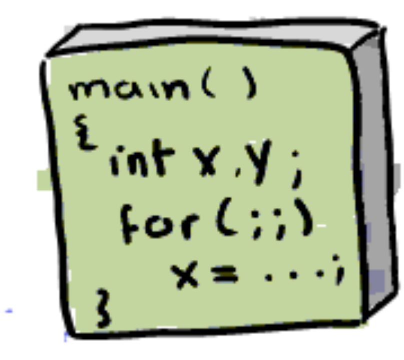
Dynamic Data Structure Excavation

or "Gimme back my symbol table!"

Asia Slowinska, Traian Stancescu,
Herbert Bos

VU University Amsterdam

Anonymous bytes only…



Goals

- Long term: reverse engineer complex software

```
push   %ebp
mov    %esp,%ebp
sub    $0xa8,%esp
mov    0x8(%ebp),%eax
lea    -0x98(%ebp),%ecx
mov    %eax,%edx
mov    $0x8c,%eax
mov    %eax,0x8(%esp)
mov    %edx,0x4(%esp)
mov    %ecx,(%esp)
call   0x29
mov    0x8(%ebp),%eax
leave
ret
nop
nop
```

```
struct employee {
   char name [128];
   int year;
   int month;
   int day;
};
struct employee*
foo (struct employee* src)
{
   struct employee dst;
   // init dst

}
```

Goals

- Long term: reverse engineer complex software
- Short term: reverse engineer data structures

```
push    %ebp
mov     %esp,%ebp
sub     $0xa8,%esp
mov     0x8(%ebp),%eax
lea     -0x98(%ebp),%ecx
mov     %eax,%edx
mov     $0x8c,%eax
mov     %eax,0x8(%esp)
mov     %edx,0x4(%esp)
mov     %ecx,(%esp)
call    0x29
mov     0x8(%ebp),%eax
leave
ret
nop
nop
```

```
struct s1{
   char f1 [128];
   int f2;
   int f3;
   int f4;
};
struct s1*
fun1 (struct s1* a1)
{
   struct s1 l1;


}
```

WHY?

Application I: legacy binary protection

- Legacy binaries everywhere
- We suspect they are vulnerable

But…

How to protect legacy code from memory corruption?
Answer: find the buffers and make sure that all accesses to them do not stray beyond array bounds.

Application II: binary analysis

- We found a suspicious binary – is it malware?
- A program crashed… - let's investigate!

But…

Without symbols, what can we do?
Answer: generate the symbols ourselves!

(demo later)

```
(gdb) print variables_function0
$1 = {field_4_bytes_0 = 0, field_4_bytes_1 = 0, pointer_struct_hostent_0 = 0xbfffeaf0,
field_8_bytes_0_unused = 579558798248313200, pointer_char_0 = 0x2cfb14
"\274\t", field_in_addr_t_0 = -1073745296,
pointer_struct_1_0 = 0x0, field_1_byte_0_unused = 0 '\000', field_1_byte_0 = 0 '\000',
field_1_byte_1 = 0 '\000', field_8_bytes_1_unused = -4611706891964220672,
inetaddr_string_0 = 0x80b0170 "www.google.com", field_4_bytes_2 = 0}
```

```
1. struct employee {
2.         char name[128];
3.         int year;
4.         int month;
5.         int day;
6. };
7.
8. struct employee e;
9. e.year = 2010;
```

?

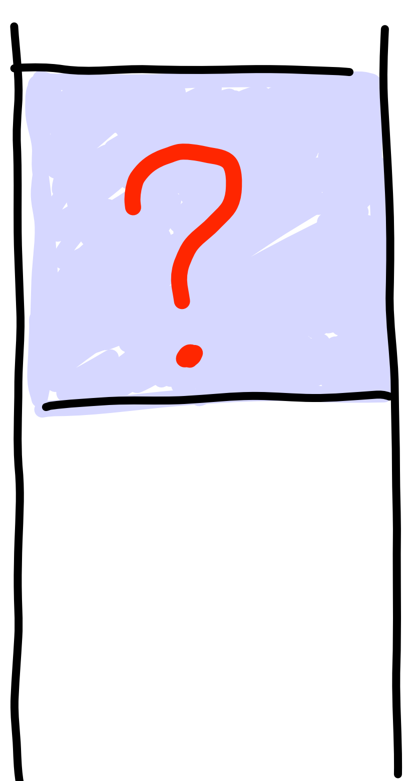
MISSING

- Data structures
- Semantics

Instr 1

Instr 2

```
1. struct employee {
2.         char name[128];
3.         int year;
4.         int month;
5.         int day
6. };
7.
8. struct employee e;
9. e.year = 2010;
```



