Full Speed in Reverse

protecting legacy binaries from memory corruption attacks

syssec

Herbert Bos

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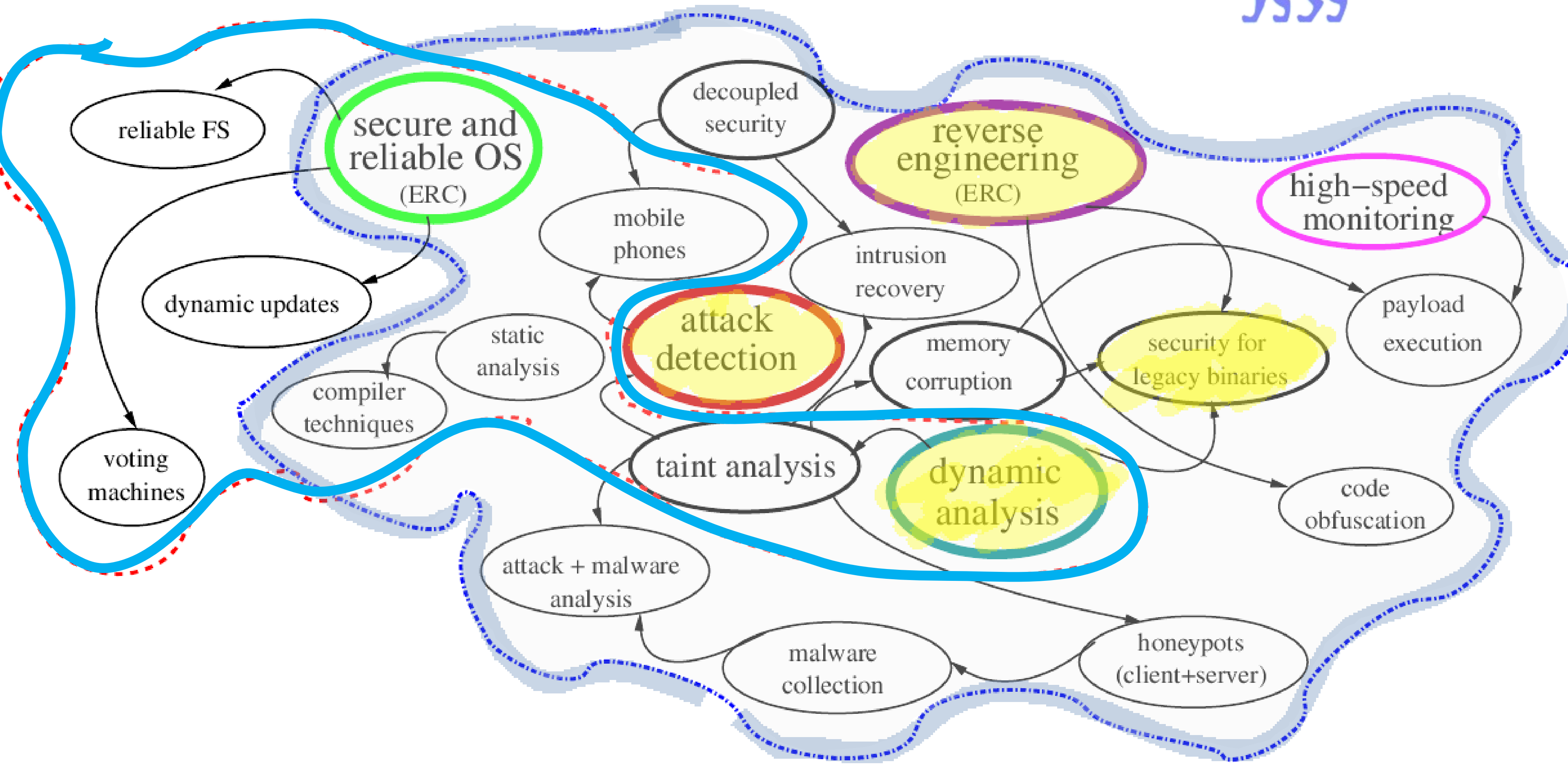

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Grants

- ERC StG “Rosetta”
- EU FP 7 Syssec
- DG Home iCode

CAN WE WIN?

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Can we stop advanced malware?

- Like Stuxnet, Duqu, Zeus, TDL4, Flame(?)

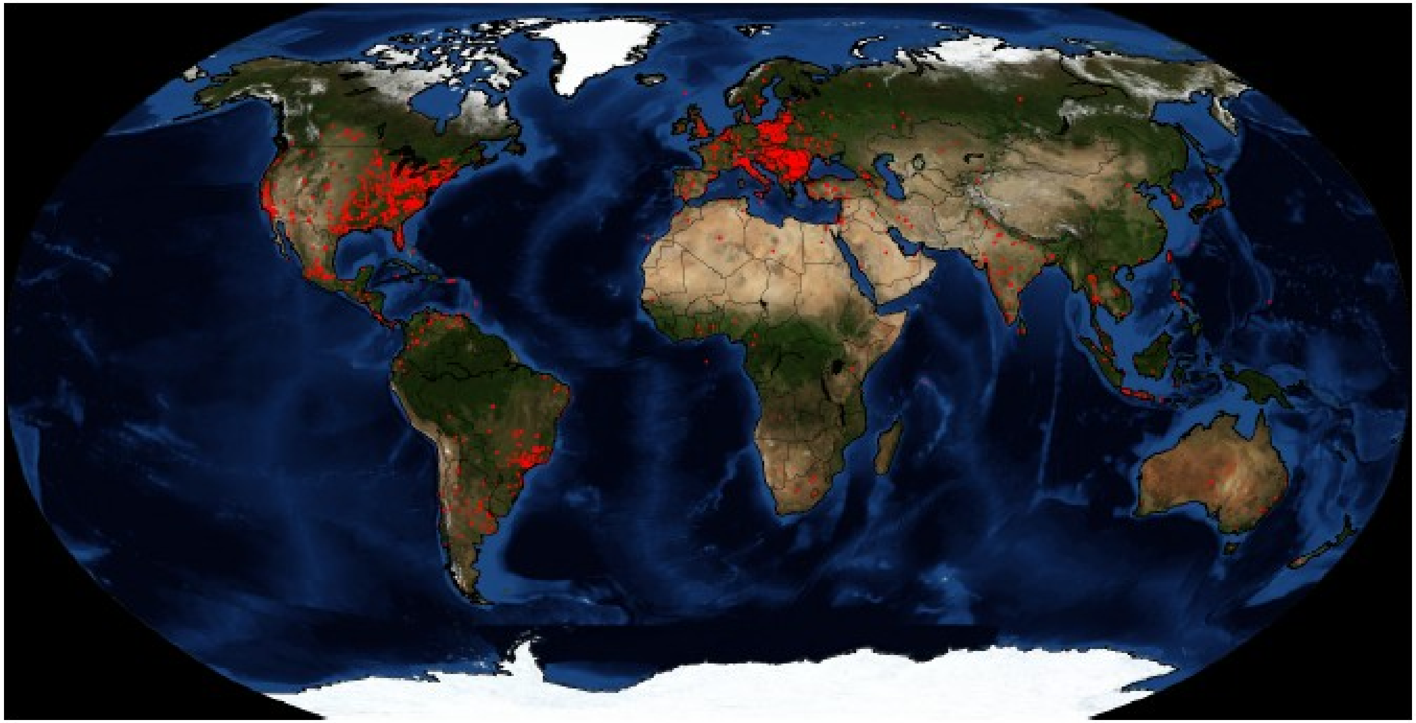
Can we stop advanced malware?

- Zeus is a banking trojan that has been around since 2007
- Sold as a DIY toolkit, anyone can create their own botnet for $4000
- In 2010, the FBI discovered an organized crime network which stole over $70m using Zeus

Can we stop advanced malware?

Zeus v3

- In May 2011, the source code of Zeus v2 was leaked
- The leaked code evolved into a new Zeus P2P variant around October
- The Zeus P2P network is currently estimated to consist of 150.000 – 200.000 peers worldwide



Can we stop advanced malware?

- We tried
  – based on the work by Dennis Andriess

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Can we stop advanced malware?

- Plan:
  - Reverse engineer relevant parts
  - Poison the botnet
-
- Reversing is hard
  - several layers of encryption and obfuscation
  -
- We dump the code *after* unpacking
  - and get 268.000 lines of assembly ☹

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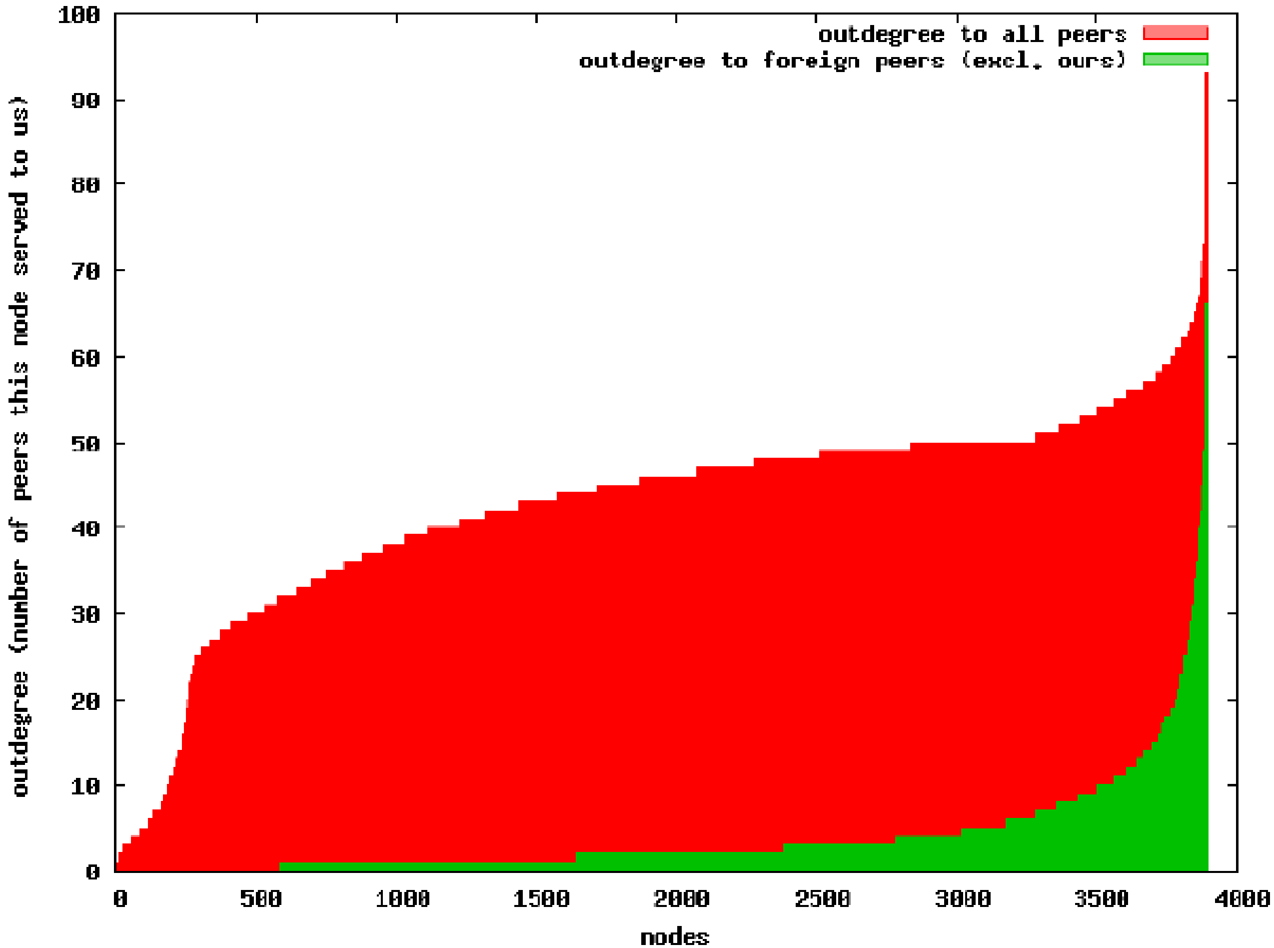
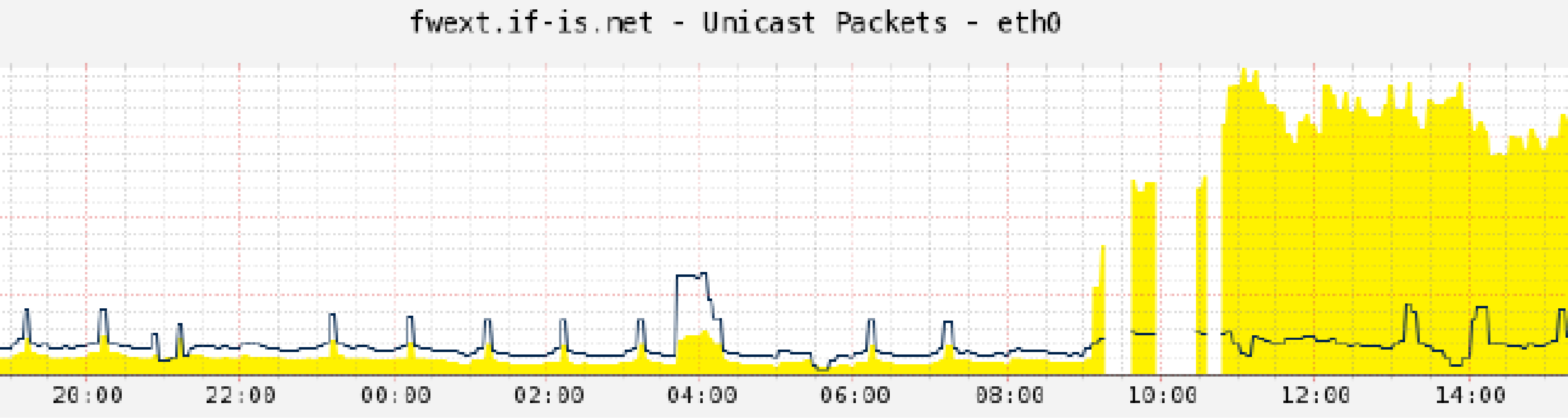
Can we stop advanced malware?

- By May 5th, a significant part of the peerlist entries in the Zeus network points to us



Can we stop advanced malware?

- Zeus strikes back
  - DDoS
  - Update that blacklists our IP addresses



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Can we stop advanced malware?

- We managed to take out 25% of the nodes
-
- In the end, we failed!
-
- Trivial to make even more resilient botnets
-

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Perhaps we need better protection

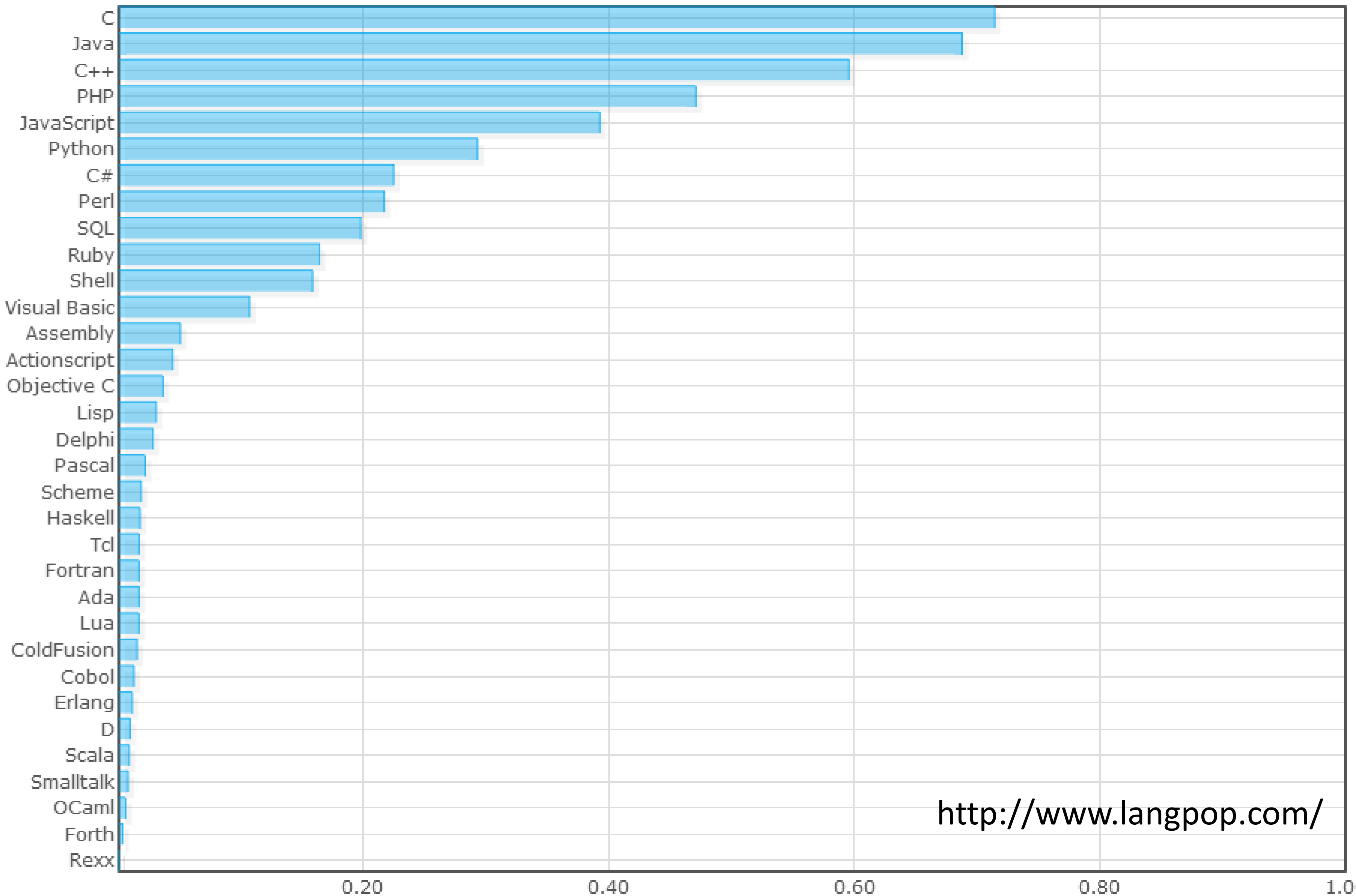
Next few slides are based on

Memory Errors: Past, Present, and Future (RAID'12)

