Polymorphing Software by Randomizing Data Structure Layout

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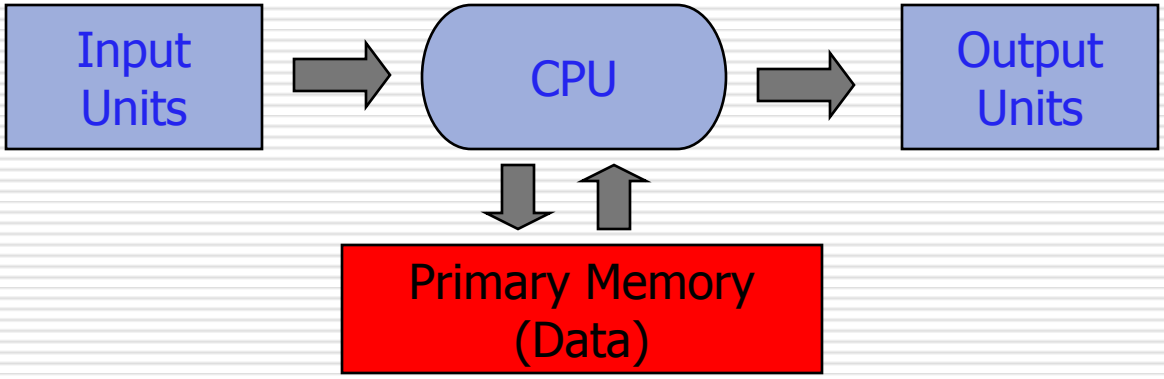
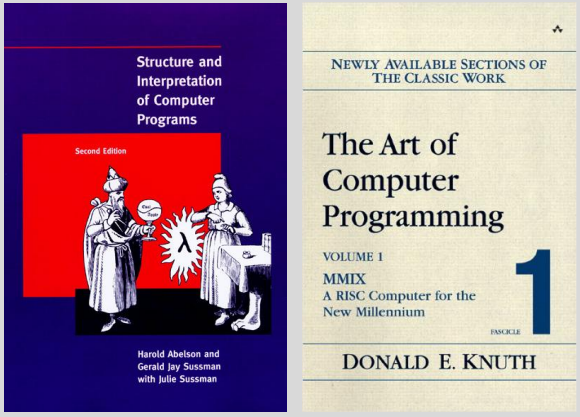
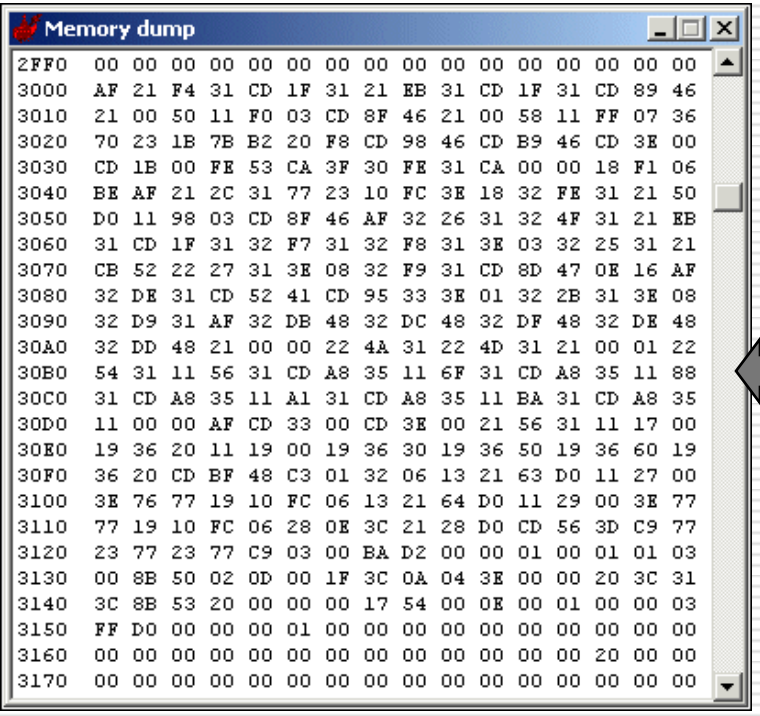
Observations: all programs use data structures

