DBI for Computer Security: Uses and Comparative

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All wrongs reversed

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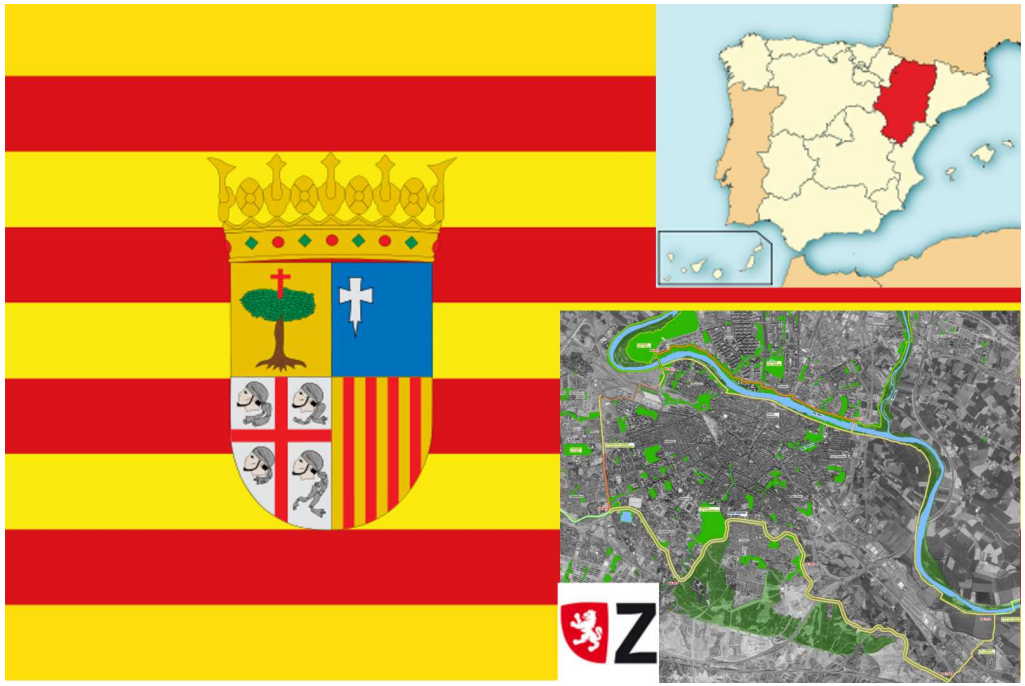
Zaragoza, Spain

June 21th, 2013

3[rd] Edition of Hack in Paris

Sequoia Lodge Hotel, Disneyland Paris

$whoami



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- Ph.D.student at University of Zaragoza
- Working currently for Technical University of Madrid
  - Performance analysis of complex systems
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  - Malware analysis (techniques and relative stuff)
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- My Ph.D. viva is next Monday! Cross fingers!! ⌣̈

Development Code License

- GPL v3
  (`http://gplv3.fsf.org/`)
- Intel Open Source License
  (`http://opensource.org/licenses/intel-open-source-license.html`)
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Source available at

`http://webdiis.unizar.es/~ricardo/files/HIP2013.tar.gz`

(VS2008 project + this slides)

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no add-ons. . . trust me ⌣̈

Outline

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DBI: What is? (I)

DBI: Dynamic Binary Instrumentation

Main Words

Instrumentation	??
Dynamic	??
Binary	??

DBI: What is? (I)

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DBI: What is? (II)

Instrumentation?

Instrumentation

- "Being able to observe, monitor and modify the behaviour of a computer program" (Gal Diskin)
- Arbitrary addition of code in executables to collect some information

DBI: What is? (II)

Instrumentation?

Instrumentation

- "Being able to observe, monitor and modify the behaviour of a computer program" (Gal Diskin)
- Arbitrary addition of code in executables to collect some information
- Analyse and control everything around an executable code
  - Collect some information
  - Arbitrary code insertion

DBI: What is? (III)

Instrumentation ??
Dynamic ??
Binary ??

DBI: What is? (III)

Instrumentation	What is happening. . .
Dynamic	??
Binary	??

DBI: What is? (III)

Instrumentation	What is happening. . .
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DBI: What is? (IV)

Dynamic?

Code analysis

- Static
  - BEFORE execution
  - All possible execution paths are explored → not extremely good for performance
- Dynamic
  - DURING the execution
  - Just one execution path (it may depend on the input data!)

DBI: What is? (V)

Instrumentation	What is happening. . .
Dynamic	??
Binary	??

DBI: What is? (V)

Instrumentation	What is happening...
Dynamic	DURING the execution...
Binary	??

DBI: What is? (V)

Instrumentation	What is happening...
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DBI: What is? (IV)

Binary?

Dynamic analysis

- Source code available
  - Source code
  - Compiler
- No source code (common case $\ddot{\smile}$)
  - Binary
    - Static (i.e., creating a new binary – with extras)
    - Dynamic
  - Environment
    - Emulation
    - Virtual
  - Debugging

DBI: What is? (VI)

Instrumentation	What is happening...
Dynamic	DURING the execution...
Binary	??

DBI: What is? (VI)

Instrumentation	What is happening...
Dynamic	DURING the execution...
Binary	of a binary (executable)...

