The System of Automatic Searching for Vulnerabilities or *how to use Taint Analysis to find vulnerabilities*

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Who is Alex Bazhanyuk

- Security Researcher
- Organizer of Defcon Ukraine Group
- Working in UC Berkley in BitBlaze project
- Solves problems of automation of RE

Who is Nikita Tarakanov

- Independent Security Researcher
- Author of some articles in][akep magazine
- Likes to reverse engineer r0 parts
- Discovered a lot of LPE vulns
- Solves problems of automation of RE

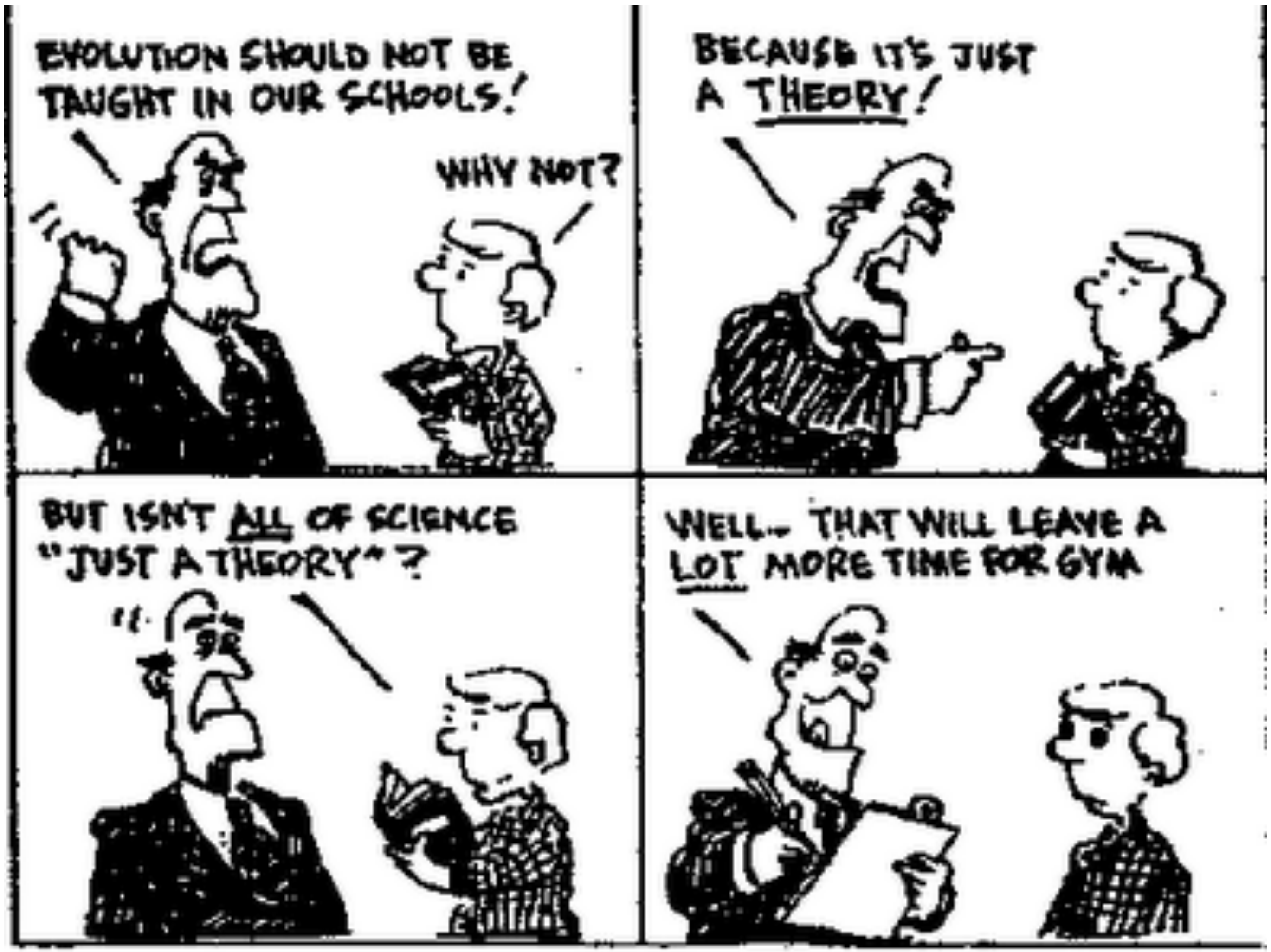
Agenda

- Intro
- Taint analysis theory
- BitBlaze theory
- SASV implementation
- Lulz Time
- Pitfalls
- Conclusion

SASV main parts

- IDA Pro plugins
- BitBlaze: Vine+utils, TEMU + plugins

Theory


EVOLUTION SHOULD NOT BE TAUGHT IN OUR SCHOOLS!
WHY NOT?
BECAUSE IT'S JUST A THEORY!
BUT ISN'T ALL OF SCIENCE "JUST A THEORY"?
WELL.. THAT WILL LEAVE A LOT MORE TIME FOR GYM

Tainting

- Taint sources:

Network, Keyboard, Memory, Disk, Function outputs

- Taint propagation: a data flow technique

Shadow memory

Whole-system

Across register/memory/disk/swapping

Fundamentals of taint analysis

Taint propagation

- If an operation uses the value of some **tainted** object, say X, to derive a value for another, say Y, then object Y becomes **tainted.** Object X taints the object Y
- Taint operator **t**
- **X→ t(Y)**
- Taint operator is transitive

X → t(Y) and Y→ t(Z), then X→ t(Z)

Static Taint Analysis

Analysis performed over *multiple paths* of a program

* Typically performed on a control flow graph (CFG):

statements are nodes, and there is an edge between nodes if there is a possible transfer of control.