- Victor van der Veen, Nitish Sharma, Lorenzo Cavallaro, Herbert Bos



The most popular language in the world



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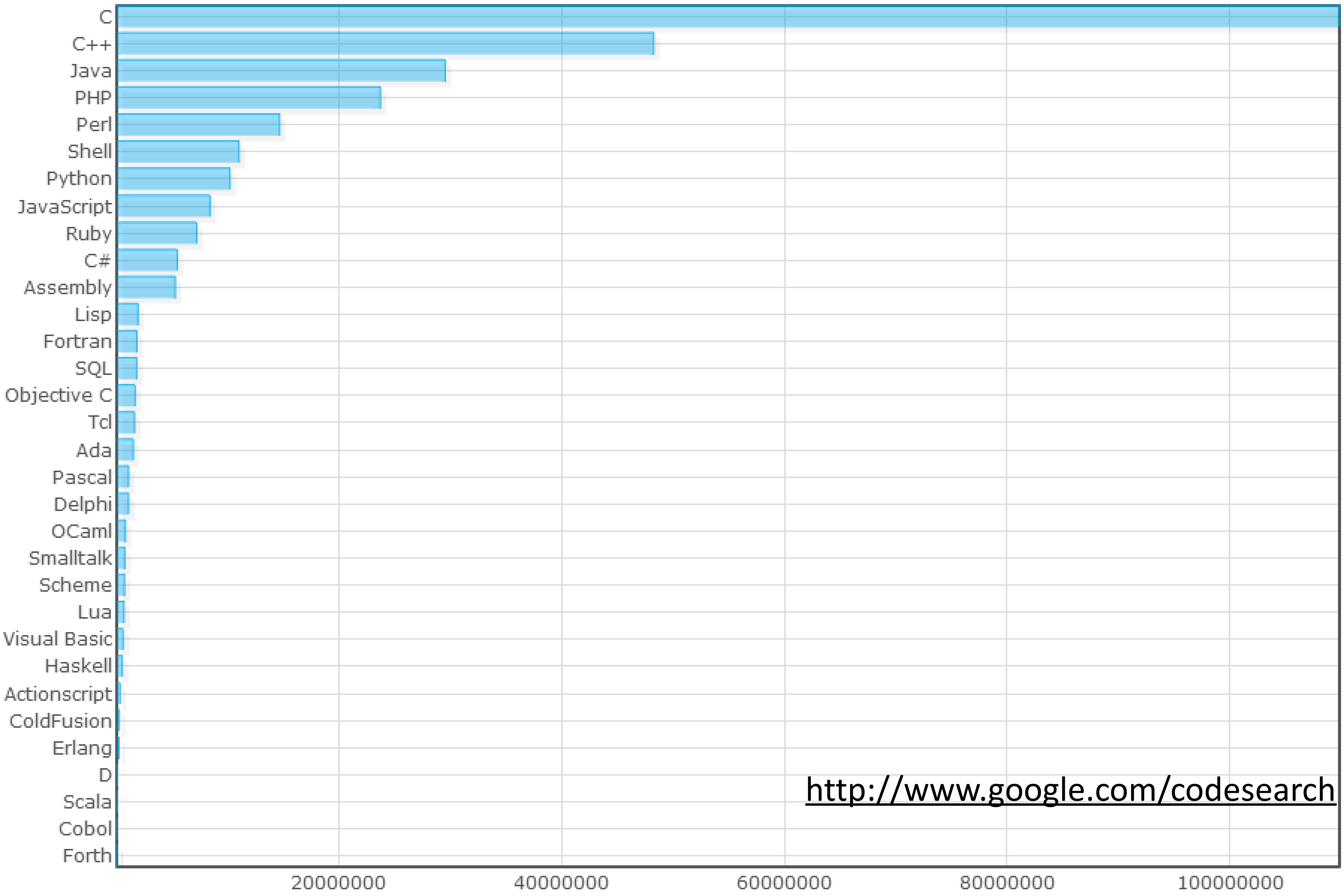
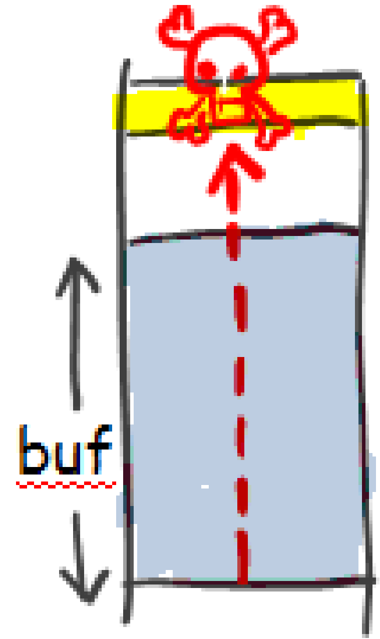


Buffer overflows

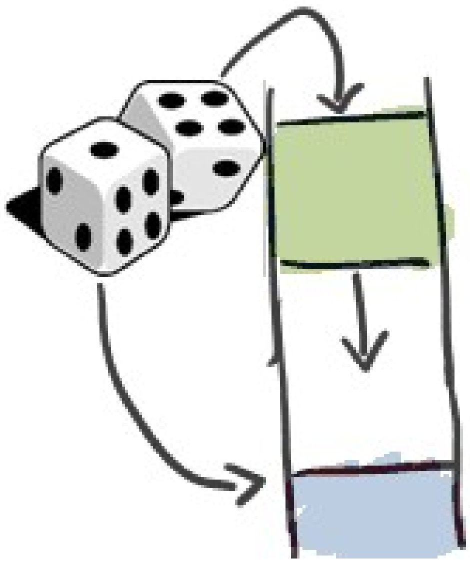
- Perpetual top-3 threat
  - SANS CWE Top 25 Most dangerous programming errors
- Most drive-by-downloads
  - infect browser, download malware
  -



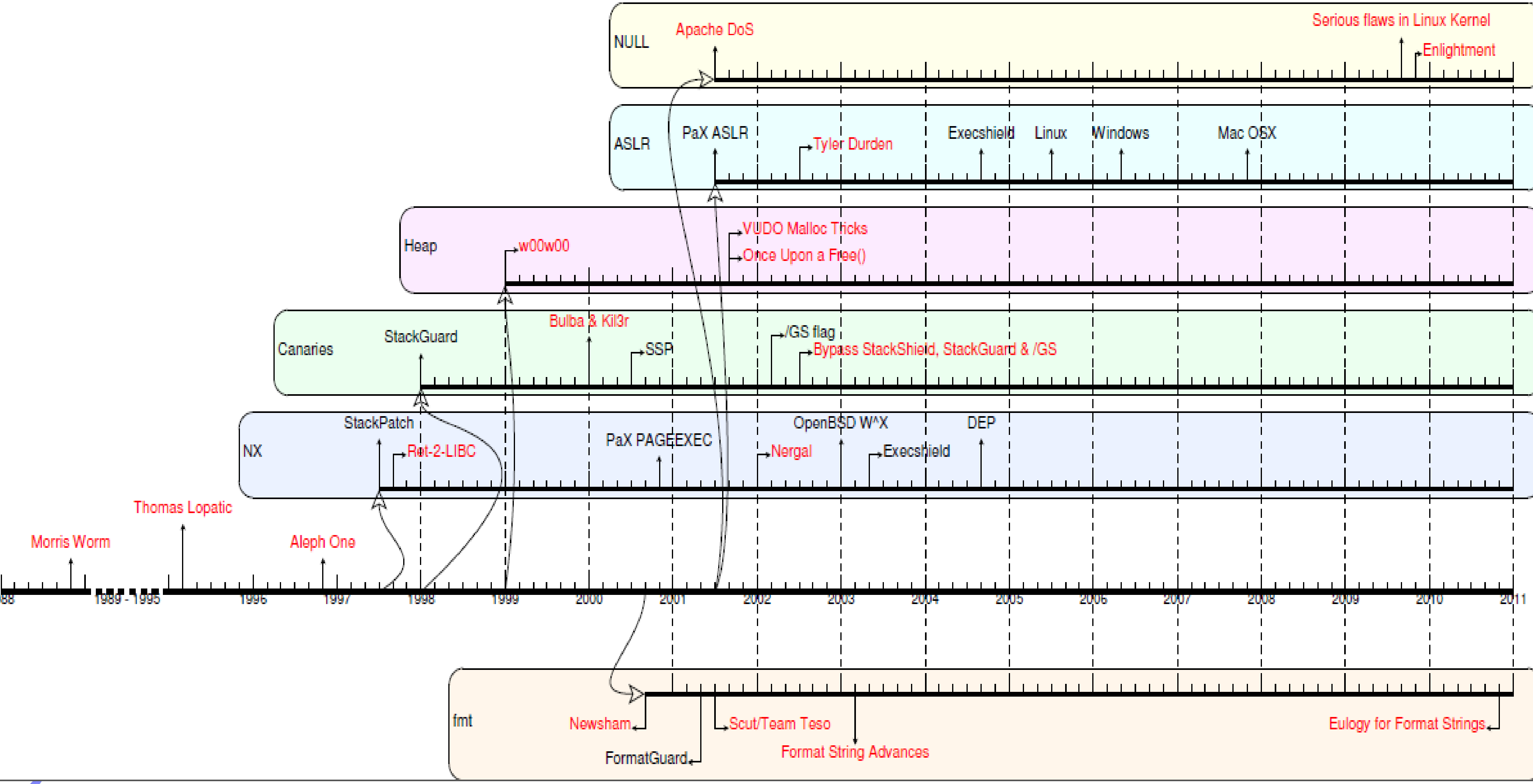
Many defensive measures

- Canaries (StackGuard and friends)
- NX bit / W⊕X
- ASLR
-

ProPolice



Evolution at work



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Still they come

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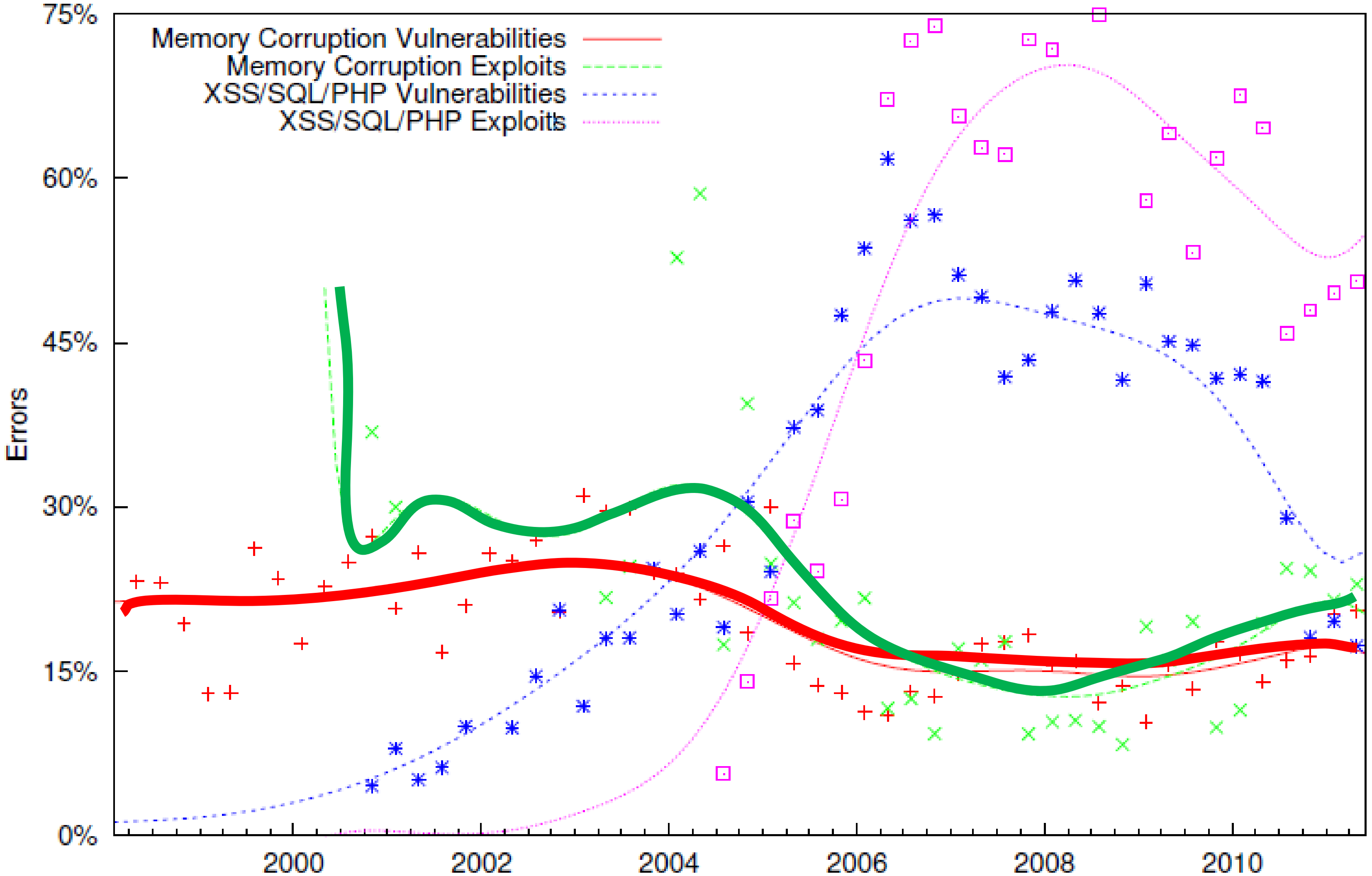
Vulnerabilities and exploits

(as percentage of total)



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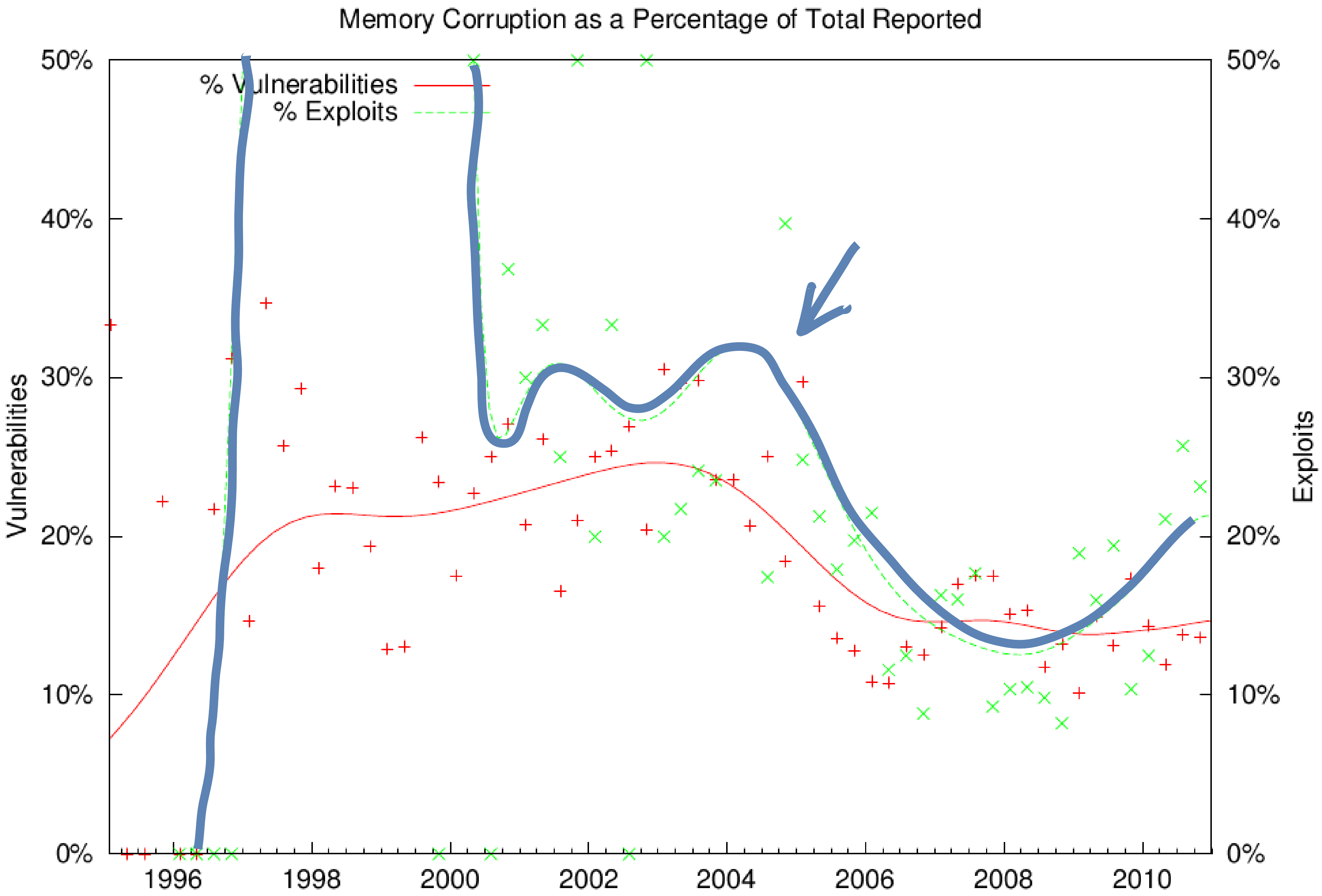

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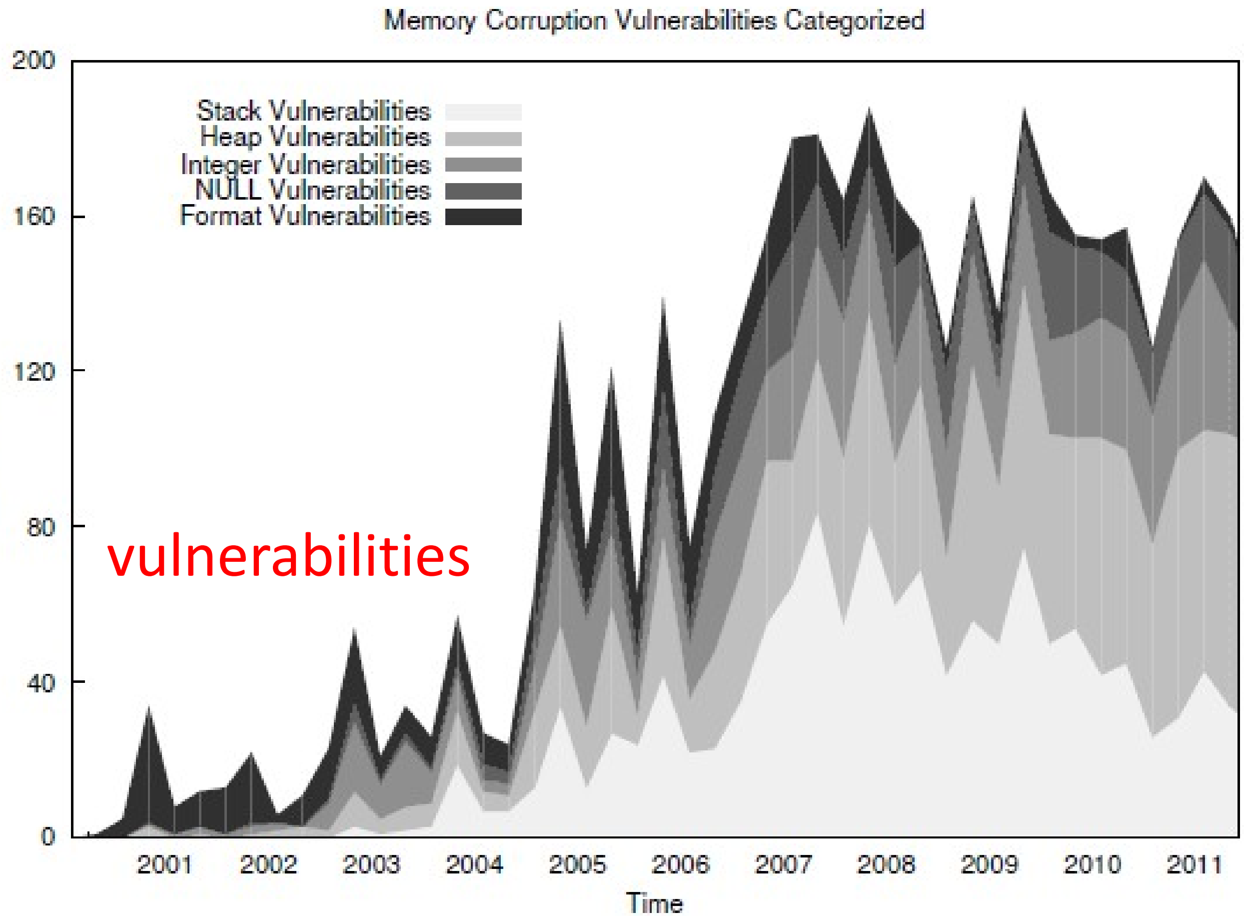

