Dynamic Data Excavation

NDSS'11

or: "Gimme back my symbol table!"

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Compilation is pseudo-unbreakable code

irreversibility assumption

Compilation is pseudo-unbreakable code

irreversibility assumption

- Most software available only in binary form
  - malware analysis is difficult
  - forensics is difficult
  - source gets lost
  - we do not know what code is doing
  - we cannot fix it

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Goals

Long term : reverse engineer complex software

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```
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
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nop
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```

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```

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

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Long term : reverse engineer complex software

Short term : reverse engineer data structures

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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*
foo (struct s1* a1)
{
    struct s1  l1;
}
```

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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

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Application II: binary analysis

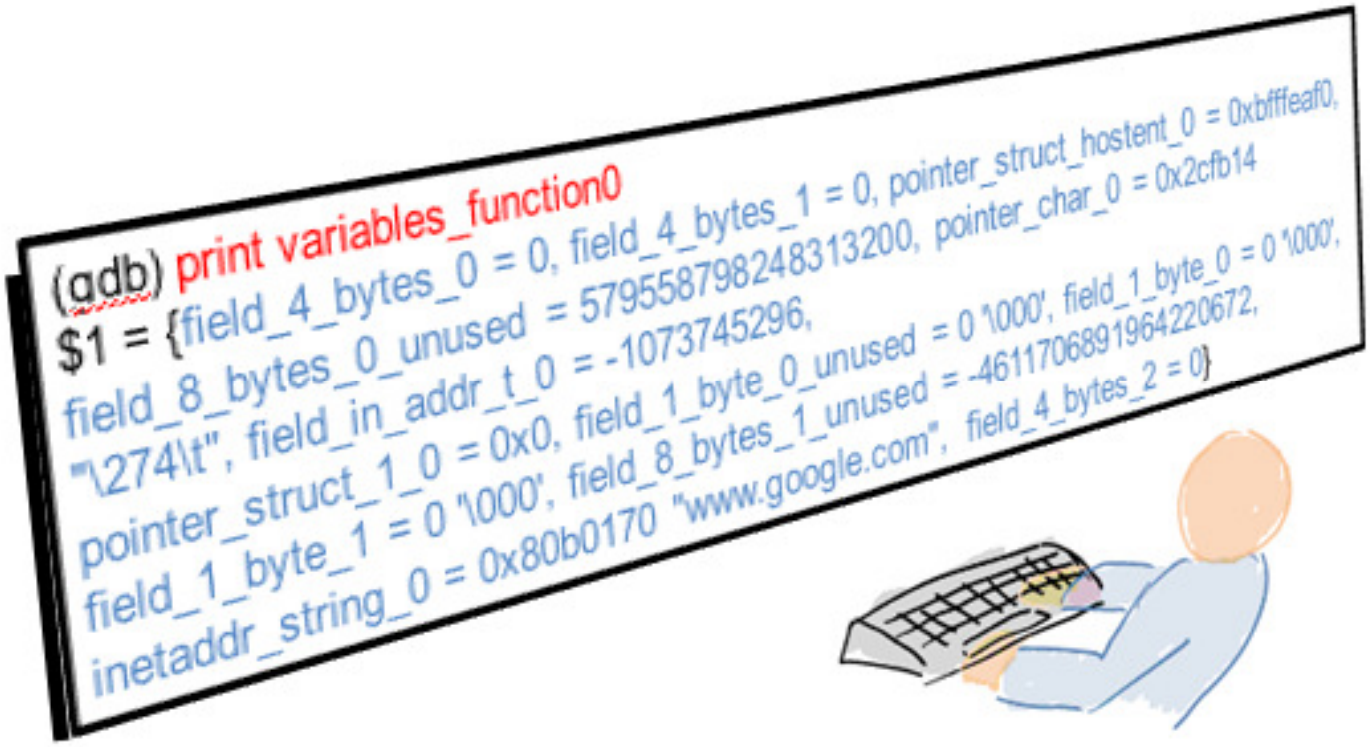
- we found a suspicious binary ➔ is it malware?
- a program crashed ➔ investigate

But…

Without symbols, what can we do?

Answer: generate the symbols ourselves!

(demo later)



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File Edit View Terminal Help
file wget.gdb <---- The binary is stripped
wget.gdb: ELF 32-bit LSB executable, Intel 80386, version 1 (SYSV), dynamically linked (uses shared libs), for GNU/Linux 2.6.15, stripped
gdb -q wget.gdb
Reading symbols from /home/ /dynamit_instrumented_binaries/wget/wget.gdb...done.
(gdb) b *0x805adb0
Breakpoint 1 at 0x805adb0
<---- Set breakpoint
(gdb) run www.google.com
Starting program: /home/ /dynamit_instrumented_binaries/wget/wget.gdb www.google.com
[Thread debugging using libthread_db enabled]
--2010-08-09 16:24:00-- http://www.google.com/
Breakpoint 1, 0x0805adb0 in function0 ()
(gdb) info scope function0
Scope for function0:
<---- Display function variables
Symbol variables_function0 is a variable with complex or multiple locations (DWARF2), length 152.
(gdb) print variables_function0
$1 = {field_4_bytes_0 = 0, field_4_bytes_1 = 0, pointer_struct_hostent_0 = 0xbfffec90, field_8_bytes_0_unused = 579558798248313200,
pointer_char_0 = 0x30bb14 '\274\t', field_in_addr_t_0 = -1073744880, 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 = -4611705105257579776,
inetaddr_string_0 = 0x80b0170 "www.google.com", field_4_bytes_2 = 0}
(gdb) watch variables_function0.pointer_struct_1_0
Hardware watchpoint 2: variables_function0.pointer_struct_1_0
(gdb) c
Continuing.
Resolving www.google.com... Hardware watchpoint 2: variables_function0.pointer_struct_1_0
Old value = (struct struct_1 *) 0x0
New value = (struct struct_1 *) 0x80b2678
0x0805af5f in function0 ()
(gdb) print /x *variables_function0.pointer_struct_1_0 <---- Display a wget structure
$2 = {field_4_bytes_0 = 0x3, pointer_struct_0_0 = 0x80b2690, field_int_0 = 0x0, field_1_byte_0 = 0x0, field_4_bytes_1 = 0x0}
(gdb) print /x *variables_function0.pointer_struct_1_0.pointer_struct_0_0
$3 = {field_4_bytes_0 = 0x2, field_in_addr_t_0 = 0x934d7d4a}
(gdb) print (char*) inet_ntoa(variables_function0.pointer_struct_1_0.pointer_struct_0_0.field_in_addr_t_0)
$4 = 0xb7fe46a0 "74.125.77.147"
(gdb) print malloc_usable_size(variables_function0.pointer_struct_1_0.pointer_struct_0_0) / sizeof(*variables_function0.pointer_struct_1_0.
pointer_struct_0_0)
$5 = 3
(gdb) print /x variables_function0.pointer_struct_1_0.pointer_struct_0_0[1] <---- the structure's fields
$6 = {field_4_bytes_0 = 0x2, field_in_addr_t_0 = 0x634d7d4a}
(gdb) print (char*) inet_ntoa(variables_function0.pointer_struct_1_0.pointer_struct_0_0[1].field_in_addr_t_0)
$7 = 0xb7fe46a0 "74.125.77.99"
(gdb) print /x variables_function0.pointer_struct_1_0.pointer_struct_0_0[2]
$8 = {field_4_bytes_0 = 0x2, field_in_addr_t_0 = 0x684d7d4a}
(gdb) print (char*) inet_ntoa(variables_function0.pointer_struct_1_0.pointer_struct_0_0[2].field_in_addr_t_0)
$9 = 0xb7fe46a0 "74.125.77.104"
(gdb)
1
2
3
4
5
6
7
8
9

Why is it difficult?

```
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;
```

Why is it difficult?

```
1. struct employee {
2.         char name[128];
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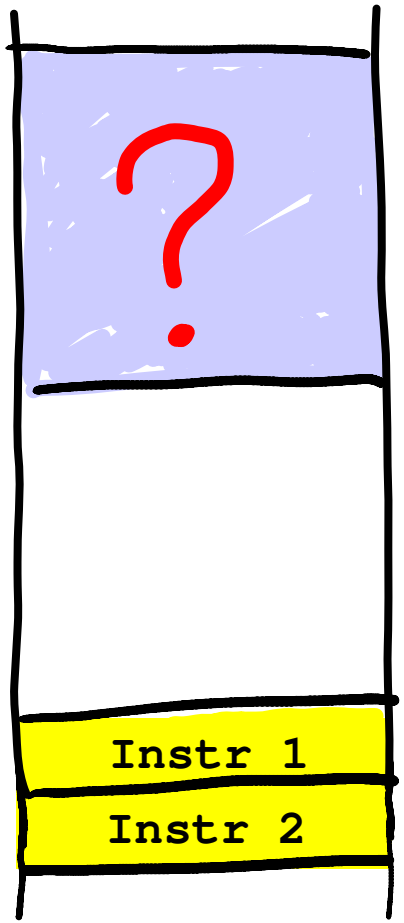

MISSING
- Data structures
- Semantics

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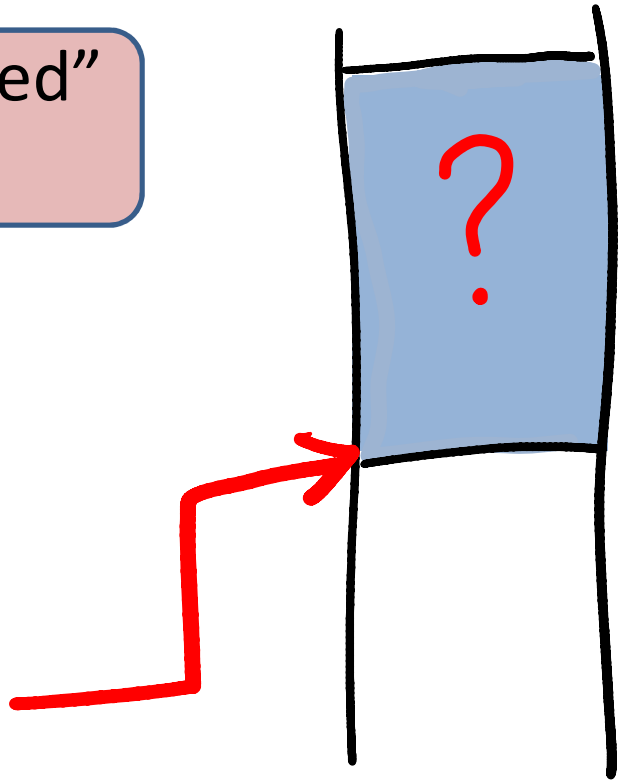
Data structures: key insight

Yes, data is “apparently unstructured”

But usage is not!