DBI: What is? (VII)

DBI advantages

Binary instrumentation: advantages

- Programming language (totally) independent
- Machine-mode vision
- We can instrument proprietary software

DBI: What is? (VII)

DBI advantages

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Dynamic Instrumentation: advantages

- No need to recompile/relink each time
- Allow to find *on-the-fly* code
- Dynamically generated code
- Allow to instrument a process in execution already (*attach*)

DBI: What is? (IIX)

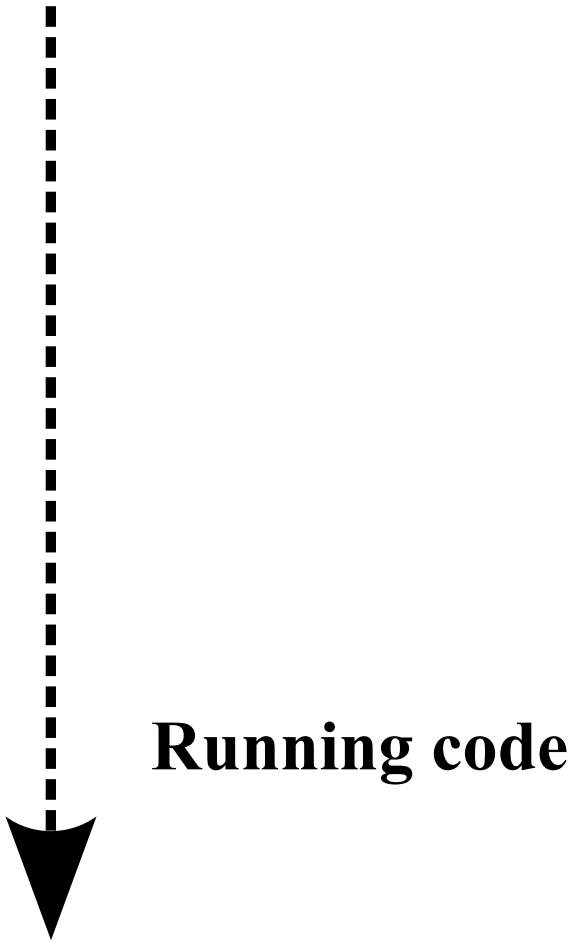
DBI disadvantages

Main disadvantages

- Overhead (by the instrumentation during execution)
- $\Downarrow$ performance (analyst hopelessness!)

How does DBI work? (I)

- Recall: arbitrary code addition during the execution of a binary



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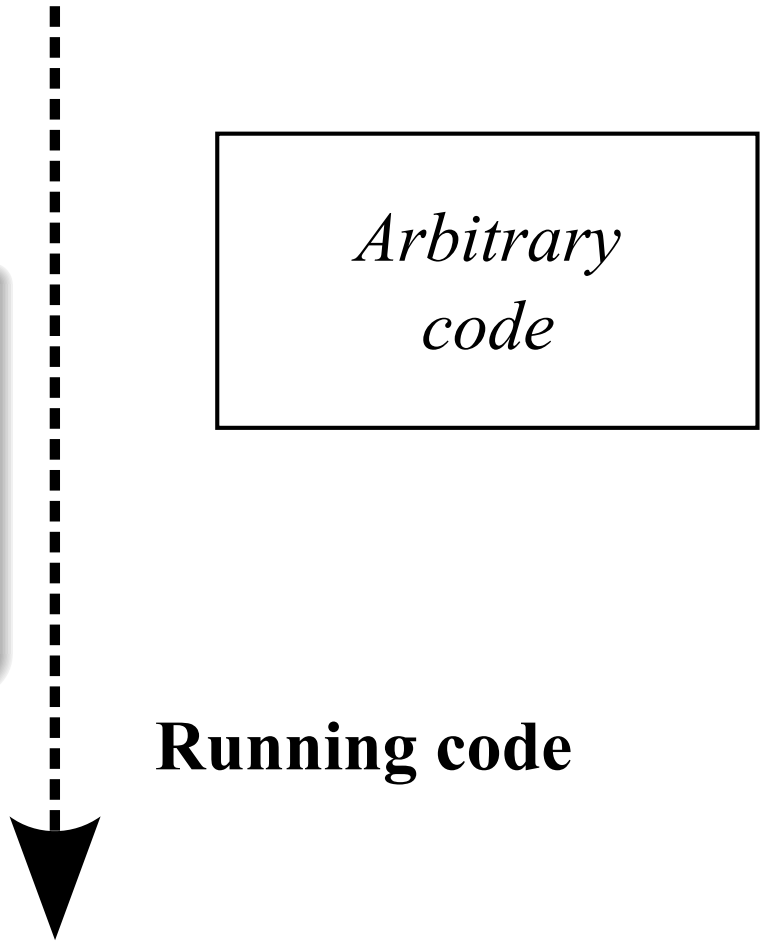