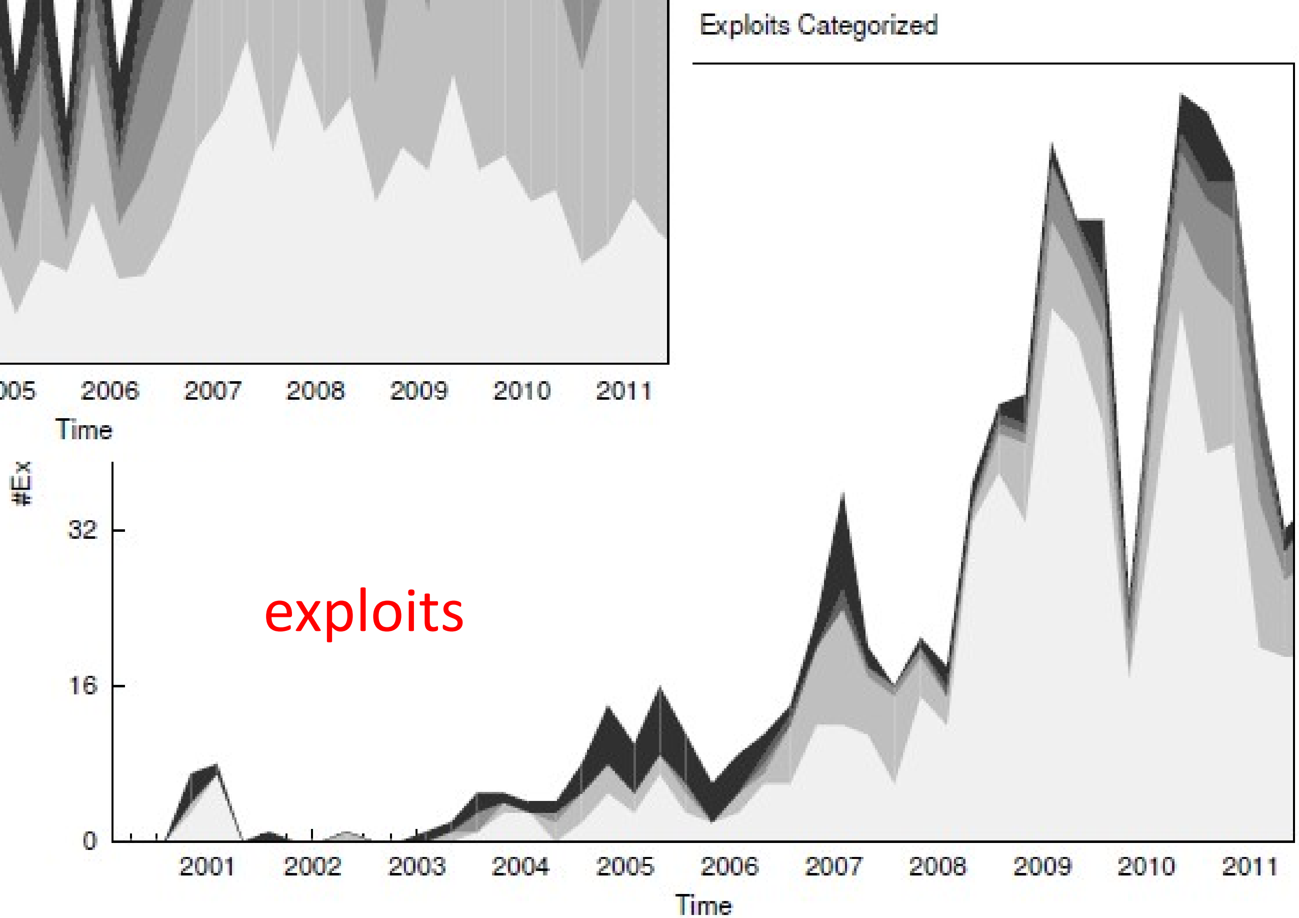

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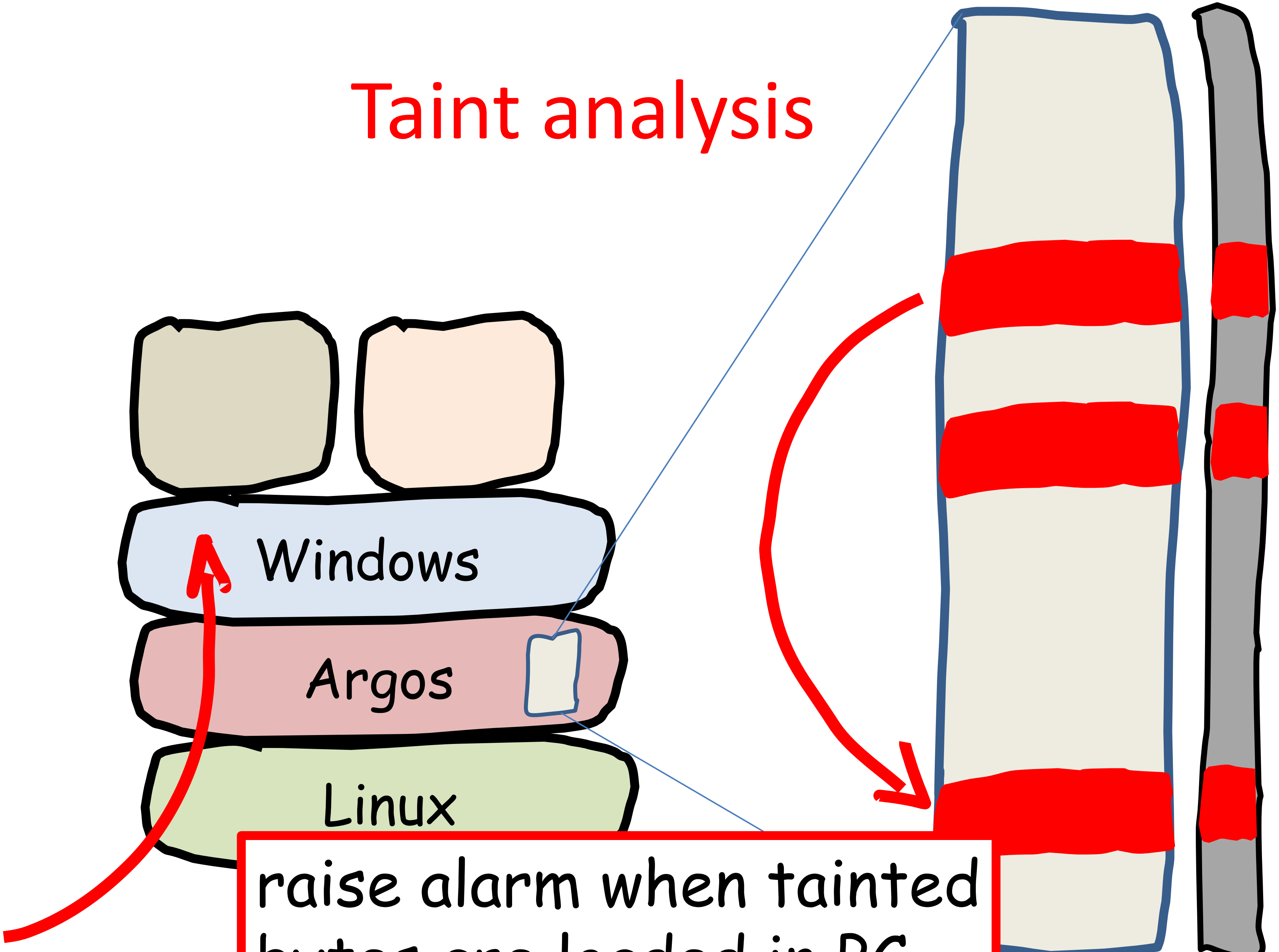
And legacy code?

- we do not have source code
  - we probably do not even have symbols
- we cannot recompile
  - most protective measures require recompilation
- we cannot protect
  -

Taint Analysis?

Taint analysis



raise alarm when tainted bytes are loaded in PC

Taint tracking: useful, but slow

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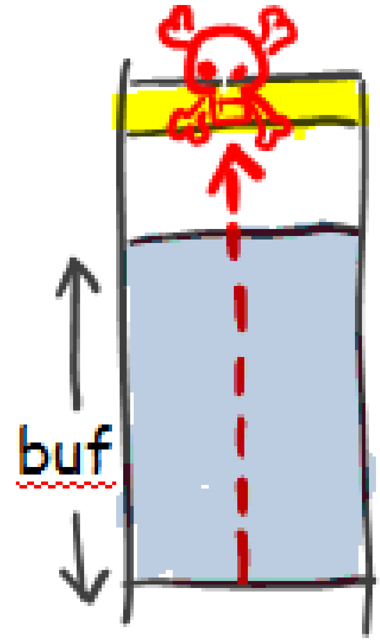
...and detects not the attack, but its manifestation.

just missed it!



...and does not detect attacks on non-control data at all!

```
void get_private_medical_data (int uid) {
  int c,i=0;
  int authorized = check(uid); // result=0 for attacker
  char patientid[8];

  printf ("Type patientid, followed by the '#' key\n");
  while (((c=getchar())!='#') patientid[i++] = c;

  if (authorized) print_medical_data (patientid);
  else printf ("sorry, you are not authorized\n");
}
```

- trivially exploitable
- not prevented by ASLR, NX, or StackGuard

BinArmor

A Body Armour
fo s

This talk is based on two papers

- Asia Slowinska, Traian Stancescu, Herbert Bos
  Howard: a dynamic excavator for reverse engineering data structures (NDSS'11)
- Asia Slowinska, Traian Stancescu, Herbert Bos
  Body armor for binaries: preventing buffer overflows without recompilation (USENIX'12)
-
-

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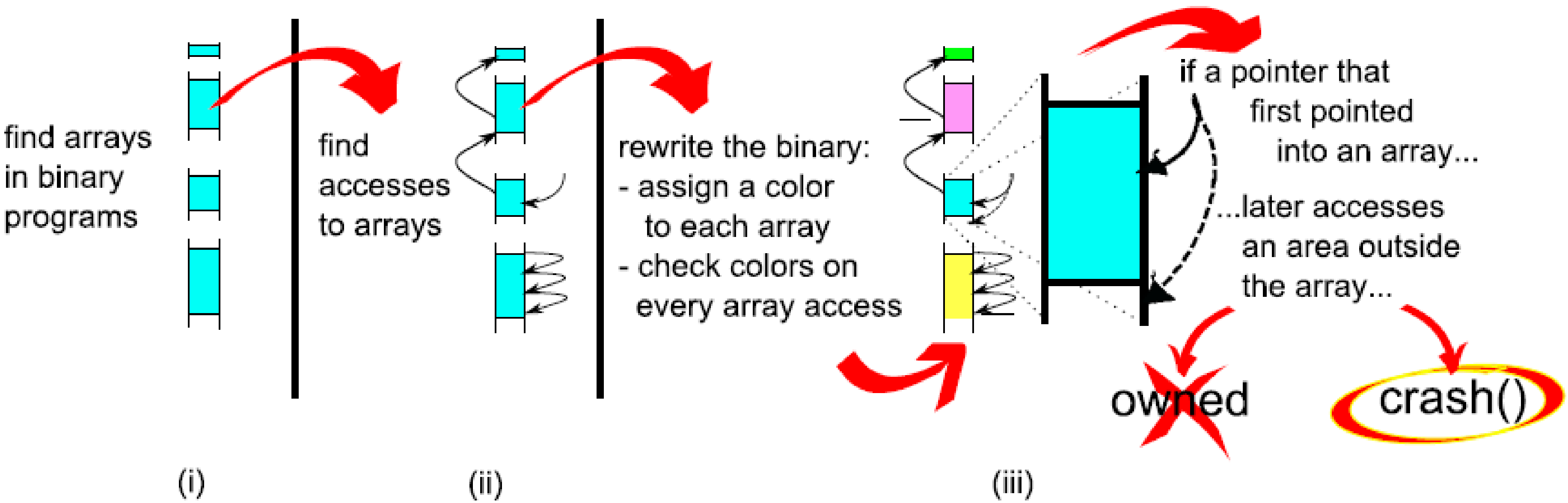
no source
no symbols
no clue?

In a nutshell...



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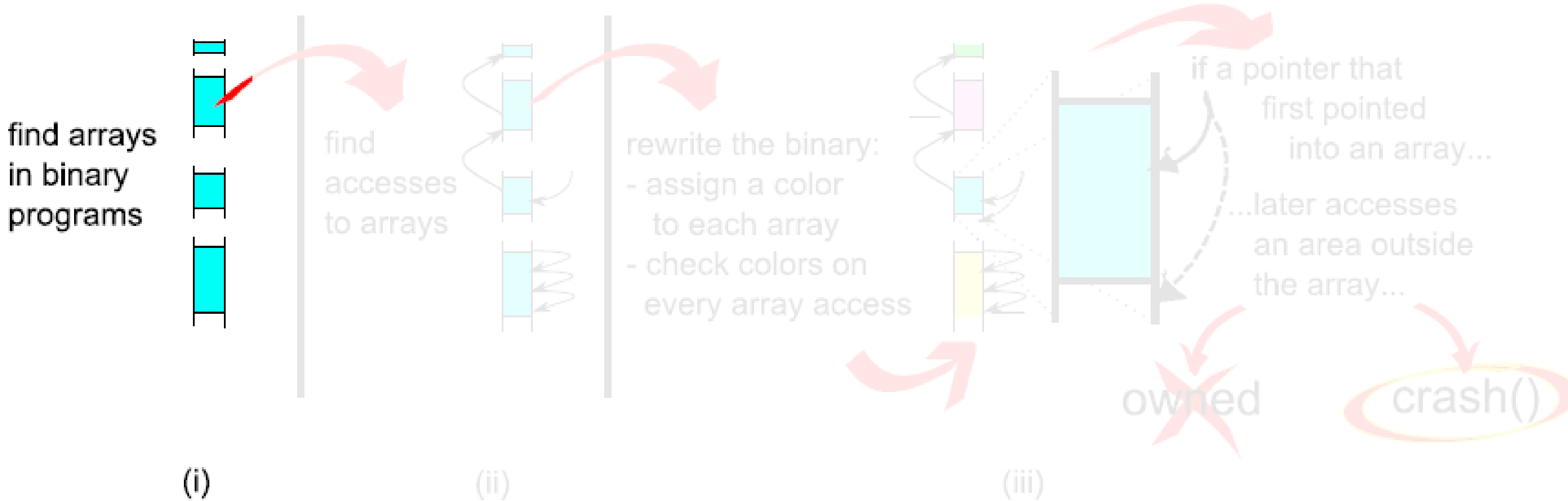

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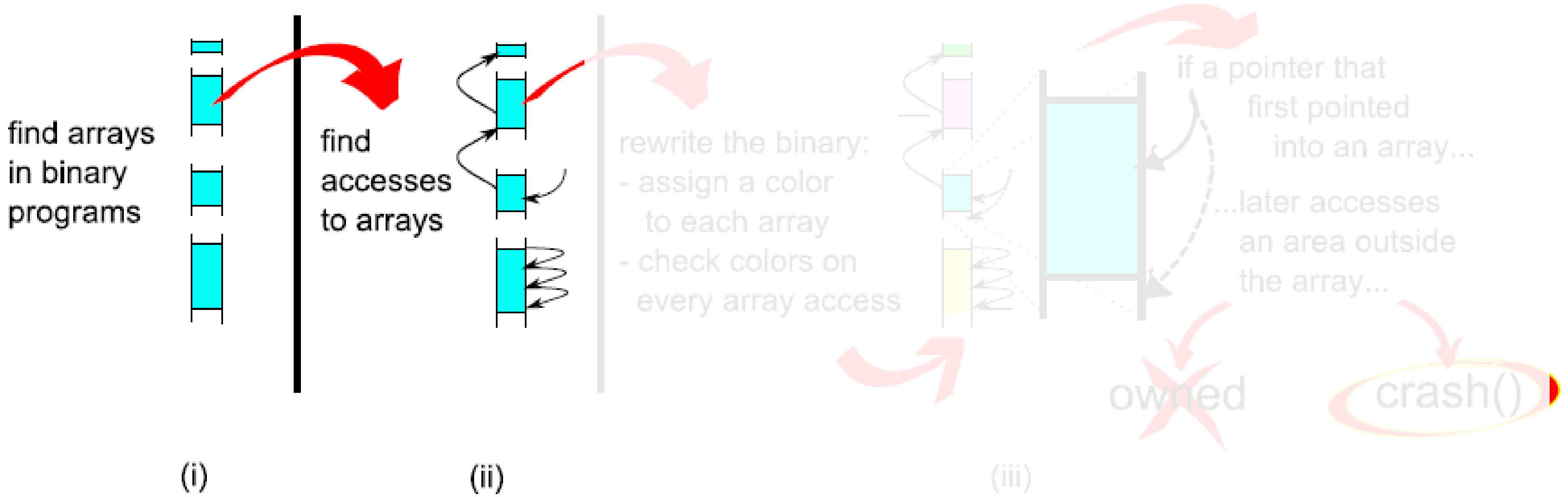

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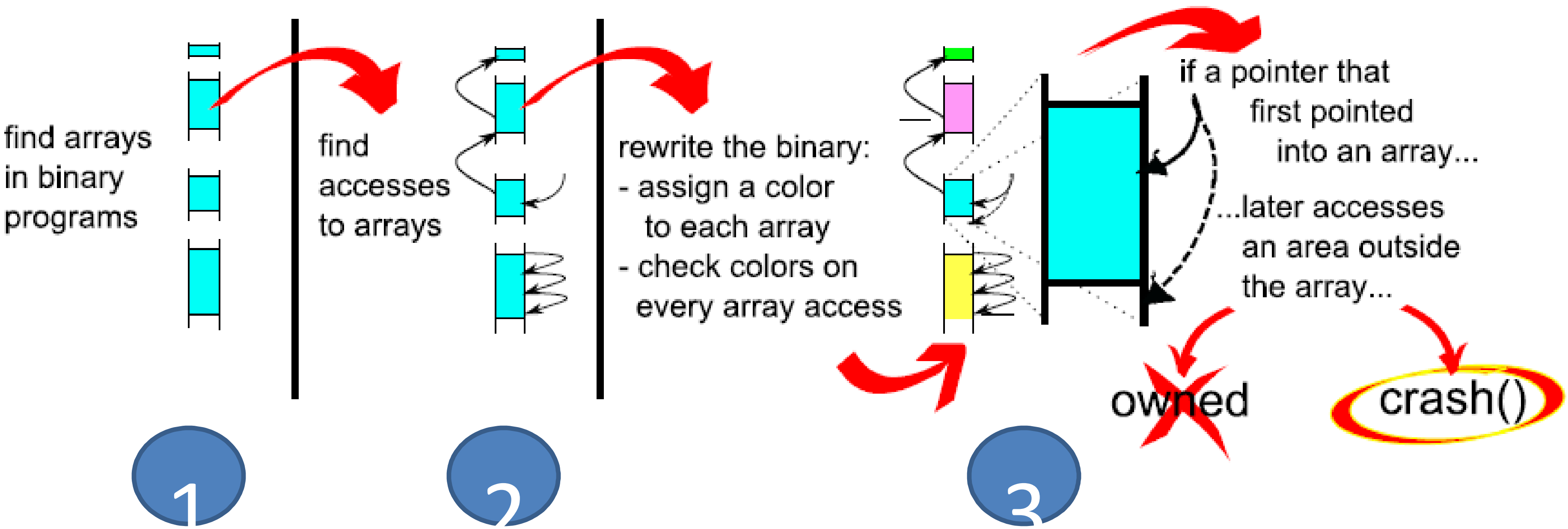

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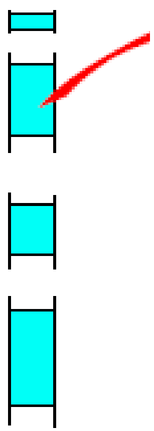
Step 1: extract the arrays



Two possibilities

– symbol tables

– stripped

➔ reverse engineering

let’s assume the latter

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Problem

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Why is it difficult?