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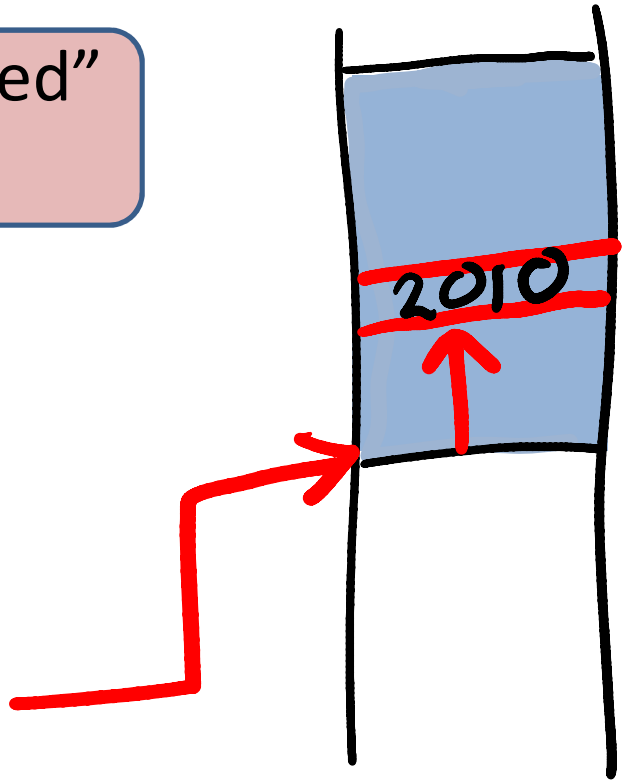

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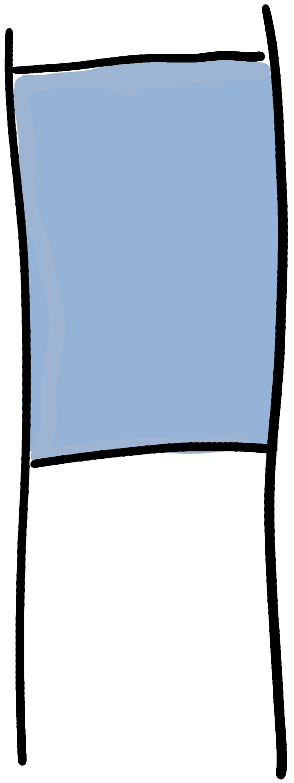
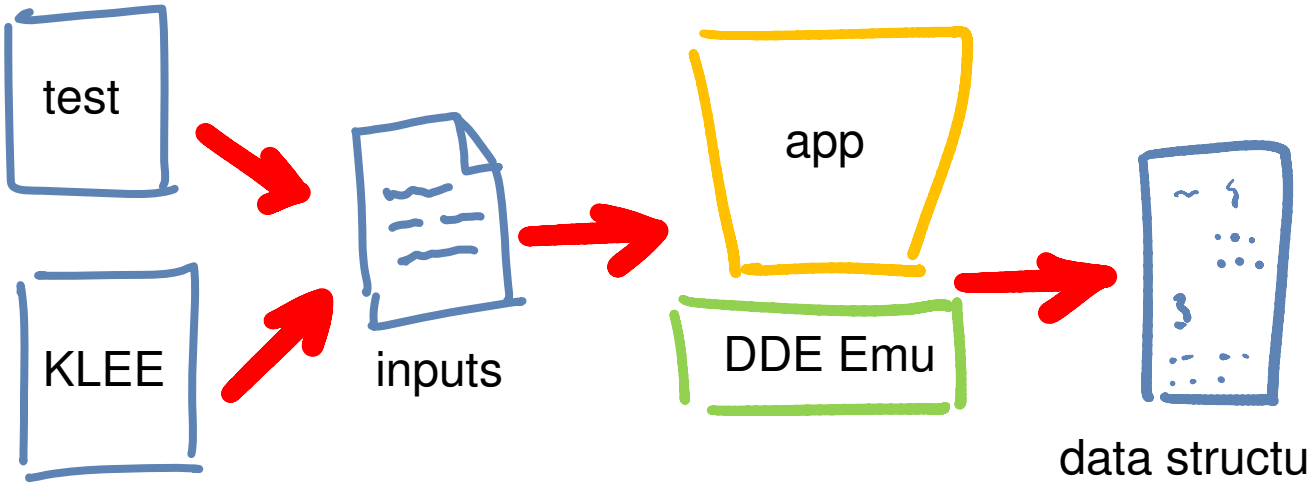
Analyse dynamically





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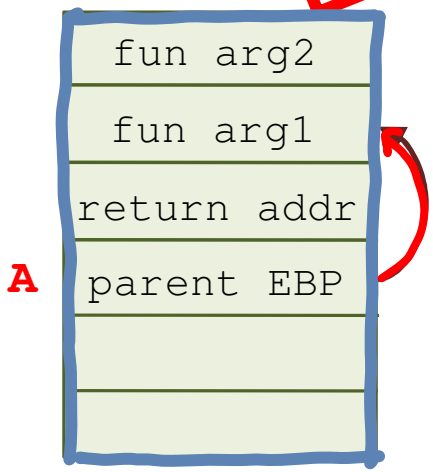
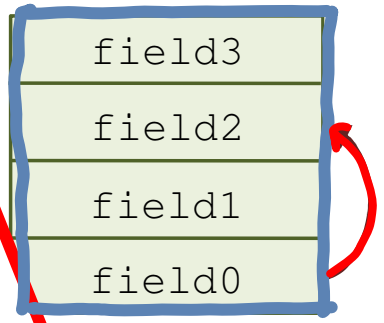
Intuition

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

1. and A is a functi
   then *(A + 8) is
   function argume

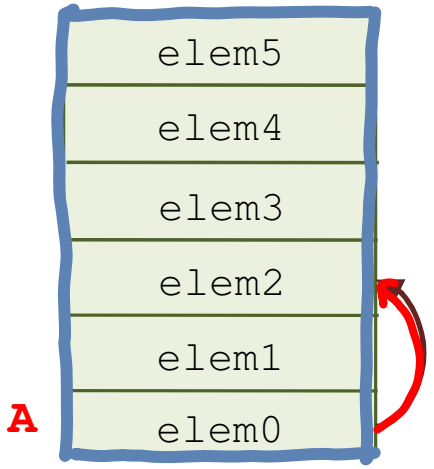


2. and A is an address of a structure, then *(A + 8) is perhaps a field in this structure



Track pointers

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



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Approach

- Track pointers
  - find root pointers
  - track how pointers derive from each other
    - for any address B=A+8, we need to know A.
- Challenges:
  - missing base pointers
    - for instance, a field of a struct on the stack may be updated using EBP rather than a pointer to the struct
  - multiple base pointers
    - e.g., normal access and `memset()`

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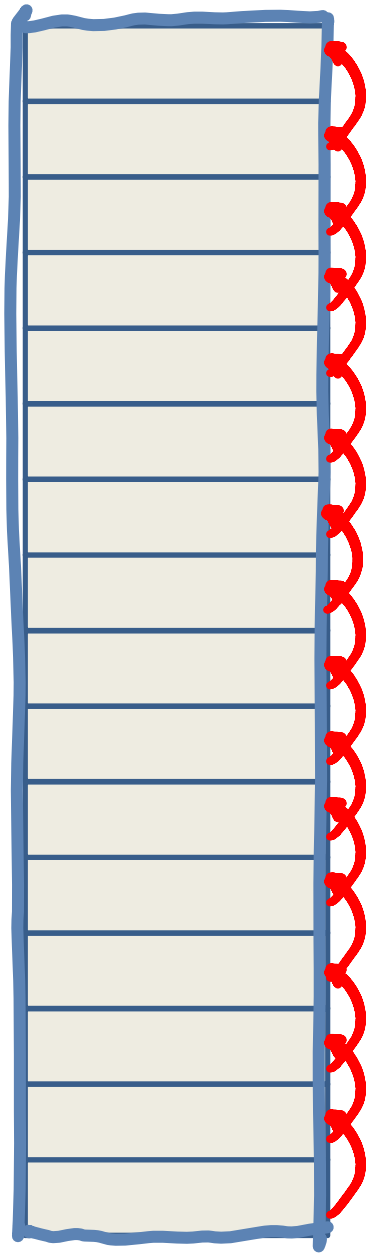
Arrays are tricky

- Detection:
  - looks for chains of accesses in a loop



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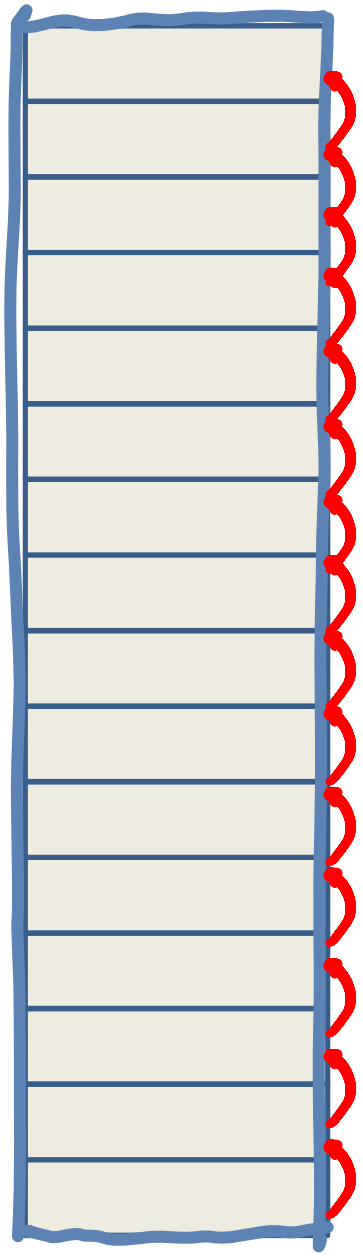

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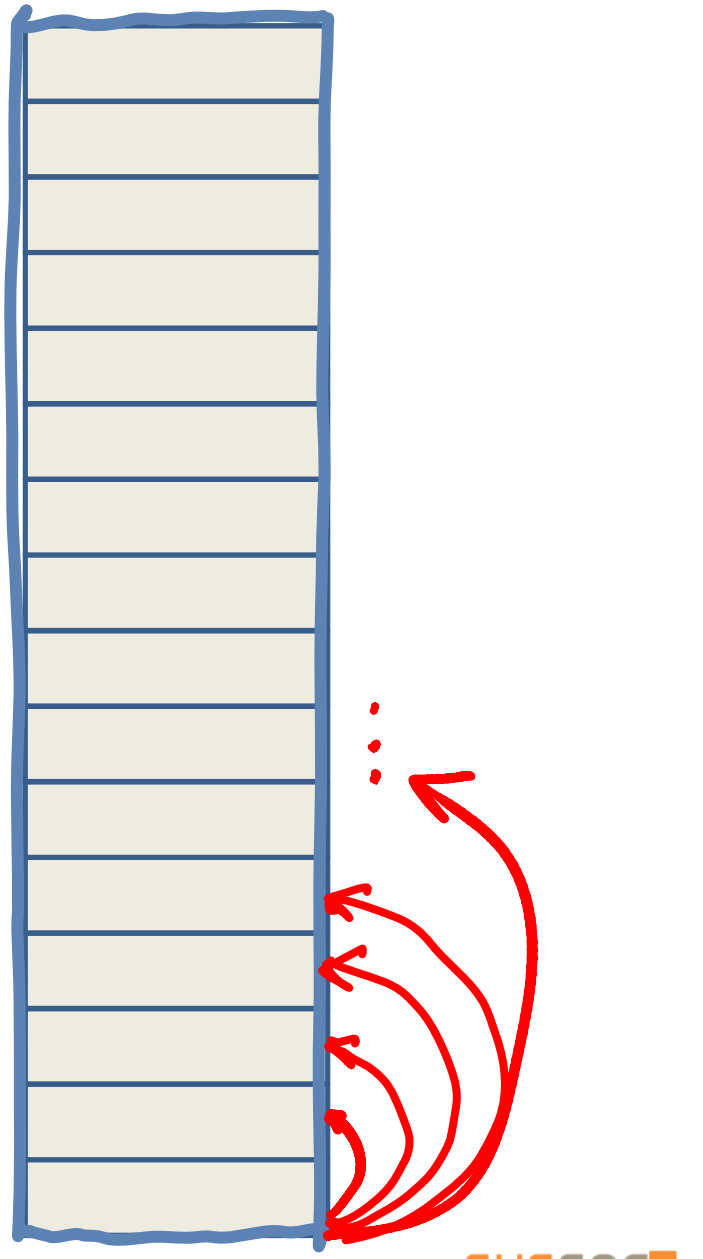

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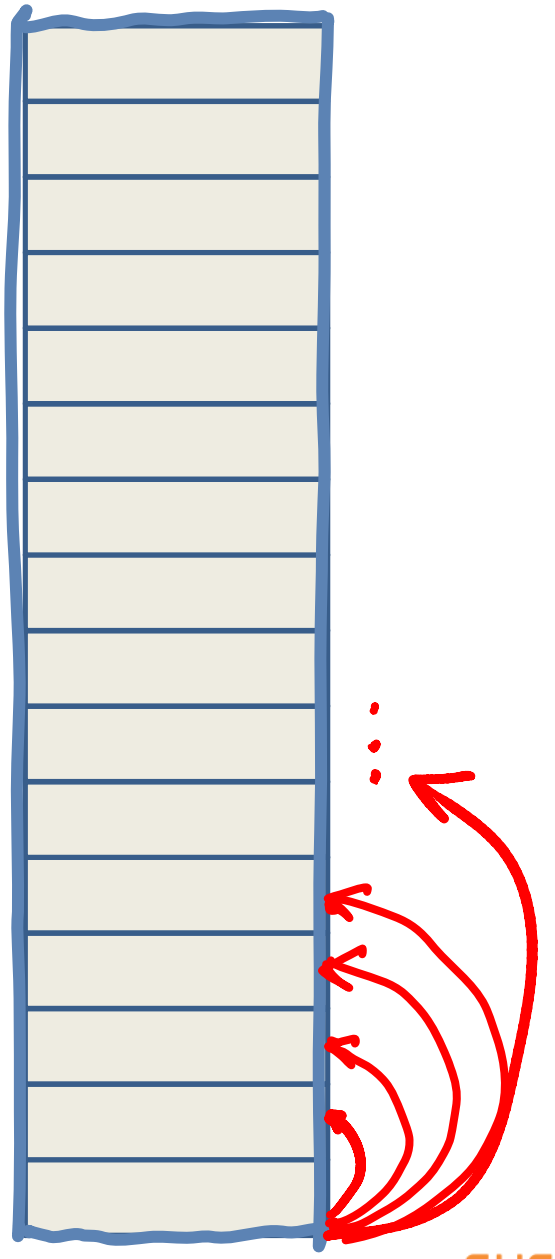
Arrays are tricky

