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Dynamic Binary Instrumentation Frameworks: I know you're there spying on me

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RECon 2012

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Agenda

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Agenda

- Who are we?
- Motivations
- What is Dynamic Binary Instrumentation?
  - What is Pin?
  - How does Pin work?
- Anti-debug and Anti-VM related work
- Anti-instrumentation techniques
- Presentation of eXait
- Applications of our research
- Future work
- Contact info

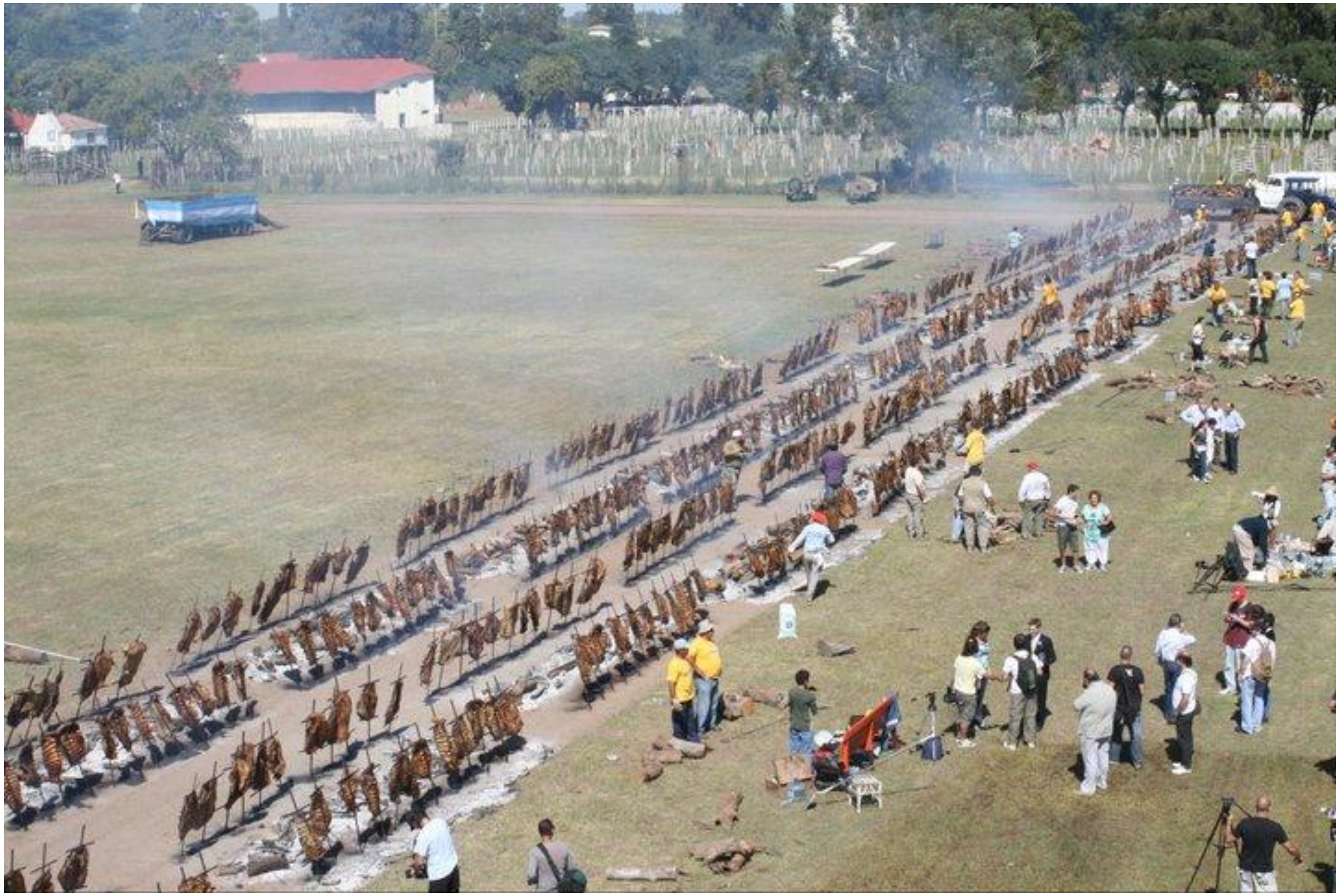
Who are we?

Who are we?

- We are exploit writers in the Exploit Writers Team of Core Security.
- We have discovered vulnerabilities in software of some major companies (CA, Adobe, HP, Novell, Oracle, IBM, Google).
- We like low-level stuff, like doing kernel exploitation, assembly programming, breaking software protections, etc.
- This is our first talk in a conference!
- We are from small towns in Argentina.

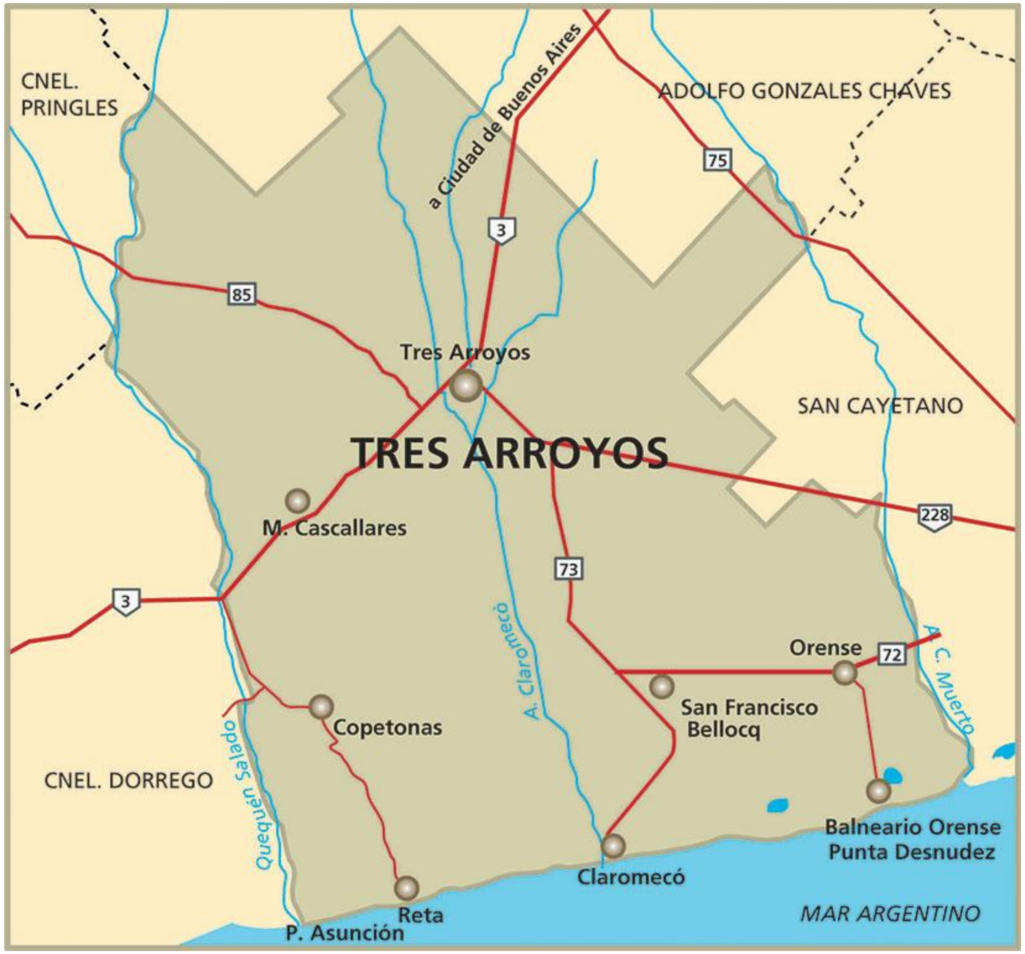
Who are we?