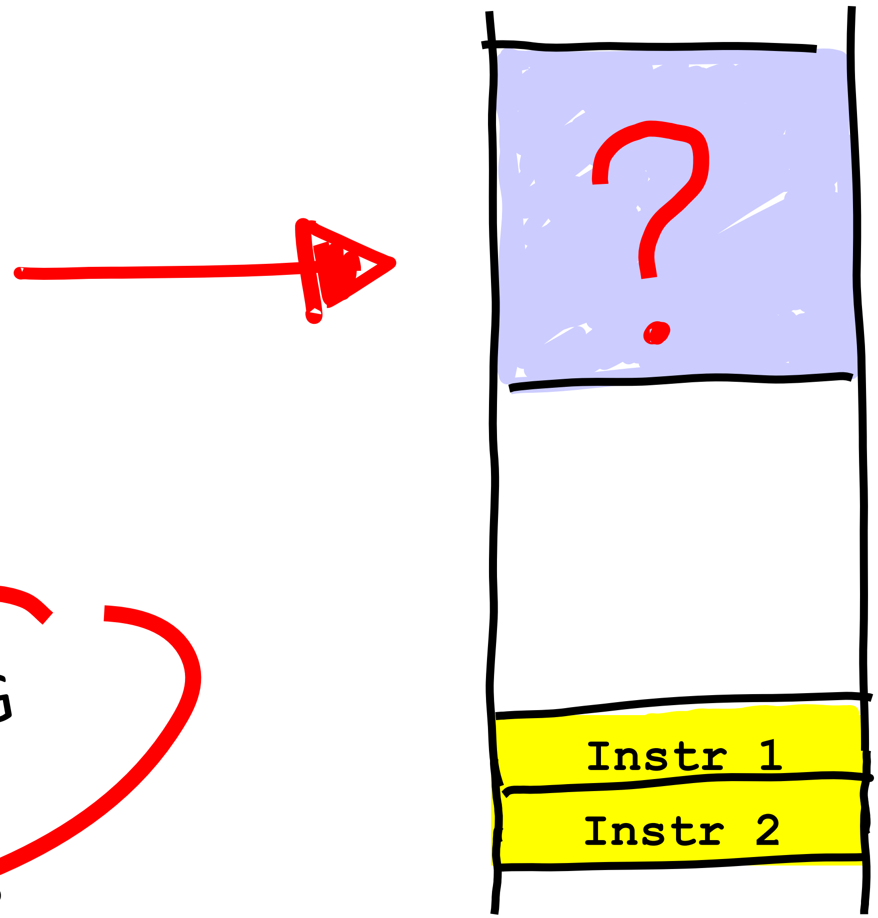
```
struct employee {
        char name[128];
        int year;
        int month;
        int day
};

struct employee e;
e.year = 2010;
```

Why is it difficult?

```c
struct employee {
        char name[128];
        int year;
        int month;
        int day
};

struct employee e;
e.year = 2010;
```



MISSING

- Data structures
-

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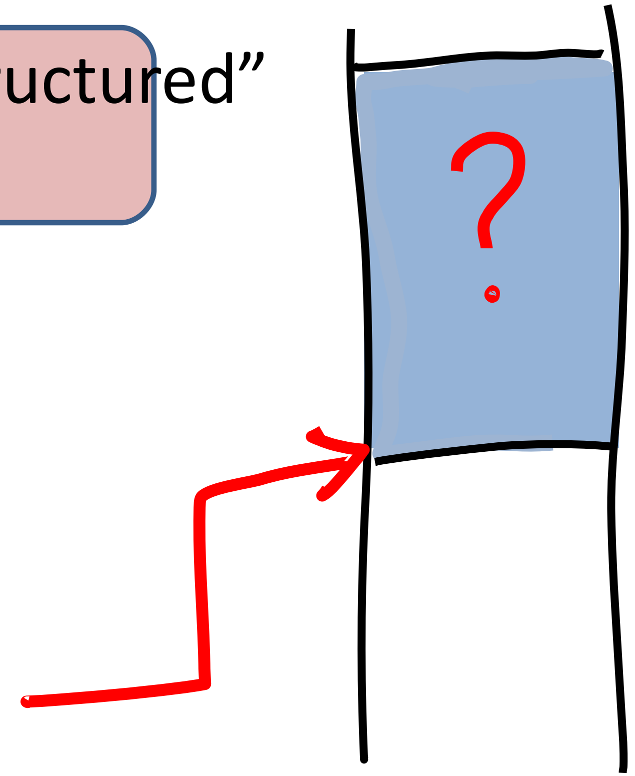
Data structures: key insight

Yes, data is “apparently unstructured”

But usage is not!



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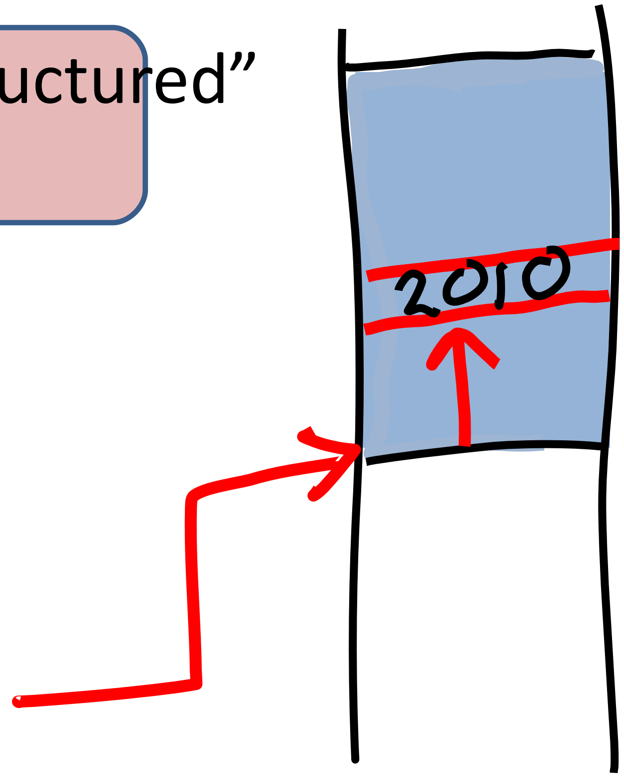

Data structures: key insight

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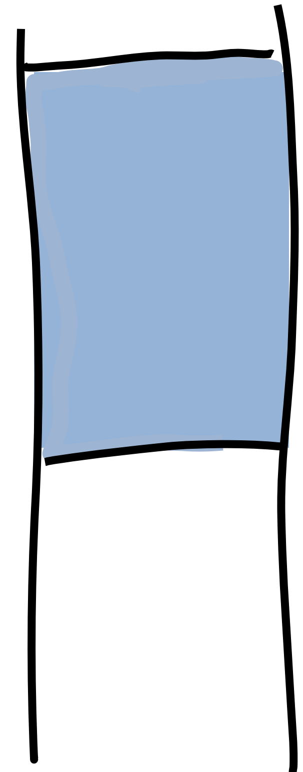
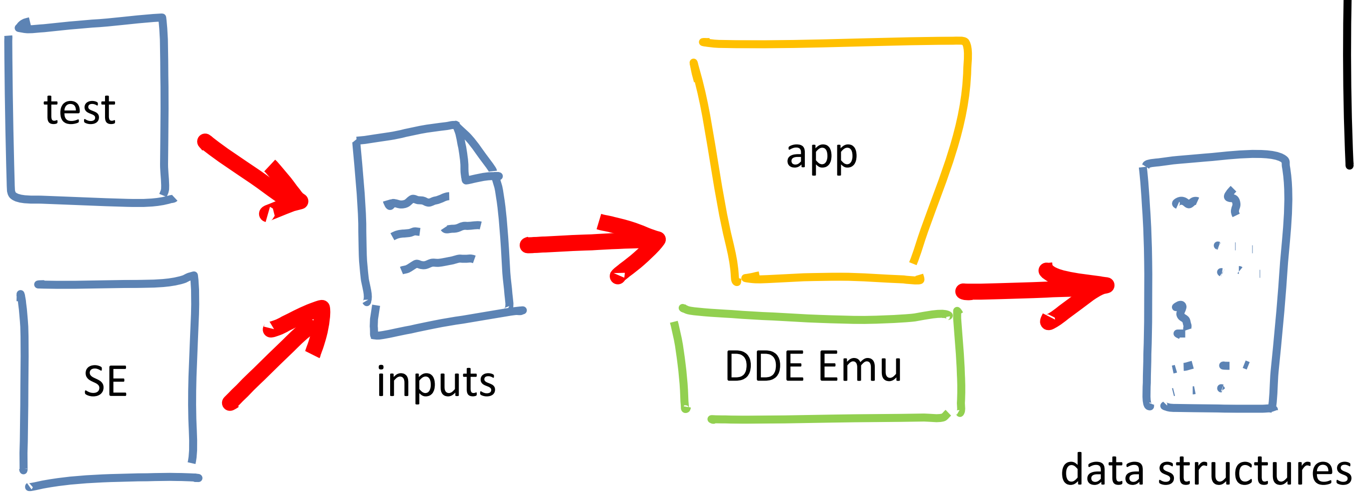
Analyse dynamically

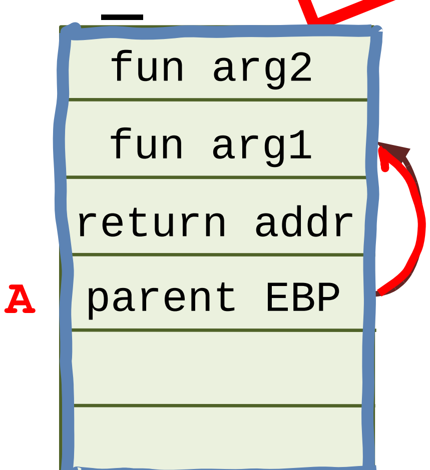




Intuition

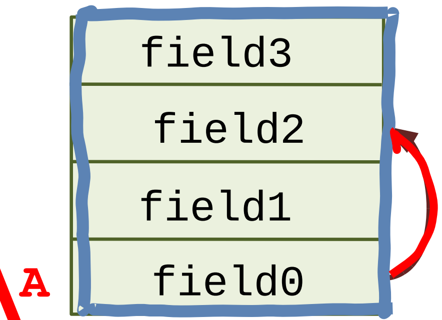
- Observe how memory is *used* at runtime to detect data structures
- E.g., if A is a point

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

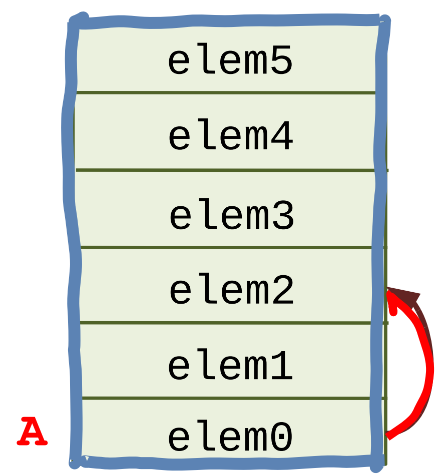


Track pointers

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

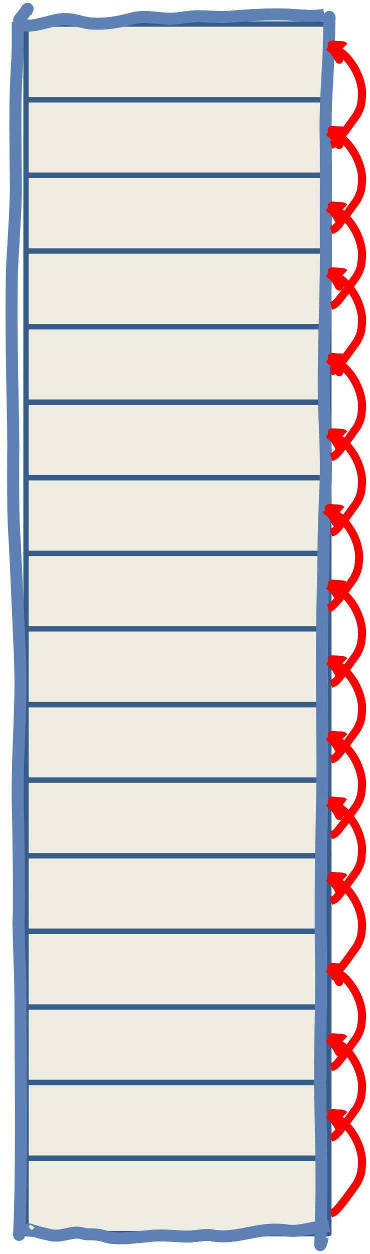


Approach

- 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()`

Arrays are tricky

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



Arrays are tricky

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  -
-

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  -
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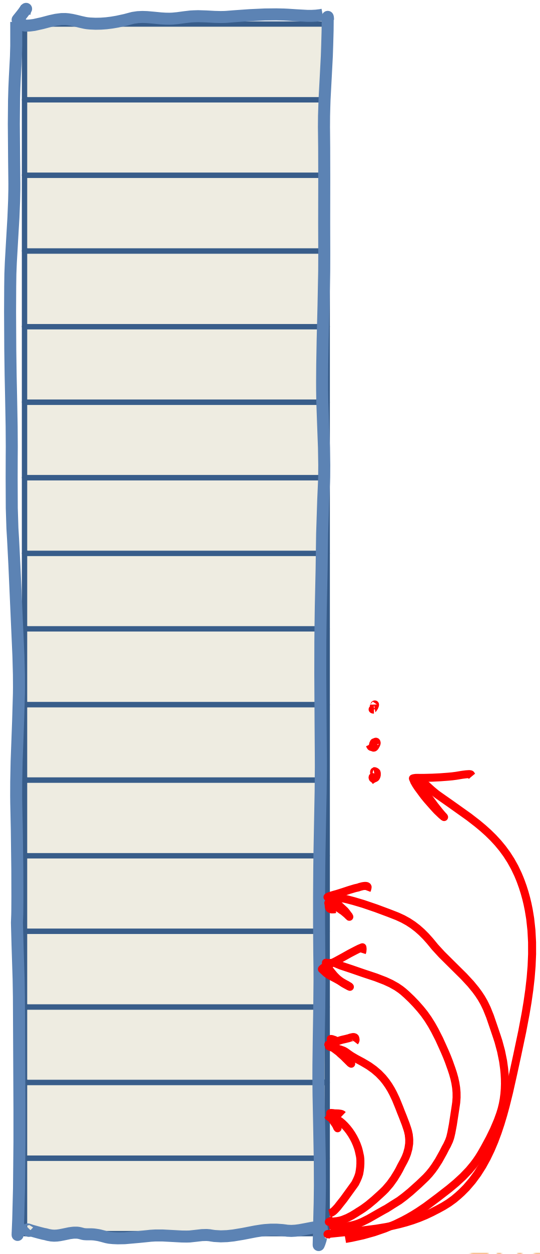
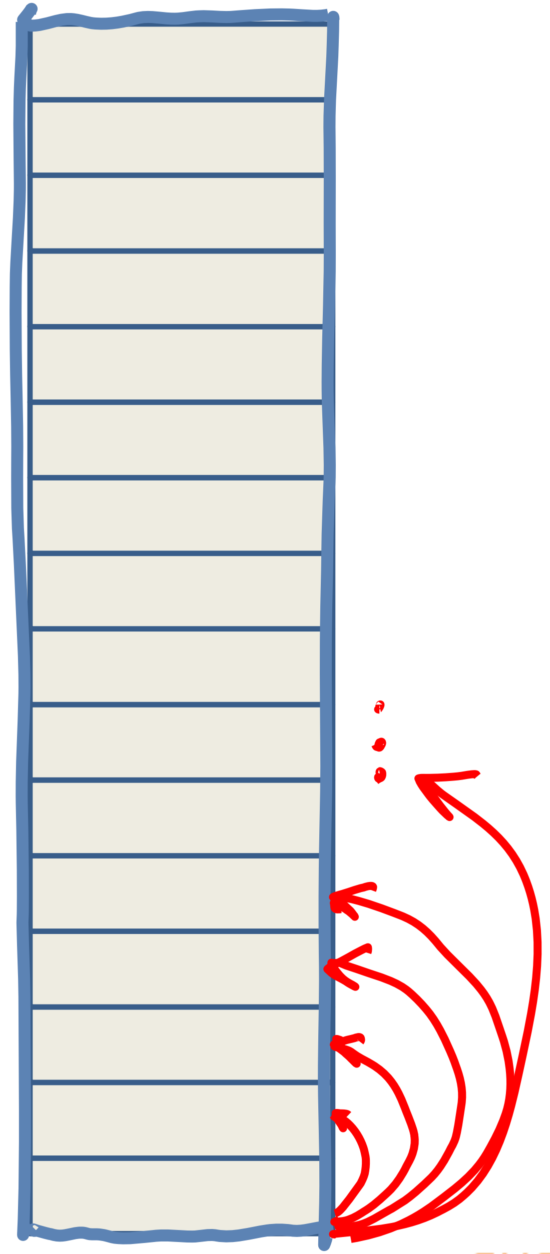


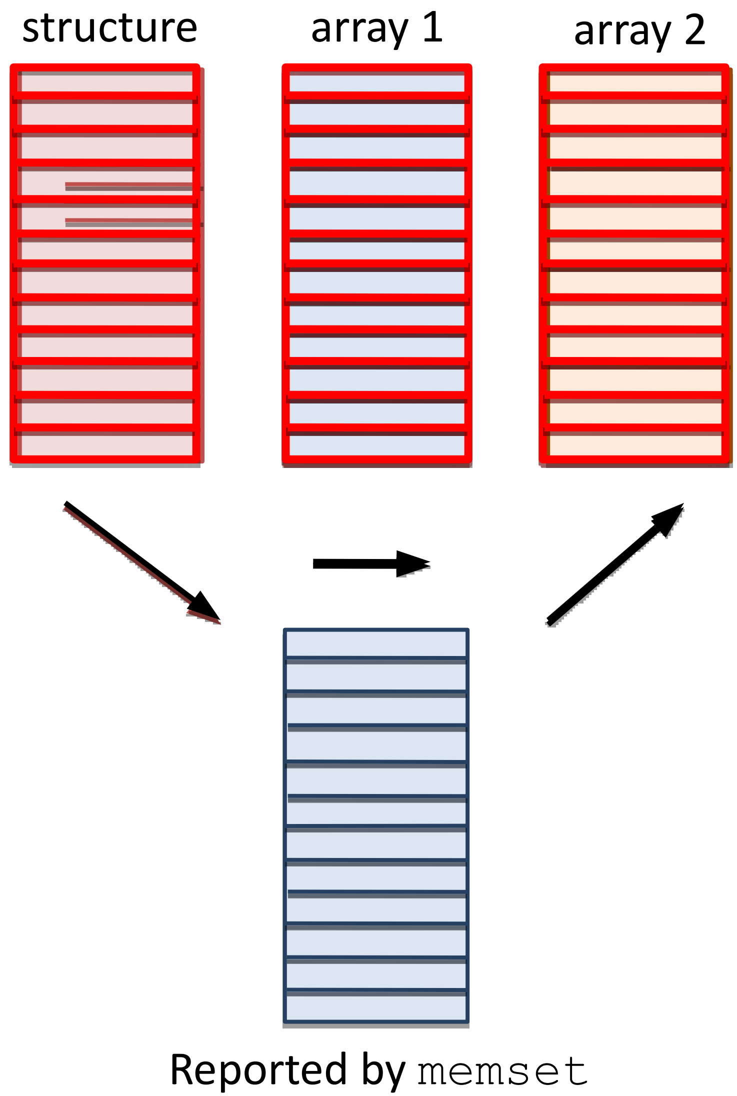
Arrays are tricky

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



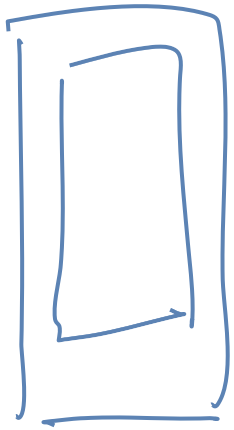
Interesting challenges

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



Further Challenges

- Arrays
  - Nested loops
  - Consecutive loops
  - Boundary elements
  -
    -



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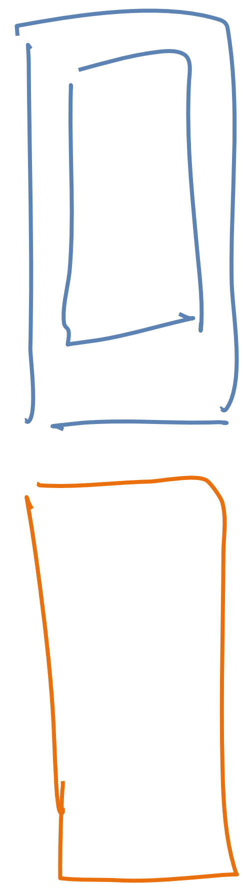

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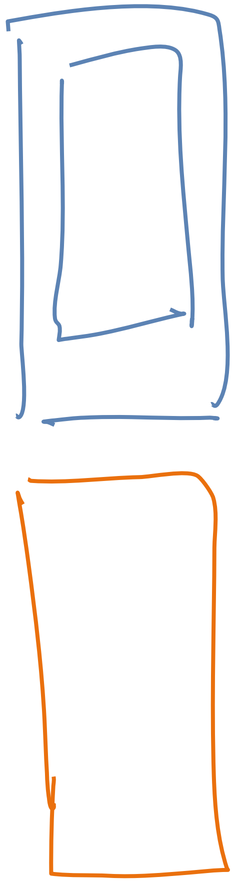