Data structures: key insight

```
1.  struct employee {
2.          char name[128];
3.          int year;
4.          int month;
5.          int day
6.  };
7.
8.  struct employee e;
9.  e.year = 2010;
```

2010

Yes, data is unstructured…
But – usage is NOT!

```
1. stru
...
       int month;
       int day
6. };
7.
8. struct employee e;
9. e.year = 2010;
```

Analyse dynamically

2010

test

KLEE/
S^2E

inputs

app

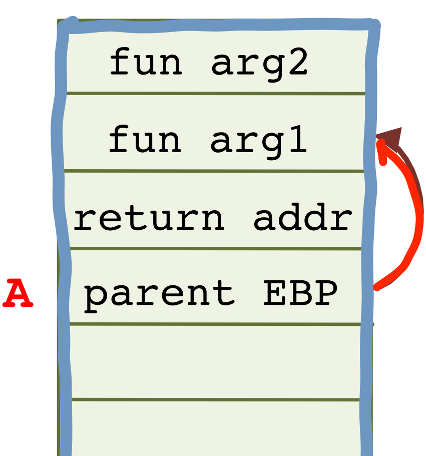
Emulator

data structures

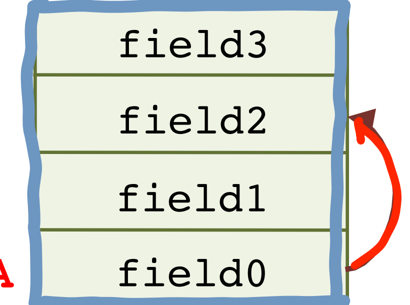
Intuition

- Observe how memory is *used* at runtime to detect data structures
- E.g., if A is a pointer…

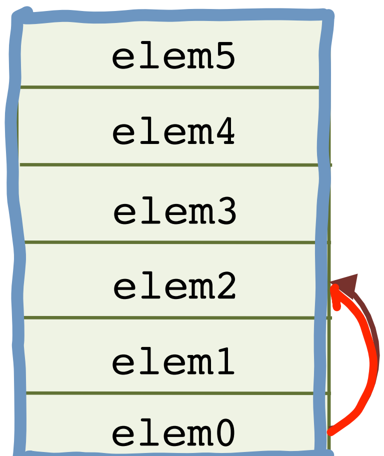
1. and A is a function frame pointer, then *(A + 8) is perhaps a function argument



2. and A is an address of a structure, then *(A + 8) is perhaps a field in this structure



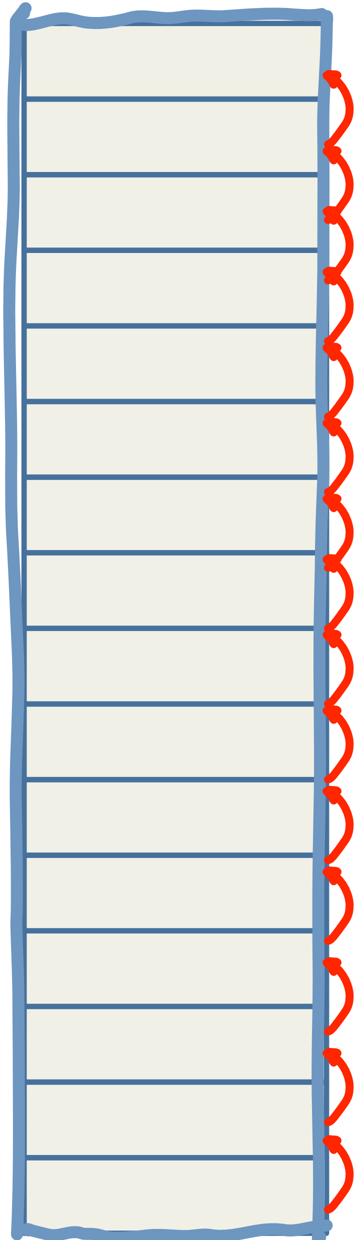
3. and A is an address of an array, then *(A + 8) is perhaps an element of this array