Nahuel is from the World 's Capital City of Asado!



Who are we?

Francisco is from a county that looks like the head of a man!



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Motivations for our work

Motivations

- Dynamic Binary Instrumentation is becoming more popular.
  - Covert debugging (Saffron - Danny Quist – BH USA 2007/Defcon 15)
  - Automatic Unpacking (Piotr Bania - 2009, Ricardo J. Rodriguez - 2012)
  - Shellcode detection (Sebastian Porst – Zynamics - 2010)
  - Taint analysis
  - Instruction tracing
  - Self-modifying code analysis (Tarte Tatin Tools - Daniel Reynaud)
  - Exploitation techniques mitigations (Richard Johnson – Snort 2012)

Motivations

- Dynamic Binary Instrumentation is becoming more popular.
  - Light and Dark side of Code Instrumentation - Dmitriy Evdokimov - ConFidEncE 2012
  - Hacking Using Dynamic Binary Instrumentation - Gal Diskin - HITB 2012 AMS
  - Improving Software Security with Dynamic Binary Instrumentation - Richard Johnson - InfoSec Southwest 2012
  - Improvements in the unpacking process using DBI techniques - Ricardo J. Rodriguez - RootedCon 2012
  - Shellcode analysis using dynamic binary instrumentation - Daniel Radu and Bruce Dang - CARO 2011
  - Vulnerability Analysis and Practical Data Flow Analysis & Visualization - Jeong Wook Oh - CanSecWest 2012

Motivations

- If this trend continues, we think that eventually anti-instrumentation techniques will arise.
- Apparently, there isn't any comprehensive public documentation on anti-instrumentation techniques.

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What is Dynamic Binary Instrumentation?

What is Instrumentation?

It's a technique to analyze and modify the behavior of a program by adding code to it.

It can be done:

- At the source code level
- At the binary code level

In turn, it can be:

- Static
- Dynamic

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What is Dynamic Binary Instrumentation?

It's a technique to analyze and modify the behavior of a **binary** program by **injecting arbitrary code** at arbitrary places while it is **executing**.

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What is Pin?

What is Pin?

- It’s the Intel’s Dynamic Binary Instrumentation Framework.
- It works on Windows, Linux and Mac OS X.
- It works on x86, amd64, Itanium and ARM (discontinued).
- Its API allows to inject C/C++ arbitrary code.

How does Pin work?

How does Pin work?

- Pin is a command line tool:
- pin.bat -t pintool.dll [pintool args] -- program.exe [program args]
- pin.bat -pid <program pid> -t pintool.dll [pintool args]

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How does Pin work?

- Pin main components:
  - Pin.exe
  - Pinvm.dll

- The code you write to instrument programs using the Pin API is compiled into pintools

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How does Pin work?

- JIT compiler.
  - Input: binary code
  - Output: equivalent code with introspection code
  - The code is generated only when it is needed

- The only code that is executed is the code generated by the JIT compiler.

- The original code remains in memory just as a reference but it is **never** executed.

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Anti-debug and Anti-VM related work

Anti-debug and Anti-VM related work

- Anti-debug techniques papers series by Peter Ferrie (http://pferrie.host22.com/).

- Anti-VM techniques papers by Peter Ferrie (same link as above).

- Dan Upton – Detection and Subversion Of Virtual Machines (http://www.cs.virginia.edu/~dsu9w/upton06detection.pdf).

Anti-debug and Anti-VM related work

- Red pill – (Joanna Rutkowska).

- On the Cutting Edge: Thwarting Virtual Machine Detection (Tom Liston – Ed Skoudis http://handlers.sans.org/tliston/ThwartingVMDetection_Liston_Skoudis.pdf).

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Anti-instrumentation techniques

Anti-instrumentation techniques

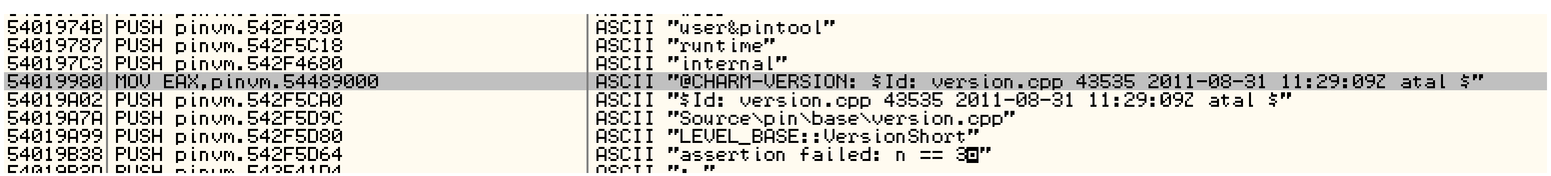
- Code and data fingerprinting of pinvm.dll
- PE characteristics fingerprint
- Handles inspection
- Time detection
- Pin’s JIT compiler code fingerprint
- Real EIP value
- Misc techniques

Anti-instrumentation techniques – Fingerprinting pinvm.dll

- Code and data fingerprinting of pinvm.dll
  - Detect by searching string patterns
  - Detect by code patterns

Fingerprinting pinvm.dll – Detect by string patterns

- Detect by string patterns
  - “@CHARM-VERSION: $Id:”
  - "build\\Source\\pin\\internal-include-windows-ia32\\bigarray.H“
  - "LEVEL_BASE::ARRAYBASE::SetTotal“
  - "Source\\pin\\base\\bigarray.cpp“



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Fingerprinting pinvm.dll – Detect by code patterns