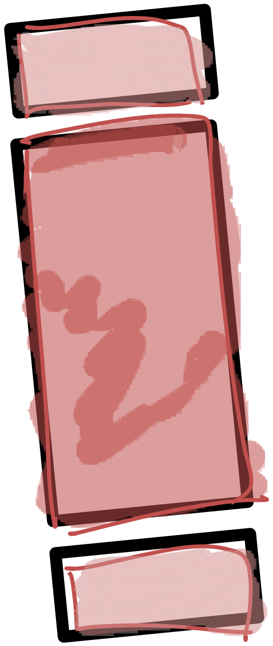

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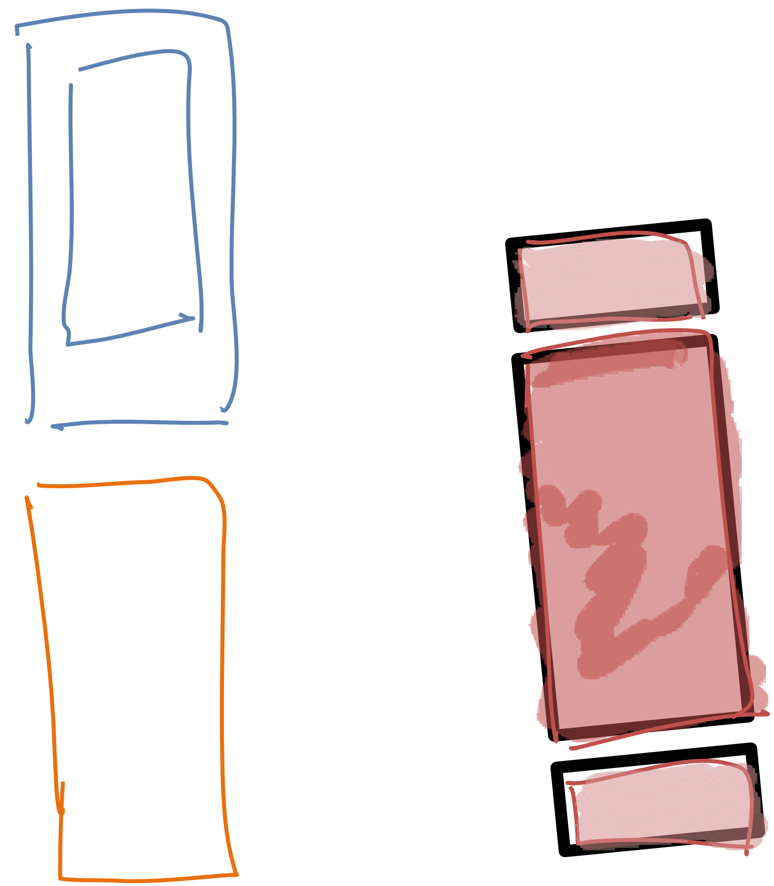

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Final mapping

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

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Also: not everything is hidden

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Key insight 2

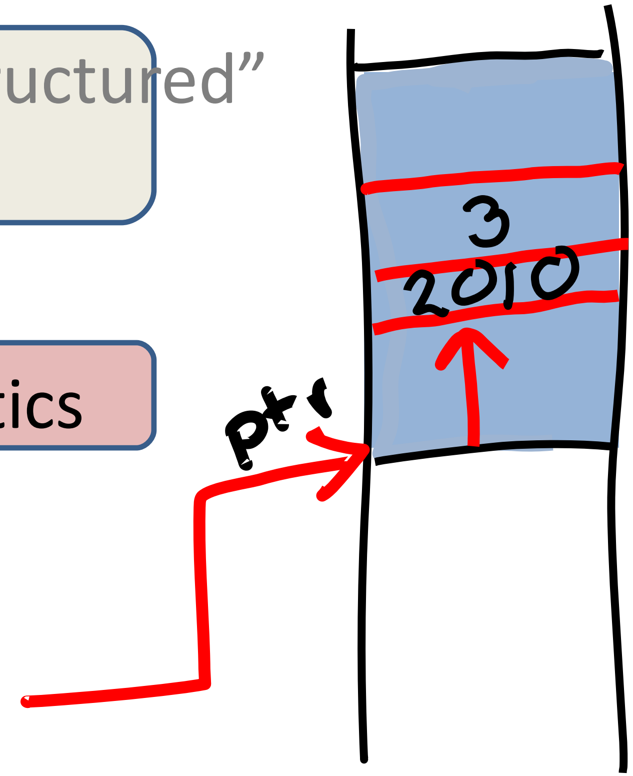
Yes, data is “apparently unstructured”

But usage is not!

Usage (again) reveals semantics

–

–



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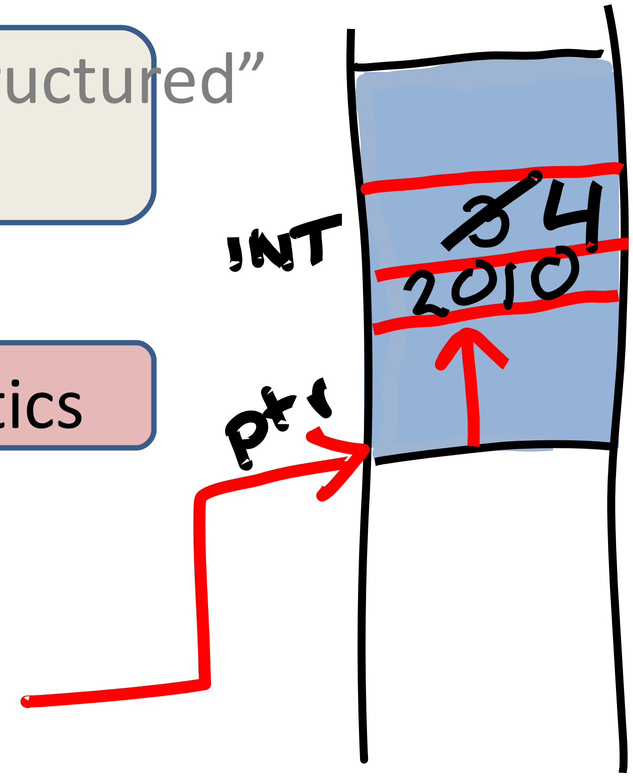

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Semantics: key insights

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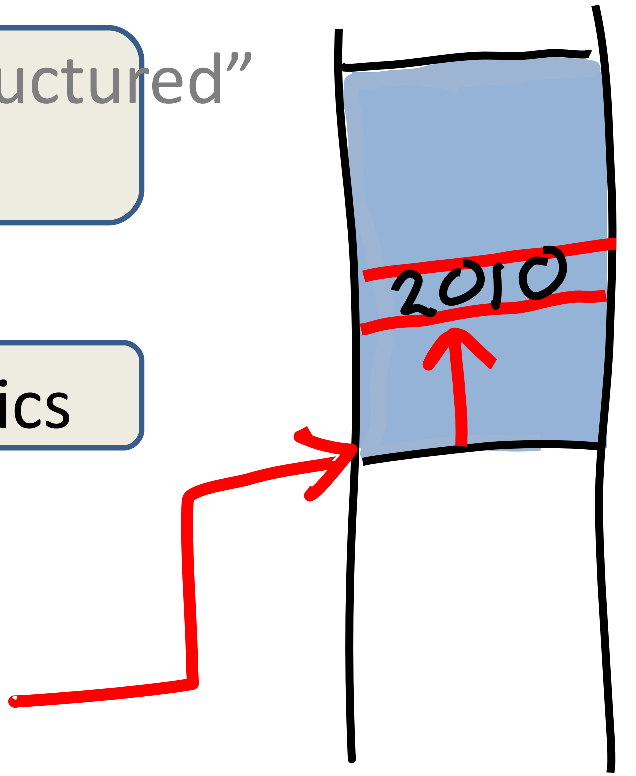

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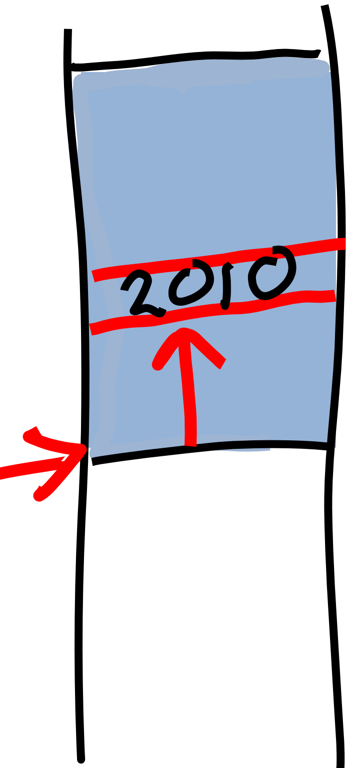

Propagate types from sources + sinks

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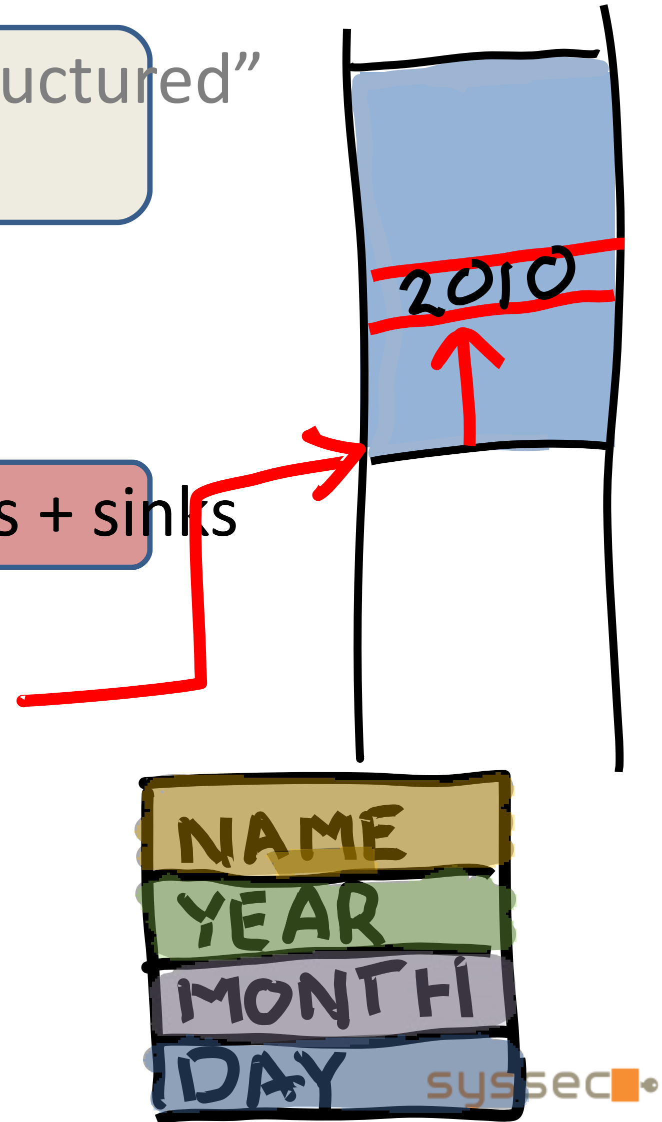

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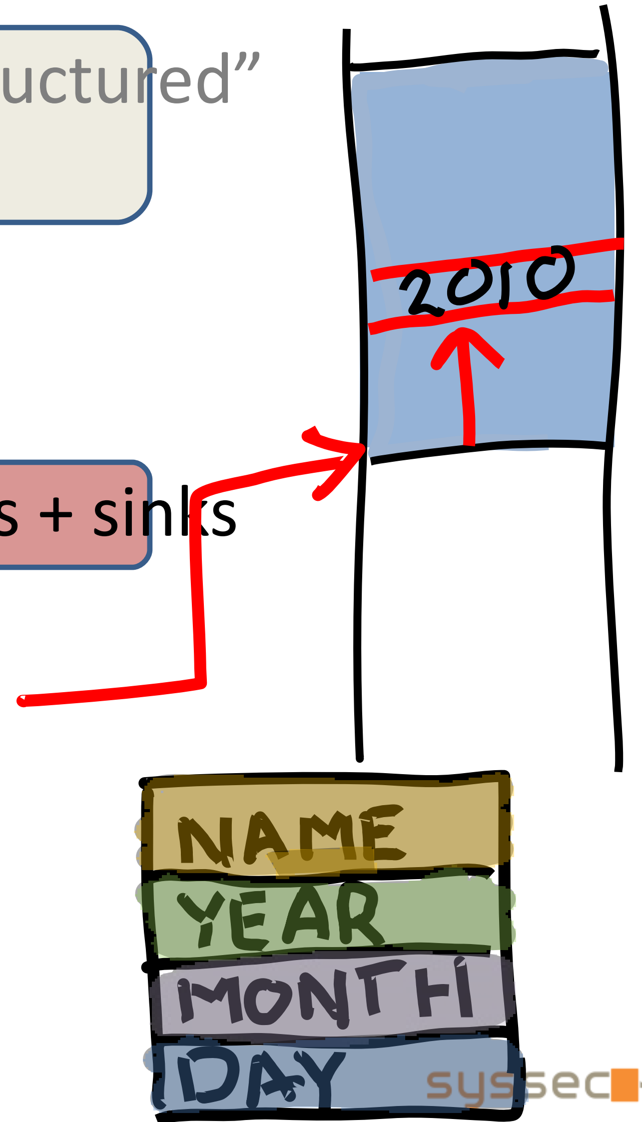

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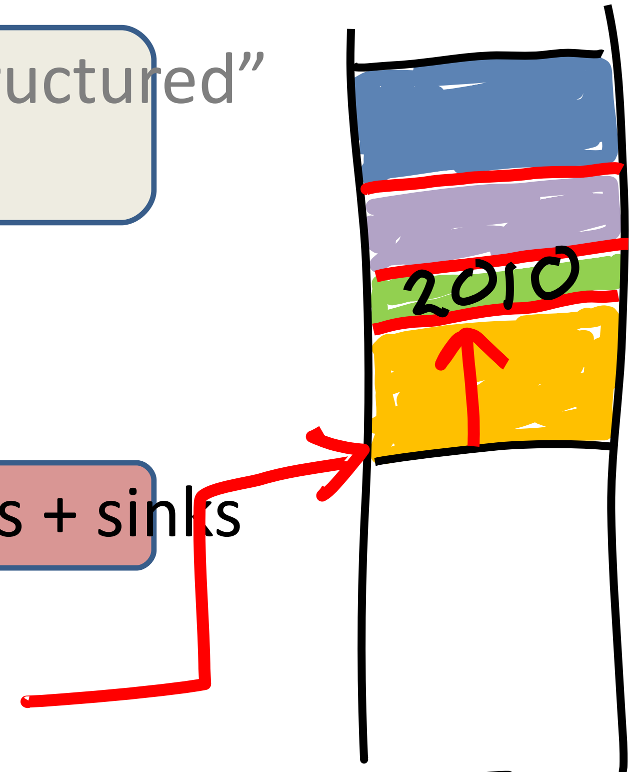

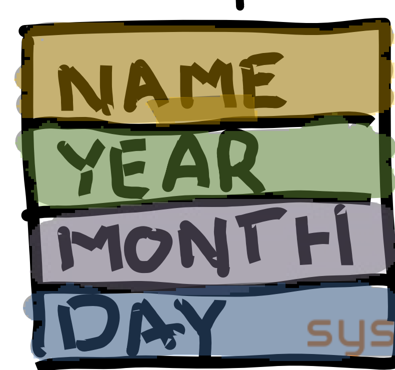

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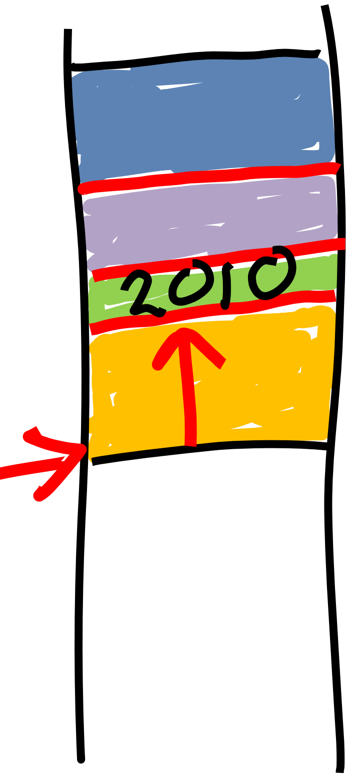

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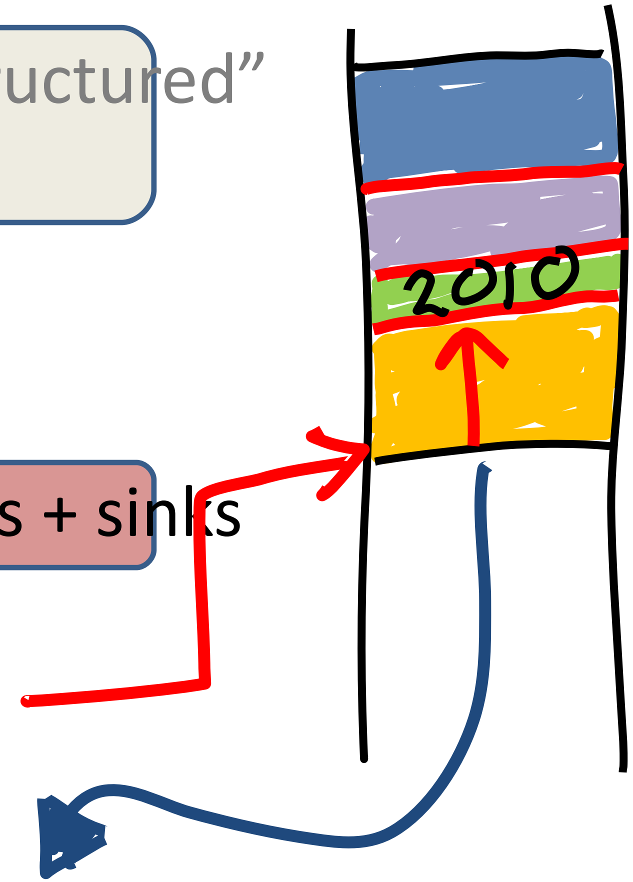

Propagate types from sources + sinks

open (“Herbert.doc”, R_ONLY)

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Propagate types from sources + sinks

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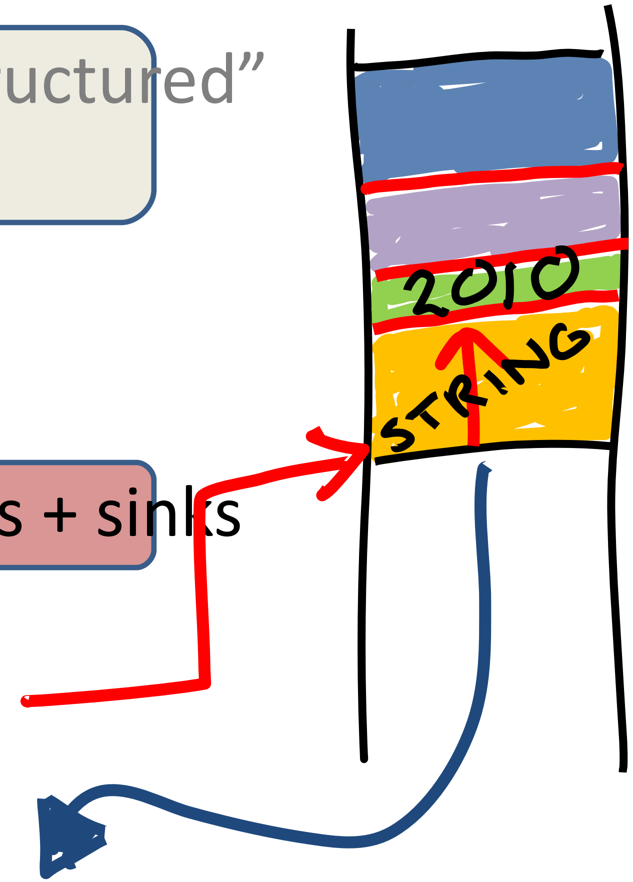

