6.823
Pin Optimizations

Adapted from: Prior 6.823 offerings, and Intel’s Tutorial at CGO 2010
What is Instrumentation?

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

- PIN does *dynamic* binary instrumentation.

  - Runtime
  - No need to re-compile or re-link.
Let's count the number of instructions!

sub $0xff, %edx

cmp %esi, %edx

jle <L1>

mov $0x1, %edi

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 x 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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```assembly
sub $0xff, %edx
cmp %esi, %edx
jle <L1>
mov $0x1, %edi
add $0x10, %eax
jmp <L2>
```
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```
6 insts

sub $0xff, %edx
cmp %esi, %edx
jle <L1>

mov $0x1, %edi
add $0x10, %eax
jmp <L2>
```
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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

• Instrumentation with Pin can be done at 3 different granularities:
  – Instruction
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    • A sequence of instructions terminated at a (conditional or unconditional) control flow changing instruction
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<table>
<thead>
<tr>
<th>Instruction</th>
<th>Basic block</th>
</tr>
</thead>
<tbody>
<tr>
<td>sub $0xff, %edx</td>
<td>cmp %esi, %edx</td>
</tr>
<tr>
<td></td>
<td>jle &lt;L1&gt;</td>
</tr>
<tr>
<td>mov $0x1, %edi</td>
<td>add $0x10, %eax</td>
</tr>
<tr>
<td></td>
<td>jmp &lt;L2&gt;</td>
</tr>
</tbody>
</table>

6 insts, 2 basic blocks, 1 trace
Recap of Pintool: Instruction Count

counter++;
sub $0xff, %edx

counter++;
cmp %esi, %edx

counter++;
je <L1>
counter++;
mov $0x1, %edi

counter++;
add $0x10, %eax
Recap of Pintool: Instruction Count

counter++;
sub $0xff, %edx

• Straightforward, but the counting can be more efficient

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
```
#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;
}
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 \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

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.
- Edge 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
Edge Counting: a Faster Version

```c
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 if (INS_IsBranchOrCall(ins))
        INS_InsertCall(ins, IPOINT_BEFORE, (AFUNPTR) docount2,
                       IARG_INST_PTR, IARG_BRANCH_TARGET_ADDR,
                       IARG_BRANCH_TAKEN, IARG_END);
}
```

2/15/2020 6.823 Spring 2020
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
Lab 1 Released

• Design 3 different types of caches
  – Virtually Indexed, Virtually Tagged
  – Physically Indexed, Physically Tagged
  – Virtually Indexed, Physically Tagged

• Memory management covered in next two lectures

• Remember to start early!
  – Experiments will take longer than Lab 0
Tips

- Ask questions on Piazza.

- `ssh <athenauusername>@vlsifarm-0X.mit.edu` or
  - `ssh <athenauusername>@eecs-ath-4X.mit.edu`
    - `eecs-ath-4X` machines are much more powerful

- Suggested reading on caches on the course website.