Arrays are tricky

Access pattern & detection:

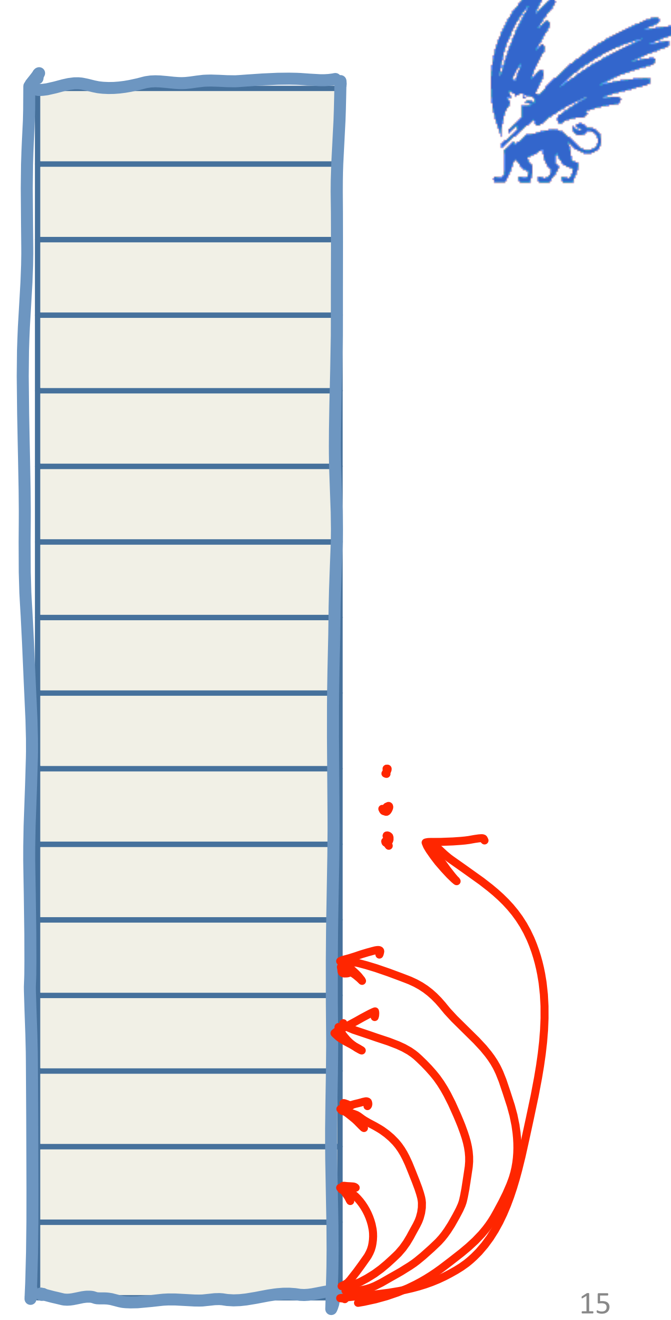
- `elem = next++;`
  - Look for chains of accesses in a loop



Arrays are tricky

Access pattern & detection:

- `elem = next++;`
  - Look for chains of accesses in a loop
- `elem = array[i];`
  - Look for sets of accesses with the same base in a linear space