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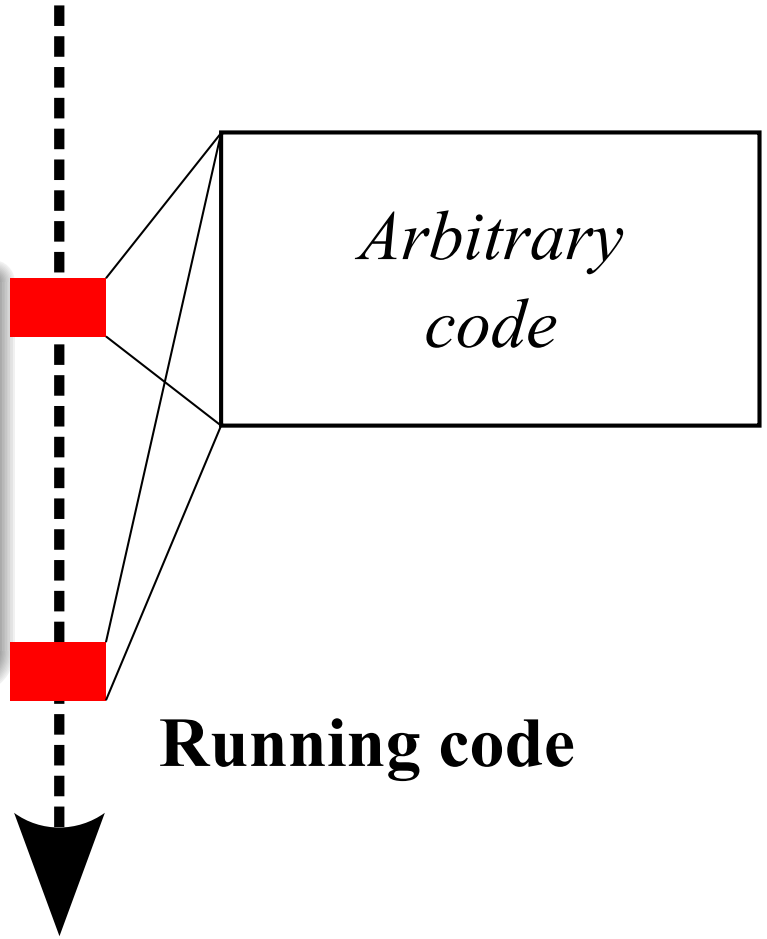
- Where? → addition places

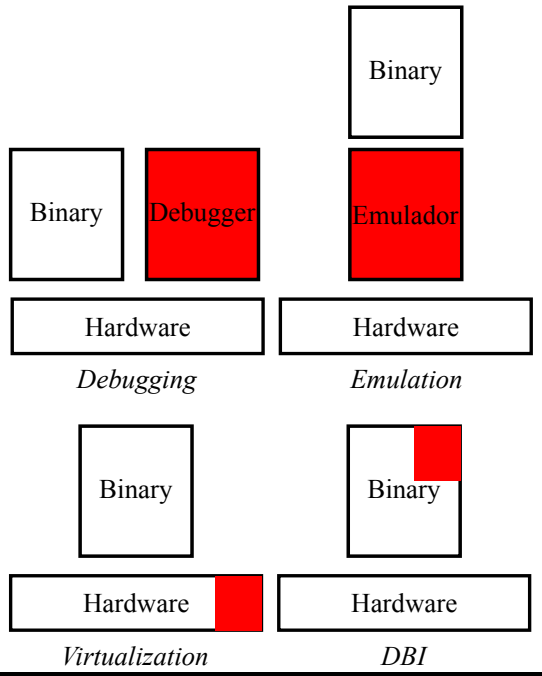


How does DBI work? (II)

Placing DBI in the context of dynamic analysis

Definition (informal)

- Executable transformation
- Total control over execution
- No need of architectural support



- Virtualization
  - Total control?
- Emulation
  - Executable transformation
- Debugging
  - Architectural support (a must. . .)

Uses of DBI in Computer Security (I)

Non security-related uses

- Code coverage and metrics

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Uses of DBI in Computer Security (II)

Secuirty-related uses

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- Privacy monitoring
- Sandboxing

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- . . .

Uses of DBI in Computer Security (III)

Some security tools that use DBI...

- Vulnerability search
  - SAGE (Microsoft)
  - Sogetis
  - Fuzzgrind
- Avalanche
- Determine
- Pincov
- Taintdroid
- VERA
- TraceSurfer
- ...

Uses of DBI in Computer Security (IV)

Its popularity is *in crescendo* (1)

- Covert Debugging: Circumventing Software Armoring, D. Quist & Valsmith, BH USA 2007/DefCon 15
- Generic Unpacking of Self-modifying, Aggressive, Packed Binary Programs (P. Bania, CoRR abs/0905.4581 2009)
- Tarte Tatin Tools: a set of plugins for malware analysis with Pin, (D. Reynaud, DeepSec 2009)
- Dynamic Binary Instrumentation for Deobfuscation and Unpacking (J-Y. Marion & D. Reynaud, DeepSec 2009)
- Dumping Shellcode with Pin (S. Porst, Zynamics 2010)
- Binary Instrumentation for Security Professionals (G. Diskin, BH USA 2011)
- Shellcode Analysis using Dynamic Binary Instrumentation (D. Radu & B. Dang, CARO 2011)

Uses of DBI in Computer Security (V)

Its popularity is *in crescendo* (2)

- Hacking using Dynamic Binary Instrumentation (G. Diskin, HITB 2012 AMS)
- Improving Unpacking Process using DBI techniques (R.J. Rodríguez, RootedCON 2012)
- Improving Software Security with Dynamic Binary Instrumentation (R. Johnson, InfoSec Southwest 2012)
- Vulnerability Analysis and Practical Data Flow Analysis & Visualization (J.W. Oh, CanSecWest 2012)
- Light and Dark side of Code Instrumentation (D. Evdokimov, CONFidence 2012)
- Dynamic Binary Instrumentation Frameworks: I know you're there spying on me (F. Falcon & N. Riva, RECon 2012)

Outline

DBI Framework: What is? (I)

- Provide a bunch of APIs for tool development
- DBA: Dynamic Binary Analysis tool
- DBAs types:
  - Light-weight
  - Heavy-weight (the use intermediate code)

DBI Framework: What is? (I)

- Provide a bunch of APIs for tool development
- DBA: Dynamic Binary Analysis tool
- DBAs types:
  - Light-weight
  - Heavy-weight (the use intermediate code)
- Main components
  - Core: just-in-time (JIT) compiler
    - Controls execution of a binary
  - Library (this is your own developed tool)
    - Where?
    - What?

$$\$ < DBI\_fw\_core > < myLibrary > < binaryToInstrument >$$

DBI Framework: What is? (II)

Use modes (most common)

- JIT
  - Modification of a (small) set of instructions before executing them
  - More robust
  - Good way for repetitive behaviour binaries (e.g., loops)
- Probe
  - Memory patching
  - Less overhead (it executes native code)
  - Not supported by all DBI fws.