- Detect by code patterns (pattern 1)

```
5418D4A6    897424 04     MOV DWORD PTR SS:[ESP+4],ESI
5418D4AA    895C24 10     MOV DWORD PTR SS:[ESP+10],EBX
5418D4AE    895424 14     MOV DWORD PTR SS:[ESP+14],EDX
5418D4B2    894C24 18     MOV DWORD PTR SS:[ESP+18],ECX
5418D4B6    894424 1C     MOV DWORD PTR SS:[ESP+1C],EAX
5418D4BA    33C0          XOR EAX,EAX
5418D4BC    894424 20     MOV DWORD PTR SS:[ESP+20],EAX
5418D4C0    8C4C24 20     MOV WORD PTR SS:[ESP+20],CS
5418D4C4    894424 28     MOV DWORD PTR SS:[ESP+28],EAX
5418D4C8    8C5C24 28     MOV WORD PTR SS:[ESP+28],DS
5418D4CC    894424 24     MOV DWORD PTR SS:[ESP+24],EAX
5418D4D0    8C5424 24     MOV WORD PTR SS:[ESP+24],SS
5418D4D4    894424 2C     MOV DWORD PTR SS:[ESP+2C],EAX
5418D4D8    8C4424 2C     MOV WORD PTR SS:[ESP+2C],ES
5418D4DC    894424 30     MOV DWORD PTR SS:[ESP+30],EAX
5418D4E0    8C6424 30     MOV WORD PTR SS:[ESP+30],FS
5418D4E4    894424 34     MOV DWORD PTR SS:[ESP+34],EAX
5418D4E8    8C6C24 34     MOV WORD PTR SS:[ESP+34],GS
```


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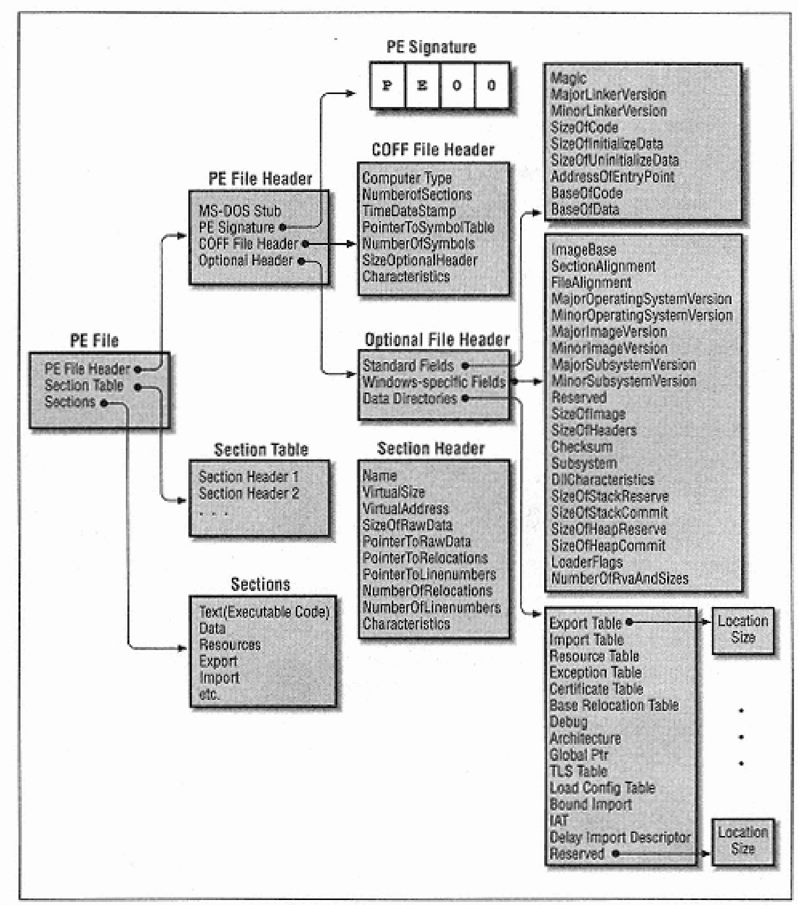
Fingerprinting pinvm.dll – Detect by code patterns

- Detect by code patterns (pattern 2)

```
01750110    CD 00          INT 0
01750112    E9 0B080000    JMP 01750922
01750117    90             NOP
01750118    CD 01          INT 1
0175011A    E9 03080000    JMP 01750922
0175011F    90             NOP
01750120    CD 02          INT 2
01750122    E9 FB070000    JMP 01750922
01750127    90             NOP
01750128    CD 03          INT 3
0175012A    E9 F3070000    JMP 01750922
0175012F    90             NOP
01750130    CD 04          INT 4
01750132    E9 EB070000    JMP 01750922
01750137    90             NOP
01750138    CD 05          INT 5
0175013A    E9 E3070000    JMP 01750922
[…]
It continues until INT FF
```

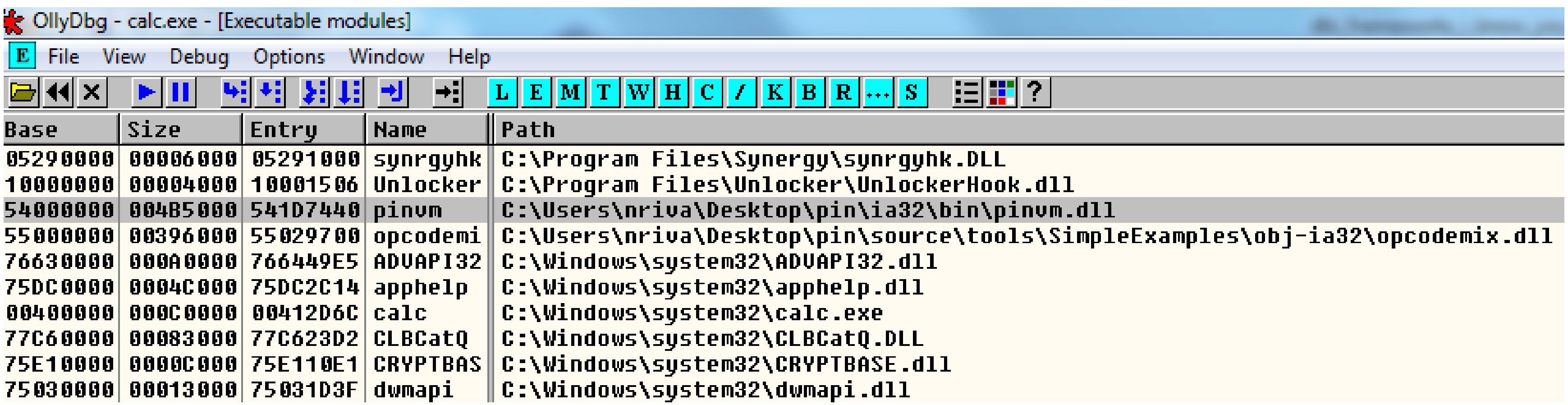
Anti-instrumentation techniques – Detect by PE characteristics