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Results

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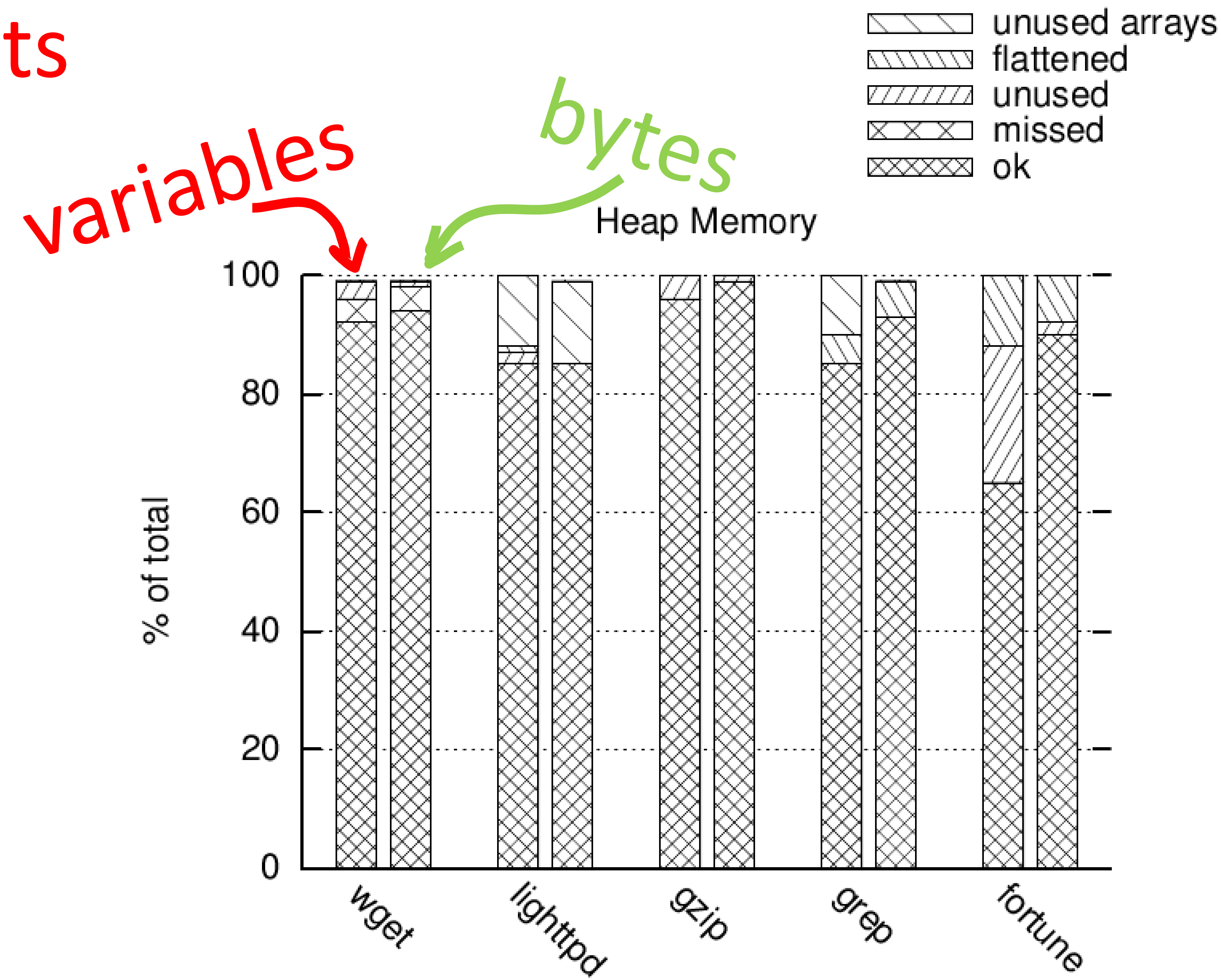
Results

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



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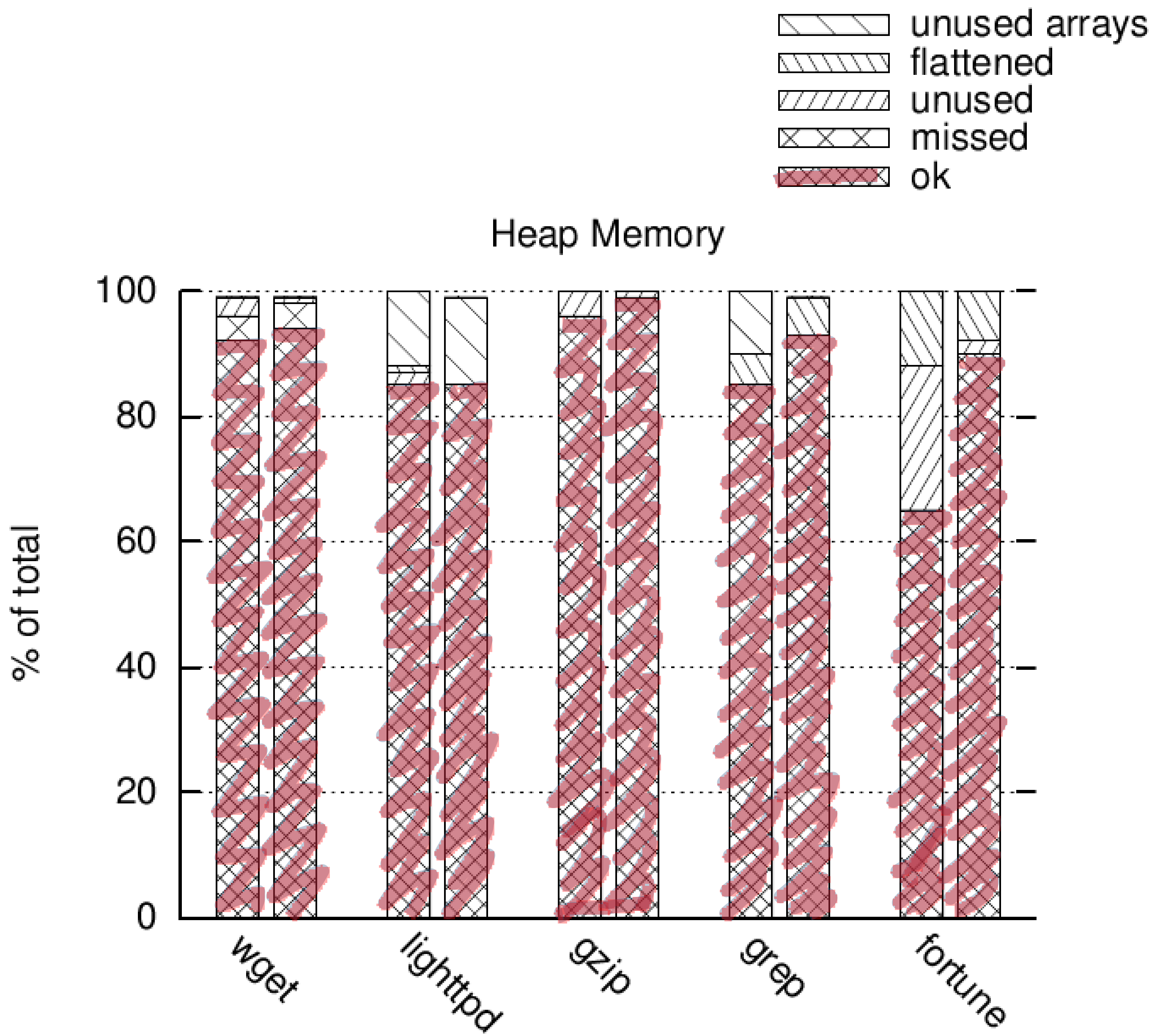

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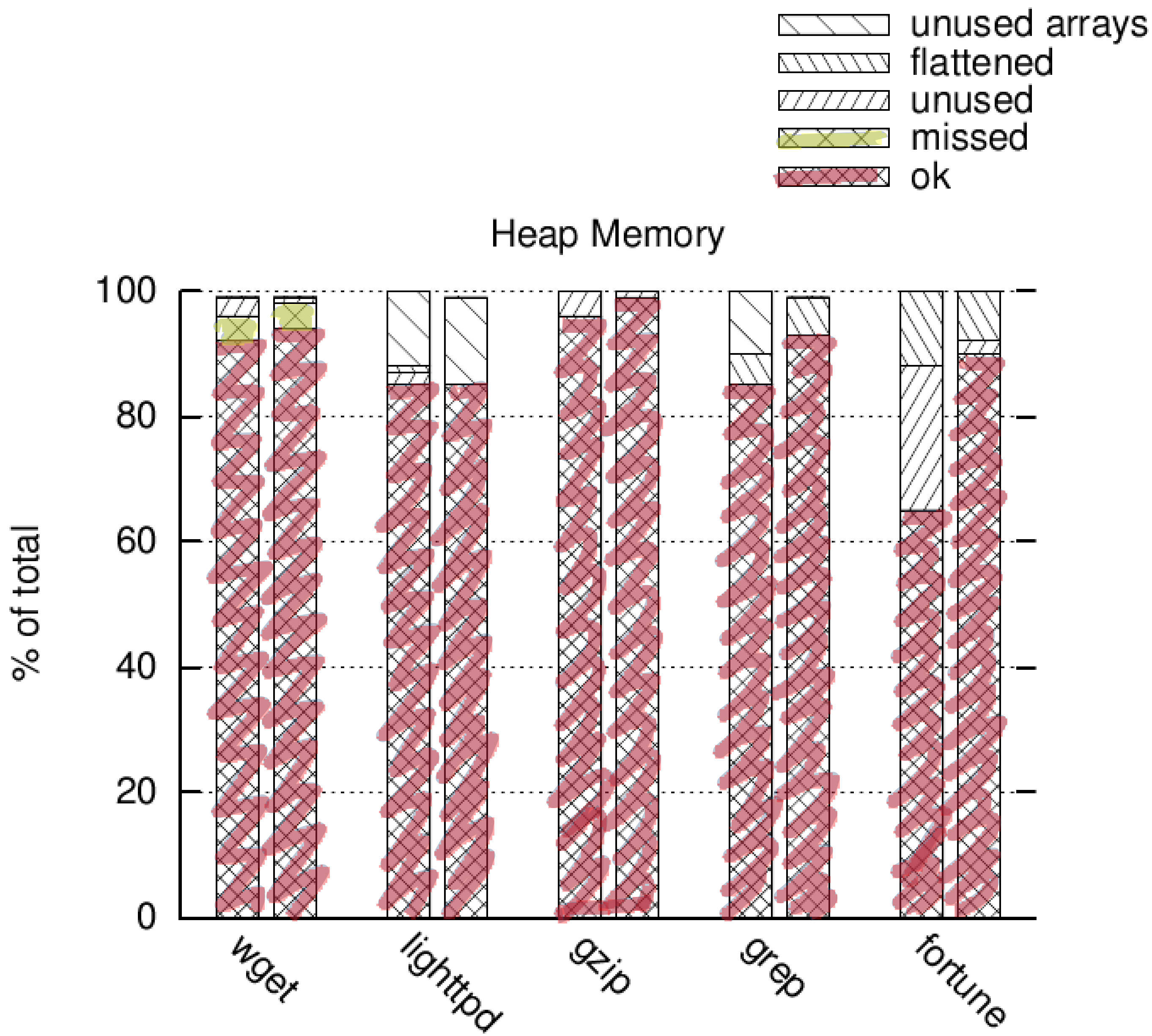

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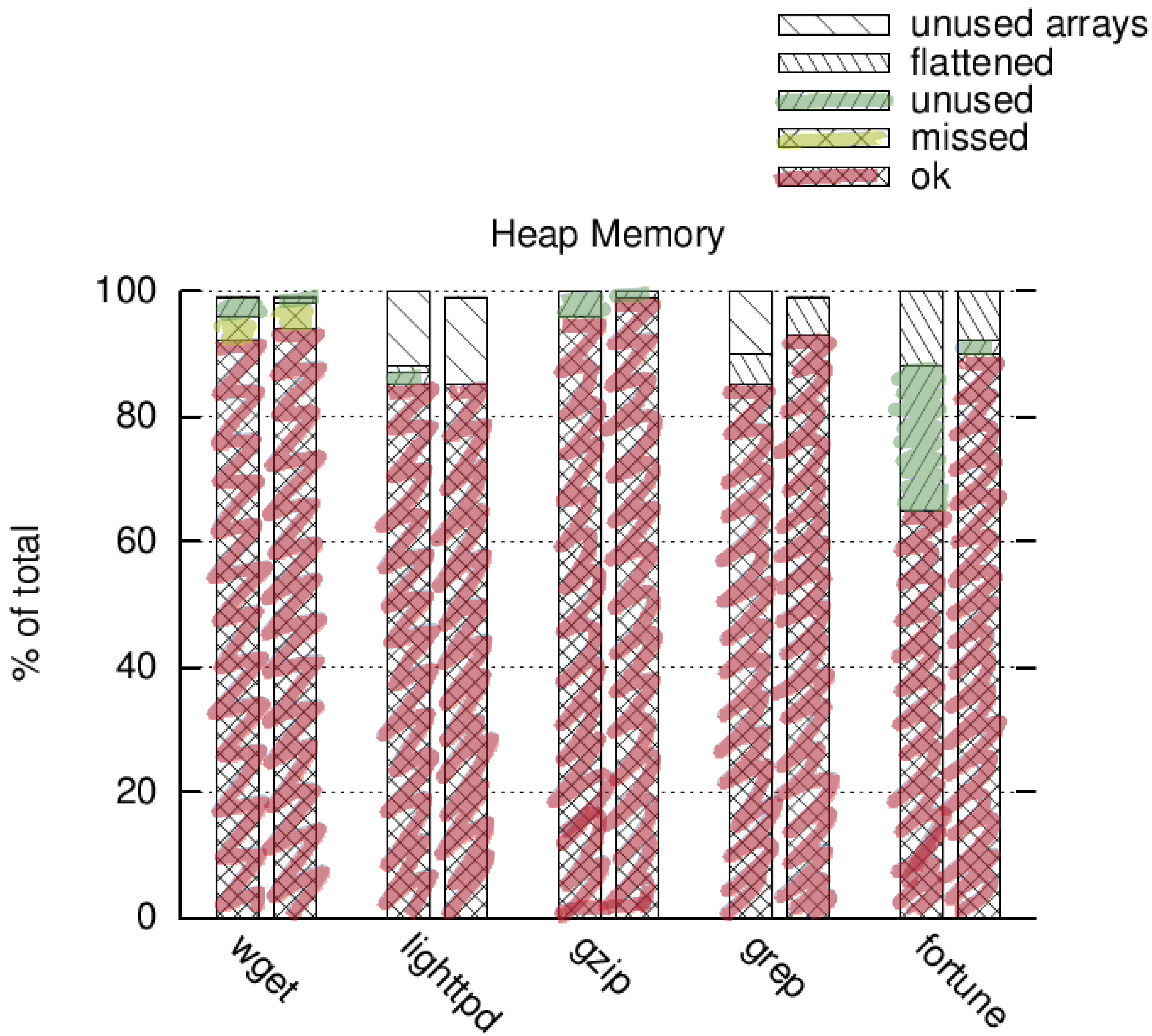
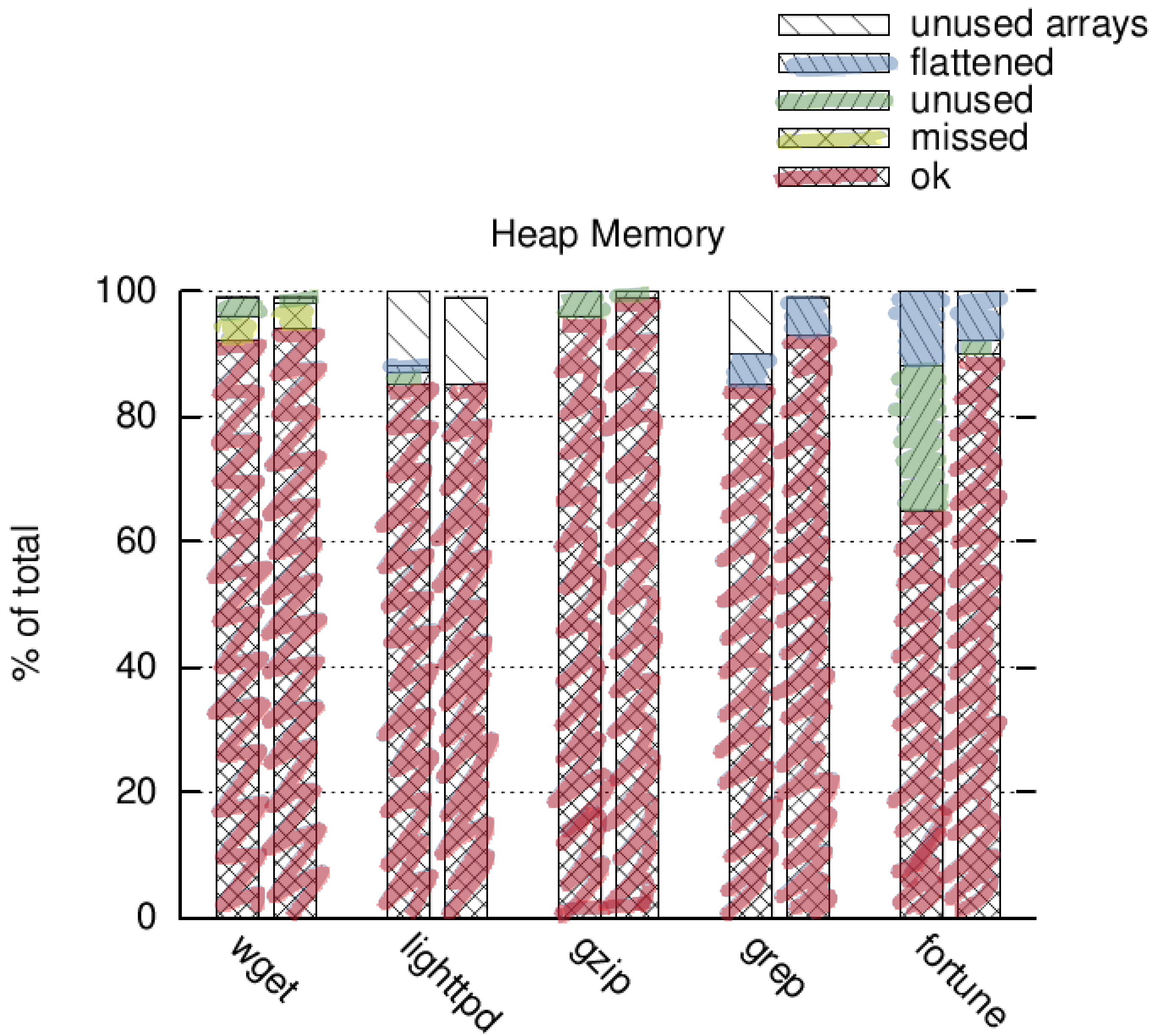