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Granularity

Instruction	Basic Block	Superblock	Trace	Routine	Image
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→ Some not supported in some DBI fws...

Types of DBI frameworks (I)

DB fws *in the wild*

Pin	DynInst	
Valgrind	Dtrace	HDtrans
DynamoRIO	Systemap	

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Mmm. . . what is the *much* better?

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DB fws *in the wild*

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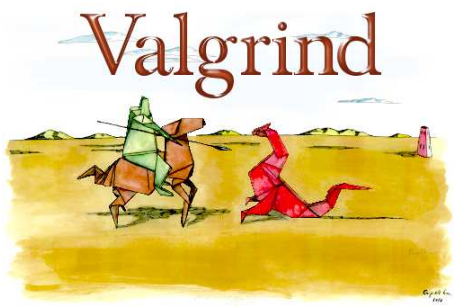
Mmm. . . what is the *much* better?

Selection criteria

- Software being maintained
- License gives access to the source code
- Free
- API provided
- O.S. and common infrastructure

Types of DBI frameworks (II)

Differences y similarities



Characteristics

- Ph.D. thesis, Univ. Cambridge
- Source code available (GNU GPL v2)
- Heavy-weight DBAs (using VEX IR as intermediate code)
- `http://www.valgrind.org`

Instruction Basic block Superblock Trace Routine IMage

Framework	Version	Supported Arch.	O.S.	Granularity
Valgrind	3.8.1 (18/09/2012)	Arm, PowerPC, s390, x86, x64	Android, OSX, Linux	I S

Types of DBI frameworks (II)

Differences y similarities

Characteristics

- Intel
- Source code available (but proprietary license)
- It allows to attach a process in execution
- `http://www.pintool.org/`

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Pin	2.12 (10/10/2012)	Arm, IA-64, x86, x64	Windows, Linux	I B T R M

Types of DBI frameworks (II)

Differences y similarities

Characteristics

- MIT, HP, Google
- Source code available (BSD-2)
- Really good docs
- `http://www.dynamorio.org/`

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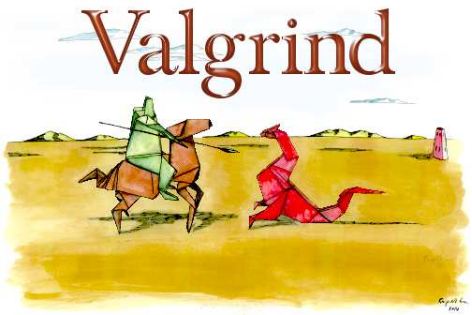

Similarities

- Injected code in C/C++
- No need of having the source code of binary to be instrumented
- GNU/Linux x86

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DBI frameworks comparative (I)

DBA tool for comparative

- Counting executed instructions
- Two granularities: instruction and basic block

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Comparative Aim

- Evaluate the performance of selected DBI fws.
- *Slowdown*: $\frac{t_{instrumented}}{t_{no\_instrumented}}$

DBI frameworks comparative (I)

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- Two granularities: instruction and basic block

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Diving into the APIs

- Pin: ↑ Documentation, ↑↑ Examples, ↑ Tutorials
- DynamoRIO: ↑↑ Documentation, ↑ Examples, ↑ Tutorials
- Valgrind: ↓ Documentation, ↓ Examples, ↓ Tutorials

DBI frameworks comparative (II)

Experimental settings

- Hardware
  - Intel Core2 Duo 2GHz 667MHz, 2GiB DDR2, HDD 120GB
- Software
  - Fedora Core 14 32bits, gcc 4.5.1, GNU Fortran 4.5.1, r3