BitBlaze: Binary Analysis Infrastructure

- Automatically extracting security-related properties from
- binary code
- Build a unified binary analysis platform for security

- Static analysis + Dynamic analysis + Symbolic Analysis

- Leverages recent advances in program analysis, formal methods, binary instrumentation…

Solve security problems via binary analysis

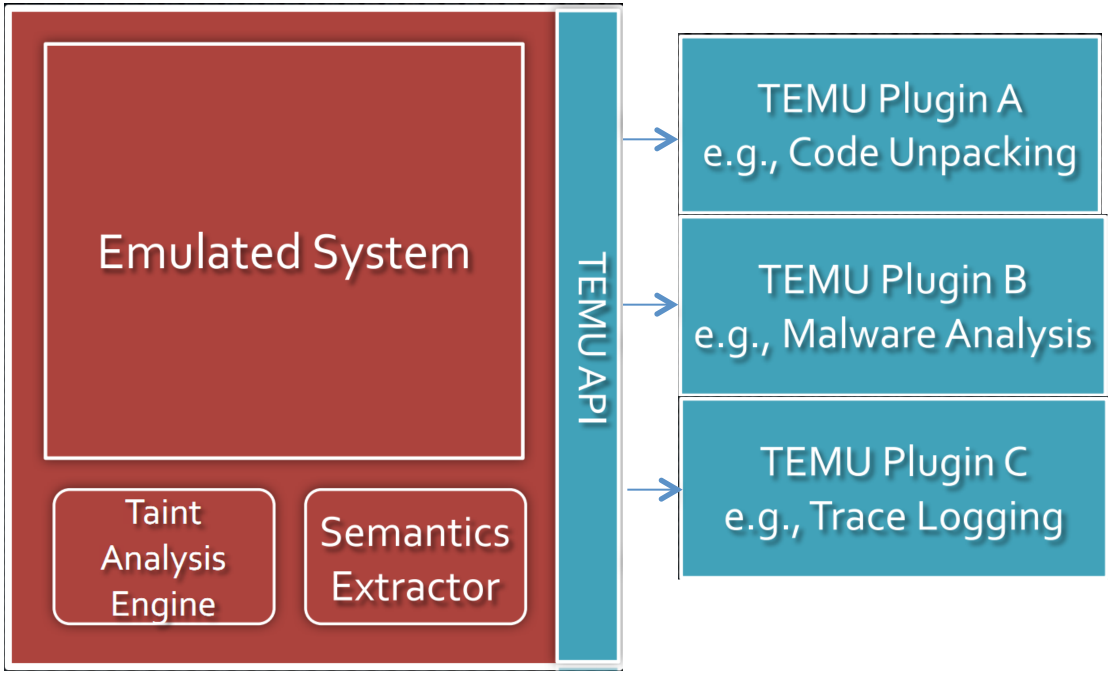
- More than a dozen different security applications
- Over 25 research publications

BitBlaze

- http://bitblaze.cs.berkeley.edu/
- TEMU,VINE
- Rudder, Panorama, Renovo

Static Analysis Component	Dynamic Analysis Component	Symbolic Exploration Components
VINE	TEMU	Rudder/ BitFuzz/FuzzBall

TEMU


Emulated System
Taint Analysis Engine
Semantics Extractor
TEMU API
TEMU Plugin A
e.g., Code Unpacking
TEMU Plugin B
e.g., Malware Analysis
TEMU Plugin C
e.g., Trace Logging

Confines TEMU

- **Only gcc-3.4**
- **Qemu 0.9.1 - TEMU**
- **Qemu 0.10 - TCG(Tiny Code Generator)-TODO**
- **Qemu 0.10 ⇔ Qemu 1.01**