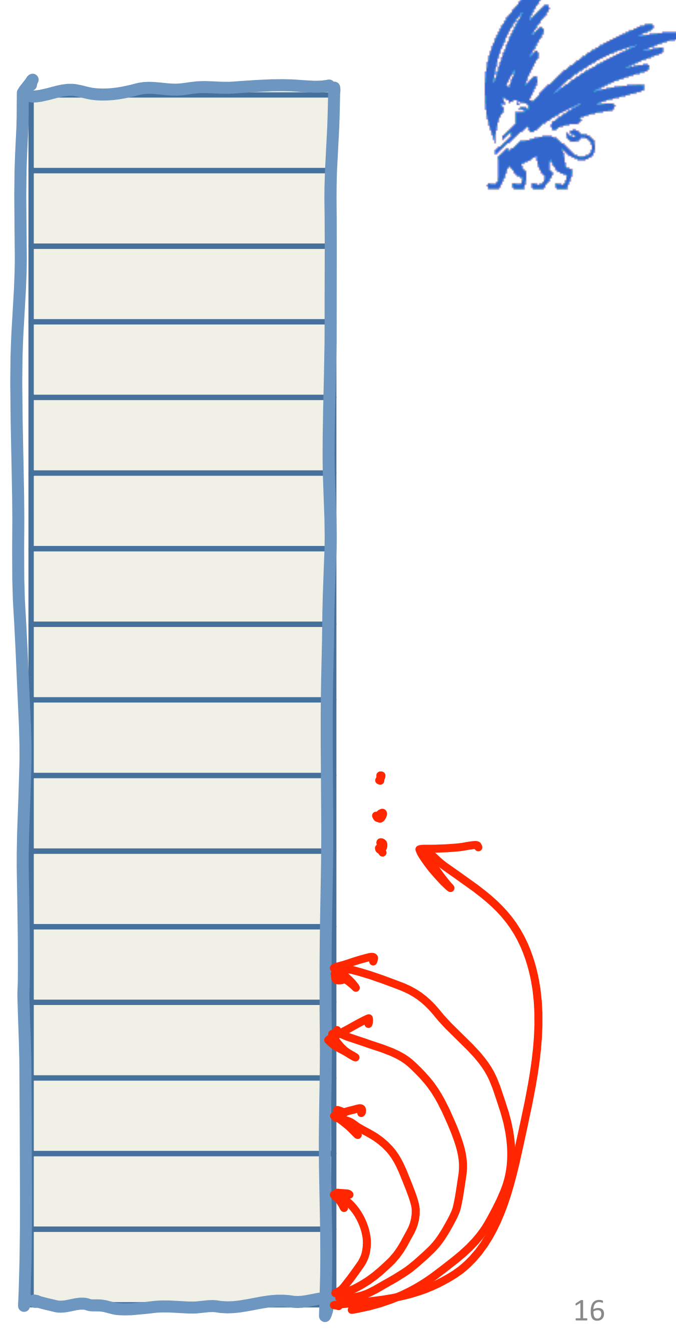
Arrays are tricky

Access pattern & detection:

- `elem = next++;`
  - Look for chains of accesses in a loop
- `elem = array[i];`
  - Look for sets of accesses with the same base in a linear space

Challenges:

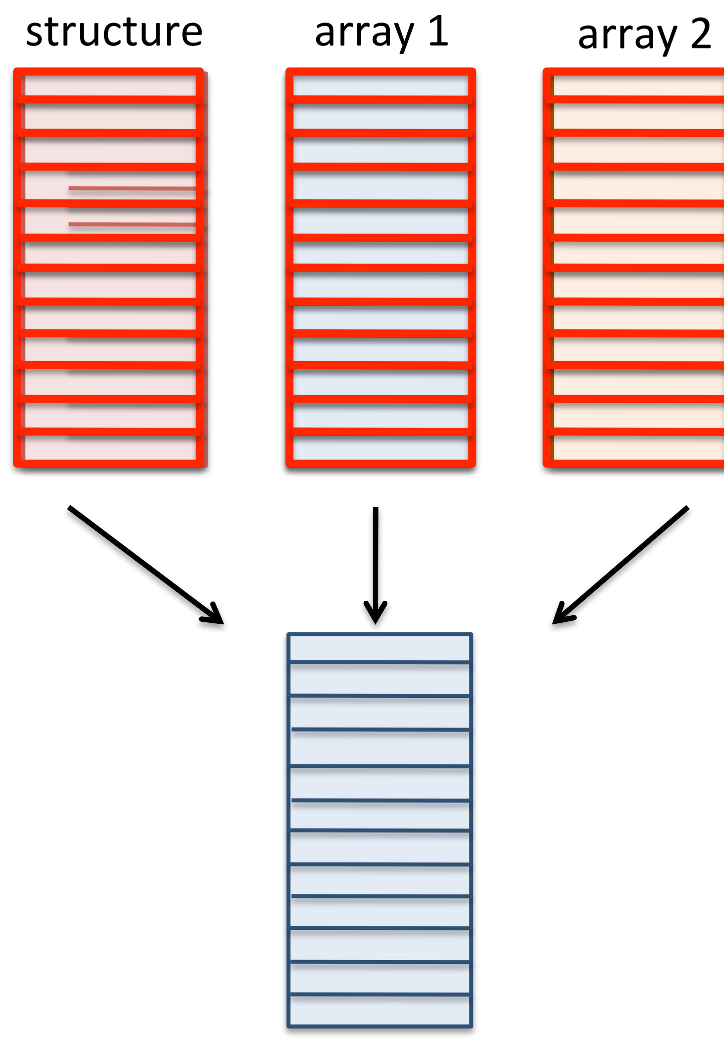
- Boundary elements accessed outside the loop
- Nested loops
- Multiple loops in sequence