1

Results

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



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1

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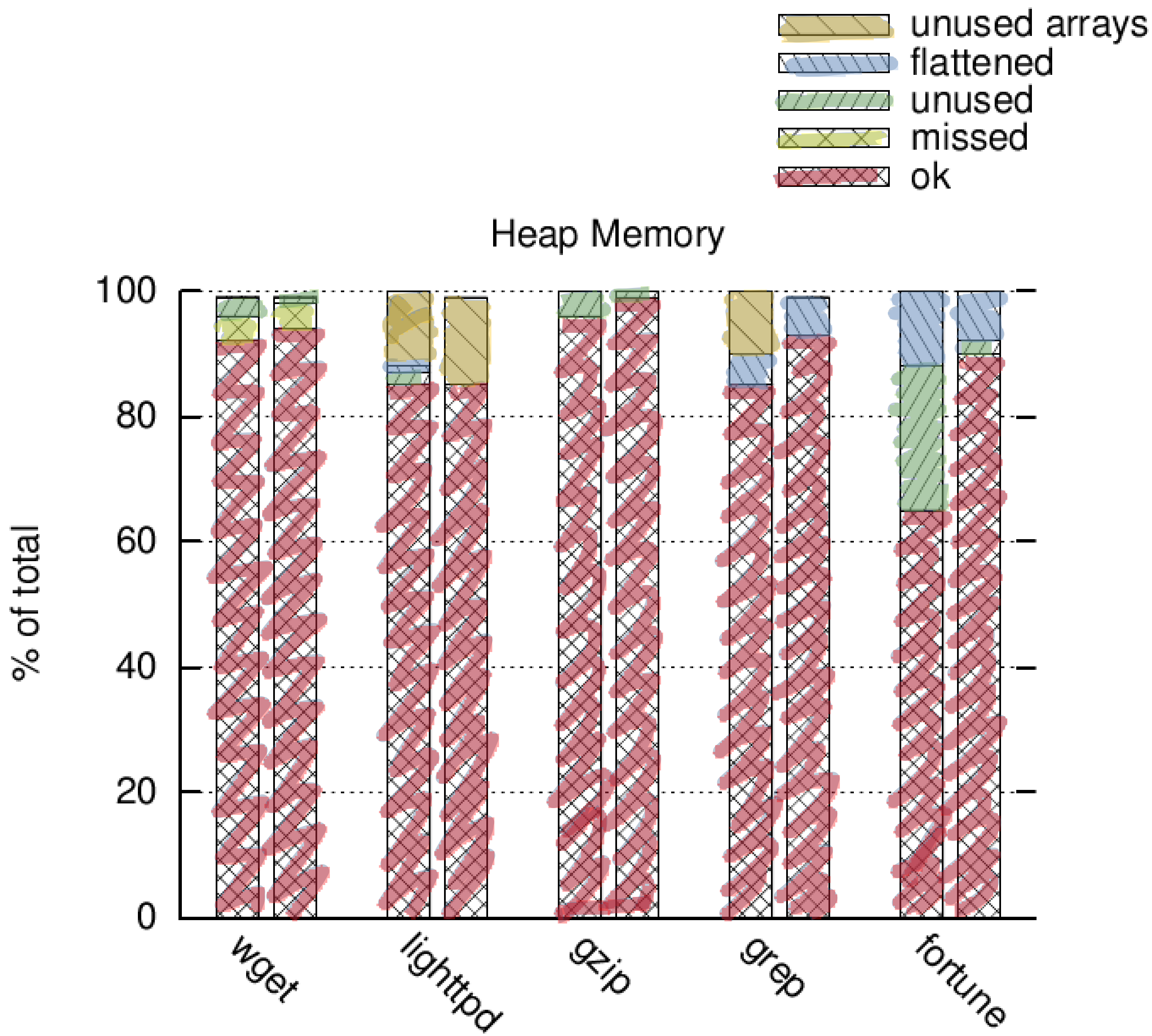

1

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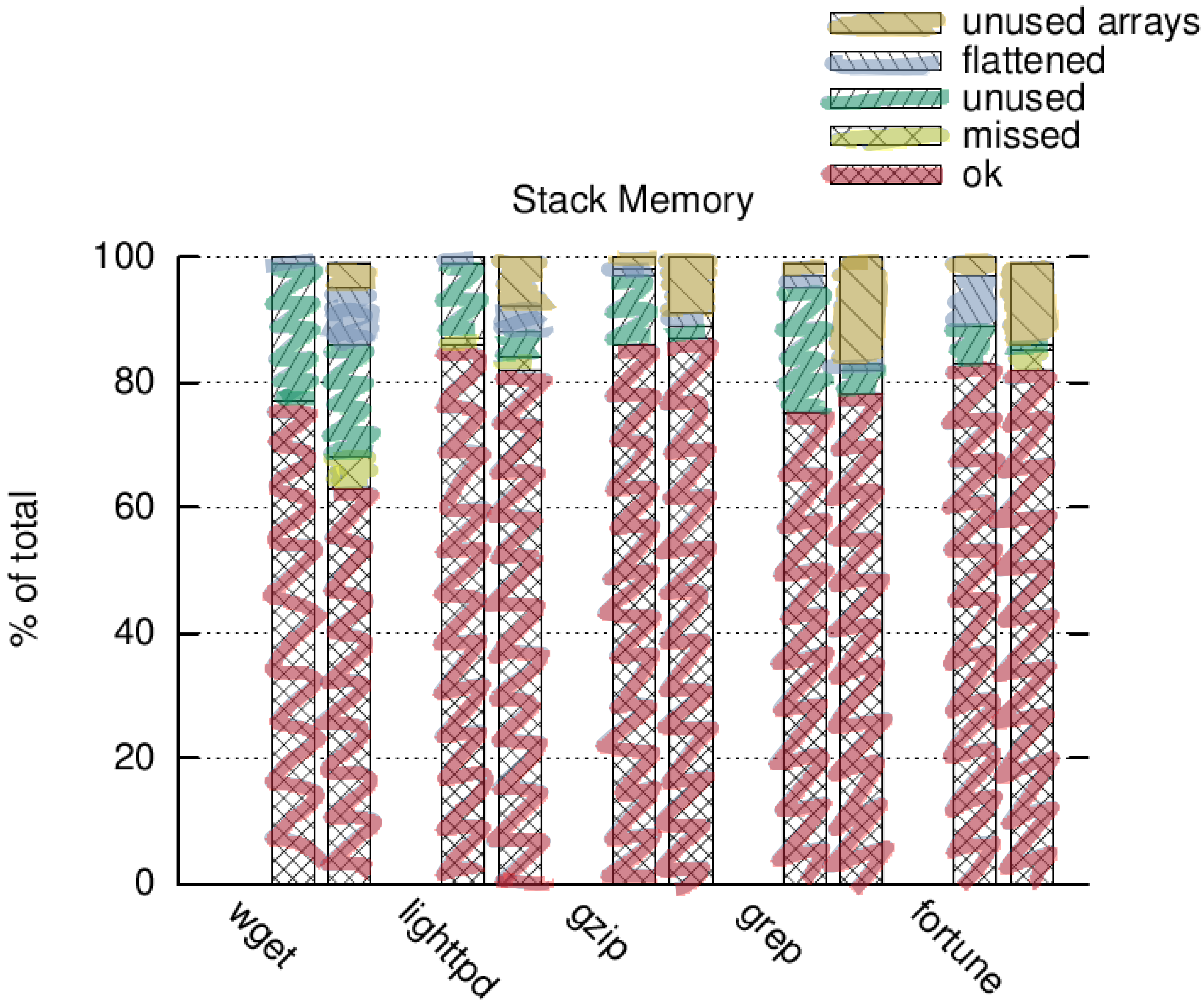

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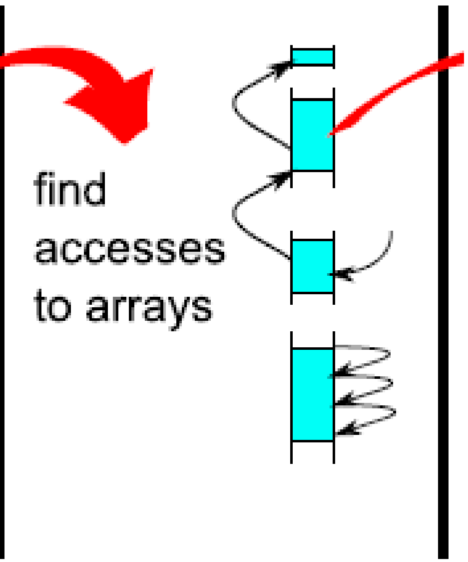
Demo?

Step 2: find array accesses



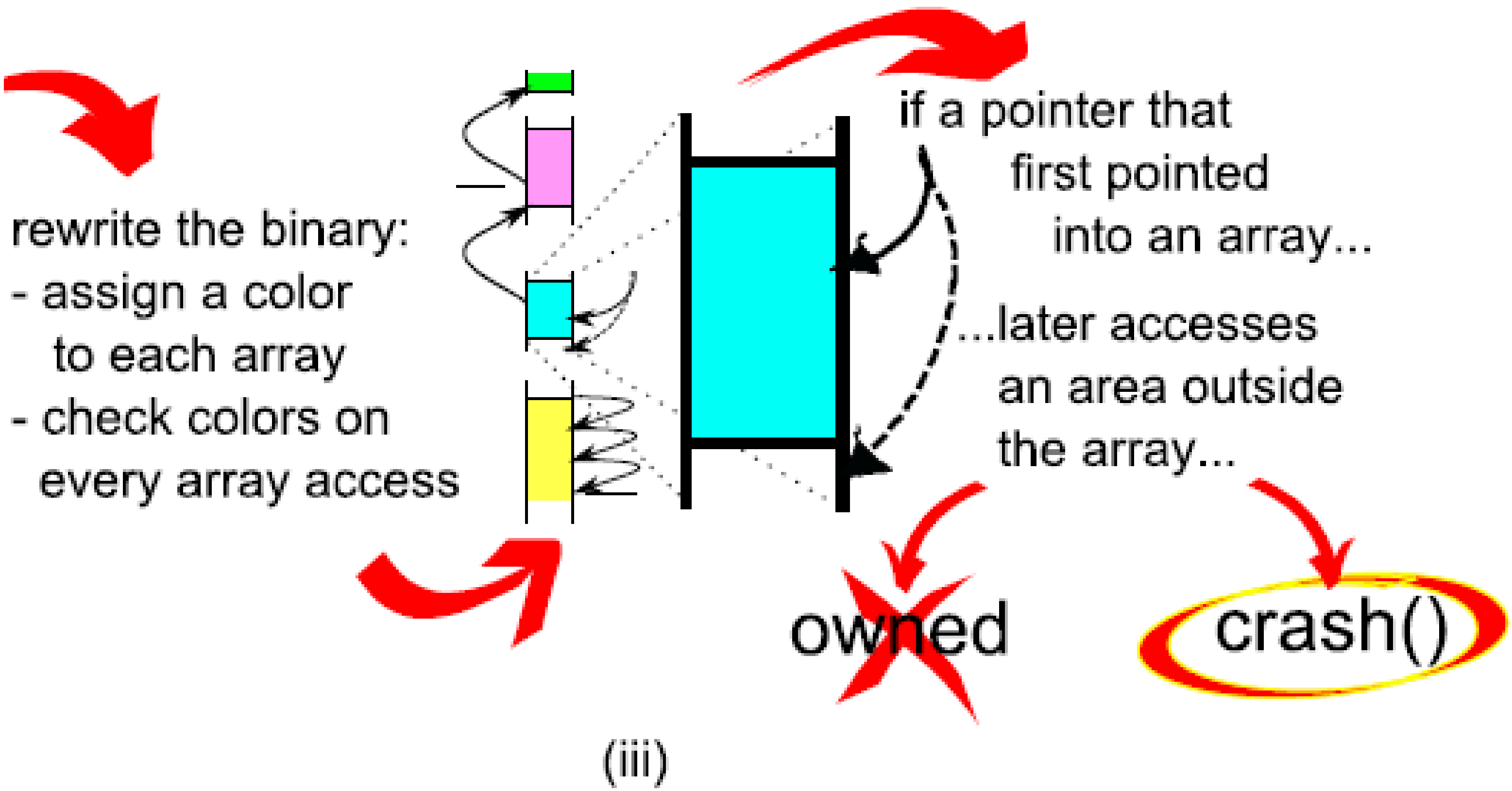
(ii)

In principle: very simple

– detect array accesses at runtime
– remember the instructions
–

Note: not complete

Step 3: rewrite the binary



Two Modes

- Protect at object level (like WIT, BBC)
  - given symbols: zero false positives
-
-
- Protect at subfield granularity (like no-one else)
  - no false positives seen in practice (but no guarantees)

THIS TALK

Focuses on the latter

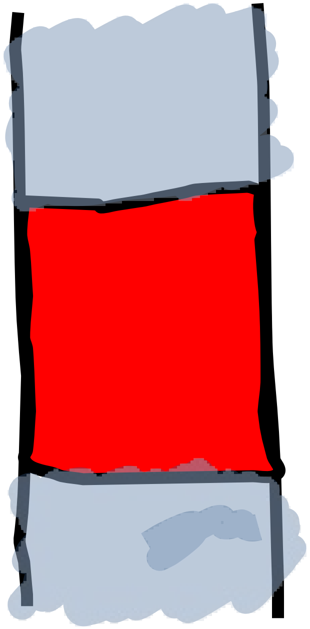
3

A colourful protection

- give all arrays a unique colour

```
p = array;
ASSIGN pointer a colour
col(p) = RED
i = 0;
while(!stop)
{
   *(p + i) = 0;


   i++;
}
```



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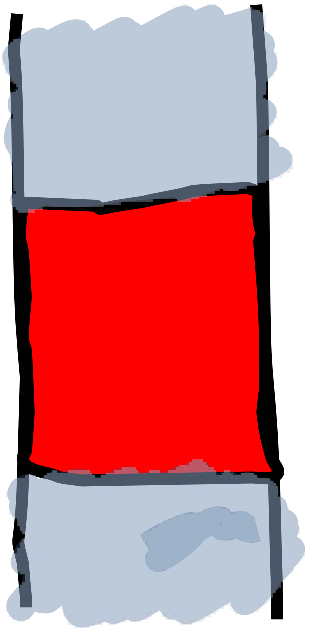
3

A colourful protection

- give all arrays a unique colour

```
p = array;
ASSIGN pointer a colour
col(p) = RED
i = 0;
while(!stop)
{
   *(p + i) = 0;
   CHECK if colours match:
    mem_col(p+i) == col(p)?
   i++;
}
```

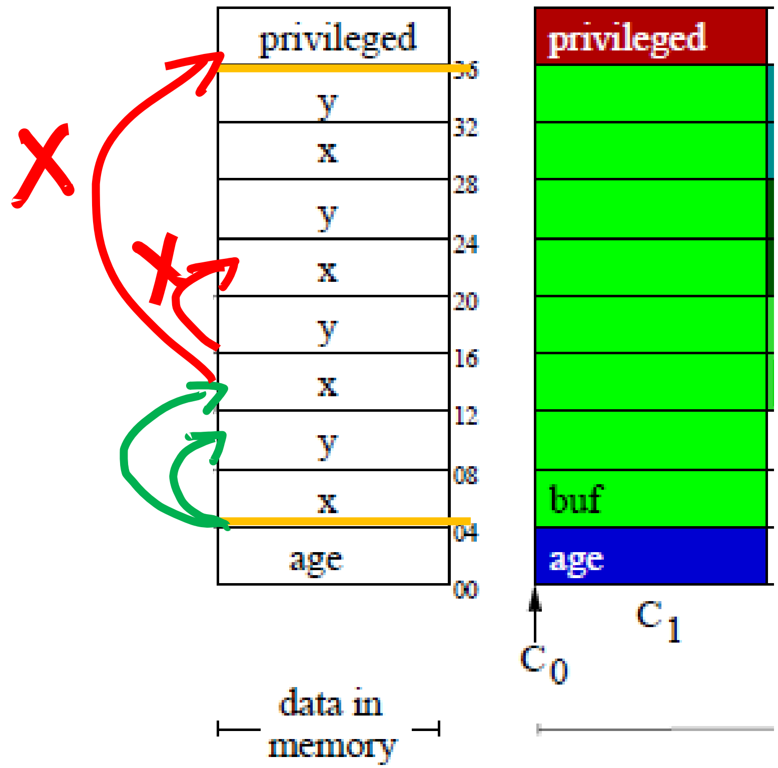


3

Reality requires subtle shades

```
typedef struct pair {
    int x;
    int y;
} pair_t;

struct s {
    int  age;
    pair_t buf[4];
    int  privileged;
};
```



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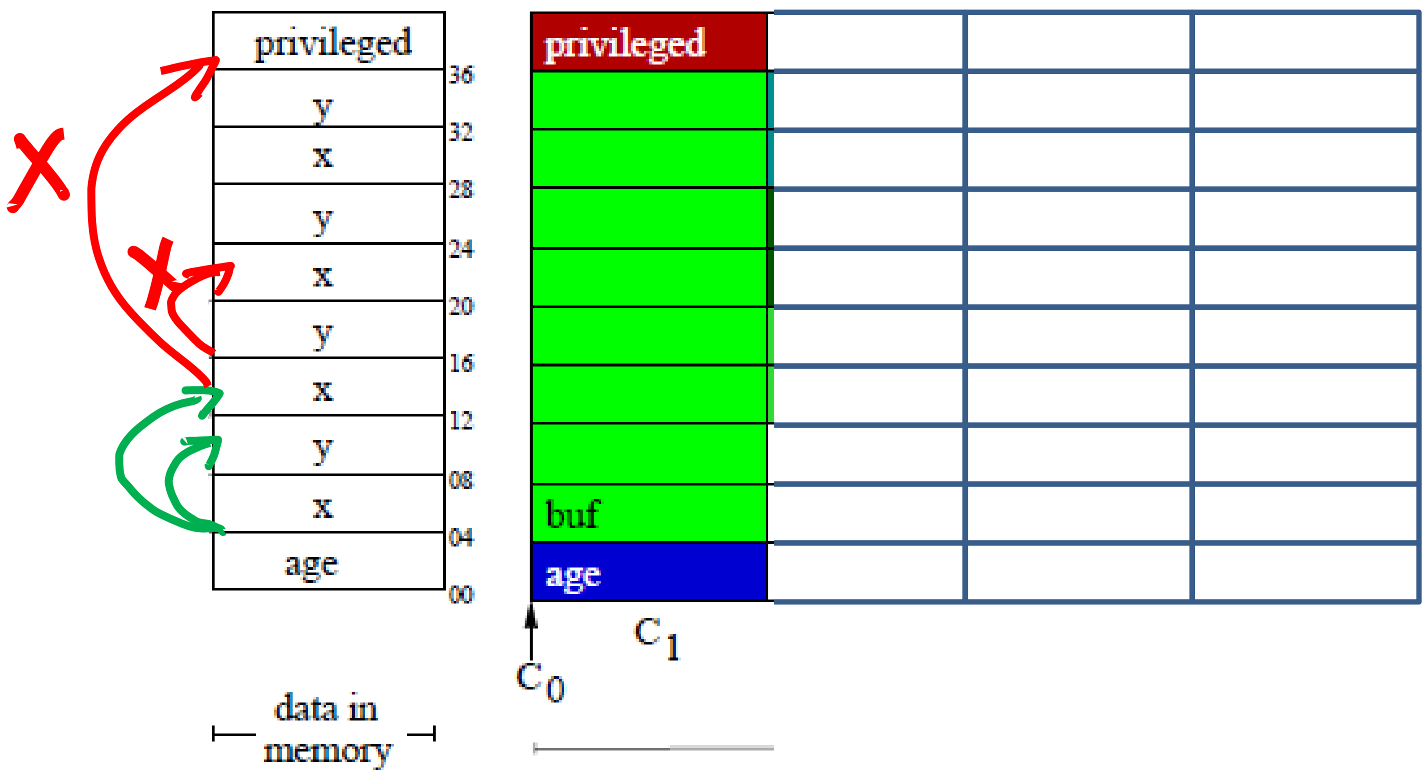

