Binary instrumentation for hackers and security professionals

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Special thanks to Tevi Devor from the PIN development team

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All code in this presentation is covered by the following:

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

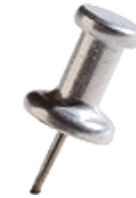
- ❑ Program analysis : performance profiling, error detection, capture & replay
- ❑ Architectural study : processor and cache simulation, trace collection

- 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

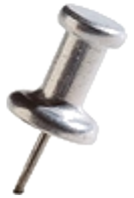


- Instrumentation – a technique to inject code into a program
- Dynamic binary instrumentation – what we will focus on today
- Instrumentation has tons of uber kwel usages for offense and defense

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:

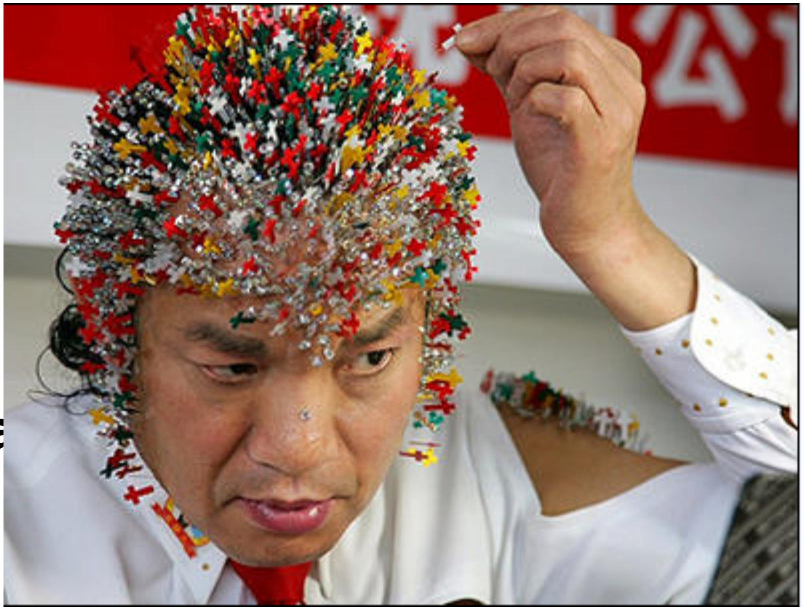
- **P**in **I**s **N**ot an acronym

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

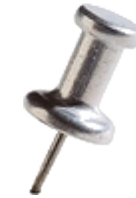
Pin availability

- **Popular and well supported**
  - 40,000+ downloads, 400+ citatio



- **Free Download**
  - **www.pintool.org**
  - **Free for non-commercial use**
  - **Includes: Detailed user manua 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 dont's apply

Instruction Counting Tool

```
#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;
}
```

Start Here

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)
{
    INS_InsertCall(ins, IPOINT_BEFORE,
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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 Granularity

- Instruction
- Basic Block
- Trace

- Routine
- Section
- Image

- Process
- Thread
- Exception

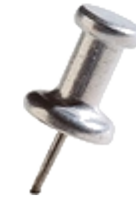
Instrumentation Points

IPOINT_BEFORE	Insert a call before an instruction or routine.
IPOINT_AFTER	Insert a call on the fall thorugh path of an instruction or return path of a routine.
IPOINT_ANYWHERE	Insert a call anywhere inside a trace or a bbl.
IPOINT_TAKEN_BRANCH	Insert a call on the taken edge of branch, the side effects of the branch are visible.

A Better Instruction Counting Tool

```
#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”

Main + Includes

```
#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;
}
```

Instrumentation Routine

```
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

```
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
}
```

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

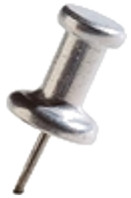
Learning more about Pin

- Website – www.pintool.org
  - 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/

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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