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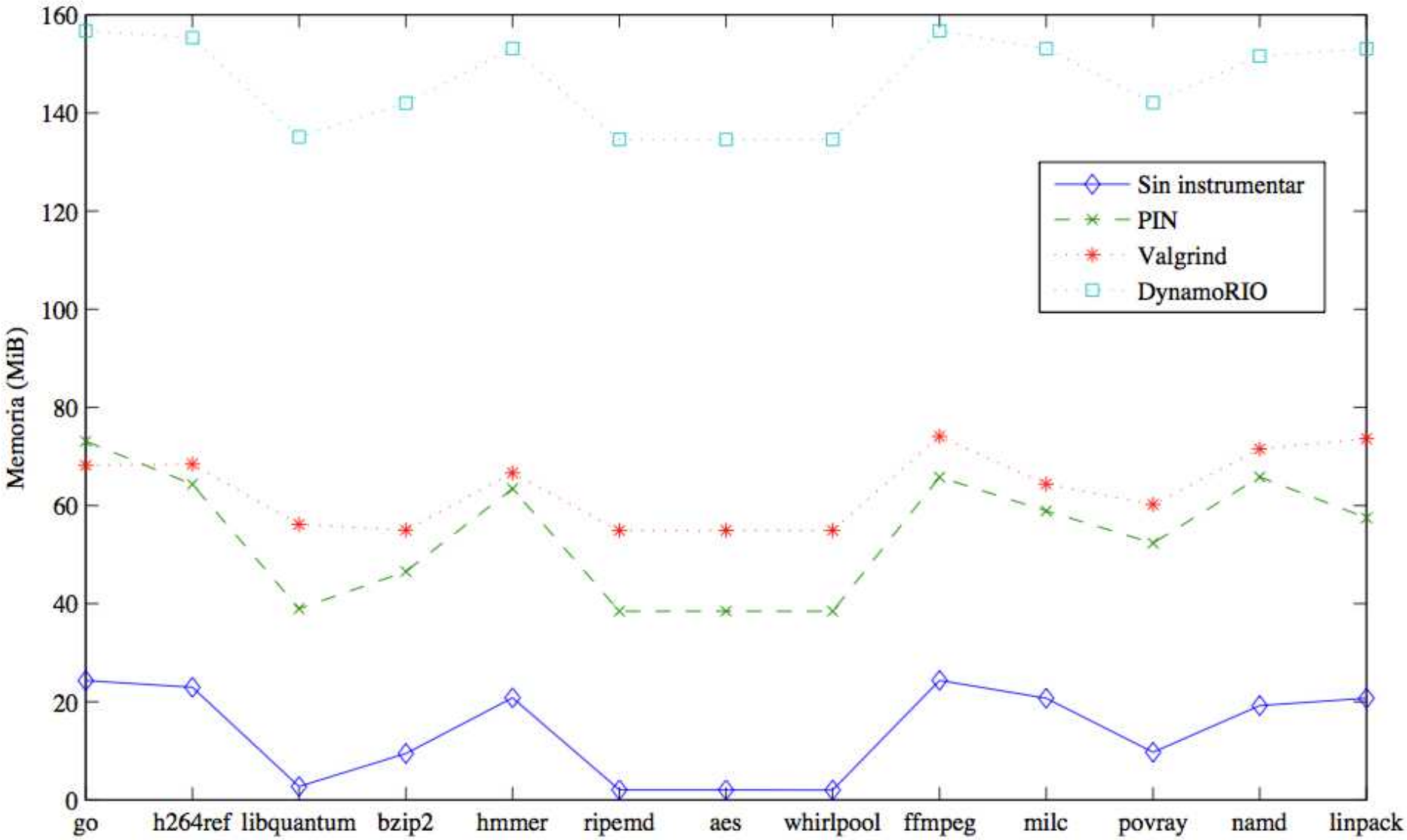
Benchmark

- Own benchmark created for the comparative
- Considered benchmarks (e.g., SPEC) discarded
- Different categories:
  - Integer computation
  - Float computation
  - I/O
  - Use of memory

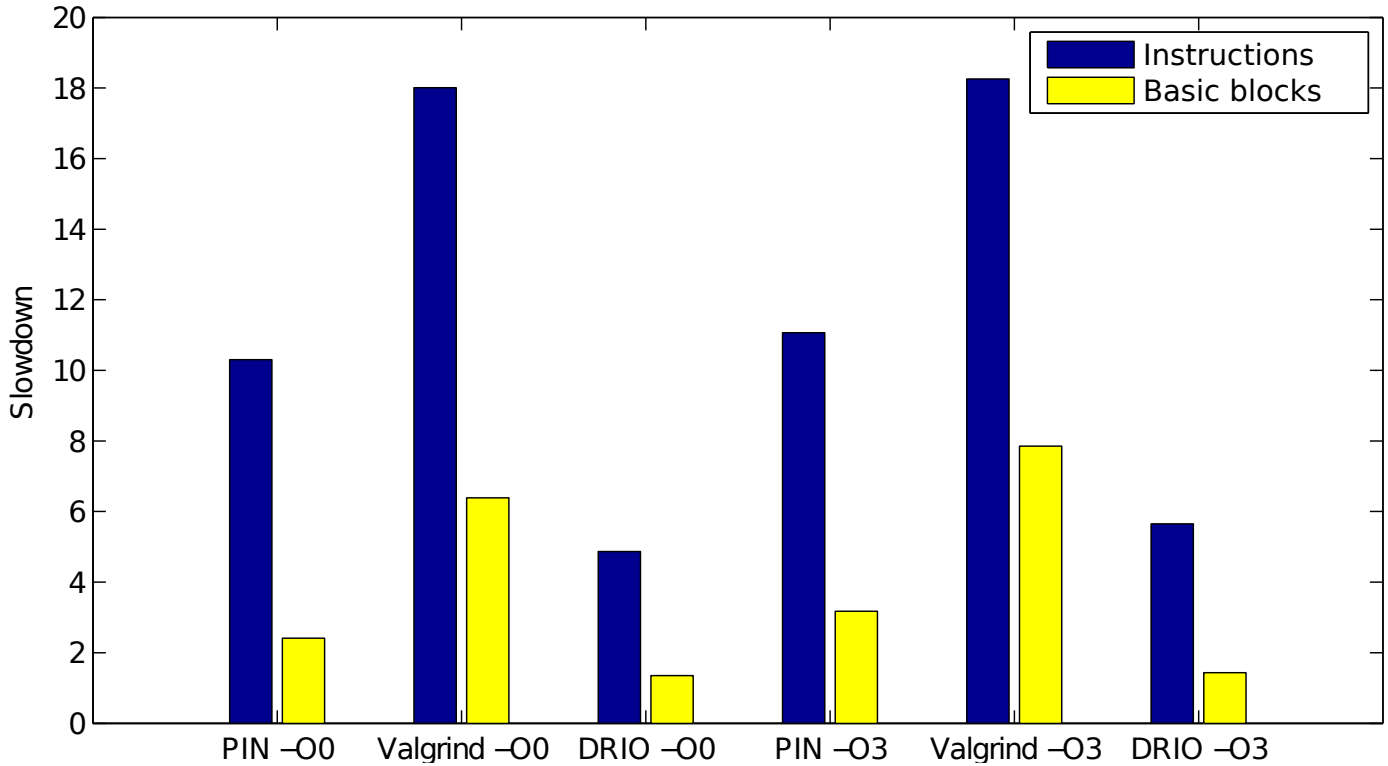
DBI frameworks comparative (III): Results (1)