- Detection:
  - looks for chains of accesses in a loop
  - and sets of accesses with same base in linear space



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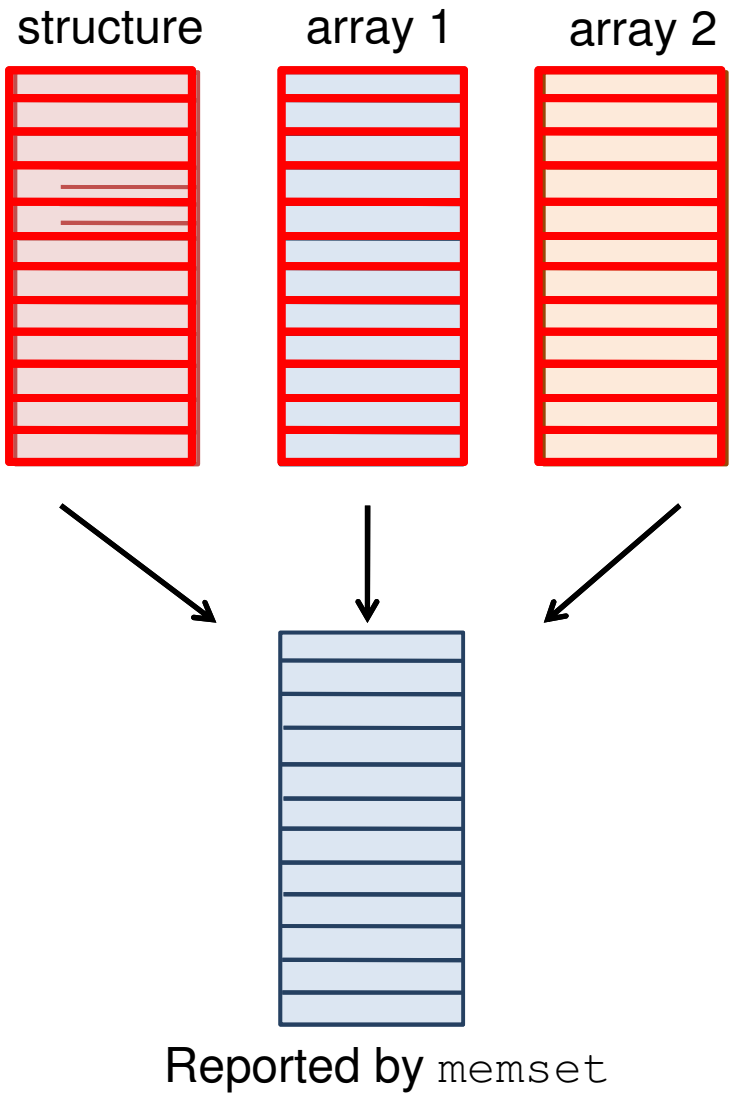
Interesting challenges

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



Challenges

- Arrays
  - Nested loops
  - Consecutive loops
  - Boundary elements

Final mapping

- map access patterns to data structures
  - static memory : on program exit
  - heap memory : on free
  - stack frames : on return

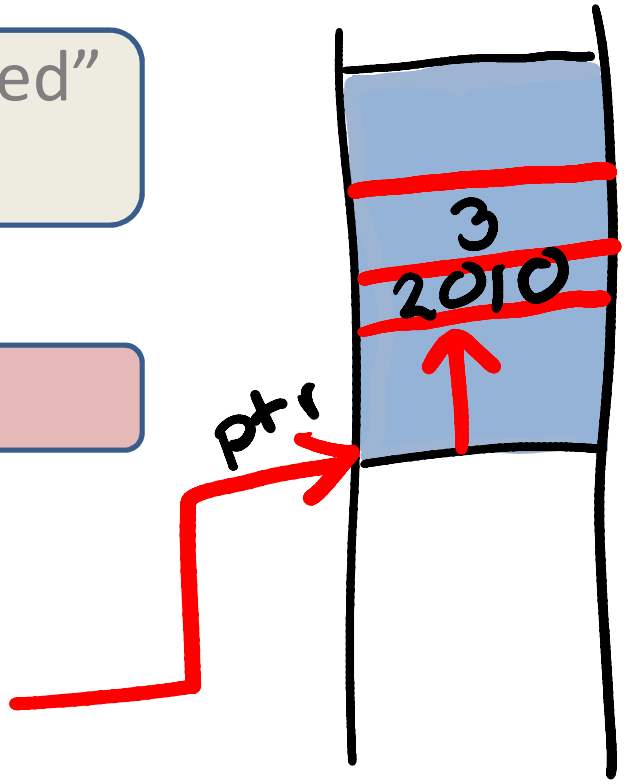
What about semantics?

Semantics: key insight

Yes, data is “apparently unstructured”

But usage is not!

Usage (again) reveals semantics



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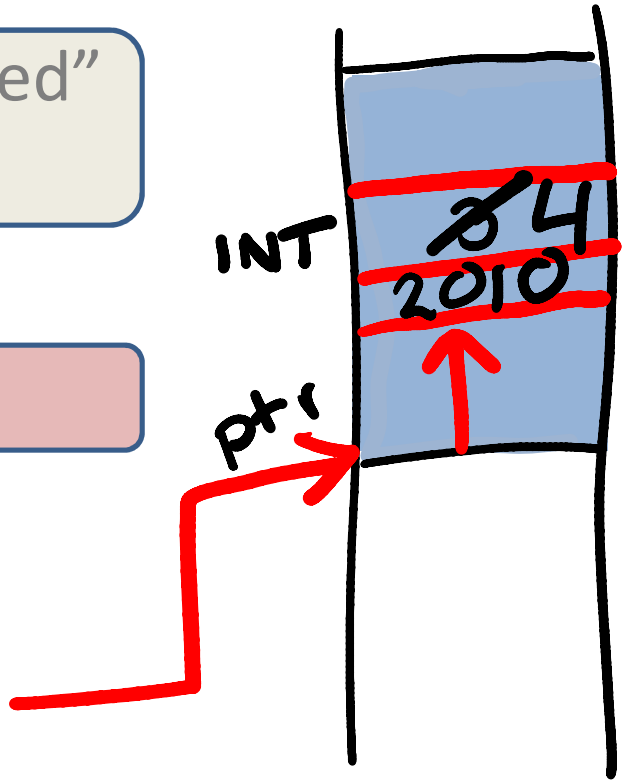

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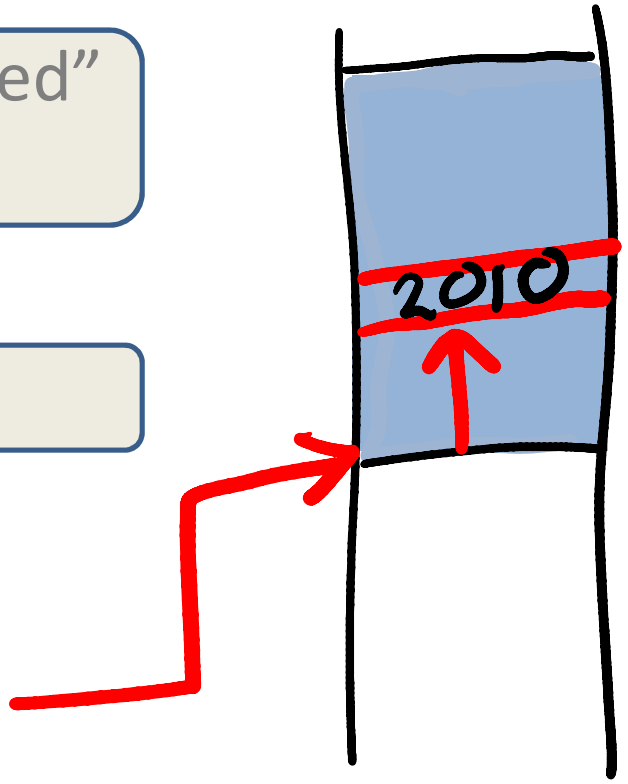

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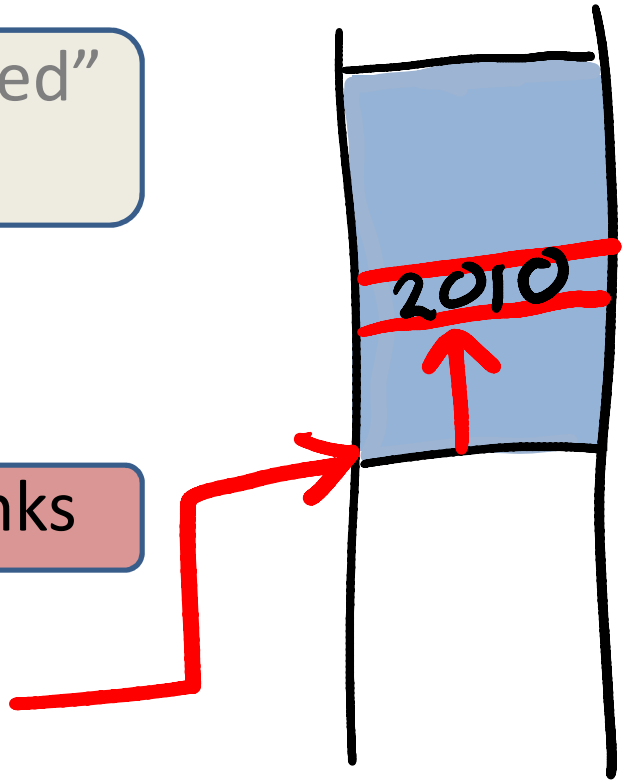
Propagate types from sources + sinks



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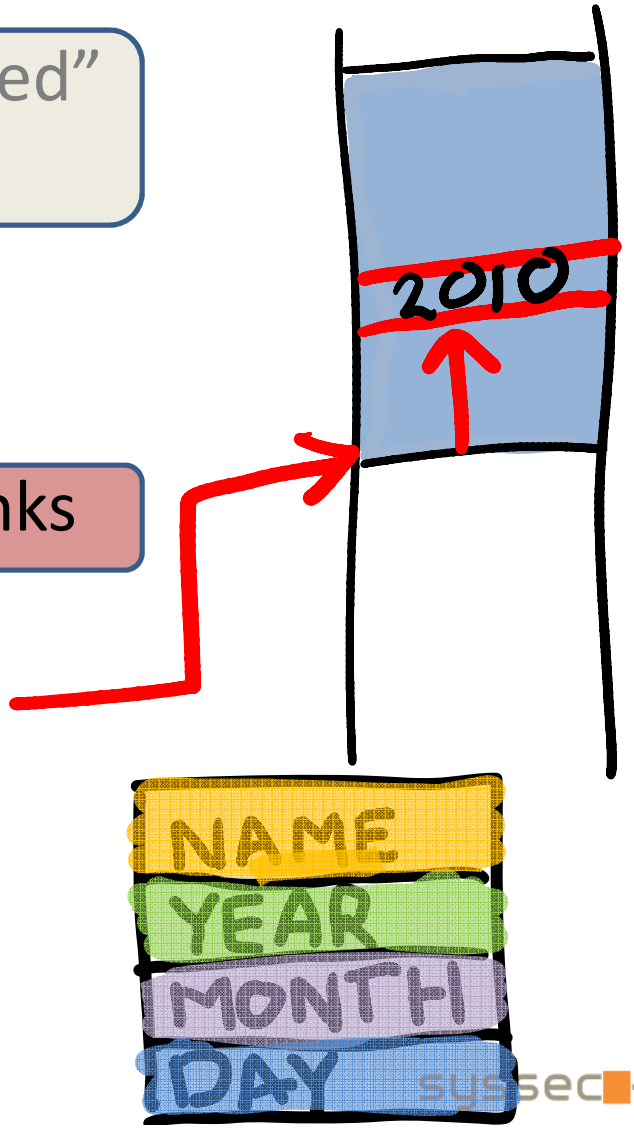

