUNTER* pedge, INT32 taken) {
    pedg->count += taken;
}
```

*Can be inlined by Pin*
Reducing Work Done in Analysis Routines

• Key:
  – Shifting computation from Analysis Routines to Instrumentation Routines whenever possible
Some other optimizations...

• Reduce the number of arguments to analysis routine.
  – For example, instead of passing TRUE/FALSE, create 2 analysis functions.

• If an instrumentation can be inserted anywhere in a basic block:
  – Let Pin know via `IPOINT_ANYWHERE` (used in `BBL_InsertCall()`)  
    – Pin will find the best point to insert the instrumentation to minimize register spilling
Takeaways..

- Reduce **frequency** of calling analysis routines by instrumenting at **the largest granularity** whenever possible.

- Reduce **the amount of work** done in analysis routines by **shifting computation** from Analysis Routines to Instrumentation Routines whenever possible.