VINE

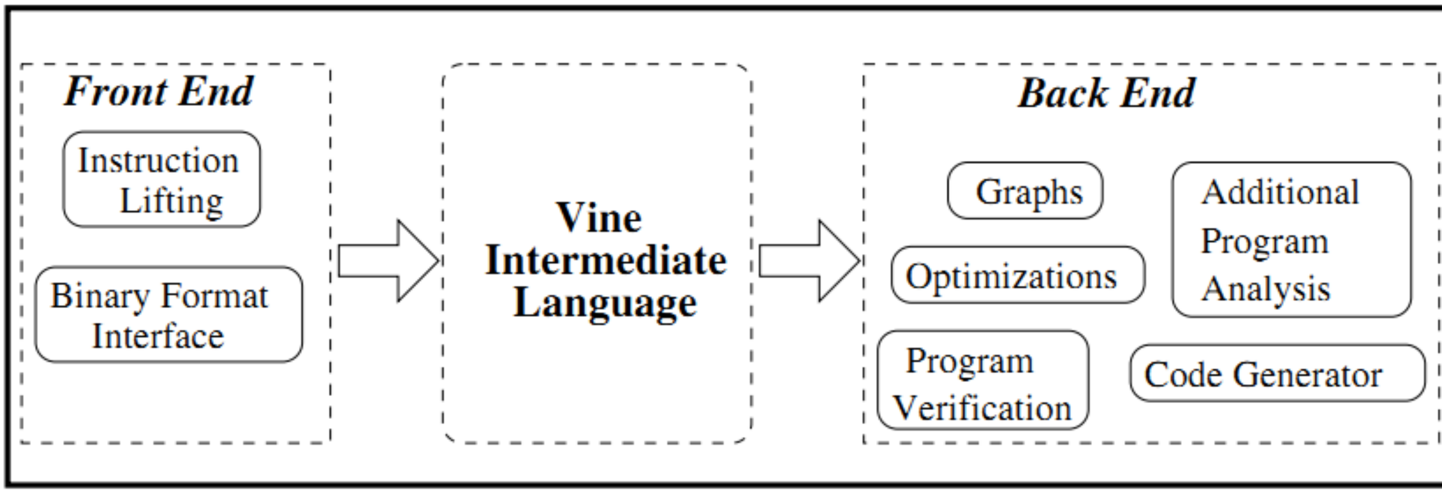


Fig. 2. Vine Overview

The Vine Intermediate Language

program	::=	*decl** *instr**
instr	::=	$var = exp$ | `jmp` *exp* | `cjmp` *exp,exp,exp* | `halt` *exp* | `assert` *exp* | `label` *integer* | `special` id_s
exp	::=	`load`(exp, exp, τ_{reg}) | `store`$(exp, exp, exp, \tau_{reg})$ | $exp \Diamond_b exp$ | $\Diamond_u exp$ | *const* | *var* | `let` $var = exp$ `in` *exp* | `cast`$(cast\_kind, \tau_{reg}, exp)$
cast_kind	::=	`unsigned` | `signed` | `high` | `low`
decl	::=	`var` *var*
var	::=	$(\text{string}, \text{id}_v, \tau)$
$\Diamond_b$	::=	$+, -, *, /, /_s, \text{mod}, \text{mod}_s, \ll, \gg, \gg_a, \&, \|, \oplus, ==, \neq, <, \leq, <_s, \leq_s$
$\Diamond_u$	::=	$-$ (unary minus), ! (bit-wise not)
value	::=	*const* | $\{n_{a1} \rightarrow n_{v1}, n_{a2} \rightarrow n_{v2}, \ldots\}: \tau_{\text{mem}}$ | $\perp$
const	::=	$n : \tau_{\text{reg}}$
τ	::=	τ_{reg} | τ_{mem} | Bot | Unit
τ_{reg}	::=	`reg1_t` | `reg8_t` | `reg16_t` | `reg32_t` | `reg64_t`
τ_{mem}	::=	`mem_t` $(\tau_{\text{endian}}, \tau_{\text{reg}})$
τ_{endian}	::=	`little` | `big` | `norm`

Example of disasm:

fc32dcec: rep stos %eax,%es:(%edi) R@eax[0x00000000][4](R) T0 R@ecx[0x00000002][4](RCW) T0 M@0xfb7bfff8[0x00000000][4](CW) T1 {15 (1231, 69624) (1231, 69625) (1231, 69626) (1231, 69627) }

fc32dcec: rep stos %eax,%es:(%edi) R@eax[0x00000000][4](R) T0 R@ecx[0x00000001][4](RCW) T0 M@0xfb7bfffc[0x00000000][4](CW) T1 {15 (1231, 69628) (1231, 69629) (1231, 69630) (1231, 69631) }

fc32dcee: mov %edx,%ecx R@edx[0x0000015c][4](R) T0 R@ecx[0x00000000][4](W) T0

fc32dcf0: and $0×3,%ecx I@0×00000000[0x00000003][1](R) T0 R@ecx[0x0000015c][4](RW) T0

fc32dcf5: andl $0×0,-0×4(%ebp) I@0×00000000[0x00000000][1](R) T0 M@0xfb5ae738[0x00000002][4](RW) T0

fc32dcf9: jmp 0x00000000fc32c726 J@0×00000000[0xffffea2d][4](R) T0

fc32c726: cmpl $0×0,-0×58(%ebp) I@0×00000000[0x00000000][1](R) T0 M@0xfb5ae6e4[0x00000000][4](R) T0

Taint info

- T0 - means that the statement did not tainted.
- T1 - means that the instruction tainted in curly brackets can be seen that there tainted and what it depends.
- Here's an example of:
- fc32dcec: rep stos% eax,% es: (% edi) R @ eax [0x00000000] [4] (R) T0 R @ ecx [0x00000001] [4] (RCW) T0 M @ 0xfb7bfffc [0x00000000] [4] (CW) T1 {15 (1231, 628) (1231, 629) (1231, 630) (1231, 631)}
- 4 bits of information tainted and they depend on the offset: 628, 629, 630, 631. 1231 - this number is origin(kind of ID that TEMU plugin sets).

appreplay

- ./vine-1.0/trace_utils/appreplay -trace font.trace -ir-out font.trace.il -assertion-on-var false-use-post-var false

where:

- appreplay - ocaml script that we run;
- -trace - the way to the trace;
- -ir-out - the path to which we write IL code.
- -assertion-on-var false-use-post-var false - flags that show the format of IL code for this to false makes it more readable text.