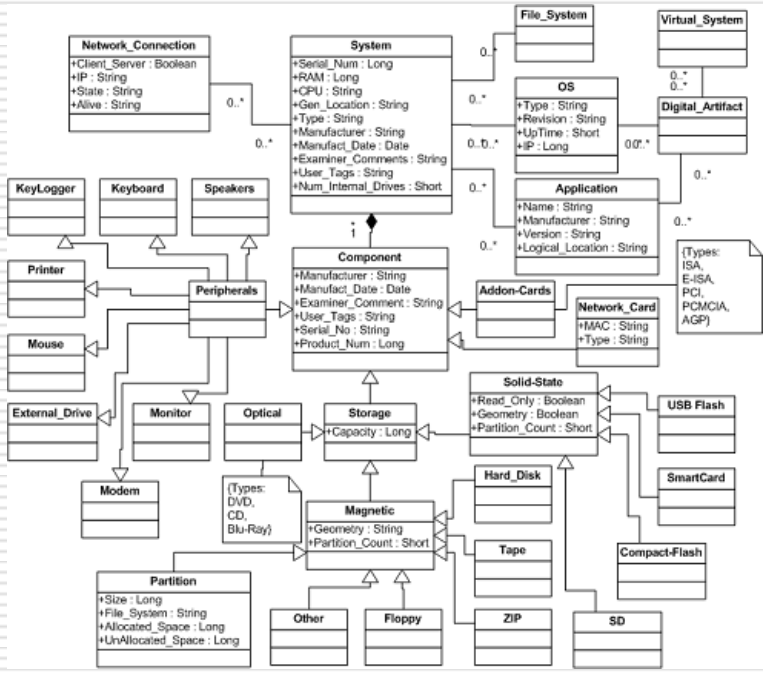




In computer science, a **data structure** is a particular way of storing and organizing data in a computer so that it can be used *efficiently*

Why we need to care about it in security?





Digital Forensics -- Identify digital evidence for an investigation

Why we need to care about it in security?

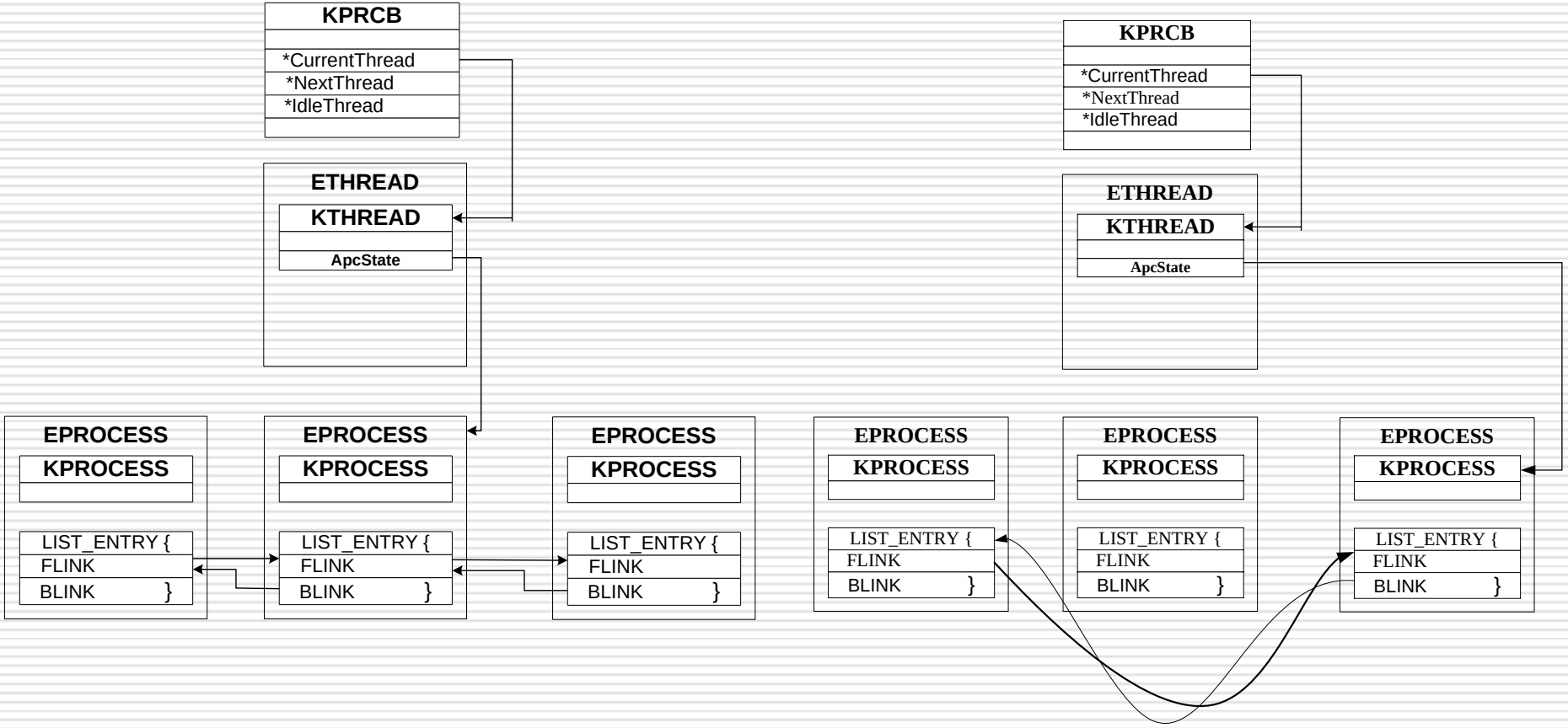
```
struct A
{
        int a;
        char b;
        int c;
        float d;
};
```