- Detect by PE characteristics
  - Detect by pinvm.dll presence
  - Detect by pinvm exported functions
  - Detect by pintools exported functions
  - Detect by sections names



Detect by PE characteristics – Detect by pinvm.dll presence

- Detect by pinvm.dll presence



Base	Size	Entry	Name	Path
05290000	00006000	05291000	synrgyhk	C:\Program Files\Synergy\synrgyhk.DLL
10000000	00004000	10001506	Unlocker	C:\Program Files\Unlocker\UnlockerHook.dll
54000000	004B5000	541D7440	pinvm	C:\Users\nriva\Desktop\pin\ia32\bin\pinvm.dll
55000000	00396000	55029700	opcodemi	C:\Users\nriva\Desktop\pin\source\tools\SimpleExamples\obj-ia32\opcodemix.dll
76630000	000A0000	766449E5	ADVAPI32	C:\Windows\system32\ADVAPI32.dll
75DC0000	0004C000	75DC2C14	apphelp	C:\Windows\system32\apphelp.dll
00400000	000C0000	00412D6C	calc	C:\Windows\system32\calc.exe
77C60000	00083000	77C623D2	CLBCatQ	C:\Windows\system32\CLBCatQ.DLL
75E10000	0000C000	75E110E1	CRYPTBAS	C:\Windows\system32\CRYPTBASE.dll
75030000	00013000	75031D3F	dwmapi	C:\Windows\system32\dwmapi.dll

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Detect by PE characteristics – Detect by pinvm exported functions

- Detect by pinvm.dll exported functions
  - PinWinMain
  - CharmVersionC

Ordinal	Function RVA	Name Ordinal	Name RVA	Name
(nFunctions)	Dword	Word	Dword	szAnsi
00000001	00019980	0000	003A041C	CharmVersionC
00000002	001D7430	0001	003A042A	CrtEnableThreadCallbacks
00000003	001D7370	0002	003A0443	DeleteCriticalSection
00000004	001D7080	0003	003A0459	FlsAlloc
00000005	001D7120	0004	003A0462	FlsFree
00000006	001D71F0	0005	003A046A	FlsGetValue
00000007	001D70D0	0006	003A0476	FlsSetValue
00000008	0002CB70	0007	003A0482	GetIpcClientData
00000009	001D6DB0	0008	003A0493	GetModuleHandleA
0000000A	001D6E60	0009	003A04A4	GetModuleHandleW
0000000B	001D6F10	000A	003A04B5	GetProcAddress
0000000C	001D72F0	000B	003A04C4	InitializeCriticalSection
0000000D	001D7260	000C	003A04DE	InitializeCriticalSectionAndSpinCou...
0000000E	003A0513	000D	003A0504	NativeTlsAlloc

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Detect by PE characteristics – Detect by pintools exported functions

- Detect by pintools exported functions
  - CharmVersionC
  - ClientIntC

Ordinal	Function RVA	Name Ordinal	Name RVA	Name
(nFunctions)	Dword	Word	Dword	szAnsi
00000001	0000BD70	0000	00300D85	?ClientInt@LEVEL_PINCLIENT@@Y...
00000002	00043E10	0001	00300DC0	CharmVersionC
00000003	0000BD80	0002	00300DCE	ClientIntC
00000004	000053A0	0003	00300DD9	CrtEnableThreadCallbacks
00000005	00001110	0004	00300DF2	main

Detect by PE characteristics – Detect by sections names

- Detect by sections names
  - Pintools sections
    - .pinclie
    - .charmve

Name	Virtual Size	Virtual Address	Raw Size	Raw Address
Byte[8]	Dword	Dword	Dword	Dword
.text	002791CC	00001000	00279200	00000400
.rdata	00085DF7	0027B000	00085E00	00279600
.data	0002541C	00301000	00002400	002FF400
.pinclie	00000380	00327000	00000400	00301800
.charmve	00000043	00328000	00000200	00301C00
.reloc	00019878	00329000	00019A00	00301E00

  - Pinvm sections
    - .charmve

Name	Virtual Size	Virtual Address	Raw Size	Raw Address
Byte[8]	Dword	Dword	Dword	Dword
.text	002E1B3E	00001000	002E1C00	00000400
.rdata	000BD5F7	002E3000	000BD600	002E2000
.data	000E7EE4	003A1000	00002E00	0039F600
.charmve	00000043	00489000	00000200	003A2400
.reloc	0002A498	0048A000	0002A600	003A2600

Anti-instrumentation techniques – Handles Inspection

- Handles inspection
    - Detect by Event handles
    - Detect by Section handles
    - Detect by Process handles

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Handles inspection – Detect Event handles

- These objects are used by Pin for IPC (Inter Process Communication)

Event	\Sessions\1\BaseNamedObjects\PIN_IPC_EventAckSetByClient_0x958_0x1484_0x3f587d5766fa
Event	\Sessions\1\BaseNamedObjects\PIN_IPC_EventSetByServer_0x958_0x1484_0x3f587d5766fa
Event	\Sessions\1\BaseNamedObjects\PIN_IPC_EventSetByClient_0x958_0x1484_0x3f587d5766fa
Event	\Sessions\1\BaseNamedObjects\PIN_IPC_EventAckSetByServer_0x958_0x1484_0x3f587d5766fa

Handles inspection – Detect by Section handles

- These objects are used by Pin for IPC (Inter Process Communication)

Section	\Sessions\1\BaseNamedObjects\PIN_IPC_FileSentByServer_0x958_0x1484_0x3f587d5766fa
Section	\Sessions\1\BaseNamedObjects\PIN_IPC_FileSentByClient_0x958_0x1484_0x3f587d5766fa

Handles inspection – Detect by Process handles

cmd.exe	4864	TRAVESTI\nriva
pin.exe	3708	TRAVESTI\nriva
calc.exe	2392	TRAVESTI\nriva
pin.exe	6108	TRAVESTI\nriva

Process	pin.exe(6108)
Process	pin.exe(6108)

Anti-instrumentation techniques – Detect by execution delay

- Detect time variations
    - Detect Pin's overhead

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Detect by execution delay – Time variations

- Detect execution delay introduced by Pin

```
printf("HMODULE: %x\n", LoadLibrary("user32.dll"));
printf("HMODULE: %x\n", LoadLibrary("ntmarta.dll"));
printf("HMODULE: %x\n", LoadLibrary("gdi32.dll"));
printf("HMODULE: %x\n", LoadLibrary("advapi32.dll"));
printf("HMODULE: %x\n", LoadLibrary("comctl32.dll"));
printf("HMODULE: %x\n", LoadLibrary("comdlg32.dll"));
printf("HMODULE: %x\n", LoadLibrary("crypt32.dll"));
printf("HMODULE: %x\n", LoadLibrary("dbghelp.dll"));
printf("HMODULE: %x\n", LoadLibrary("ole32.dll"));
printf("HMODULE: %x\n", LoadLibrary("urlmon.dll"));
```

- Non-instrumented execution ≈ 15 to 30 miliseconds.
- Instrumented execution ≈ 1200 to 1500 miliseconds.
- Depends on your machine's power.