Example of IL code:

- Begins with the declaration of variables:
- INPUT - it's free memory cells, those that are tested in the very beginning (back in temu), input into the program from an external source.

```
var cond_000017_0x4010ce_00_162:reg1_t;

var cond_000013_0x4010c3_00_161:reg1_t;
var cond_000012_0x4010c0_00_160:reg1_t;
var cond_000007_0x4010b6_00_159:reg1_t;
var INPUT_10000_0000_62:reg8_t;
var INPUT_10000_0001_63:reg8_t;
var INPUT_10000_0002_64:reg8_t;
var INPUT_10000_0003_65:reg8_t;
var mem_arr_57:reg8_t[4294967296];  – memory as an array
var mem_35:mem32l_t;
```

```
R_EAX_5:reg32_t =
0×73657930:reg32_t;
{
var idx_144:reg32_t;
var val_143:reg8_t;
idx_144:reg32_t =
0x12fef0:reg32_t;
val_143:reg8_t =
INPUT_10000_0000_62:reg
8_t;
mem_arr_57[idx_144:reg32
_t + 0:reg32_t]:reg8_t =
cast((val_143:reg8_t &
0xff:reg8_t) >>
0:reg8_t)L:reg8_t;
```

```
T_32t2_60:reg32_t =
    R_ESP_1:reg32_t;
T_32t1_59:reg32_t =
    T_32t2_60:reg32_t +
    0x1c8:reg32_t;
T_32t3_61:reg32_t =((
cast(mem_arr_57[T_32t1_59:reg32_t
    + 0:reg32_t]:reg8_t)U:reg32_t
<< 0:reg32_t
|
cast(mem_arr_57[T_32t1_59:reg32_t
    + 1:reg32_t]:reg8_t)U:reg32_t
<< 8:reg32_t)
|
cast(mem_arr_57[T_32t1_59:reg32_t
    + 2:reg32_t]:reg8_t)U:reg32_t
<< 0×10:reg32_t)
|
cast(mem_arr_57[T_32t1_59:reg32_t
    + 3:reg32_t]:reg8_t)U:reg32_t
<< 0×18:reg32_t
;
R_EAX_5:reg32_t =
    T_32t3_61:reg32_t;
}
```

What is STP and what it does?

- STP - constraint solver for bit-vector expressions.
- separate project independent of the BitBlaze
- To produce STP code from IL code:
- ./vine-1.0/utils/wputil trace.il -stpout stp.code
- where the input is IL code, and the output is STP code

STP program example


```
mem_arr_57_8 : ARRAY BITVECTOR(64) OF BITVECTOR(8);
INPUT_10000_0000_62_4 : BITVECTOR(8);
ASSERT( 0bin1 =
(LET R_EAX_5_232 =
0hex73657930
IN
(LET idx_144_233 =
0hex0012fef0
IN
(LET val_143_234 =
INPUT_10000_0000_62_4
IN
(LET mem_arr_57_393 =
(mem_arr_57_8 WITH [(0bin00000000000000000000000000000000 @ BVPLUS(32,
idx_144_233,0hex00000000))] := (val_143_234;0hexff)[7:0])
…….
IN
(cond_000017_0x4010ce_00_162_392;0bin1))))))));
```

Is this expression false?

QUERY (FALSE);

And give a counter example:

COUNTEREXAMPLE;

STP output example

- How to ask for a decision to STP:

- ./stp stp.code
- Example of STP output:

ASSERT(INPUT_10000_0001_63_5 = 0×00);

ASSERT(INPUT_10000_0002_64_6 = 0×00);

ASSERT(INPUT_10000_0000_62_4 = 0×61);

ASSERT(INPUT_10000_0003_65_7 = 0×00);

Invalid.

SASV Components:

