Binary instrumentation for hackers and security professionals

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Part 1

INTRODUCTION
Agenda

• Introduction
  – What is Instrumentation
  – Why should you care? Potential usages

• PIN – A binary instrumentation engine
  – About PIN
    – Understanding PIN – a case study in instruction counting

• A practical example – catching “double-free”

• Advanced stuff and closing notes
  – Probe mode and JIT mode
  – Advanced PIN capabilities
  – Alternatives
  – How to learn more
  – Call for action
Instrumentation

A technique that inserts code into a program to collect run-time information

- Program analysis: performance profiling, error detection, capture & replay
- Architectural study: processor and cache simulation, trace collection

- Source-Code Instrumentation
- Static Binary Instrumentation
- **Dynamic Binary Instrumentation**
  - **Instrument code just before it runs (Just In Time – JIT)**
    - No need to recompile or re-link
    - Discover code at runtime
    - Handle dynamically-generated code
    - Attach to running processes
Why should you care?

• The previous slide didn’t mention all potential usages
• Potential security related usages:
  – Sandboxing & Forcing security practices
  – Behavior-based security
  – Pre-patching
  – Reversing, unpacking & de-obfuscation
  – SW analysis, for example - Parallel studio
    – Thread checking
    – Memory checking
  – Taint-analysis
  – Anti-viruses
  – Automated vulnerability classification / analysis
  – Deterministic replay
  – ...

• Do you have tool ideas? Let me know and I might help
Part 1 - Summary

• Instrumentation – a technique to inject code into a program

• Dynamic binary instrumentation – what we will focus on today

• Instrumentation has tons of uber kwel usages for offense and defense
Part 2

PIN – A DYNAMIC BINARY INSTRUMENTATION ENGINE
What Does “Pin” Stand For?

• **Three Letter Acronyms @ Intel**
  - TLAs
  - $26^3$ possible TLAs
  - $26^3 - 1$ are in use at Intel
  - Only 1 is not approved for use at Intel
  - Guess which one:

• **Pin Is Not** an acronym
Pin Instrumentation

• Multi-platform:
  – Linux
  – Windows
  – OS X (not supported anymore)

• Multi-architecture:
  – IA32
  – x86-64 (aka Intel64 / AMD64)
  – Itanium (aka IA64, only Linux)
  – ARM (not supported anymore)

• Robust & Efficient
Pin availability

• Popular and well supported
  – 40,000+ downloads, 400+ citations

• Free Download
  – www.pintool.org
  – Free for non-commercial use
  – Includes: Detailed user manual, Pin tools

• Pin User Group (PinHeads)
  – http://tech.groups.yahoo.com/group/pinheads/
  – Pin users and Pin developers answer questions
Pin and Pin Tools

- Pin – the instrumentation **engine**
- Pin Tool – the instrumentation **program**

Pin provides a framework, the Pin Tool uses the framework to do something meaningful

- Pin Tools
  - Written in C/C++ using Pin APIs
  - Many open source examples provided with the Pin kit
  - Certain do’s and don’t’s apply
# Instruction Counting Tool

```c
#include "pin.h"

UINT64 icount = 0;

void docount() { icount++; }

void Instruction(INS ins, void *v) {
    INS_InsertCall(ins, IPOINT_BEFORE, (AFUNPTR)docount, IARG_END);
}

void Fini(INT32 code, void *v) {
    std::cerr << "Count " << icount << endl;
}

int main(int argc, char * argv[]) {
    PIN_Init(argc, argv);
    INS_AddInstrumentFunction(Instruction, 0);
    PIN_AddFiniFunction(Fini, 0);
    PIN_StartProgram();    // Never returns
    return 0;
}
```
Instrumentation vs. Analysis

- **Instrumentation routines** define where instrumentation is inserted
  - e.g., before instruction
    - Occurs *first time* an instruction is executed

- **Analysis routines** define what to do when instrumentation is activated
  - e.g., increment counter
    - Occurs *every time* an instruction is executed
Instruction Counting Tool

#include "pin.h"

UINT64 icount = 0;

void docount() { icount++; }

void Instruction(INS ins, void *v) {
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int main(int argc, char * argv[]) {
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    PIN_AddFiniFunction(Fini, 0);
    PIN_StartProgram();  // Never returns
    return 0;
}
Instrumentation Granularity

- Instruction
- Basic Block
- Trace
- Routine
- Section
- Image
- Process
- Thread
- Exception
## Instrumentation Points