Anti-instrumentation techniques – JIT compiler detection

- Detect the JIT compiler
  - Detect ntdll.dll hooks
  - Detect by page permissions
  - Detect by common API calls

JIT compiler detection – Detect by common API calls

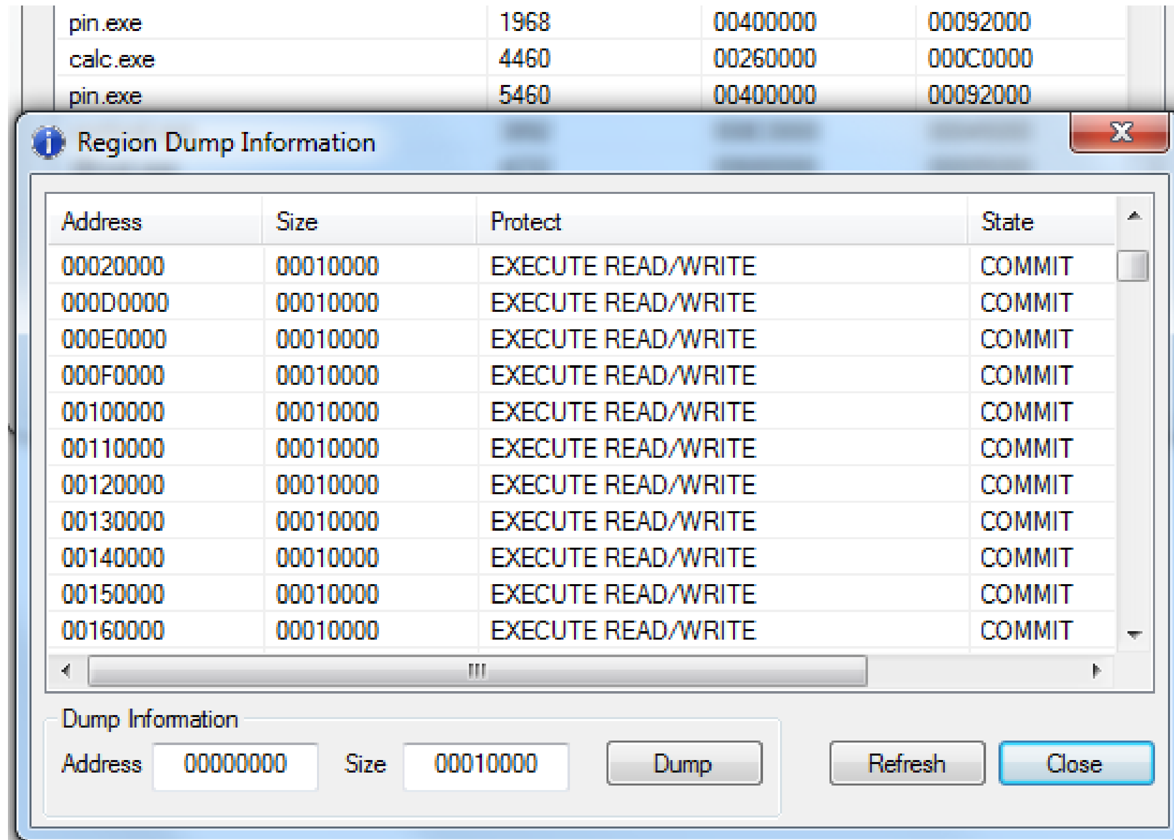
- Detect by ntdll.dll hooks

```
77610038 KiUserApcDispatcher          $- E9 C367BBDC   JMP pinvm.541C6800
776100EC KiUserCallbackDispatcher     $- E9 FB66BBDC   JMP pinvm.541C67EC
77610134 KiUserExceptionDispatcher    $- E9 EF66BBDC   JMP pinvm.541C6828
77639E49 LdrInitializeThunk           $- E9 C6C9B8DC   JMP pinvm.541C6814
```

JIT compiler detection – Detect by page permissions

- Detect by page permissions

- This technique may not work with programs which already have a JIT compiler.



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JIT compiler detection – Detect common API calls

- Detect by common API calls
  - ZwAllocateVirtualMemory
    - AllocationType = MEM_COMMIT | MEM_RESERVE
    - Protect = PAGE_EXECUTE_READWRITE
- This technique may not work with programs which already have a JIT compiler.

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Anti-instrumentation techniques – Real EIP value

- Real EIP value

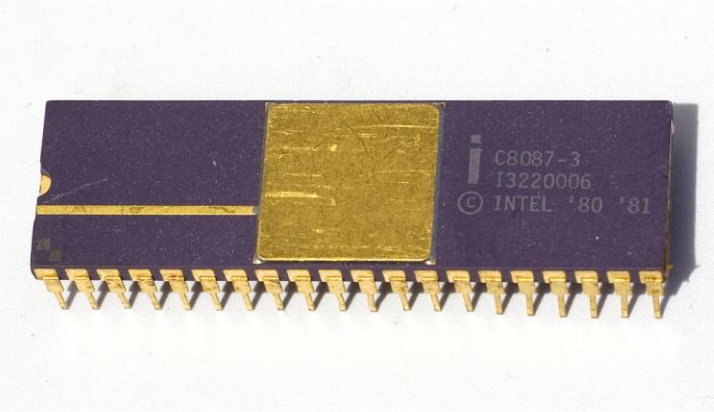
(Remember that: the original code remains in memory just as a reference but it is **never** executed)