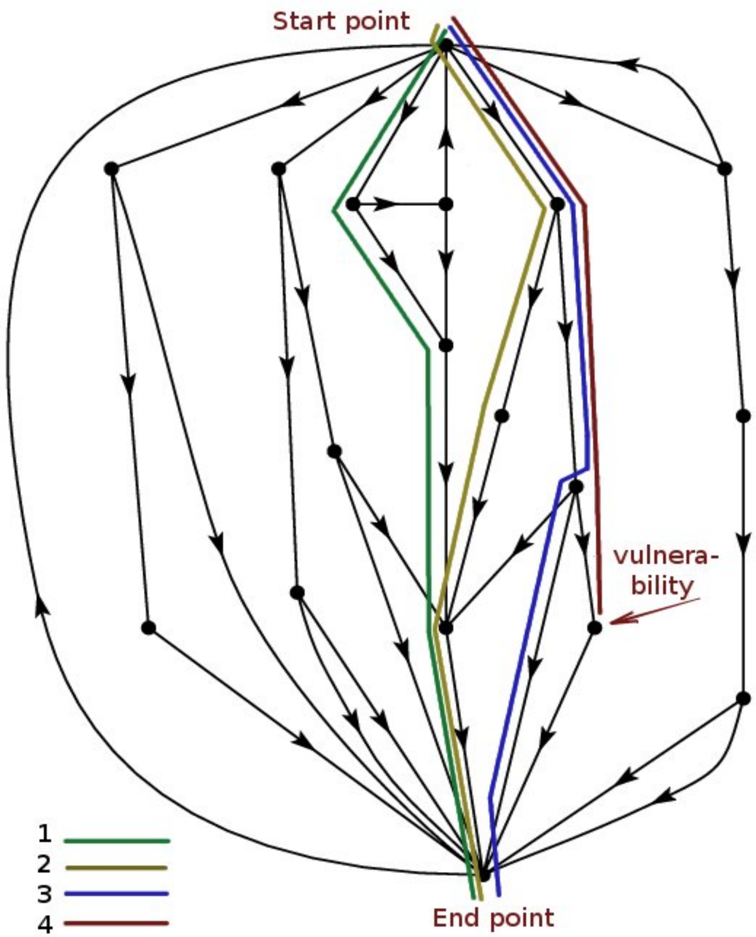
- **Temu** (tracecap: start/stop tracing. Various additions to tracecap(hooks etc.))
- **Vine** (appreplay, wputil)

- **STP**

- **IDA plugins:**
- - *DangerousFunctions* – finds calls to malloc,strcpy,memcpy etc.
- - *IndirectCalls* – indirect jumps, indirect calls.
- - *ida2sql* (zynamics) –idb in the mysql db. (http://blog.zynamics.com/2010/06/29/ida2sql-exporting-ida-databases-to-mysql/)

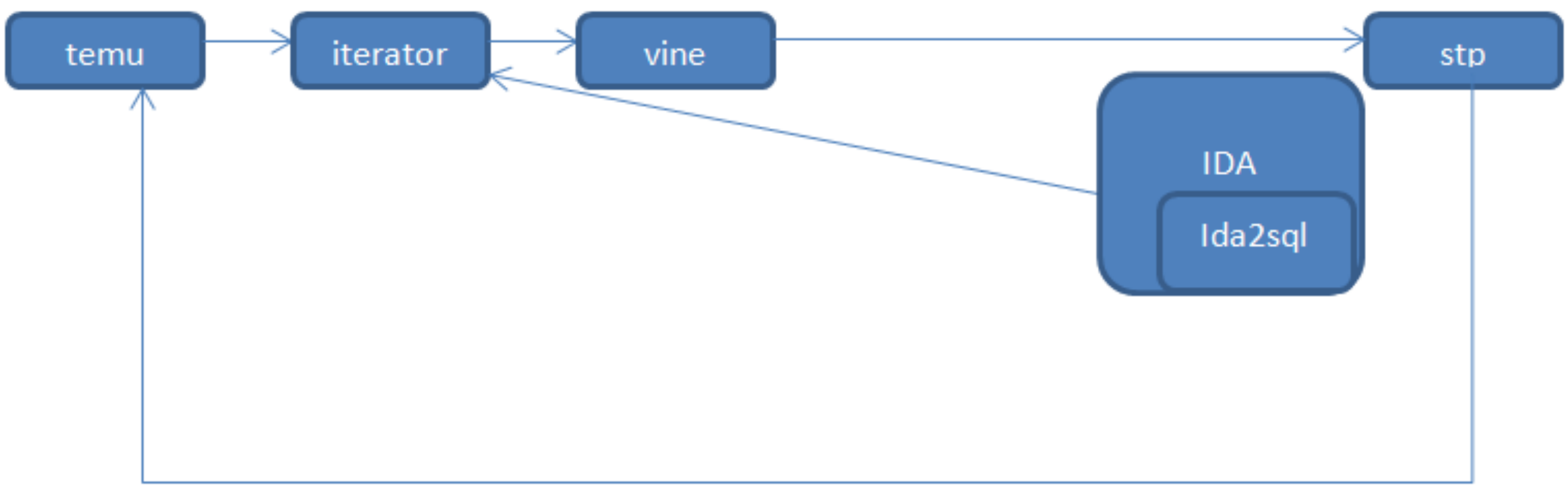
- **Iterators** – wrapper for temu, vine, stp.
- **Various publishers –** for DeviceIoControl etc.

How does SASV work?