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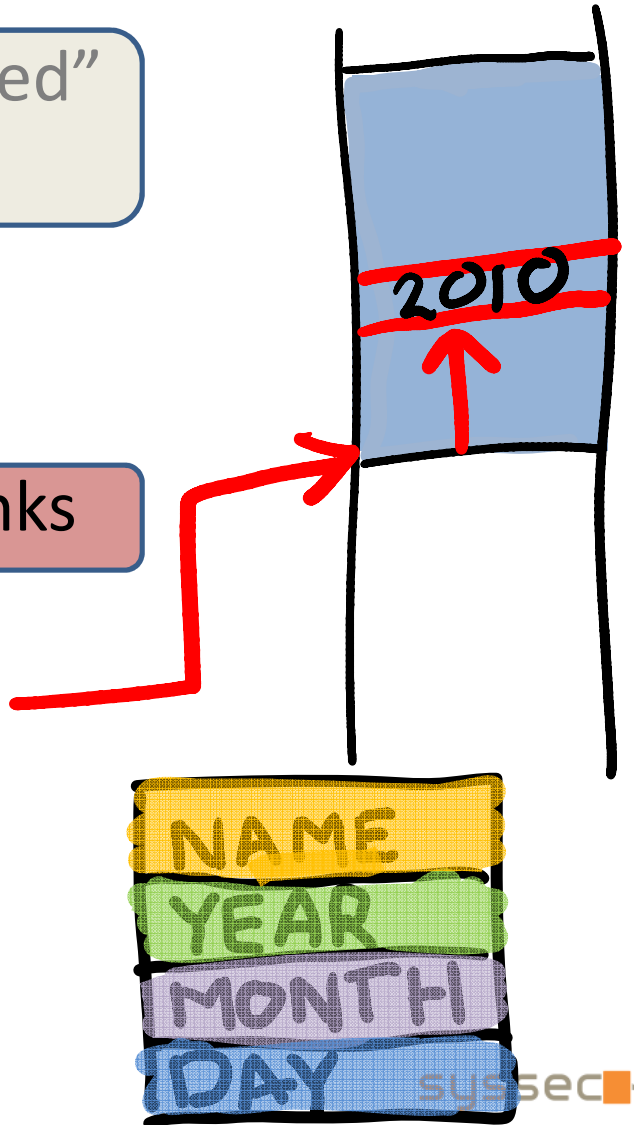

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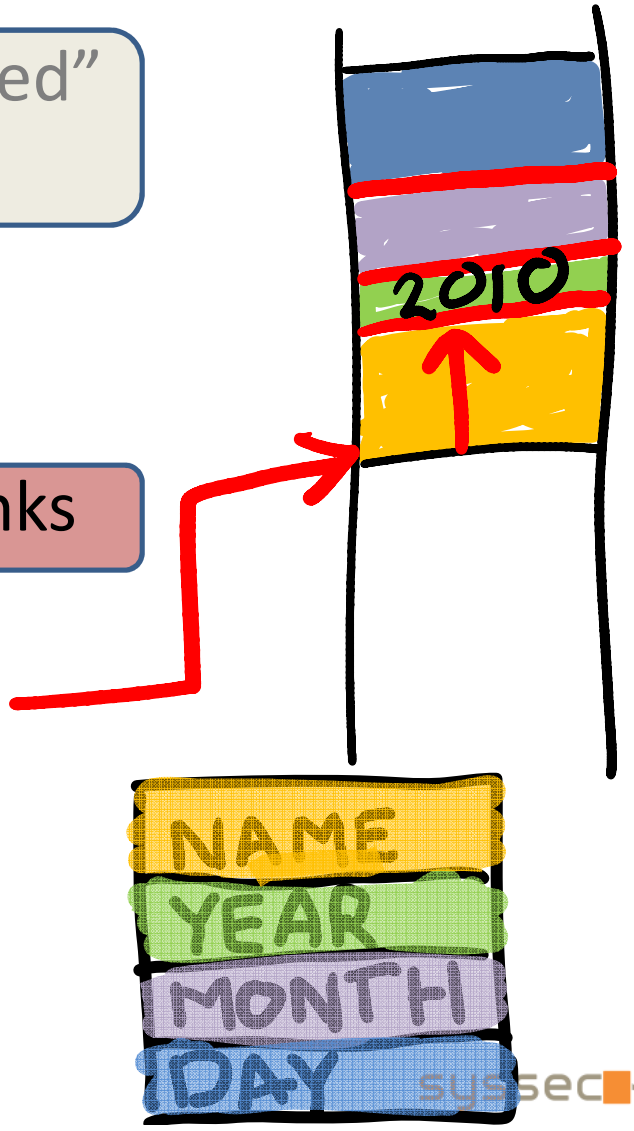

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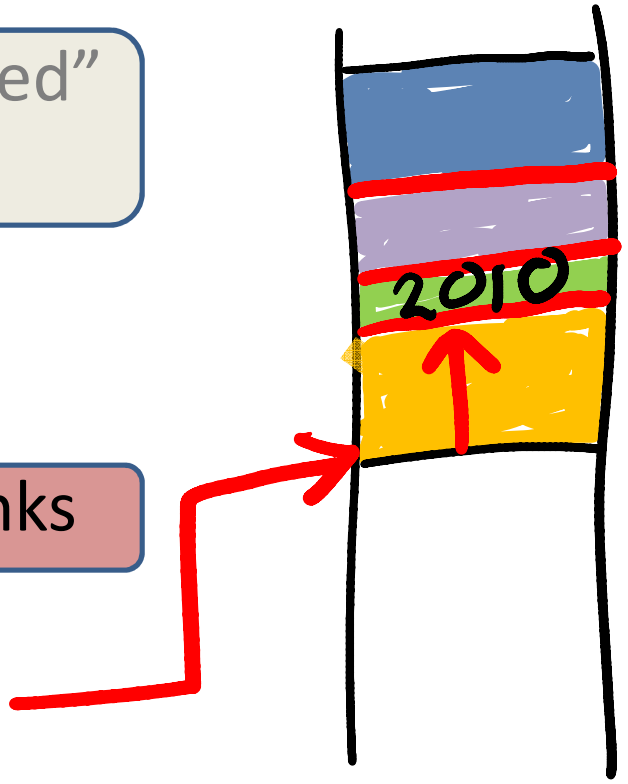

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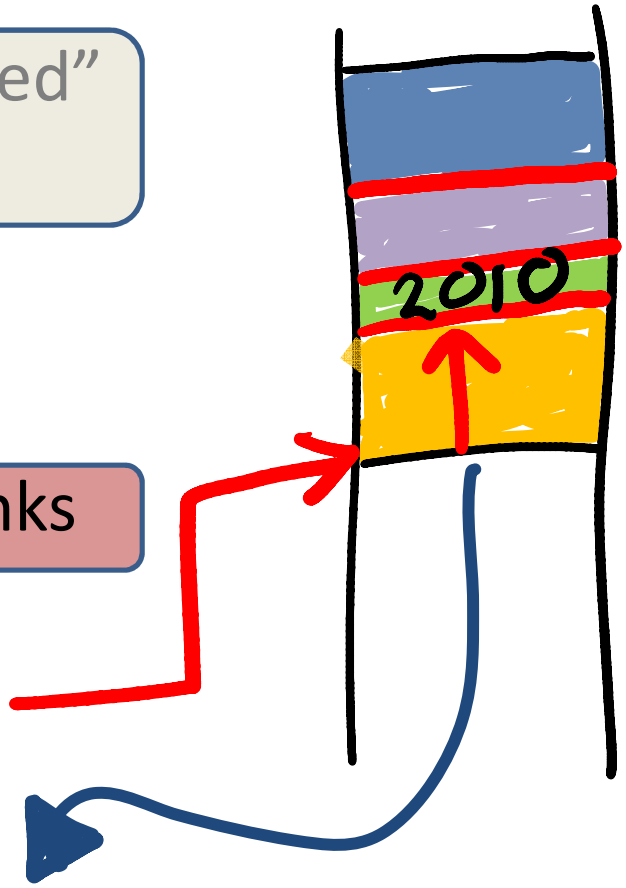

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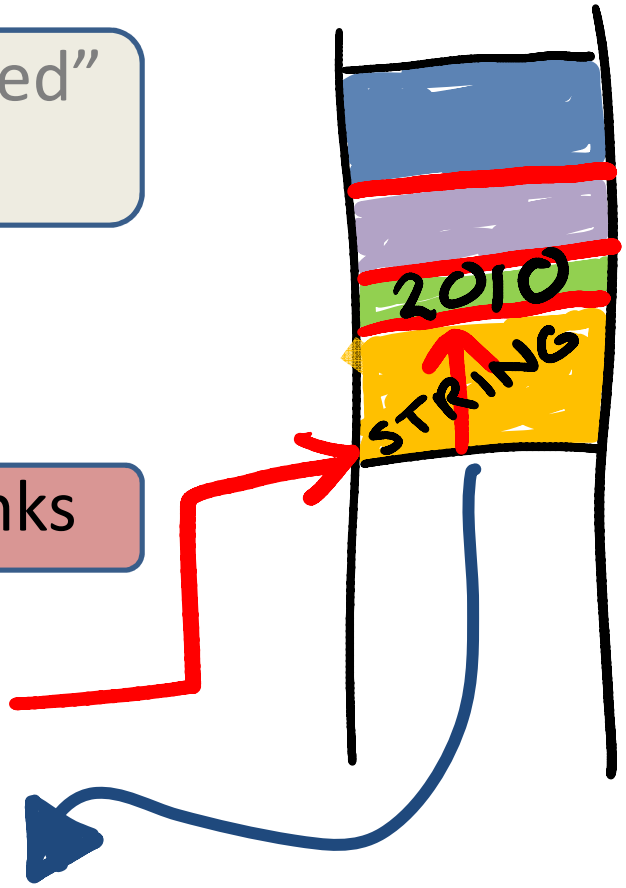

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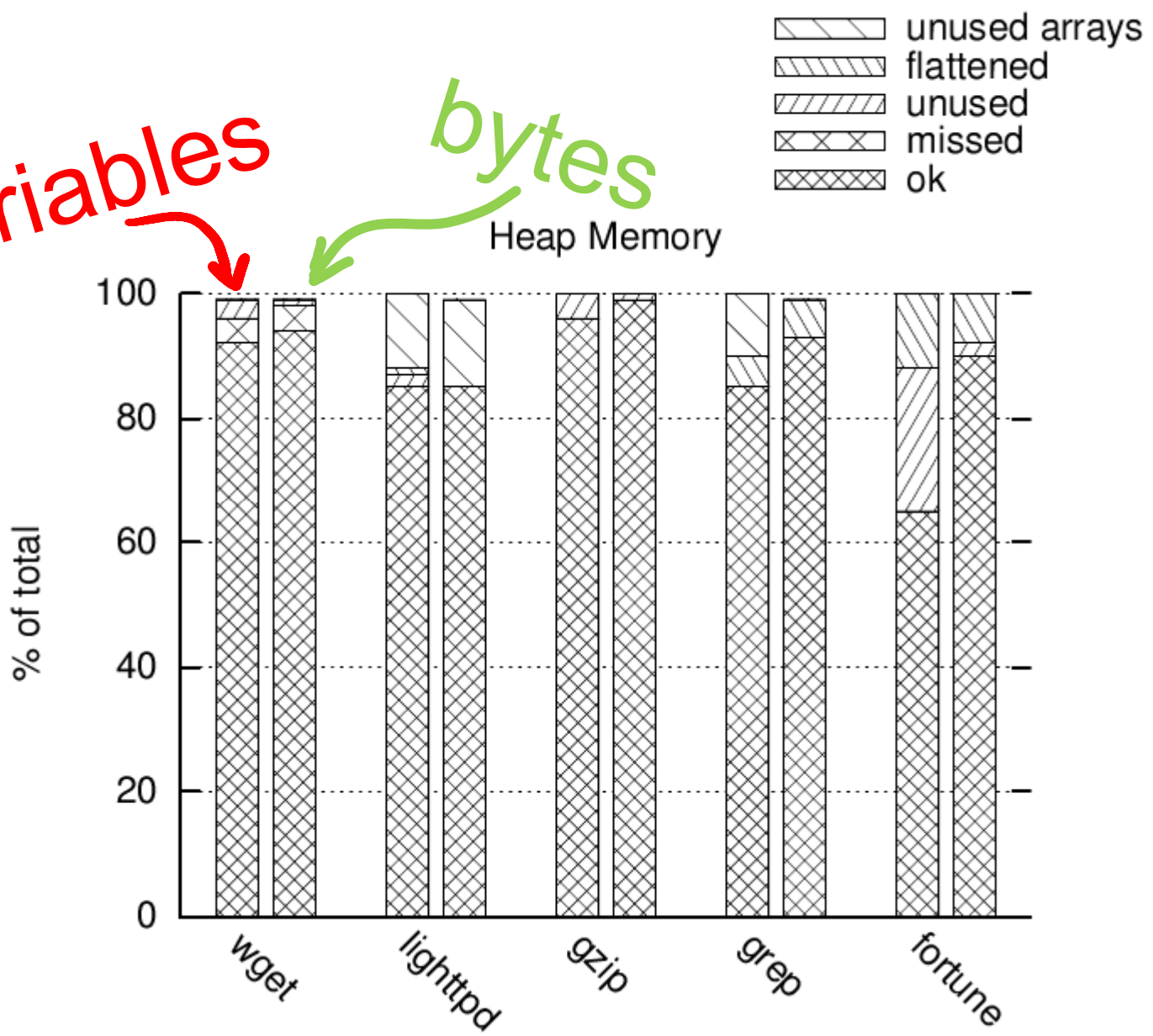
Results