  - Detect by FSTENV
  - Detect by FSAVE
  - Detect by FXSAVE

  - Detect by Interruptions

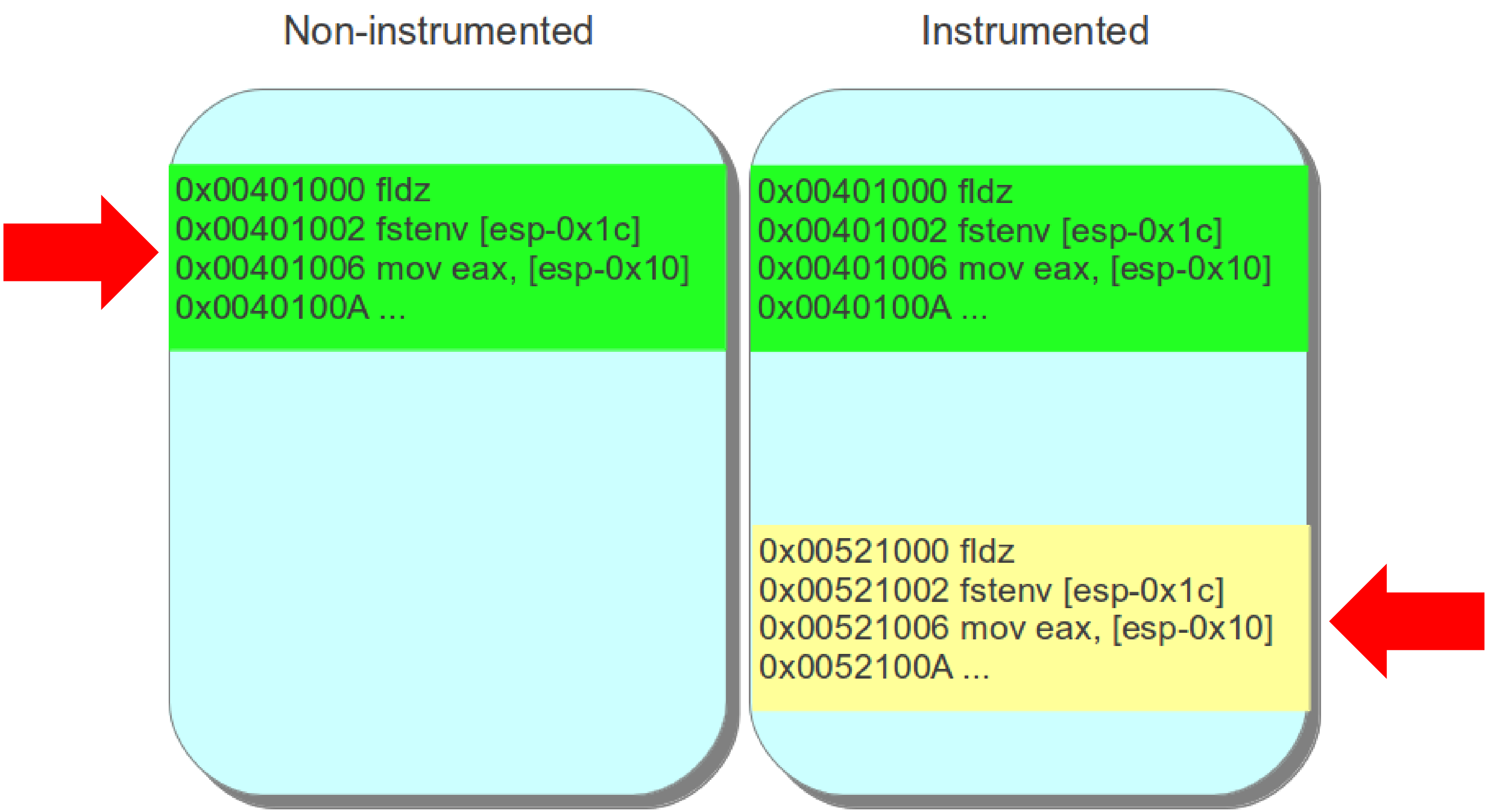
Real EIP value – Detect by FSTENV

```
__asm
{
    fldz;
    fstenv [esp-0x1c];
    mov eax, [esp-0x10];
    mov RealEIP, eax;
}
```



- FSTENV saves the FPU environment, which includes the instruction pointer.
- Alternative: FNSTENV

Real EIP value – Detect by FSTENV



Real EIP value – Detect by FSTENV

```
VirtualQuery((LPCVOID)RealEIP, &mbi, sizeof(mbi));

if((DWORD)hGlobalModule == (DWORD)mbi.AllocationBase)
    return NOTDETECTED;
else
    return DETECTED;
```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Real EIP value – Detect by FSAVE

```
__asm
{
  FLDZ
  FSAVE (108-BYTE) PTR SS:[ESP-6C]
  MOV EAX,DWORD PTR SS:[ESP-60]
}
```

- FSAVE stores the FPU state (FPU environment + register stack).
- Alternative: FNSAVE

Real EIP value – Detect by FXSAVE

```
__asm
{
        LEA EAX, [ESP-0x20C];
        AND EAX, 0xFFFFFFF0;
        FLDZ;
        FXSAVE [EAX];
        MOV EAX, [EAX+8];
}
```

- FXSAVE writes the state of the x87 FPU + MMX registers + SSE registers.

Real EIP value – Detect by Interruptions

```
__asm {
        xor eax,eax;
        xor edx,edx;
        int 0x2e;
        nop;
        mov RealEIP, edx;
    }
```

- This technique was documented by the corkami project (http://code.google.com/p/corkami/).
- This technique only works on 32 bits systems (Windows XP/Vista/Seven).
- Does not work on WoW64 (it raises an exception).

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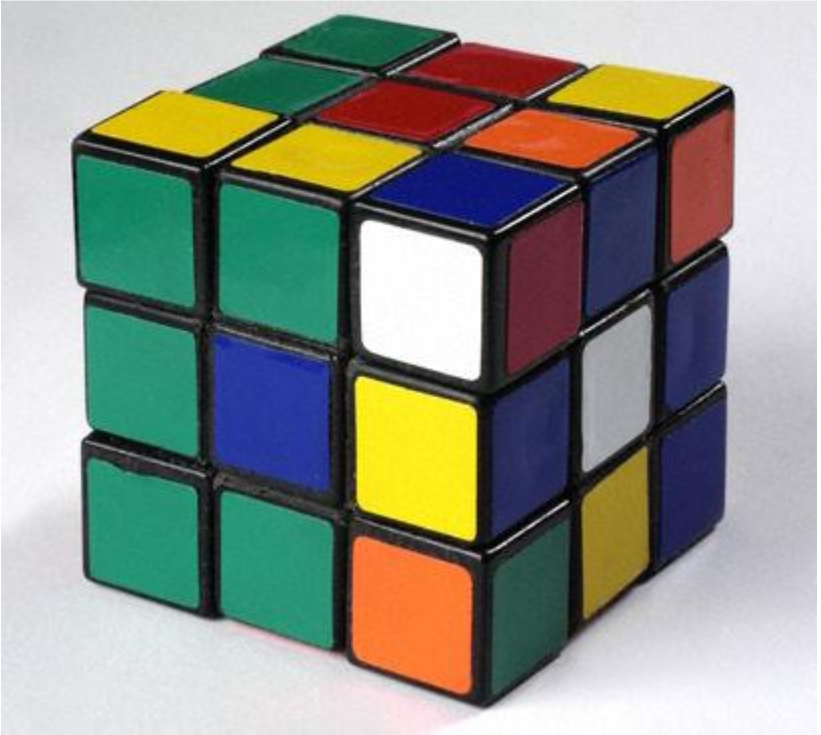
Anti-instrumentation techniques - Misc techniques

- Misc techniques
  - Detect by Argv
  - Detect by parent process
  - Detect by SYSENTER emulation