SASV

- Scheme:

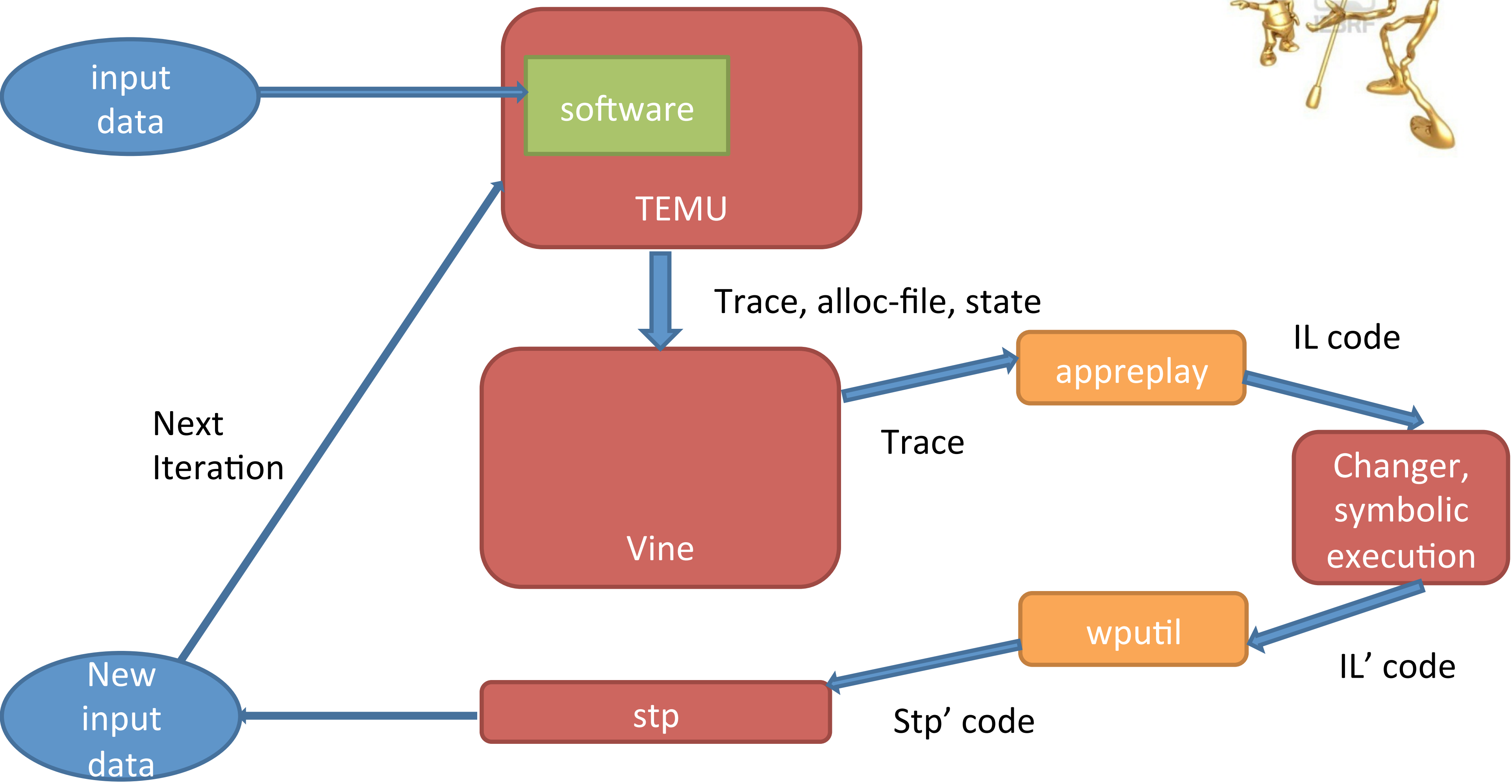


- Min Goal: max coverage of the dangerous code
- Max Goal: max coverage of the all code

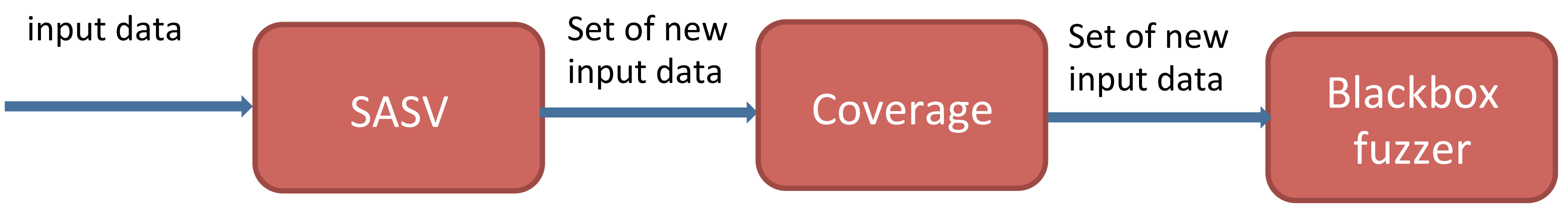
SASV basic algorithm

1. Work of IDA plugins -> dangerous places
2. Publisher(s) -> invoke targeted code
3. TEMU -> trace
4. Trace -> appreplay -> IL
5. IL -> change path algo -> IL’
6. IL’ -> wputil -> STP_prorgam’
7. STP_prorgam’ -> STP -> data for **n+1** iteration
8. Goto #2