Results

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



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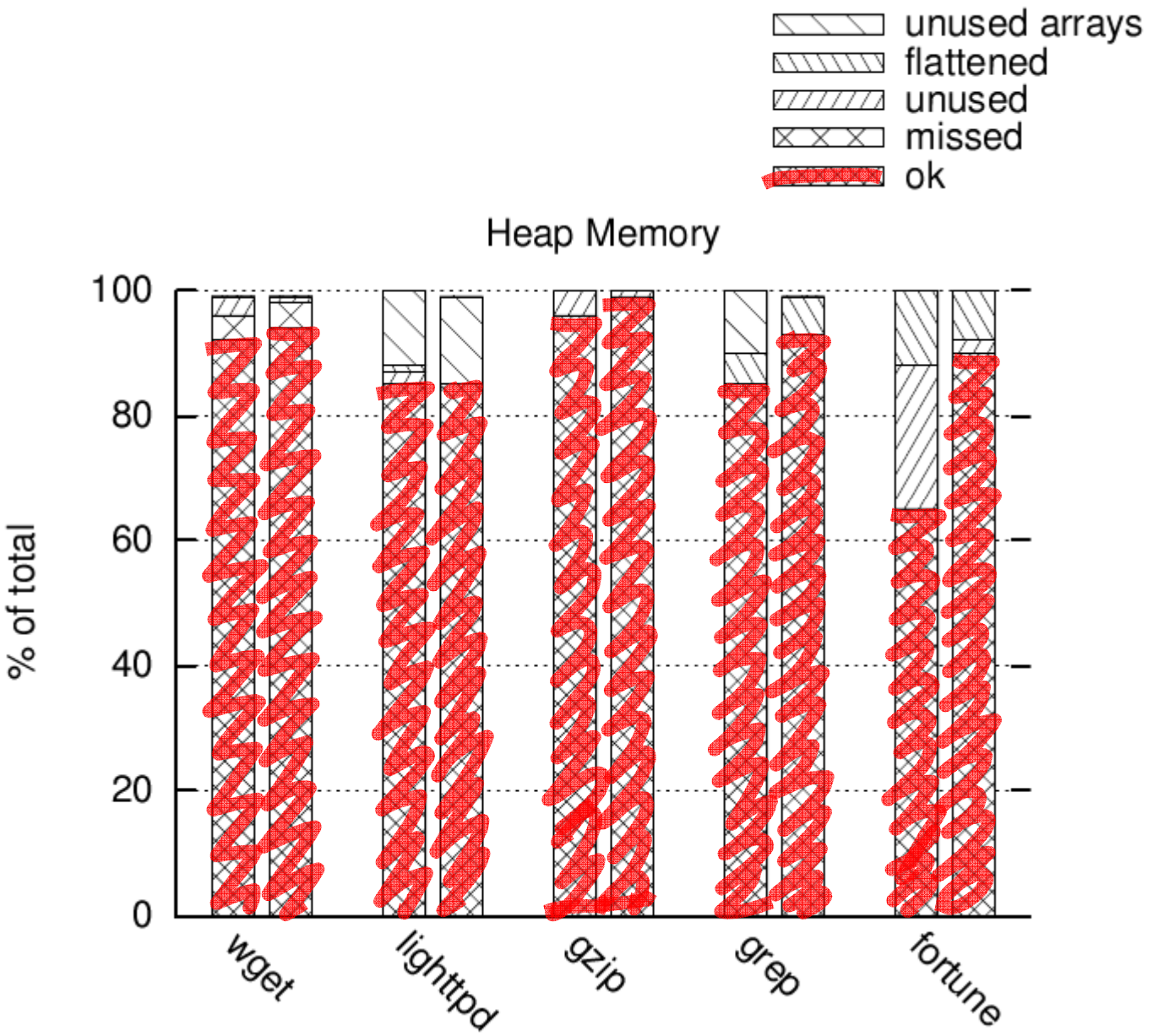

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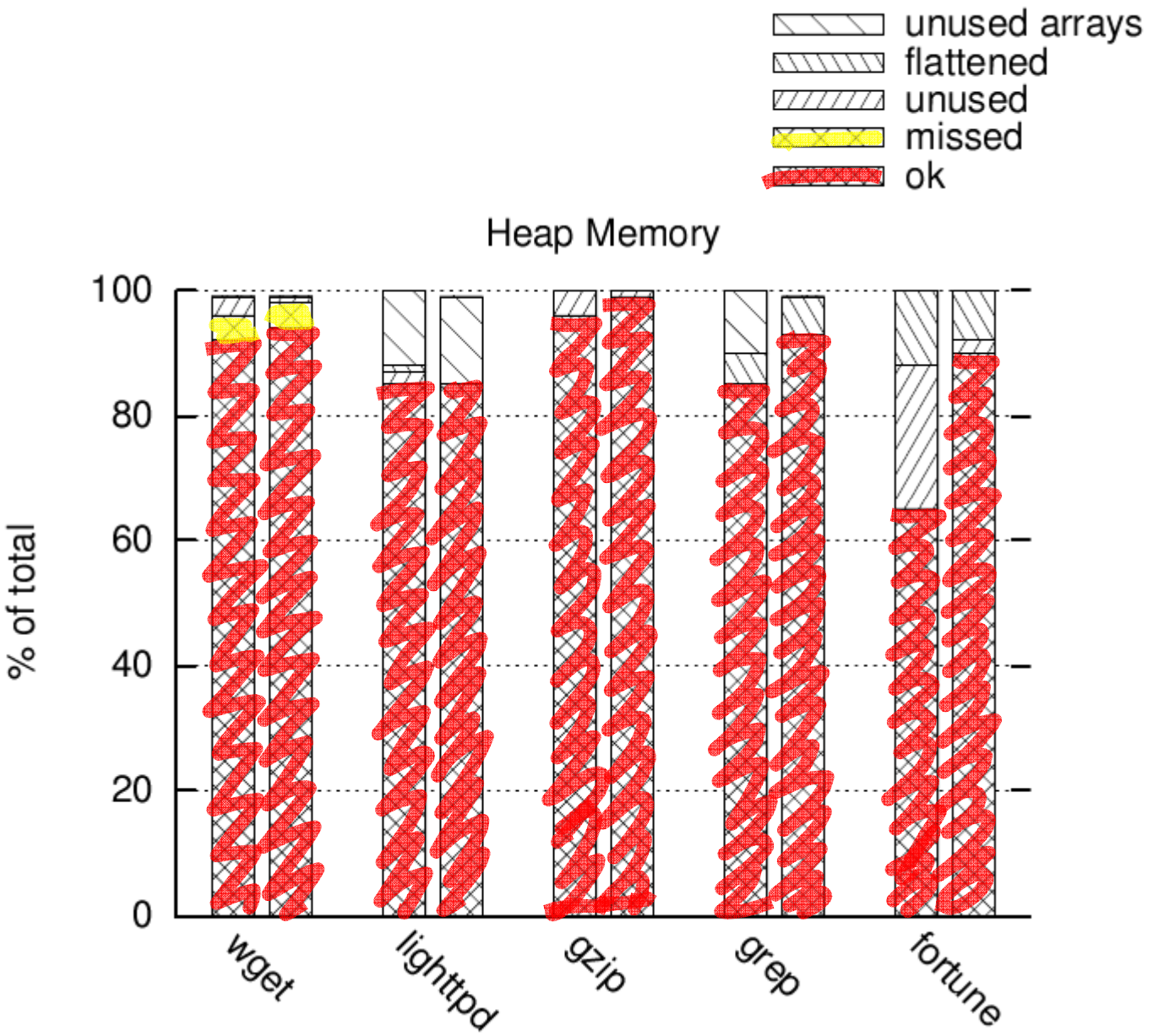

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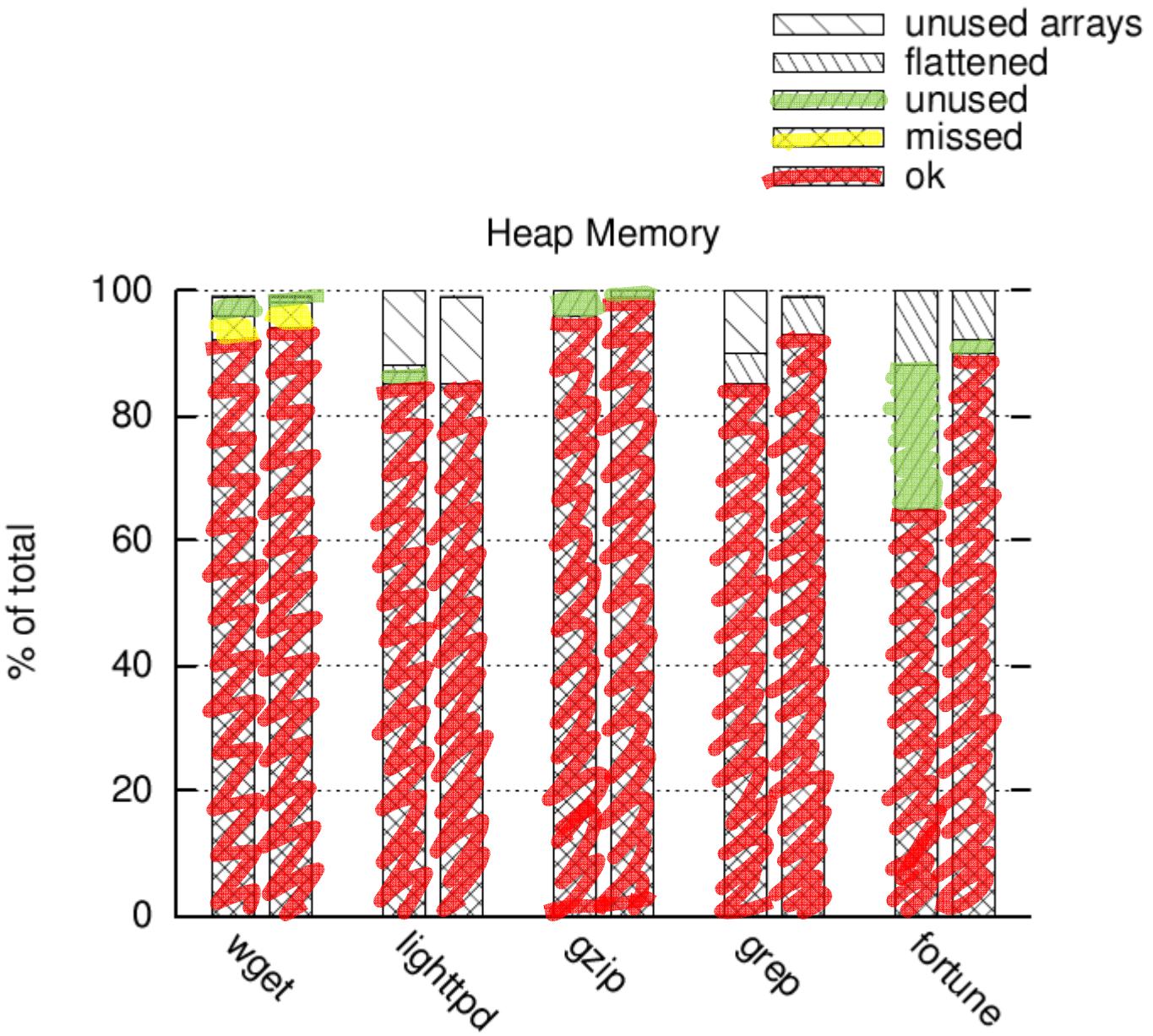