Average of memory consumption



DBI frameworks comparative (III): Results (2)

Slowdown by instrumentations



DBI frameworks comparative (III): Results (3)

Conclusions

- ✓ Running optimised code or (int/float) computation → DynamoRIO
- X Slower solution → Valgrind
- Memory consumption
  - ✓ ↓ Pin
  - X ↑ DynamoRIO

Some funny things discovered during the research...

- No. of instructions differs among the DBI fws. → each one starts in a different point
- Bug detected when 80-bit numbers rounding in 32 and 64 bits archs. (Valgrind)
  - Already reported :((`https://bugs.kde.org/show_bug.cgi?id=19791`)

DBI frameworks comparative (III): Results (4)

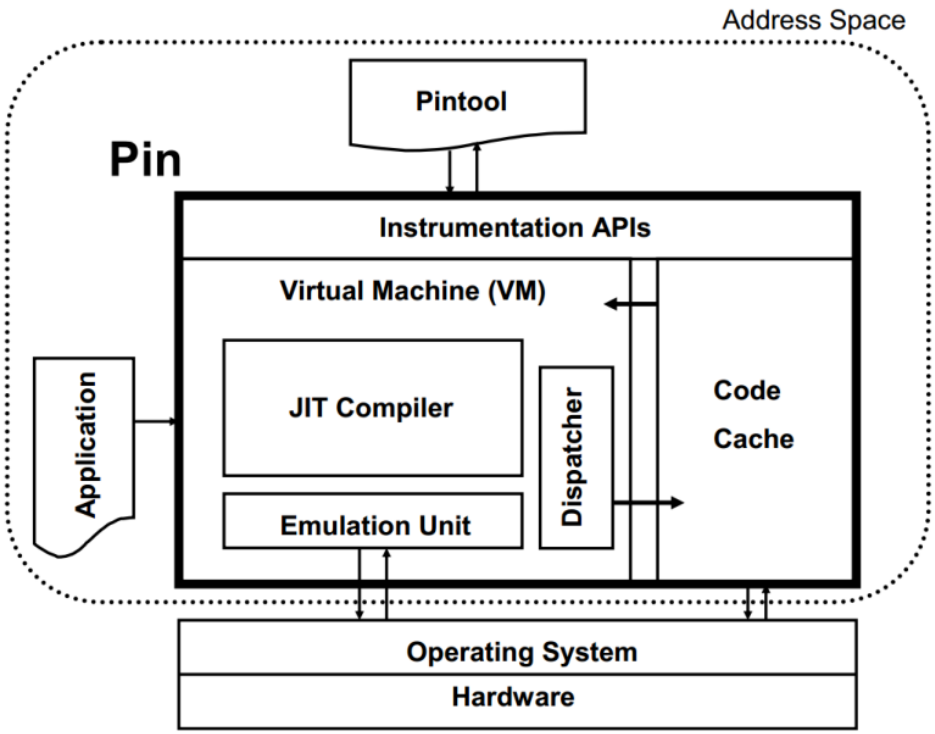
Technical Report

- Estudio comparativo de frameworks de Instrumentación Dinámica de Ejecutables (J.A. Artal)
  - Fro Spanish guys... (we should write some paper soon on this)

`http://webdiis.unizar.es/~ricardo/files/PFC.Estudio.Frameworks.DBI/Memoria_PFC_EstudioDBI.pdf`

Outline

Developing DBAs with Pin: Pintools (I)



- VM + code cache + API instrumentation
- DBA → Pintool
- VM: JIT + emulator + dispatcher