More challenges

Examples:

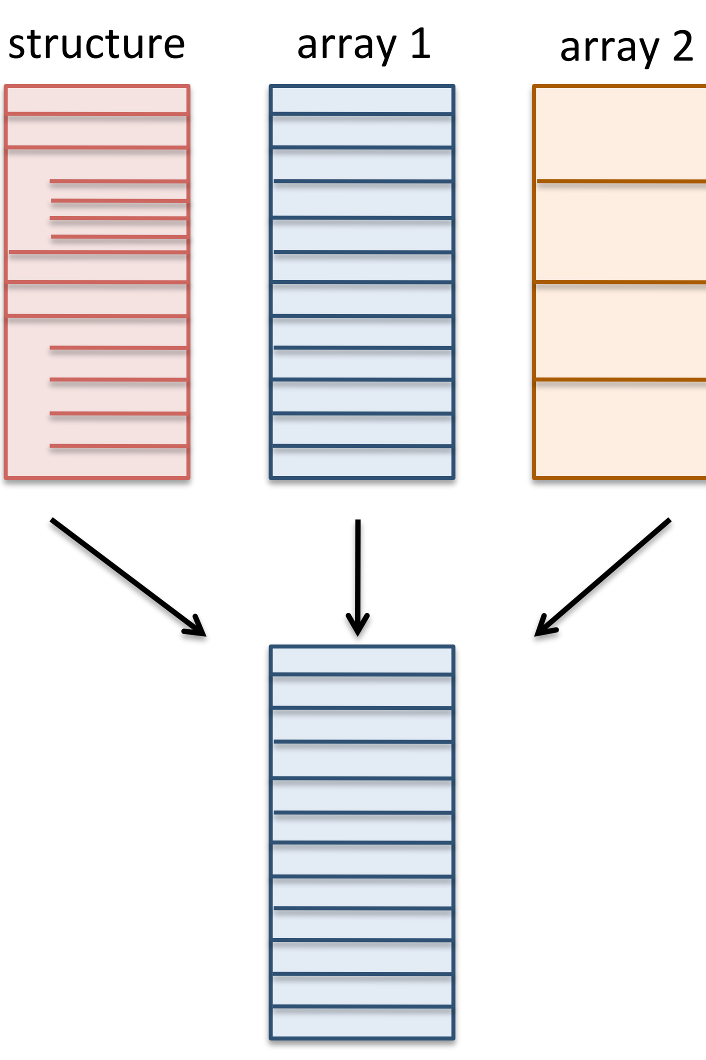
- Decide which memory accesses are relevant
  - Problems caused by e.g., `memset`–like functions



More challenges

Examples:

- Decide which memory accesses are relevant
  - Problems caused by e.g., `memset`–like functions
- Even more in the paper ☺



Results in terms of accuracy – heap memory

variables

bytes

Heap Memory

Prog	LoC
wget	46K
fortune	2K
grep	24K
gzip	21K
lighttpd	21K

unused arrays
flattened
unused
missed
ok

% of total

100
80
60
40
20
0

wget
lighttpd
gzip
grep
fortune

demo now

```
(gdb) print variables_function0
$1 = {field_4_bytes_0 = 0, field_4_bytes_1 = 0, pointer_struct_hostent_0 = 0xbfffeaf0,
field_8_bytes_0_unused = 579558798248313200, pointer_char_0 = 0x2cfb14
"\274\t", field_in_addr_t_0 = -1073745296,
pointer_struct_1_0 = 0x0, field_1_byte_0_unused = 0 '\000', field_1_byte_0 = 0 '\000',
field_1_byte_1 = 0 '\000', field_8_bytes_1_unused = -4611706891964220672,
inetaddr_string_0 = 0x80b0170 "www.google.com", field_4_bytes_2 = 0}
```

Conclusions

- We *can* recover data structures by tracking memory accesses
- We believe we can protect legacy binaries
- We are working on data coverage