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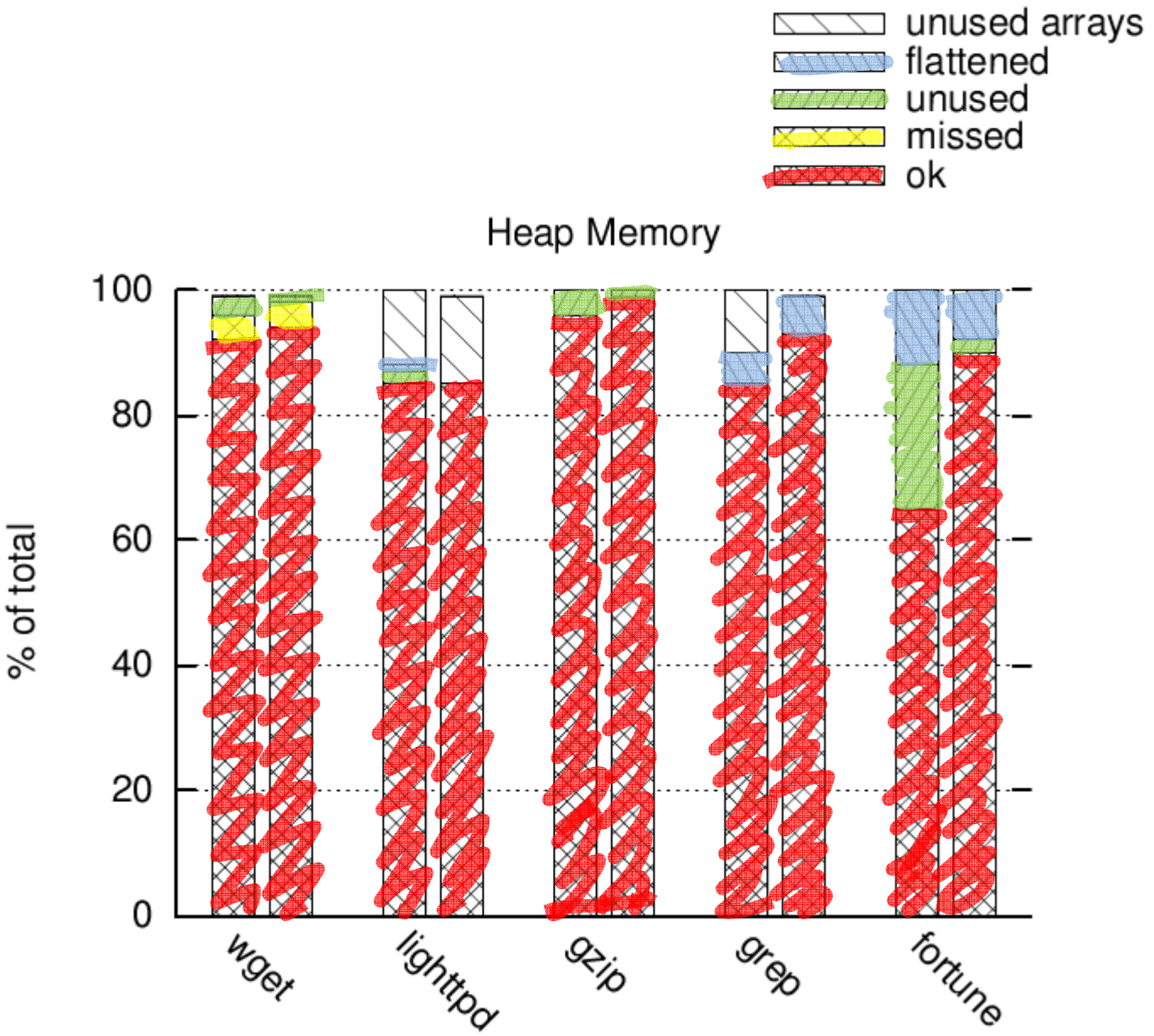

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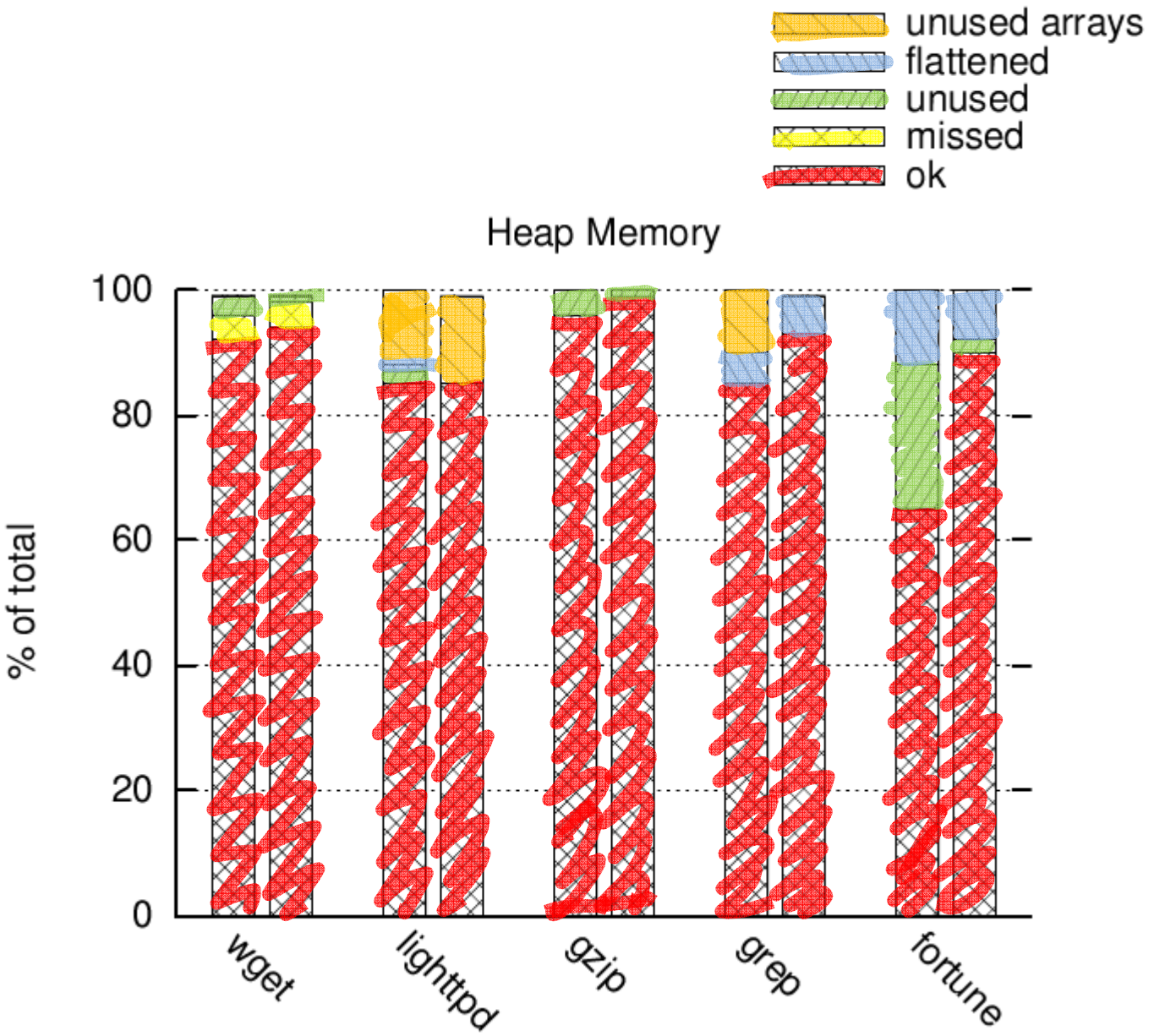

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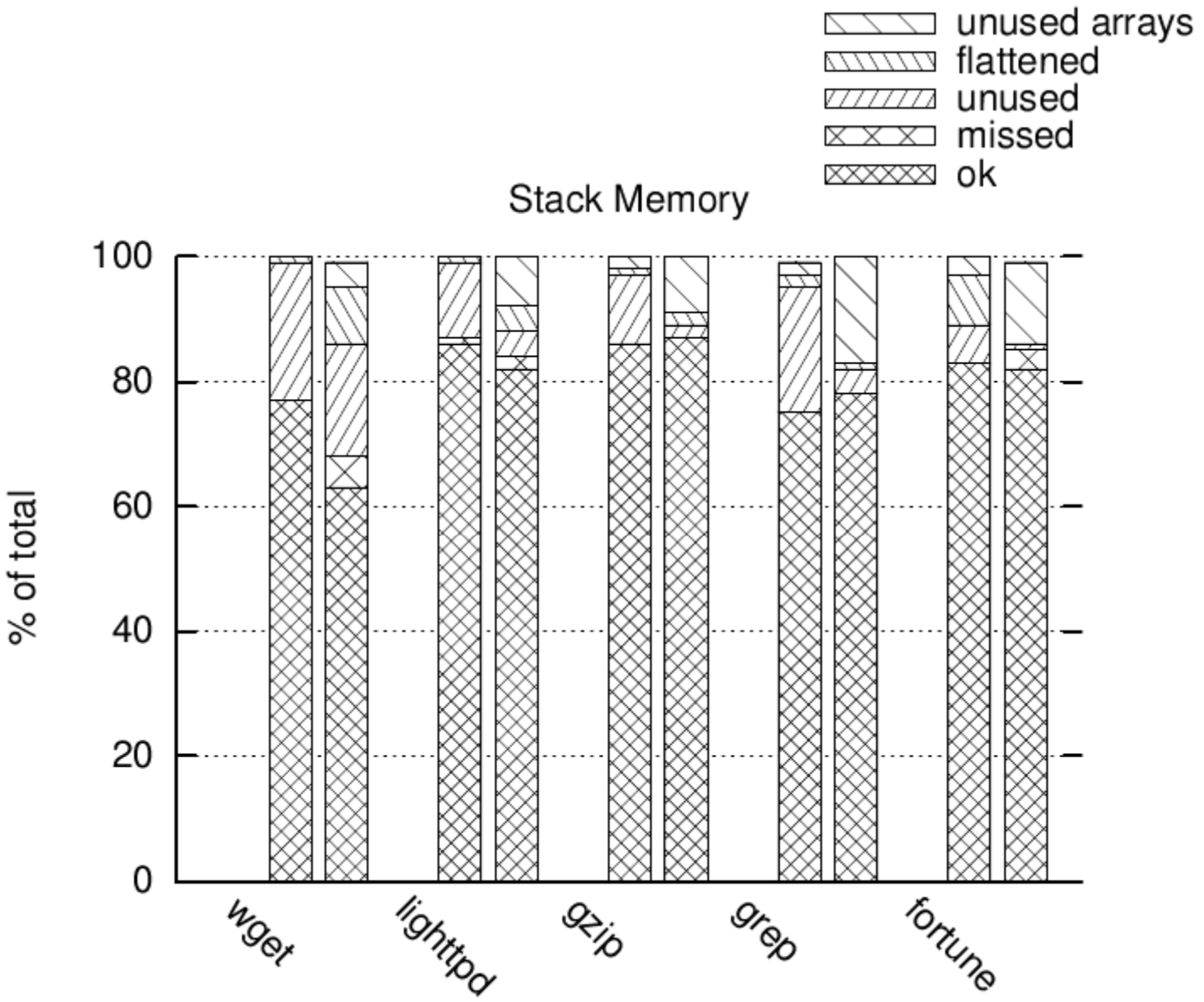