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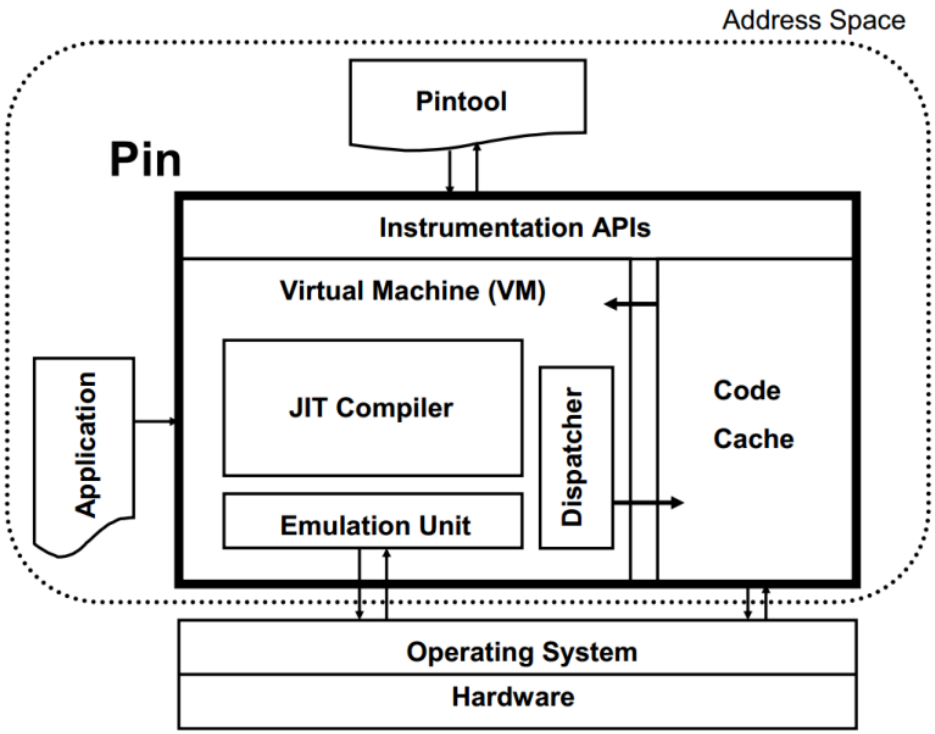

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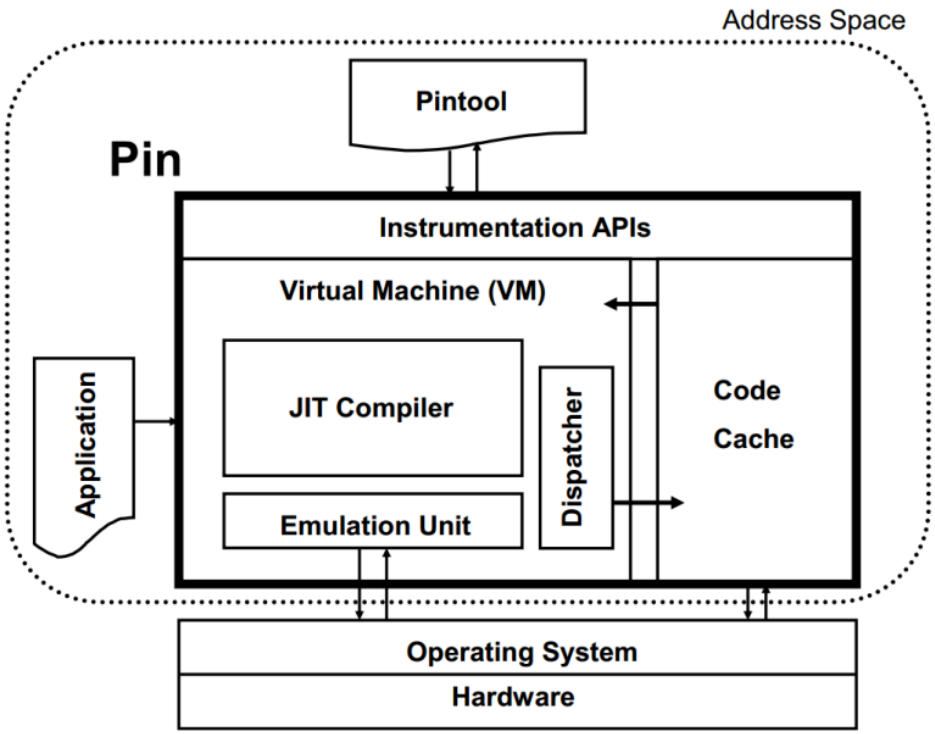

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- VM: JIT + emulator + dispatcher
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- Works on the O.S.: *user-space*

Developing DBAs with Pin: Pintools (II)

An example: `inscount.cpp`

```
#include "pin.H"

//Instruction counter
static UINT64 icount = 0;

// Called before every instruction is executed
VOID docount() { icount++; }

// Called every time a new instruction is encountered
VOID Instruction(INS ins, VOID *v){
    // Insert a call to docount before every instruction, no arguments are passed
    INS_InsertCall(ins, IPOINT_BEFORE, (AFUNPTR)docount, IARG_END);
}

// Called when the application exits
VOID Fini(INT32 code, VOID *v){
    std::cout << "Count " << icount << endl;
}

int main(int argc, char * argv[]){
    PIN_Init(argc, argv);
    INS_AddInstrumentFunction(Instruction, 0);
    PIN_AddFiniFunction(Fini, 0);
    PIN_StartProgram(); // no returns
    return 0;
}
```

DBI vulnerability search (I): Double Free

Demo: `DoubleFreeDBA.dll`

Vulnerability description

- CWE-415 (`http://cwe.mitre.org/data/definitions/415.html`)
- Call `free()` with the same @ $\rightarrow$ corrupt memory
- *"Doubly freeing memory may result in a write-what-where condition, allowing an attacker to execute arbitrary code"*

DBA developed with Pin (`DoubleFreeDBA.dll`)

- Where?
  - APIs `RtlAllocateHeap` (after), `RtlAllocateFree` (before)
- What?
  - `RtlAllocateHeap`: keeps returned @ in a list
  - `RtlAllocateFree`: removes @ from list, and reports if not found!