=

```
struct A
{
        int a;
        char b;
        int c;
        float d;
};
```

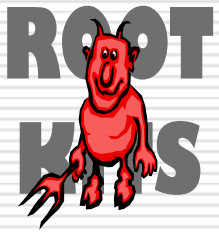
Laika [OSDI'08]: Using Data structure as a classifier → Malware Signature

Why we need to care about it in security?



ROOT KITS

Motivation



DSLR: Polymorphing data structure layout

Data structure signature

Outline

- Motivation
- Technical Challenges
- Design & Implementation
- Evaluation
- Related Work
- Conclusion

Technical Challenges (I)

- Randomizability of Data structure
  - Network communication

```
41 struct udphdr {
42      u_int16_t   uh_sport;       /* source port */
43      u_int16_t   uh_dport;       /* destination port */
44      u_int16_t   uh_ulen;        /* udp length */
45      u_int16_t   uh_sum;         /* udp checksum */
46 };
```

Technical Challenges (I)

- Randomizability of Data structure
  - Network communication
  - Standard definition (e.g., stdio.h)

```
/usr/include/fstab.h
...
57 struct fstab
58   {
59     char *fs_spec;          /* block special device name */
60     char *fs_file;          /* file system path prefix */
61     char *fs_vfstype;       /* File system type, ufs, nfs */
62     char *fs_mntops;        /* Mount options ala -o */
63     const char *fs_type;    /* FSTAB_* from fs_mntops */
64     int fs_freq;            /* dump frequency, in days */
65     int fs_passno;          /* pass number on parallel dump */
66   };
67
```

Technical Challenges (I)

- Randomizability of Data structure
  - Network communication
  - Standard definition (e.g., stdio.h)
  - Zero length array

```
struct stringlib
{
        int length;
        char str[0];
};
```

Technical Challenges (I)

- Randomizability of Data structure
  - Network communication
  - Standard definition (e.g., stdio.h)
  - Zero length array
  - Directly using data offset to access some fields

```
p=&struct_a;
var_a=*(p+4);
```

Technical Challenges (I)

- Randomizability of Data structure
  - Network communication
  - Standard definition (e.g., stdio.h)
  - Zero length array
  - Directly using data offset to access some fields
  - Initialized data structure

```
struct role = { "Hamlet", 7, FALSE, "Prince of Denmark", "Kenneth Branagh"};
```