Diagram for new path in graph



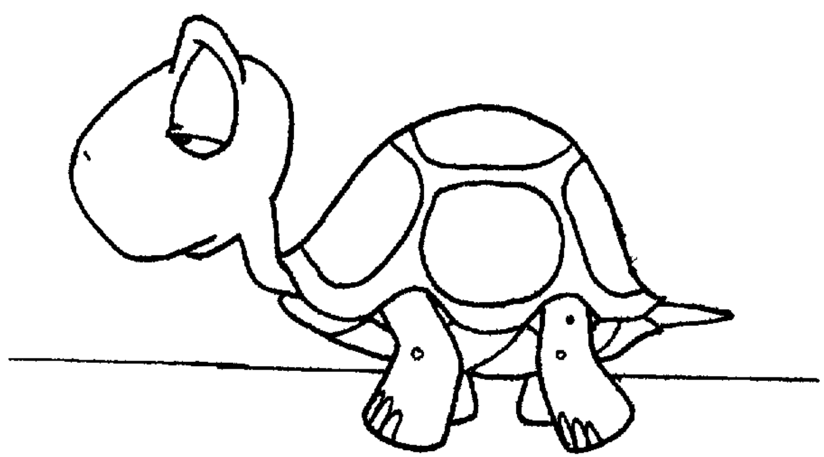
Combo system: Dumb+Smart



Disadvantages

- Definition of the vulnerability is difficult task.
- Performance – speed of tracing in TEMU is

AWFUL



Overhead

- Ideally – 1/1000.
- In Reality - 1/(X * 10000)
- Where X is dynamic and could be 1 to 10^N
- Depends on your target (r3, r0)
- Hooks quantity, etc

Implementation(Vine<->TEMU) issues

- VEX != XED
- VEX is part of valgrind - used for R3.
- Formula only for single thread.


TO DO
TASKS
ERRANDS
No.
01
02
03
04
05
06
07
08
09
10
CORRESPONDENCE
NOTES
ALL DONE
"Make a list—you'll feel better."

Get rid of that damned QEMU!

- Move taint propagation to Hypervisor!
- Damn good idea!
- But a lot of code to port/rewrite

Automation of Exploit Generation

- Build Primitives (correct exploitation state)!
- A lot of exploit mitigations
- EIP tainted != pwnage (nowadays)

S2E + SASV

S2E=Qemu+Klee

Klee=LLVM+Stp

- Input data => taint analysis (new concept)
- Support ARM
- Support Qemu 0.12


AV

Vulnerabilities in drivers

- Overflows: stack, pool, integer
- Pointer overwrite
- Null pointer dereference(Plague)
- Race condition(Plague)
- Various logical vulnerabilities(how to automate?)

Example of issue

- Total = var1 * var2 (var – could be const)
- Mem = malloc(Total)
- For(i=0;i<var;i++)memcpy(Mem,

  Mem2,CONST)
- Free(Mem)

Define Vulnerability (Memory corruption)

- var = var1 operation var2
- Mem = alloc(heap, stack)(var)
- Mem[var3] = var4
- Could var3 > var (write out-of-bounds) ?

Define vulnerability

1. tainted eip. (very rare in real life, look at KingSoft AV)

2. pointers and operations on them.

3. buffer overflow (hook *alloc function and change size of alloc).

4. integer operations and results(VSA).

5. Threads race condition – is there using of synchronising functions?

Attack vectors(r3->r0)

- **IOCTL**
- SSDT hooks(Native & Shadow)
- various notification routines

DeviceIoControl

- Parameters:
  - hDevice
  - *dwIoControlCode*
  - *lpInBuffer*
  - *nInBufferSize*
  - *lpOutBuffer*
  - *nOutBufferSize*
  - *lpBytesReturned*
  - *lpOverlapped*

Concept

IOCTL:

Data to taint:

– *dwIoControlCode* - to get list of supported ioctl codes

– *lpInBuffer - pointer(METHOD_NEITHER) and data (METHOD_BUFFERED)*

– *nInBufferSize - size ranges*

– *lpOutBuffer - pointer(METHOD_NEITHER) and data (METHOD_BUFFERED)*

– *nOutBufferSize- size ranges*

Tracing only driver code

Shaming examples

- Lulz Time!

GData Lulz #0:MiniIcpt.sys

- Ioctl code 0x83170180 (METHOD_BUFFERED)
- Untrusted data goes to FtlReleaseContext
- Leads to decrement arbitrary memory
- Leads to control of EIP
- TotalCare 2011->2012(20 months old 0day)
- Wooot TotalCare 2013 fixed feature ☹

GData Lulz #1: GDNdisIc.sys

- What about control over Ndis Filter?
- 0x830020E0 – NPD + switching on/off
- 0x83002108 –switching on/off AutoPilot
- First trigger as non-interesting vuln(NPD)
- But log from DbgPrint shows Lulz

Agnitum(?) VBEngNT.sys FAIL

- VBEngNT.sys – NOT Agnitum code
- VBEngNT.sys – from VirusBuster!
- Plays dll role in kernel land
- 50(!!!) vulnerable functions – one stupid bug
- Full trust on pointers
- Using by several(over 8) products
- Test before you buy some r0(!!!) code!!!