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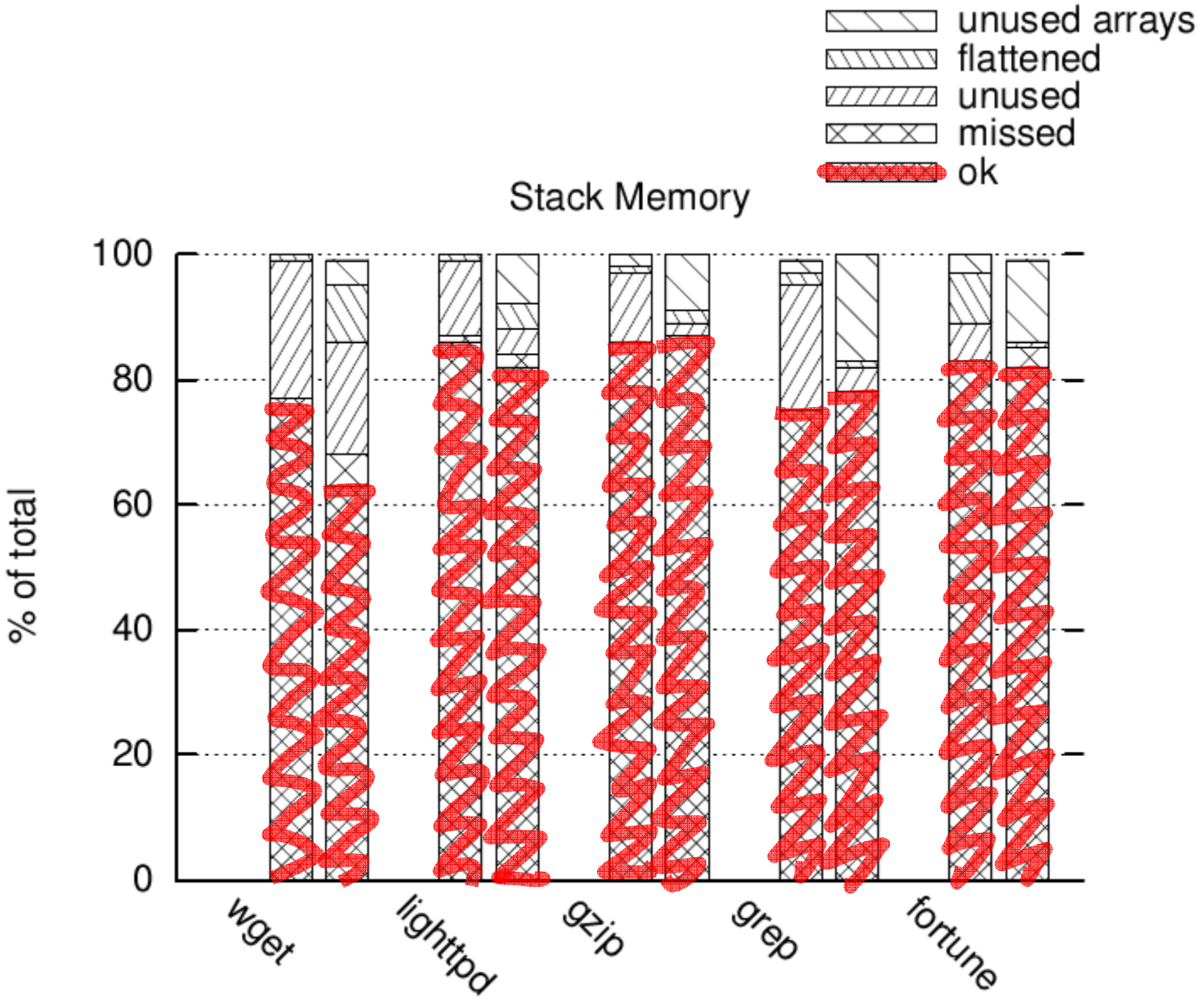
Results

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



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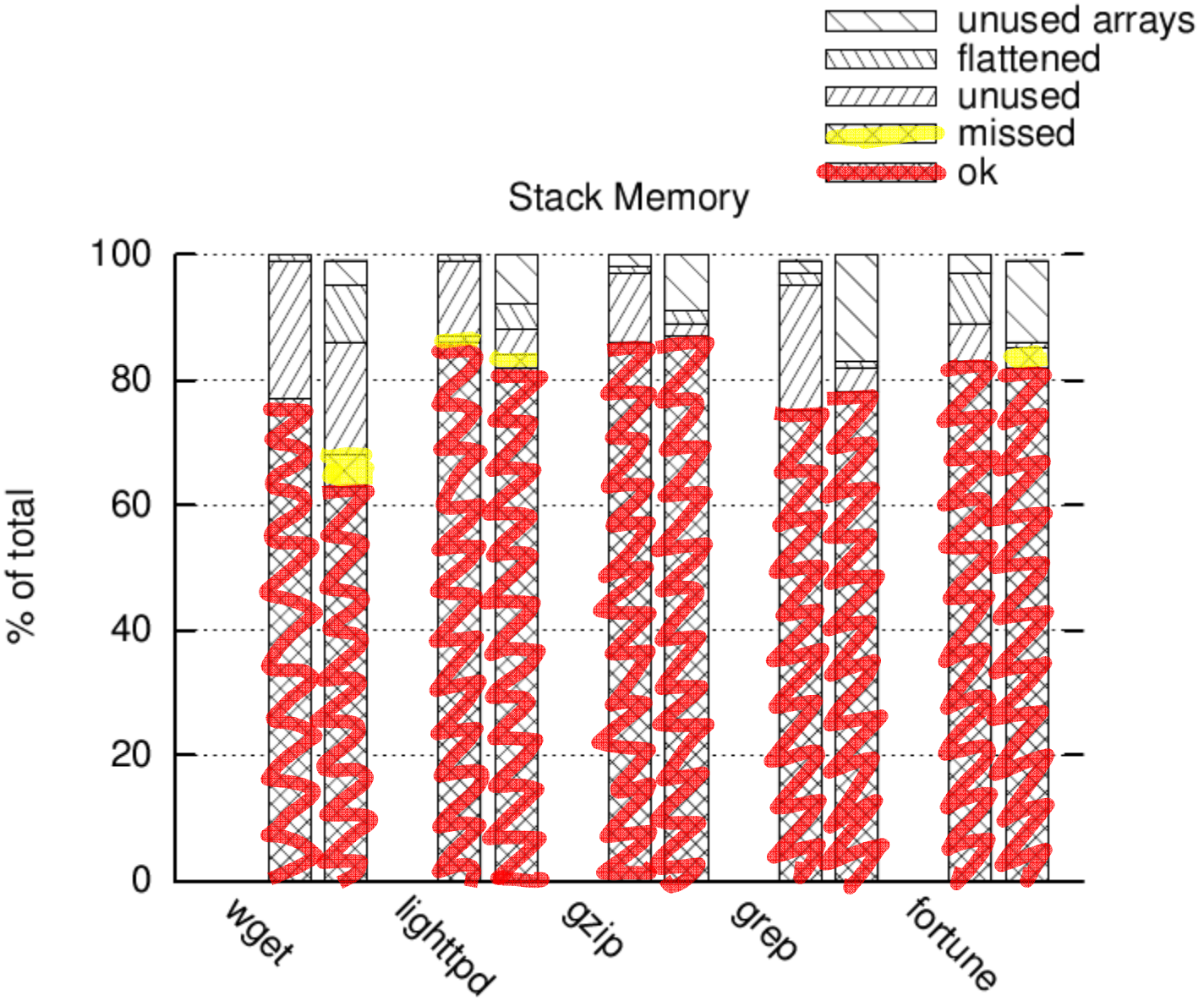

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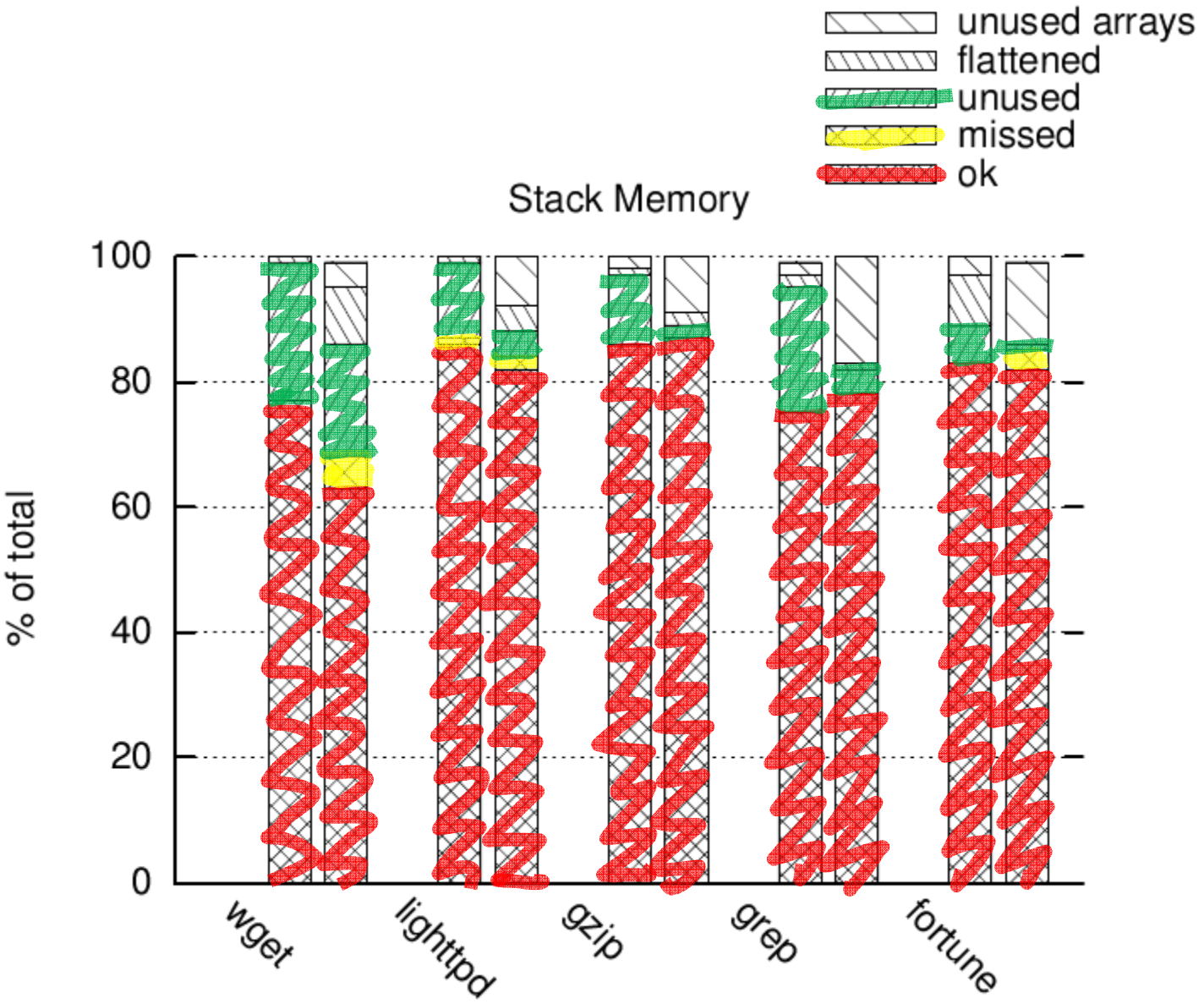