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- CWE-415 (`http://cwe.mitre.org/data/definitions/415.html`)
- Call `free()` with the same @ $\rightarrow$ corrupt memory
- *"Doubly freeing memory may result in a write-what-where condition, allowing an attacker to execute arbitrary code"*

DBA developed with Pin (`DoubleFreeDBA.dll`)

- Where?
  - APIs `RtlAllocateHeap` (after), `RtlAllocateFree` (before)
- What?
  - `RtlAllocateHeap`: keeps returned @ in a list
  - `RtlAllocateFree`: removes @ from list, and reports if not found!

Friendly reminder: Make a demo...

DBI vulnerability search (II): Buffer Overflow (1)

Demo: `BufferOverflowDBA.dll`

Vulnerability description

- CWE-120 (`http://cwe.mitre.org/data/definitions/120.html`)
- Copy a buffer without restrictions → arbitrary code execution
- *"Buffer overflows often can be used to execute arbitrary code [...]. Buffer overflows generally lead to crashes [...]."*

DBA developed with Pin (`BufferOverflowDBA.dll`)

- Works around `scanf`
- Where? → API `scanf` (before)
- What?
  - Checks parameters seeking buffers without limits
- Improvements: extend to other vulnerable APIs (e.g., `strcpy`)

DBI vulnerability search (II): Buffer Overflow (1)

Demo: `BufferOverflowDBA.dll`

Vulnerability description

- CWE-120 (`http://cwe.mitre.org/data/definitions/120.html`)
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DBA developed with Pin (`BufferOverflowDBA.dll`)

- Works around `scanf`
- Where? → API `scanf` (before)
- What?
  - Checks parameters seeking buffers without limits
- Improvements: extend to other vulnerable APIs (e.g., `strcpy`)

Friendly reminder: Make a demo...

DBI vulnerability search (II): Buffer Overflow (2)

Demo: `ProtectRetAddrDBA.dll`

Vulnerability description

- CWE-120 (`http://cwe.mitre.org/data/definitions/120.html`)
- Copy a buffer without restrictions → arbitrary code execution
- *"Buffer overflows often can be used to execute arbitrary code [...]. Buffer overflows generally lead to crashes [...]."*

DBA developed with Pin (`ProtectRetAddrDBA.dll`)

- Where? → every `CALL` (before) o `RETN` (before) in `.text` section
- What?
  - `CALL` → stores legitimate return address ($EIP + size(CALL)$)
  - `RETN` → checks if retn address is in the list...
- Detected 6 retn changes in `ntdll.dll` library!!

DBI vulnerability search (II): Buffer Overflow (2)

Demo: `ProtectRetAddrDBA.dll`

Vulnerability description

- CWE-120 (`http://cwe.mitre.org/data/definitions/120.html`)
- Copy a buffer without restrictions → arbitrary code execution
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Friendly reminder: Make a demo...

DBI vulnerability search (III): Taint analysis

Demo: `TaintAnalysisDBA.dll`

DBA developed with Pin (`TaintAnalysisDBA.dll`)

- Taint analysis of `scanf` parameters
- Where? $\rightarrow$ API `scanf` (after)
- What?
  - Trace all registers/memory zones contaminated from the input data

DBI vulnerability search (III): Taint analysis

Demo: `TaintAnalysisDBA.dll`

DBA developed with Pin (`TaintAnalysisDBA.dll`)

- Taint analysis of `scanf` parameters
- Where? $\rightarrow$ API `scanf` (after)
- What?
  - Trace all registers/memory zones contaminated from the input data

Friendly reminder: Make a demo...

DBI vulnerability search (IV): Reverse Engineering

Demo: `EasyPasswordDBA.dll` – very naif example

DBA developed with Pin (`EasyPasswordDBA.dll`)

- Seeking for the correct key
- *Hook* when calling to string comparison `lstrcmpA`
- Where?
  - API `lstrcmpA` (before)
- What?
  - Log all function parameters

DBI vulnerability search (IV): Reverse Engineering

Demo: `EasyPasswordDBA.dll` – very naif example

DBA developed with Pin (`EasyPasswordDBA.dll`)

- Seeking for the correct key
- *Hook* when calling to string comparison `lstrcmpA`
- Where?
  - API `lstrcmpA` (before)
- What?
  - Log all function parameters
- This is not longer valid for current apps... isn't it? ☺

DBI vulnerability search (IV): Reverse Engineering

Demo: `EasyPasswordDBA.dll` – very naif example

DBA developed with Pin (`EasyPasswordDBA.dll`)

- Seeking for the correct key
- *Hook* when calling to string comparison `lstrcmpA`
- Where?
  - API `lstrcmpA` (before)
- What?
  - Log all function parameters
- This is not longer valid for current apps... isn't it? ☺

Friendly reminder: Make a demo...

Outline

Conclusions

- DBI frameworks: fast and easy development → high potential
- NO need of (too much) advanced O.S. programming knowledge
  - We can focus in what really matters: our DBA tool
- Disadvantages:
  - DBI API knowledge
  - Execution time

Recall about the DBI fws. comparison...

- ✓ Running optimised code or (int/float) computation → DynamoRIO
- X Slower solution → Valgrind
- Memory consumption
  - ✓ ↓ Pin
  - X ↑ DynamoRIO

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- Francisco Falcon & Nahuel Riva
- CrackLatinoS (CLS)
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- Hack in Paris staff, thank you guys & gals!
- To you for hearing me stoically...

DBI for Computer Security: Uses and Comparative

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All wrongs reversed

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3[rd] Edition of Hack in Paris

Sequoia Lodge Hotel, Disneyland Paris