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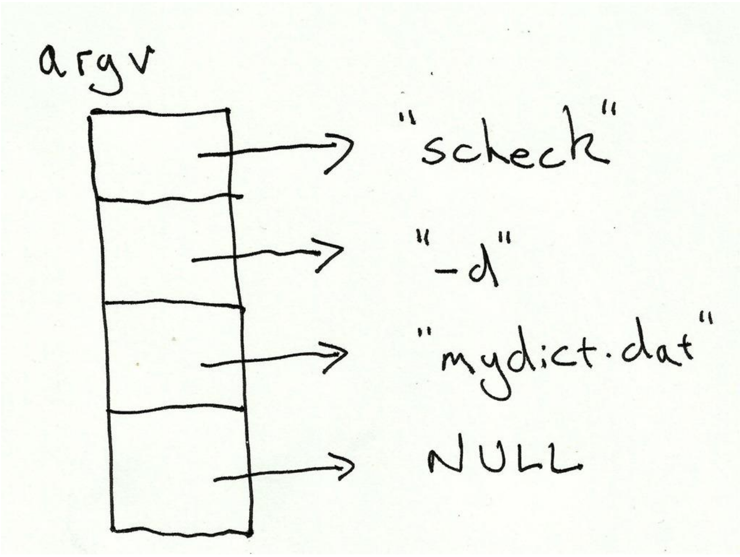
Misc techniques – Detect by argv

- Detect by argv

We get the argv array of our parent process by searching within the memory of our process.



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Misc techniques – Detect by argv

- Detect by argv

000305C8 000305F0 ASCII "**C:\pin\\ia32\bin\pin.exe**"
000305CC 00030610 ASCII "-p32"
000305D0 00030618 ASCII "C:\pin\\ia32\bin\pin.exe"
000305D4 00030638 ASCII "-p64"
000305D8 00030640 ASCII "C:\pin\\intel64\bin\pin.exe"
000305DC 00030660 ASCII "**-t**"
000305E0 00030668 ASCII “**tools\SimpleExamples\obj-ia32\opcodemix.dll**"
000305E4 000306A0 ASCII "**--**"
000305E8 000306A8 ASCII "**C:\dummy.exe**"
000305EC FEEEFEEE

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Misc techniques – Detect by parent process

- Detect by parent process

cmd.exe	4864	TRAVESTI\nriva
pin.exe	3708	TRAVESTI\nriva
calc.exe	2392	TRAVESTI\nriva
pin.exe	6108	TRAVESTI\nriva

- Will not work when instrumenting a process by attaching it.

Misc techniques – Detect by SYSENTER emulation

- Detect by SYSENTER emulation
  - Eloi Vanderbeken in 2011 found a bug in the way Pin emulates the SYSENTER instruction
  - Normal execution ring0 – ring3: the execution continues in `ntdll!KiFastSystemCallRet`
  - Instrumented execution ring0 – ring3: continues in the instruction following the SYSENTER
  - The last affected version of Pin is build 39599, Feb 28, 2011
  - Discussion of this bug can be found here: http://tech.groups.yahoo.com/group/pinheads/message/6363

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Misc techniques – Detect by SYSENTER emulation

```
__asm
{
    //invalid syscall
    mov eax, 0x42424242;
    push retaddress;
    mov edx, esp;
    //Sysenter
    _emit 0x0F;
    _emit 0x34;
    //if execution reaches here, it means that it's being
    instrumented
    mov detected, DETECTED;
    jmp endasm;
    retaddress:
    //normal execution should continue here after the sysenter
        mov detected, NOTDETECTED;
    endasm:
}
```

Keep in mind that …

- All the presented techniques have different levels of reliability.
- So, you may combine them to be more accurate when detecting Pin.

eXait – eXtensible Anti-Instrumentation Tester

eXait – eXtensible Anti-Instrumentation Tester

- There are benchmark-like tools to test:
  - Anti-Virtualization techniques (ScoopyNG - Trapkit)

C:\WINDOWS\system32\cmd.exe

```
C:\Documents and Settings\Administrator\Desktop\ScoopyNG>ScoopyNG.exe

####################################################
::       ScoopyNG - The VMware Detection Tool      ::
::              Windows version v1.0               ::

[+] Test 1: IDT
IDT base: 0x8003f400
Result  : Native OS


[+] Test 2: LDT
LDT base: 0xdead0000
Result  : Native OS


[+] Test 3: GDT
GDT base: 0x8003f000
Result  : Native OS


[+] Test 4: STR
STR base: 0x28000000
```


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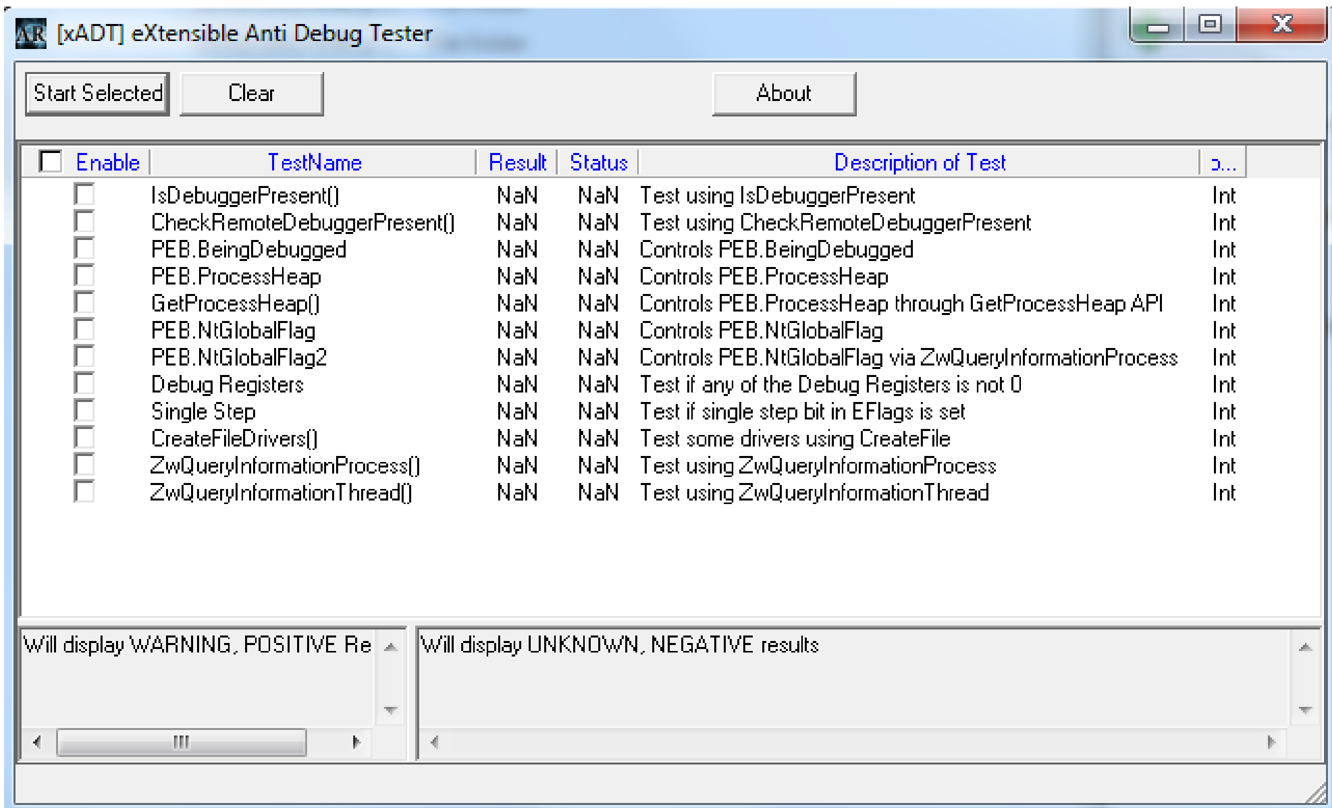
eXait – eXtensible Anti-Instrumentation Tester