<table>
<thead>
<tr>
<th>Instrumentation Point</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IPOINT_BEFORE</strong></td>
<td>Insert a call before an instruction or routine.</td>
</tr>
<tr>
<td><strong>IPOINT_AFTER</strong></td>
<td>Insert a call on the fall thorough path of an instruction or return path of a routine.</td>
</tr>
<tr>
<td><strong>IPOINT_ANYWHERE</strong></td>
<td>Insert a call anywhere inside a trace or a bbl.</td>
</tr>
<tr>
<td><strong>IPOINT_TAKEN_BRANCH</strong></td>
<td>Insert a call on the taken edge of branch, the side effects of the branch are visible.</td>
</tr>
</tbody>
</table>
A Better Instruction Counting Tool

```c
#include "pin.H"

UINT64 icount = 0;

void PIN_FAST_ANALYSIS_CALL docount(INT32 c) { icount += c; }

void Trace(TRACE trace, void *v) { // Pin Callback
    for(BBL bbl = TRACE_BblHead(trace);
        BBL_Valid(bbl);
        bbl = BBL_Next(bbl))
        BBL_InsertCall(bbl, IPOINT_ANYWHERE,
            (AFUNPTR)docount, IARG_FAST_ANALYSIS_CALL,
            IARG_UINT32, BBL_NumIns(bbl),
            IARG_END);
}

void Fini(INT32 code, void *v) { // Pin Callback
    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;
}
```
Summary of Part 2

• Pin is a dynamic binary instrumentation engine
• Pin is available freely for non-commercial purposes
• Pin is the engine, Pin Tools are programs controlling the engine

• Instrumentation routines are called once, analysis routines are called every time
• There are many levels of granularity
  – You should try to use the lowest answering your needs
• You can change instrumentation points
Part 3

A PRACTICAL EXAMPLE CATCHING “DOUBLE-FREE”
#include "pin.H"
#include <iostream>
#include <iomanip>
#include <algorithm>
#include <list>

int main(int argc, char *argv[]) {
    // Initialize pin & symbol manager
    PIN_InitSymbols();
    PIN_Init(argc, argv);

    // Register Image to be called to instrument functions.
    IMG_AddInstrumentFunction(Image, 0);

    PIN_StartProgram();  // Never returns

    return 0;
}
VOID Image(IMG img, VOID *v) { 
    // Find the malloc() function and add our function after it
    RTN mallocRtn = RTN_FindByName(img, "malloc");
    if (RTN_Valid(mallocRtn))
    {
        RTN_Open(mallocRtn);
        RTN_InsertCall(mallocRtn, IPOINT_AFTER, (AFUNPTR)MallocAfter,
                        IARG_FUNCRET_EXITPOINT_VALUE, IARG_END);
        RTN_Close(mallocRtn);
    }

    // Find the free() function and add our function before it
    RTN freeRtn = RTN_FindByName(img, "free");
    if (RTN_Valid(freeRtn))
    {
        RTN_Open(freeRtn);
        RTN_InsertCall(freeRtn, IPOINT_BEFORE, (AFUNPTR)FreeBefore,
                        IARG_ADDRINT, "free",
                        IARG_FUNCARG_ENTRYPOINT_VALUE, 0,
                        IARG_END);
        RTN_Close(freeRtn);
    }
}
Analysis routines

```cpp
list<ADDRINT> MallocAddrs;

VOID MallocAfter(ADDRINT ret)
{
    // Save teh address returned by malloc in our list
    MallocAddrs.push_back(ret);
}

VOID FreeBefore(CHAR * name, ADDRINT target)
{
    list<ADDRINT>::iterator p;

    p = find(MallocAddrs.begin(), MallocAddrs.end(), target);
    if (MallocAddrs.end() != p)
    {
        p = MallocAddrs.erase(p);
    } // Delete this from the allocated address list
    else
    {
        // We caught a Free of an un-allocated address
        cout << hex << target << endl;
    } // Using cout is not a good practice, I do it for the example only
} // Using cout is not a good practice, I do it for the example only
```
Summary of part 3

• It is relatively simple to write Pin Tools

• Writing a tool to catch double free is very simple and takes less than 50 lines of actual code

• Using simple tools we can catch vulnerabilities relatively easily

• Did anyone notice the flaw in the tool?
Part 4
ADVANCED STUFF AND CLOSING NOTES
Probe mode and JIT mode

- **JIT Mode**
  - Pin creates a modified copy of the application on-the-fly
  - Original code never executes
    - More flexible, more common approach

- **Probe Mode**
  - Pin modifies the original application instructions
  - Inserts jumps to instrumentation code (trampolines)
    - Lower overhead (less flexible) approach
Advanced Pin APIs

- Transparent debugging and extending the debugger
- Attaching and detaching
- System call instrumentation
- Managing Exceptions and Signals
- Instrumenting a process tree
- Accessing Decode API
- CONTEXT* and IARG_CONST_CONTEXT, IARG_CONTEXT
- Fast buffering API
- Pin Code-Cache API
Alternative instrumentation engines

- DyanmoRIO
- Valgrind
- Dtrace
- SystemTap (based on kprobes)
- Frysk
- GDB can also be seen as a DBI
- Bistro (EOL)

- Add your favorite DBI engine here
Learning more about Pin

• Website – [www.pintool.org](http://www.pintool.org)
  – Free Pin kit downloads
  – Many open source Pin Tool examples
  – An extensive manual
  – Links to papers and extensive tutorials given in conferences

• PinHeads - Mailing list / newsgroup
  – [http://tech.groups.yahoo.com/group/pinheads/](http://tech.groups.yahoo.com/group/pinheads/)
Call for action

• Start learning and using binary instrumentation
• Create your own Pin Tools and share with the DC9723 community and all the security community

• Did anybody come up with a tool idea?
  – Feel free to contact me
QUESTIONS?

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