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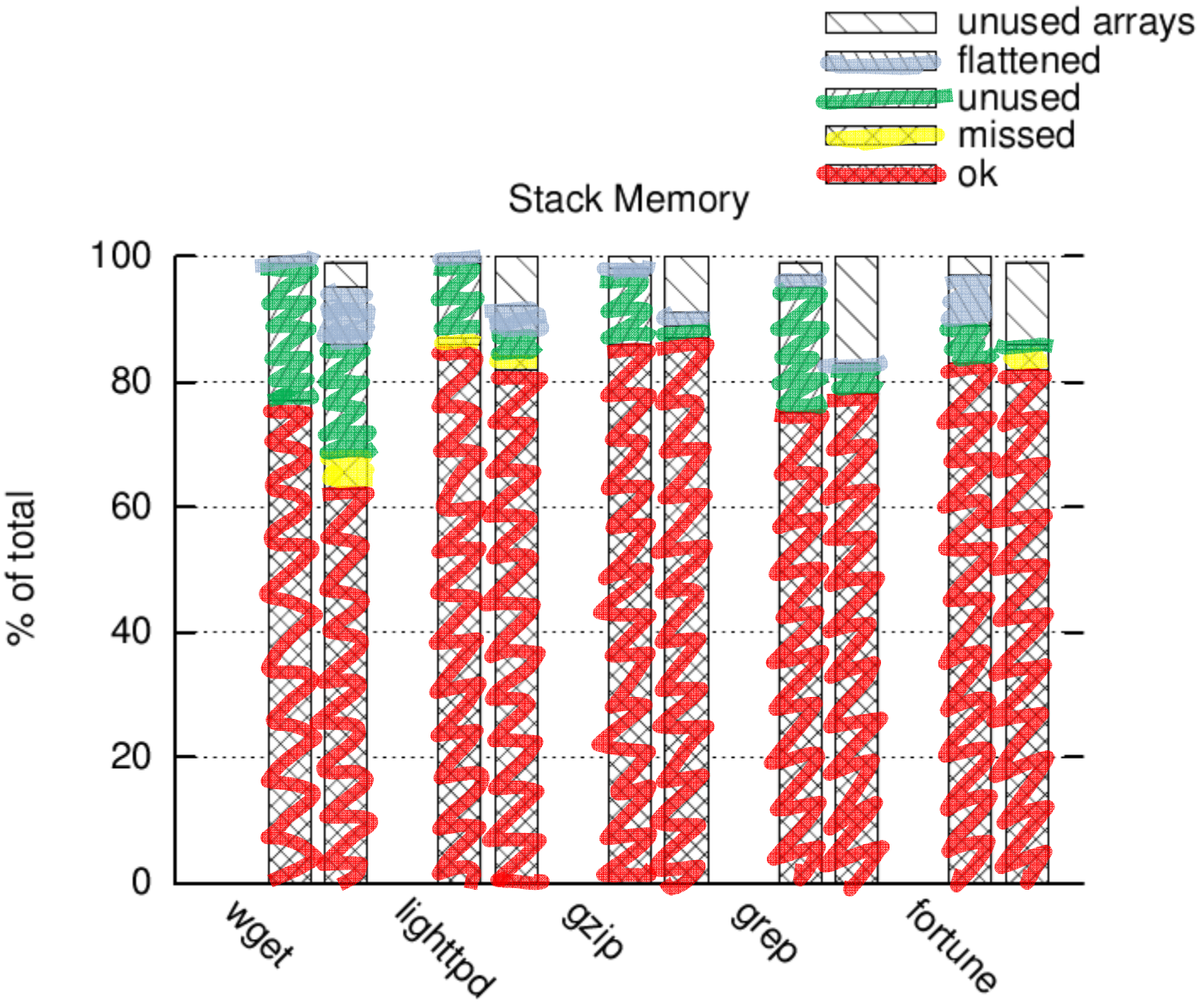

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Prog	LoC
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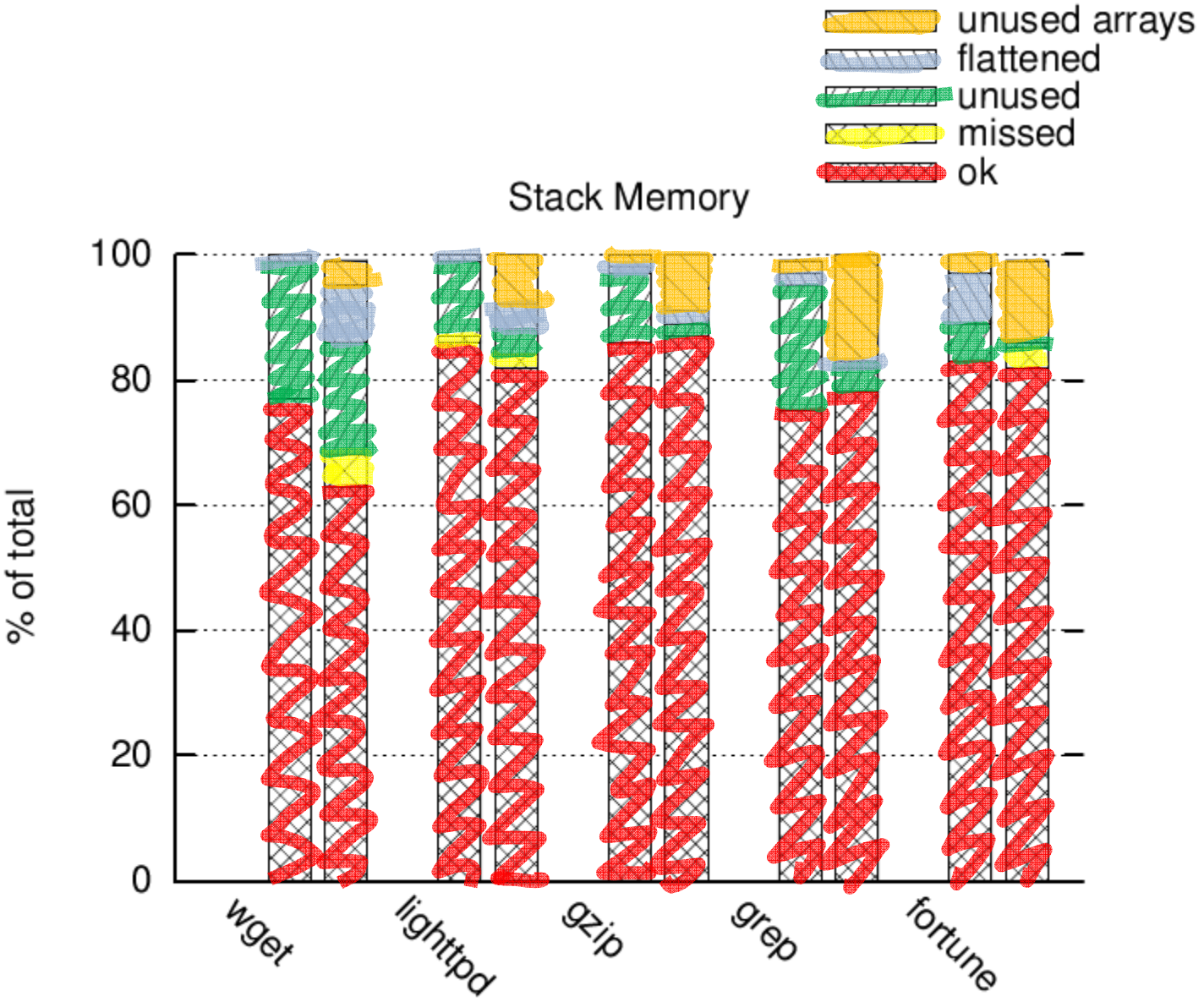

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EU FP7 Network of Excellence in Systems Security

- consolidate Systems Security research in Europe
- promote cybersecurity education
- identify threats and vulnerabilities of the *Current and Future Internet*
- create active research roadmap in the area
- develop a joint working plan to conduct State-of-the-Art collaborative research.

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Conclusions

- We *can* recover data structures by tracking memory accesses
- We believe we can protect legacy binaries
- We need to work on data coverage

http://www.cs.vu.nl/~herbertb/papers/trdatastruct-ir-cs-57.pdf

http://www.few.vu.nl/~asia/papers/pdf_files/dde_tr10.pdf

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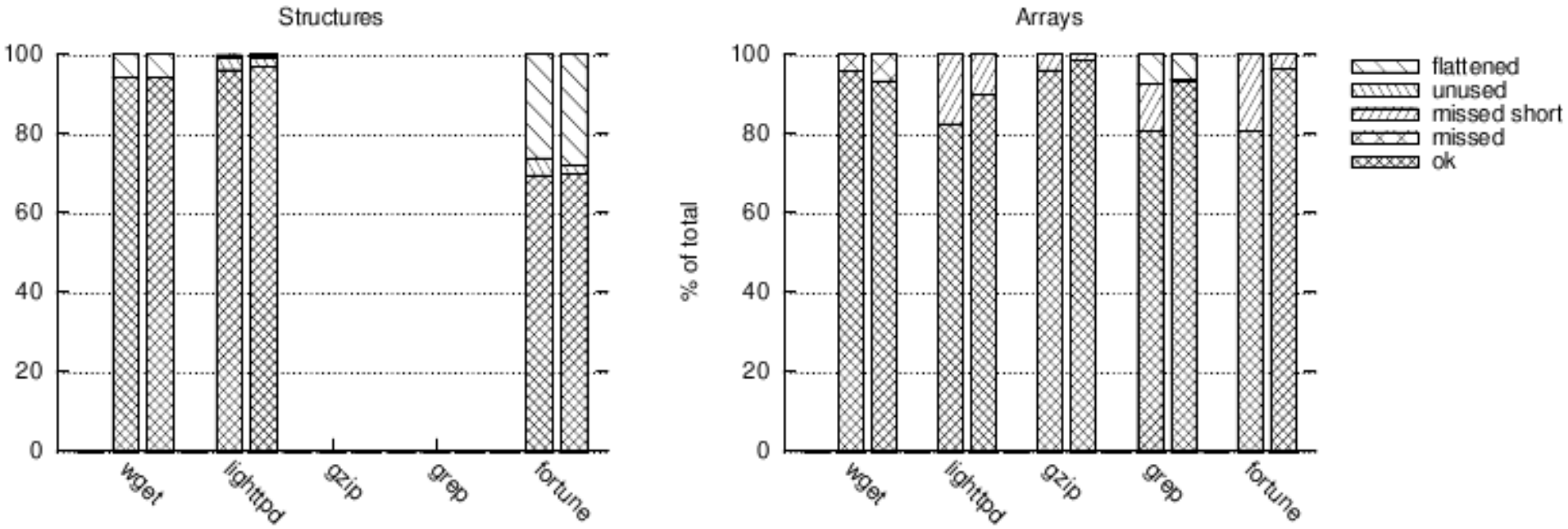
More details



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```
asia@dolphin:~/vu/dynamit_instrumented_binaries/wget$ file wget.gdb
wget.gdb: ELF 32-bit LSB executable, Intel 80386, version 1 (SYSV), dynamically linked (uses
      shared libs), for GNU/Linux 2.6.15, stripped
asia@dolphin:~/vu/dynamit_instrumented_binaries/wget$ gdb -q wget.gdb
Reading symbols from /home/asia/vu/dynamit_instrumented_binaries/wget/wget.gdb...done.
(gdb) b *0x805adb0
Breakpoint 1 at 0x805adb0
(gdb) run www.google.com
[Thread debugging using libthread_db enabled]
--2010-09-27 15:33:44--  http://www.google.com/

Breakpoint 1, 0x0805adb0 in function0 ()
(gdb)
```

```
(gdb) info scope function0
Scope for function0:
Symbol variables_function0 is a variable with complex or multiple locations (DWARF2), length
    152.
(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 = 5795587982483132O0, 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}
(gdb) watch variables_function0.pointer_struct_1_0
Hardware watchpoint 2: variables_function0.pointer_struct_1_0
(gdb) continue
Resolving www.google.com... Hardware watchpoint 2: variables_function0.pointer_struct_1_0

Old value = (struct struct_1 *) 0x0
New value = (struct struct_1 *) 0x80b2678
0x0805af5f in function0 ()
(gdb)
```

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```
(gdb) print /x *variables_function0.pointer_struct_1_0
$2 = {field_4_bytes_0 = 0x3, pointer_struct_0_0 = 0x80b2690, field_int_0 = 0x0, field_1_byte_0 = 0x0,
      field_4_bytes_1 = 0x0}
(gdb) print /x *variables_function0.pointer_struct_1_0.pointer_struct_0_0
$3 = {field_4_bytes_0 = 0x2, field_in_addr_t_0 = 0x634d7d4a}
(gdb) print (char*) inet_ntoa(variables_function0.pointer_struct_1_0.pointer_struct_0_0.field_in_addr_t_0)
$4 = 0xb7fe46a0 "74.125.77.99"
(gdb) print malloc_usable_size(variables_function0.pointer_struct_1_0.pointer_struct_0_0)
      /sizeof(*variables_function0.pointer_struct_0_0)
$5 = 3
(gdb) print /x variables_function0.pointer_struct_1_0.pointer_struct_0_0[1]
$6 = {field_4_bytes_0 = 0x2, field_in_addr_t_0 = 0x684d7d4a}
(gdb) print (char*) inet_ntoa(variables_function0.pointer_struct_1_0.pointer_struct_0_0[1].field_in_addr_t_0)
$7 = 0xb7fe46a0 "74.125.77.104"
(gdb) print /x variables_function0.pointer_struct_1_0.pointer_struct_0_0[2]
$8 = {field_4_bytes_0 = 0x2, field_in_addr_t_0 = 0x934d7d4a}
(gdb) print (char*) inet_ntoa(variables_function0.pointer_struct_1_0.pointer_struct_0_0[2].field_in_addr_t_0)
$9 = 0xb7fe46a0 "74.125.77.147"
(gdb)
```

```
(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}
```

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