Technical Challenges (I)

- Randomizability of Data structure
  - Network communication
  - Standard definition (e.g., stdio.h)
  - Zero length array
  - Directly using data offset to access some fields
  - Initialized data structure
  - …

- *How to spot the randomizable data structures*

Programmer has the confidence

Technical Challenges (II)

- How to randomize a data structure
  - (1) Reorder the Field

```
struct A
{
        int a;
        char b;
        int c;
        float d;
};
```

```
struct A
{
        char b;
        int a;
        float d;
        int c;
};
```

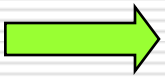
#m fileds → **m!**

#n data structures, #m fields each →**variance** **$(m!)^n$**

Technical Challenges (II)

- How to randomize a data structure
  - (1) Reorder the Field
  - (2) Insert Garbage fields

```
struct A
{
        int a;
        int b;
};
```



```
struct A
{
        int a;
        Garbage;
        int b;
};
```

Technical Challenges (II)

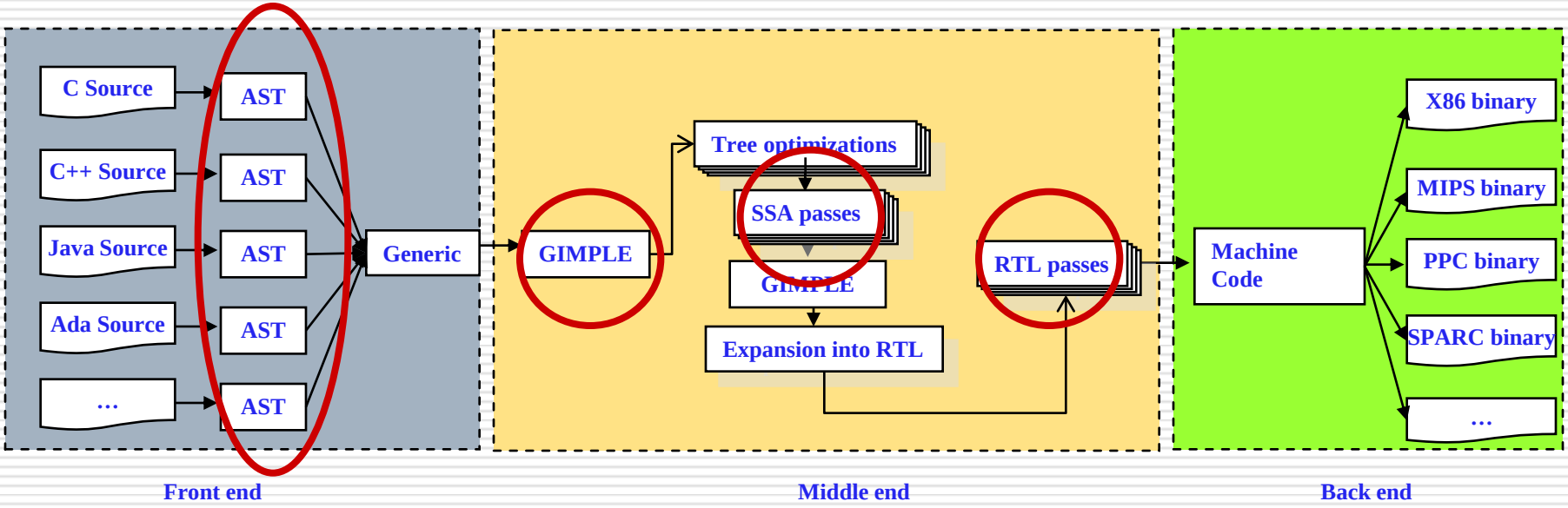
- How to randomize a data structure
  - (1) Reorder the Field
  - (2) Insert Garbage fields
  - (3) Split the struct

```
struct A
{
        int a;
        char b;
        int c;
        float d;
};
```

```
struct A1
{
        int a;
        int c;
};
```