Microsoft Features

- METHOD_BUFFERED “signal”
- METHOD_IN/OUT_DIRECT
- ProbeForRead/ProbeForWrite – known for ages, but MS itself FAILS sometime

GData Lulz #2: TS4nt.sys

- New!!!!
- Total Care 2013(future!!!)
- Processes several ioctls
- METHOD_BUFFERED “signal” (NPD)
- Uses pointer than check – smart!

METHOD_BUFFERED “signal”

- CA Internet Security KmxFw(0x85000800)
- CA Internet Security KmxAmrt(0x8E000800)
- CA Internet Security KmxCfg (0x8700004A)
- CA Internet Security KmxCfg (0x87000800)
- Total 4 stupid shutdown features of HIPS! :D

Vipre ISS 2012 SBREDrv.sys

- Rebooting Ioctls: 0x22C418, 0x22C1C, 0x22C0CC
- Kernel Pool Corruptions:0x22C104, 0x22C108, 0x22C10C, 0x22C110, 0x22C124, 0x22C180
- Total 3(features) + 6 vulns
- + also presented in Unthreat,LavaSoft products

TrendMicro tmtdi.sys #1

- Ioctl code 0x220044 (METHOD_BUFFERED)
- No range check for size
- Just check for correct address – NPD check (MmIsAddressValid)
- Pool corruption in cycle
- No control of overflowing data ☹

TrendMicro tmtdi.sys #1

- .text:0001D881 mov edi, [ebx+0Ch]
- .text:0001D884 push edi ; our buffer
- .text:0001D885 call esi ; **MmIsAddressValid**
- .text:0001D887 test al, al
- .text:0001D889 jz loc_1DDAB
- .text:0001D88F push [ebp+output_buff_size]
- .text:0001D892 push edi
- .text:0001D893 push offset rules_list
- .text:0001D898 call ioctl_0x220044_vuln
- [..]

TrendMicro tmtdi.sys #1

- .text:000156EA mov ebx, [ebp+**our_buffer_size_controlled**]
- .text:000156ED mov [ebp+NewIrql], al
- .text:000156F0 mov eax, **dword_22CA0**
- .text:000156F5 mov edx, offset **dword_22CA0**
- .text:000156FA cmp eax, edx
- .text:000156FC jz short loc_15748
- [..]
- .text:00015700 mov ecx, [eax+0Ch]
- .text:00015703 mov [ebx], ecx
- .text:00015705 mov ecx, [eax+10h]
- .text:00015708 mov [ebx+4], ecx
- .text:0001570B mov ecx, [eax+14h]
- .text:0001570E mov [ebx+8], ecx ← write outside of the pool chunk
- .text:00015711 mov ecx, [eax+18h]
- .text:00015714 mov [ebx+0Ch], ecx

TrendMicro tmtdi.sys #2

- Ioctl code 0x220030
- Range check for inbuff_size >= 0x2AA
- Range check for outbuff_size >= 0x4D0
- Allocs pool memory for const size 0x4D0
- And…
- Zeroing it with outbuff_size length! LOL

TrendMicro tmtdi.sys #2

- .text:0001D704 cmp [ebp+inbuff_size], 2AAh
- .text:0001D70B jb loc_1DDAB
- .text:0001D711 mov esi, **4D0h**
- .text:0001D716 cmp [ebp+output_buff_size], esi
- .text:0001D719 jb loc_1DDAB
- .text:0001D71F push 746D74h ; Tag
- .text:0001D724 push esi ; NumberOfBytes
- .text:0001D725 push 0 ; PoolType
- .text:0001D727 call ds:ExAllocatePoolWithTag
- [..]

TrendMicro tmtdi.sys #2

- .text:0001D74B push edi ; pool_mem_const_size
- .text:0001D74C lea eax, [ebp+output_buff_size]
- .text:0001D74F push eax ; output_buff_size
- .text:0001D750 push [ebp+NewIrql] ; inbuff
- .text:0001D753 push 220030h ; ioctl_code
- .text:0001D758 call ioctl_several_ioctl_codes
- [..]
- .text:00014918 **mov esi, [ebp+output_buff_size]**
- [..]
- .text:00014977 push dword ptr [esi] ;
- .text:00014979 push 0 ;
- .text:0001497B push [ebp+**pool_mem_const_size**] ;
- .text:0001497E call memset

TrendMicro tmnciesc.sys

- Ioctl code 0x222404
- Kernel Pool Corruption
- Your homework ;)

Pitfalls of taint analysis

- Indirect propagation
- Flat model problem(data is tainted, pointer is not) – strlen problem
- Const values tainting(switch problem)
- More taint info(levels) – more overhead

Pitfalls of tainting r0

- Taint info lost
- Check of system variables
- System defense mechanism(s) (win32k.sys WATCHDOG BugCheck)

Pitfalls of tainting r0(IOCTL)

- KeGetPreviousMode
- IoGetCurrentProcess
- Even hooking NtDeviceIoControlFile!

Conclusions

- Quality -> security level
- Taint analysis is not key to every vuln
- SASV just another approach to automate RE
- Sucks for userland software analysis
- Nice approach for kernel land
- But fails sometimes ;)
- MS should fuzz/test/analyze what it signs!

Thanks, ☺

- Questions?

http://twitter.com/#!/ABazhanyuk
http://twitter.com/#!/NTarakanov