- There are benchmark-like tools to test:
  - Anti-Debugging techniques (xADT- Shub Nigurrath)



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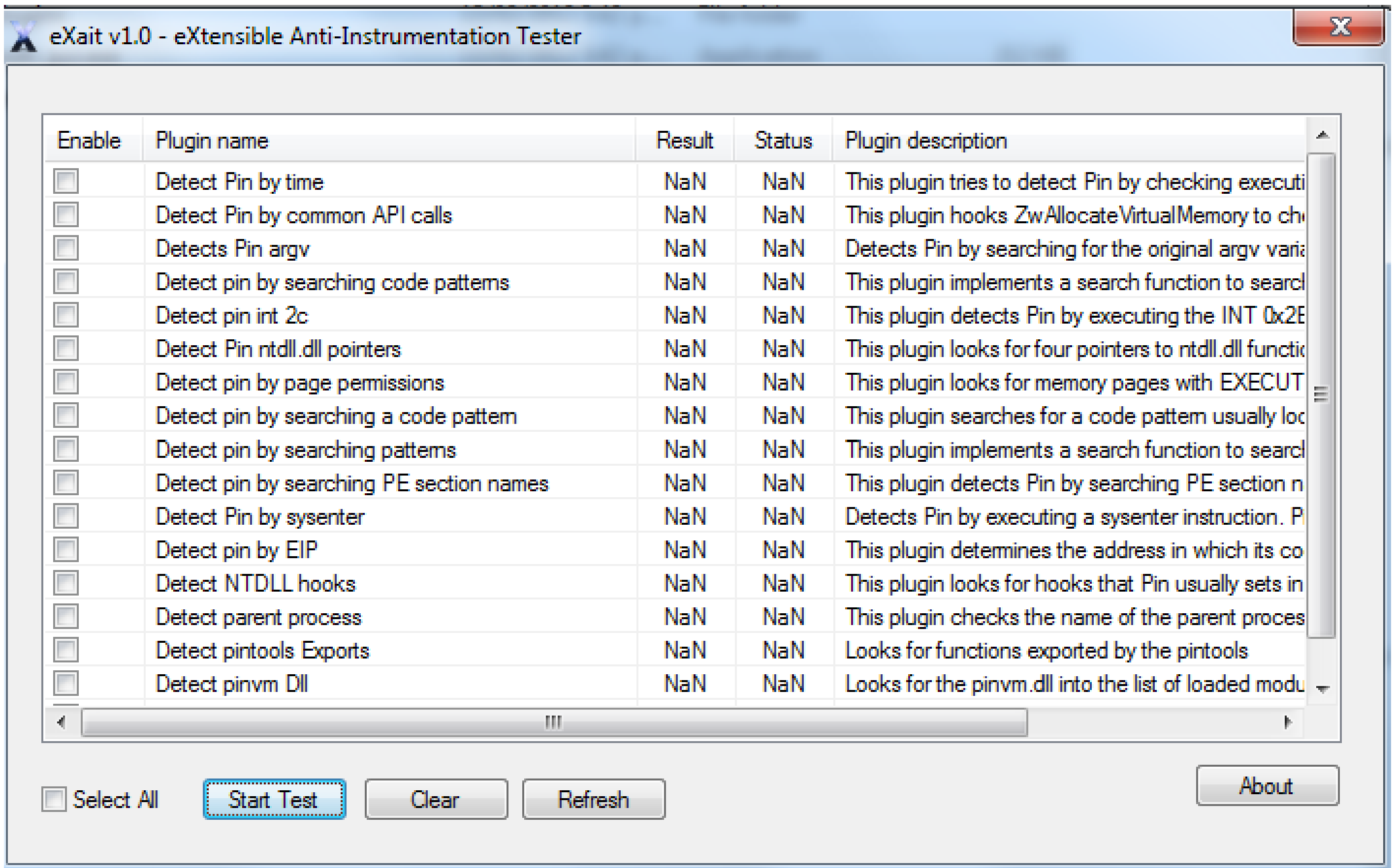
eXait – eXtensible Anti-Instrumentation Tester

- eXait is the eXtensible Anti-Instrumentation Tester tool.
- It was written in C using Visual C++ Express 2008.
- It has a plugin architecture.
- It is open-source code (BSD license).
- It has more than 15 plugins to test all the techniques presented in this talk.

eXait – eXtensible Anti-Instrumentation Tester



eXait – eXtensible Anti-Instrumentation Tester

- eXait comes in two flavors: console and GUI.
- You can write your own plugins for eXait, check the project wiki.
- We are waiting for your contribution.

eXait – eXtensible Anti-Instrumentation Tester

- eXait can be downloaded from:

http://corelabs.coresecurity.com

Applications of our research

Applications of our research

- Each one of the discussed techniques can be included in any software that wants to protect itself against dynamic binary analysis:
    - Packers
    - Malware
    - Shellcodes?

Future work

Future work

- Extend our research to other DBI frameworks (DynamoRIO, Valgrind, DynInst, ERESI, Fjalar).
- Further our research to other platforms and architectures.
- Find new anti-instrumentation techniques (obvious!!!).

Future work

- Create a library for pintools to bypass anti-instrumentation techniques.

- Things to discuss in this field:
    - How to implement it as generic as possible?
    - Is this a never ending story? Who wins, if anyone?

It’s show time!. Demo.

Acknowledgments & Greetings

Acknowledgments & Greetings

- Fernando Russ
  - for coordinating our research and feedback
- Gal Diskin
  - for his feedback about the presentation
- Ariel Futoransky
  - for his ideas for further research
- RECon Organizers

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Questions?

Thank you.