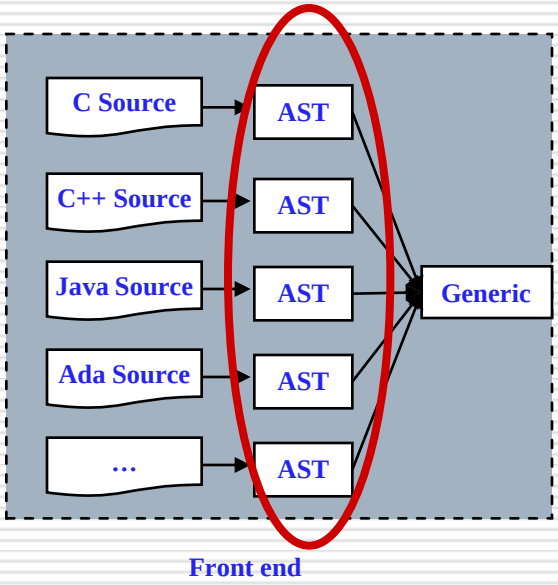
```
struct A2
{
        char b;
        float d;
};
```

Design in GCC



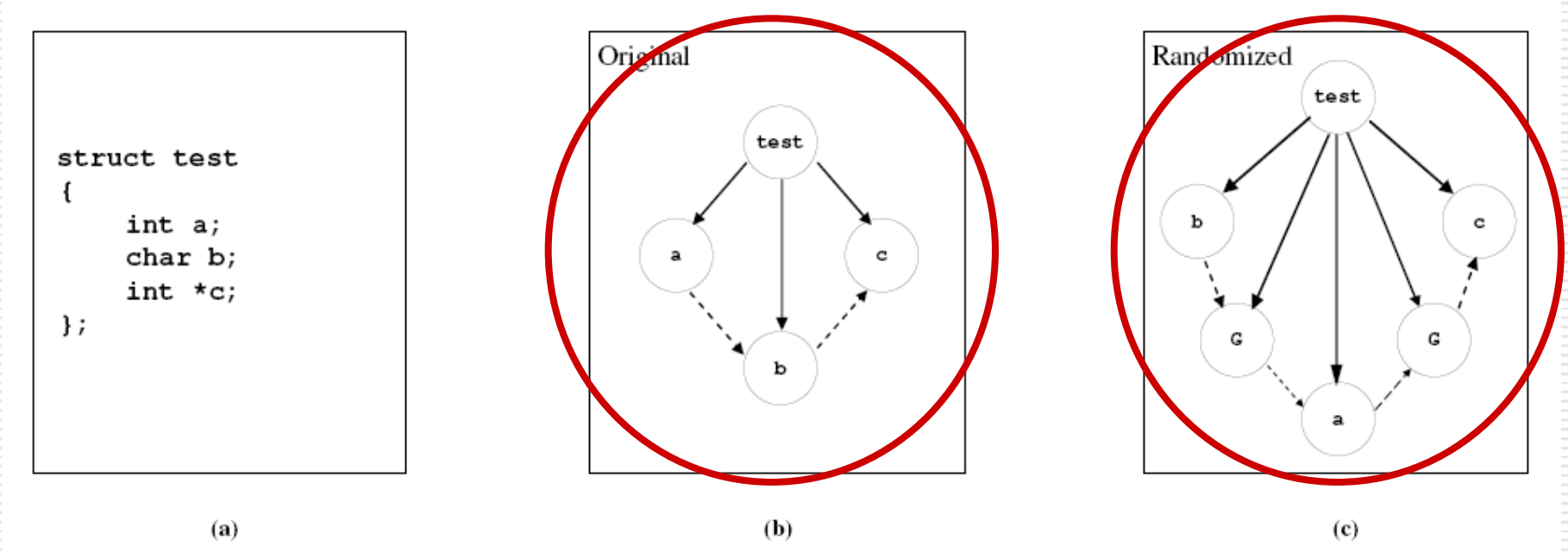
Four Intermediate Representations: AST, GIMPLE, SSA, RTL

Instrument at AST because of



- (1) Much more original information
  - The type and scope information for data structures
- (2) Easier to understand and modify
- (3) No need to touch specific memory addresses, and the instructions.

Examples



Randomized “AST”

How to use our compiler

<obfuscate-specifier> ::= **__obfuscate__((<obfuscate-list>))**
<obfuscate-list> ::= <obfuscate-property>
| <obfuscate-list>, <obfuscate-property>
<obfuscate-property> ::= **ε | __reorder__ | __garbage__**

```
1 class Test
2 {
3     int a;
4     char b;
5     int *c;
6     ...
7 } __obfuscate__ (( __reorder__ ));
```

```
 1 #include <stdio.h>
 2 struct Test
 3 {
 4     int a;
 5     char b;
 6     int *c;
 7 } __obfuscate__ (( __reorder__ , __garbage__ ));
 8 __obfuscate__ (( __reorder__ )) int main(void)
 9 {
10     int loc1 = 1;
11     char loc2 = 'n';
12     char loc3[4];
13     printf(" The address in struct:
14             %x , %x , %x\n", &t.a, &t.b, &t.c);
15     printf(" The address in local:
16             %x, %x, %x\n",&loc1,&loc2,&loc3);
17     return 0;
18 }
```

Evaluation on Estimation of Randomizability

Program	LOC	Struct	class	w
42-Virus	0.88	1/1	-	4E5
Slapper	2.44	26/30	-	5E47
pingrootkit	4.81	26/27	-	5E15
Mood-nt	5.31	36/37	-	8E119
tnet-1.55	11.56	14/17	-	7E82
Suckit	24.71	110/111	-	9E159
agobot3	245.44	23/31	50/50	2E1106
patch2.5.4	11.53	5/7	-	4E3
bc-1.06	14.29	20/21	-	6E56
tidy4	15.95	9/18	-	2E52
ctags-5.7	27.22	51/79	-	3E668
openssh4.3	76.05	63/80	-	4E1271

Most of the programmer defined data structure is randomizable

Evaluations against rootkit attacks

Randomized "task_struct"

Rootkit	Attack Vector	Prevented?
adore-ng 0.56	LKM	√
enyelkm 1.2	LKM	√
override	LKM	√
fuuld	DKOM-/dev/kmem	√
intoxnia ng2	LKM	X
Mood nt	/dev/kmem	X

No data structure involved in these attacks

Evaluation on Signature Evasion

Benchmark	Binary	Code diversity	Mixture Ratio
7zip-4.6.4 (A)	502K	4.26%	0.50942826
7zip-4.6.4 (B)	504K	5.88%	0.51487480
agobot3-0.2.1 (A)	1.18M	6.18%	0.70016150
agobot3-0.2.1 (B)	1.19M	6.34%	0.60932887

Laika[osdi'08] uses a mixture ratio to quantify similarity: the closer the value is to 0.5, the higher the similarity

7-zip only has 25 data structures randomized, and it has more than 80 unandomizable one (library). Agobot has 49 "stucts", and 50 classes in its own

Limitation & Future work

- AST vs. GIMPLE, SSA, RTL
- Automatic Identification of the Randomizability
- Struct/Class split
- Variant Instance is generated by compiling

Related work

- Security through Diversity [Forrest et al. 1997]
  - Address Space Randomization (ASR) (e.g., Kernel Patch [PAX], Loader [SRDS'03], Source code [Sec'05], binary code [Sec'03])
  - Instruction Set Randomization (ISR) [CCS'03]
  - Data Randomization (e.g., PointGuard [Sec'03])
  - Operating System Interfaces Randomization (e.g., RandSys[SRDS'07])
  - Multi-variant System (e.g, N-variant[Sec'05], Die-hard[PLDI'06])
- Layout Manipulations and Obfuscations in Compilers
  - Propolice
  - Cache aware layout reorganization optimization [GCC Developers' Summit '05, '07, PLDI'04]

Conclusion

- DSLR -- A new software randomization technique
- *Thwart data structure need-to-know attack*
  - Rootkit

- *Increase the bar for software defense*
  - Forensics analysis
  - Data structure based signature (false negatives)

Source code (GPL)
http://www.cs.purdue.edu/homes/zlin/dimva09.html

Q&A

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