3

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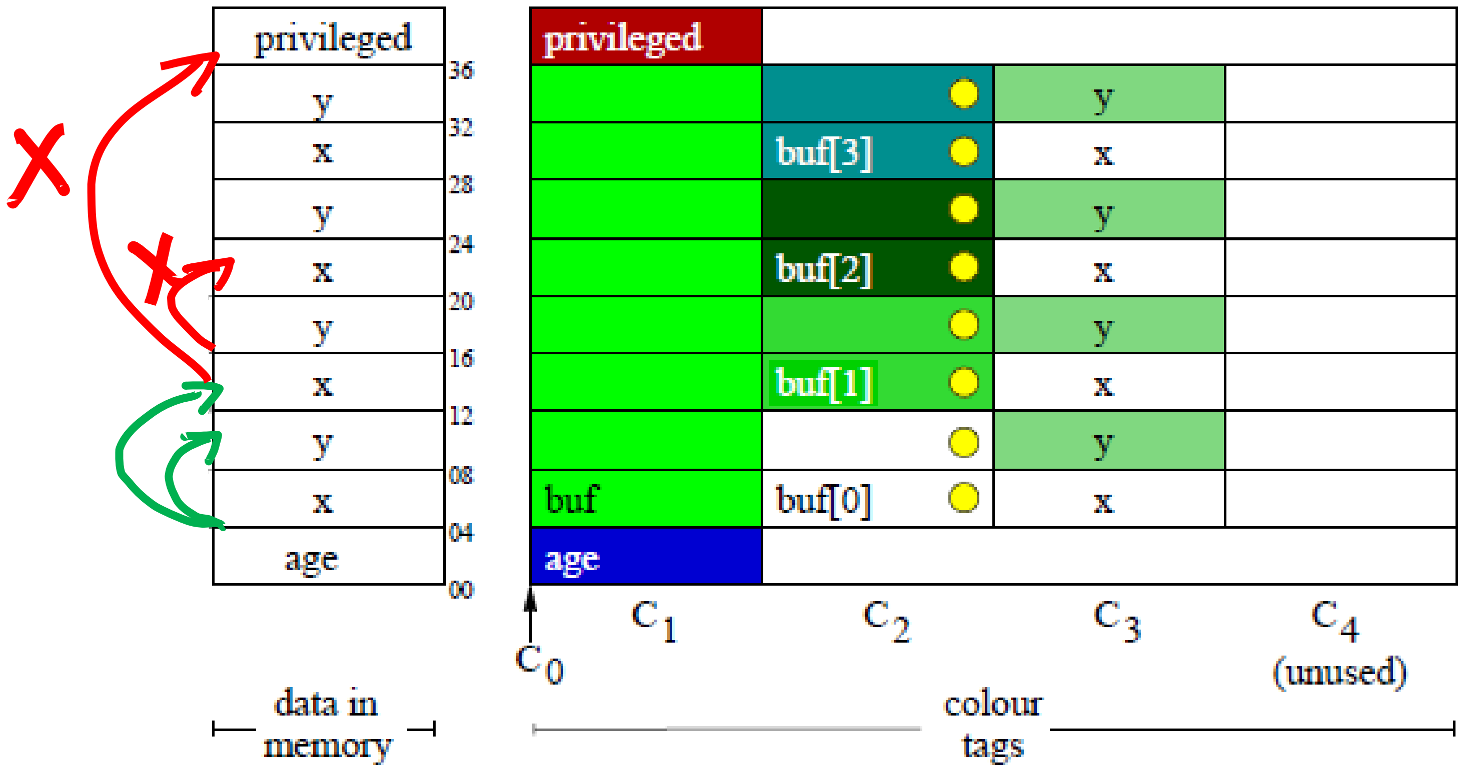

3

In reality

```
typedef struct pair {
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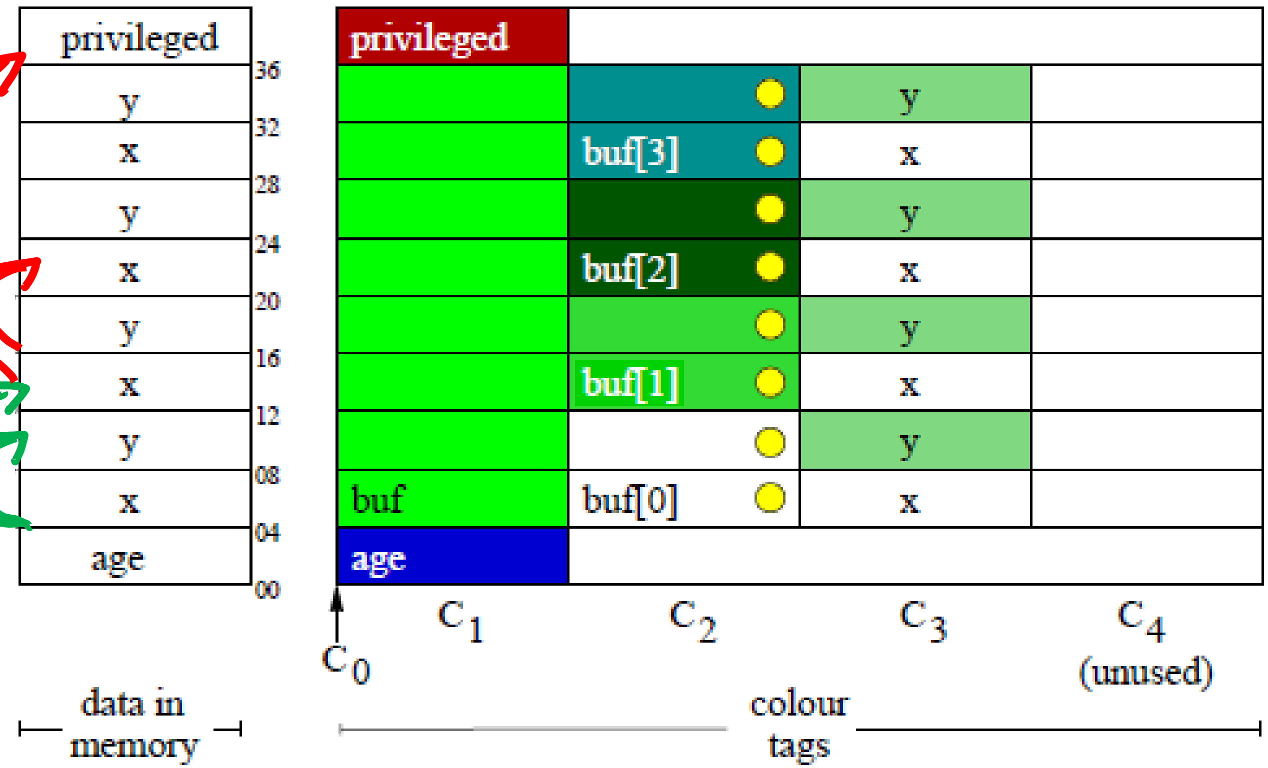

Check: does the pointer colour match that of the location pointed to?
(left to right, in all shades, with blanks serving as wild cards)

3

Unfortunately, some code is colour blind!

```
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} pair_t;

struct s {
    int  age;
    pair_t buf[4];
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};
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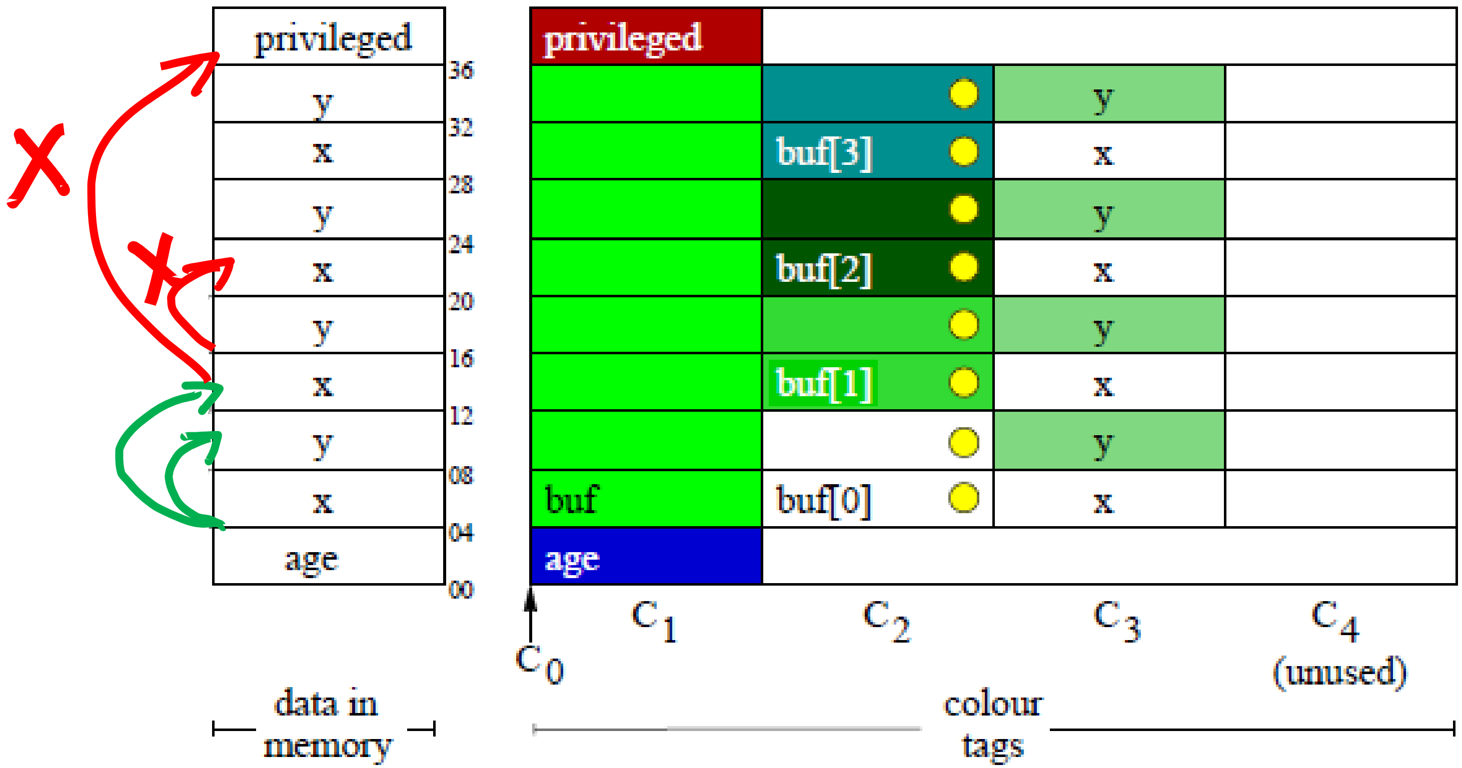


```
int *p;
for (p=objptr, p<sizeof(*objptr); p++) *p = 0;
```

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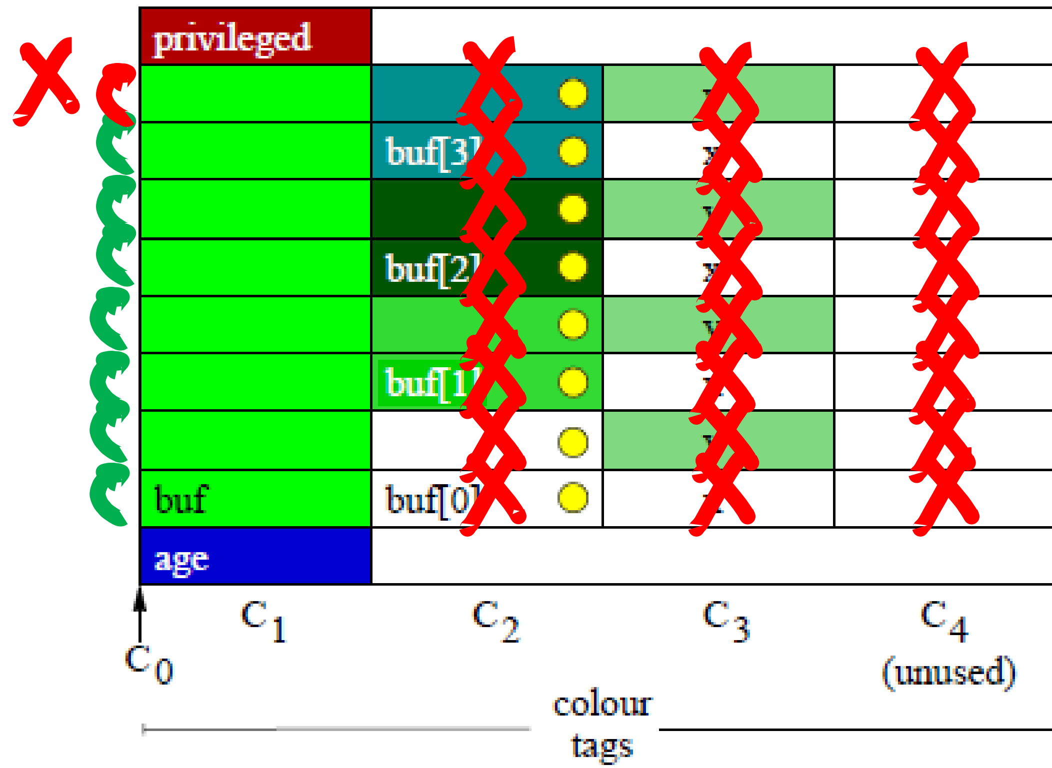
So we mask some shades

```
/* initialize the buffer */
int *p;
int len = 4; //buf length

for(p = mystruct.buf;
  p < mystruct.buf+len;
  p++)
{
    *p = 0;
}
```



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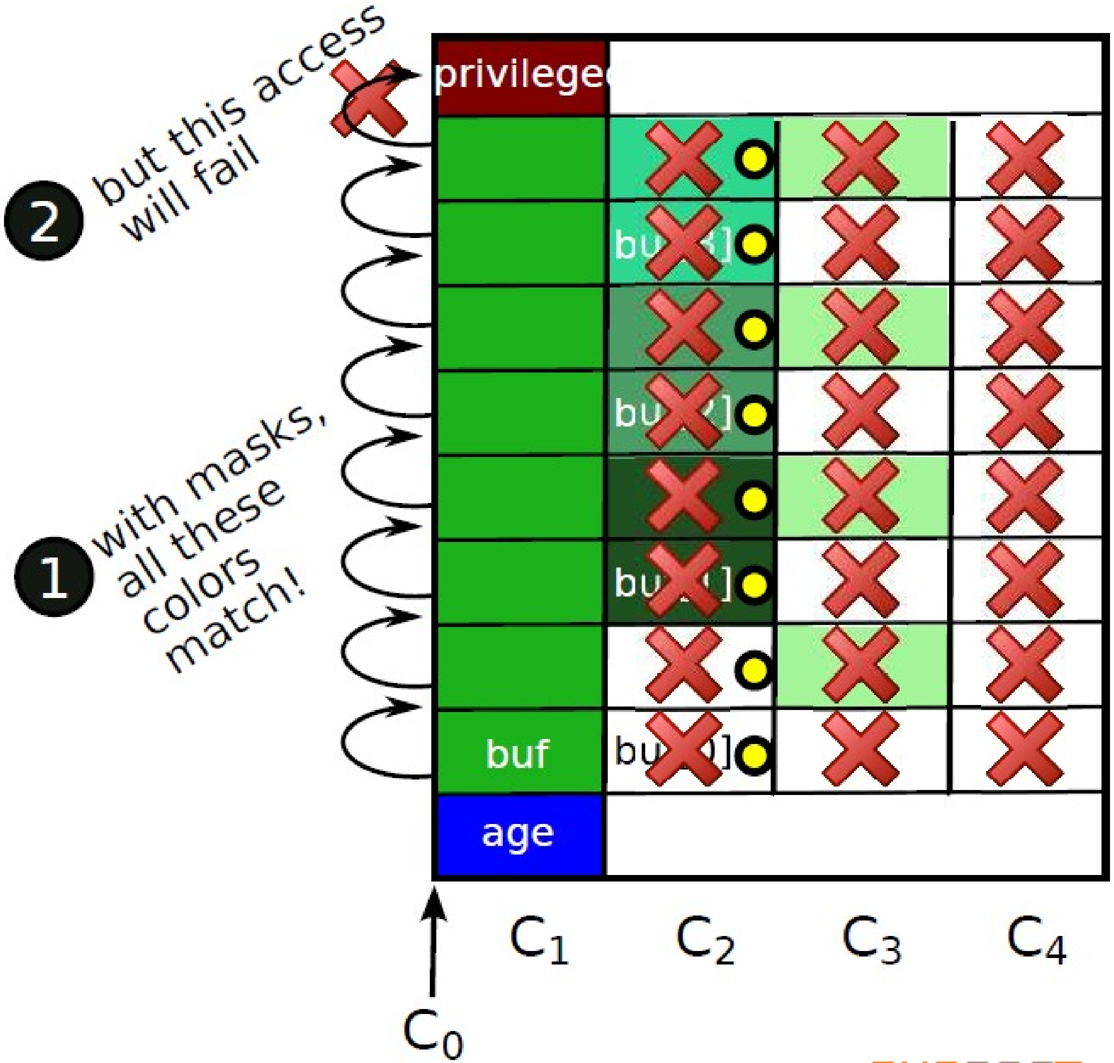
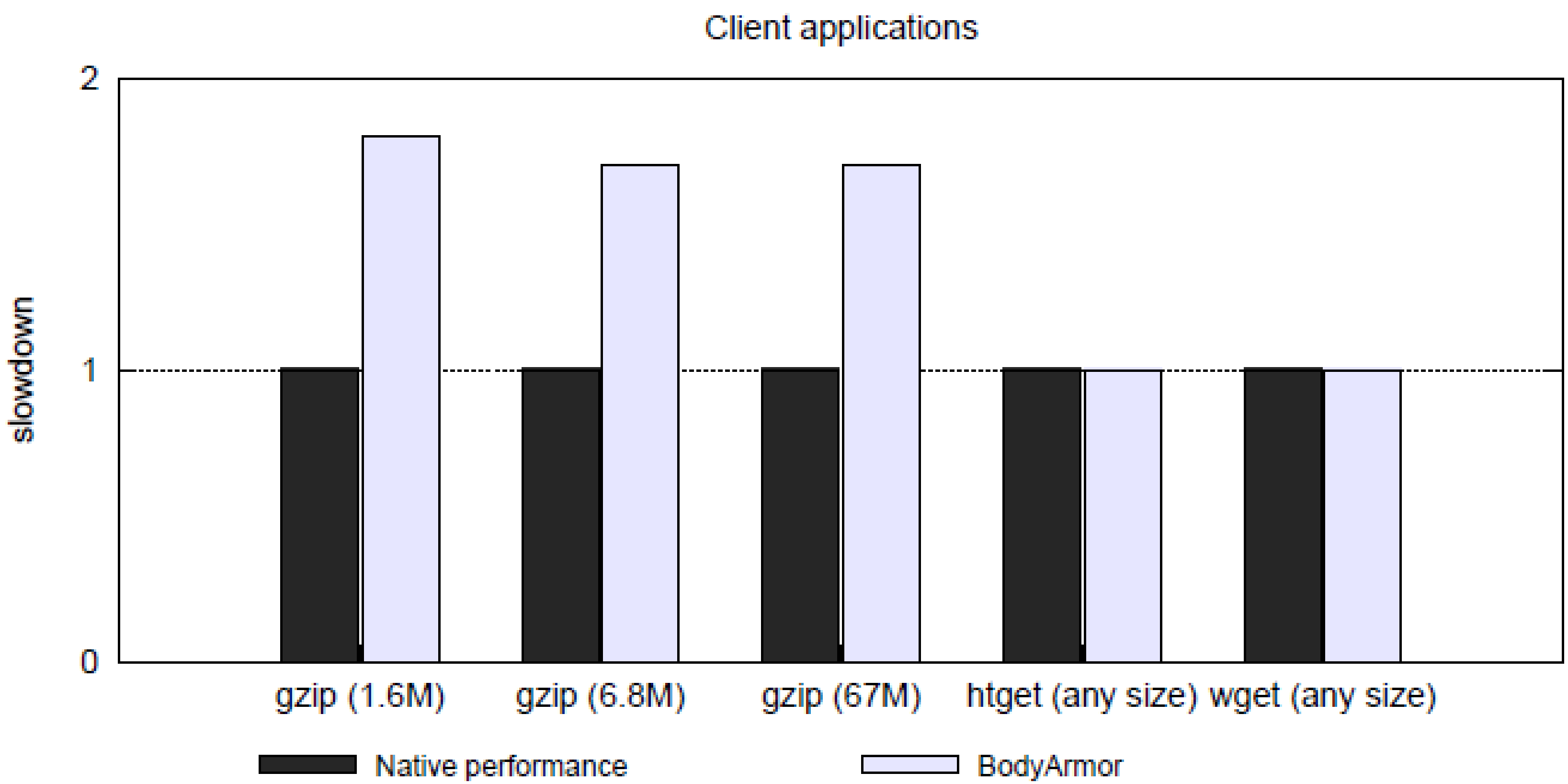
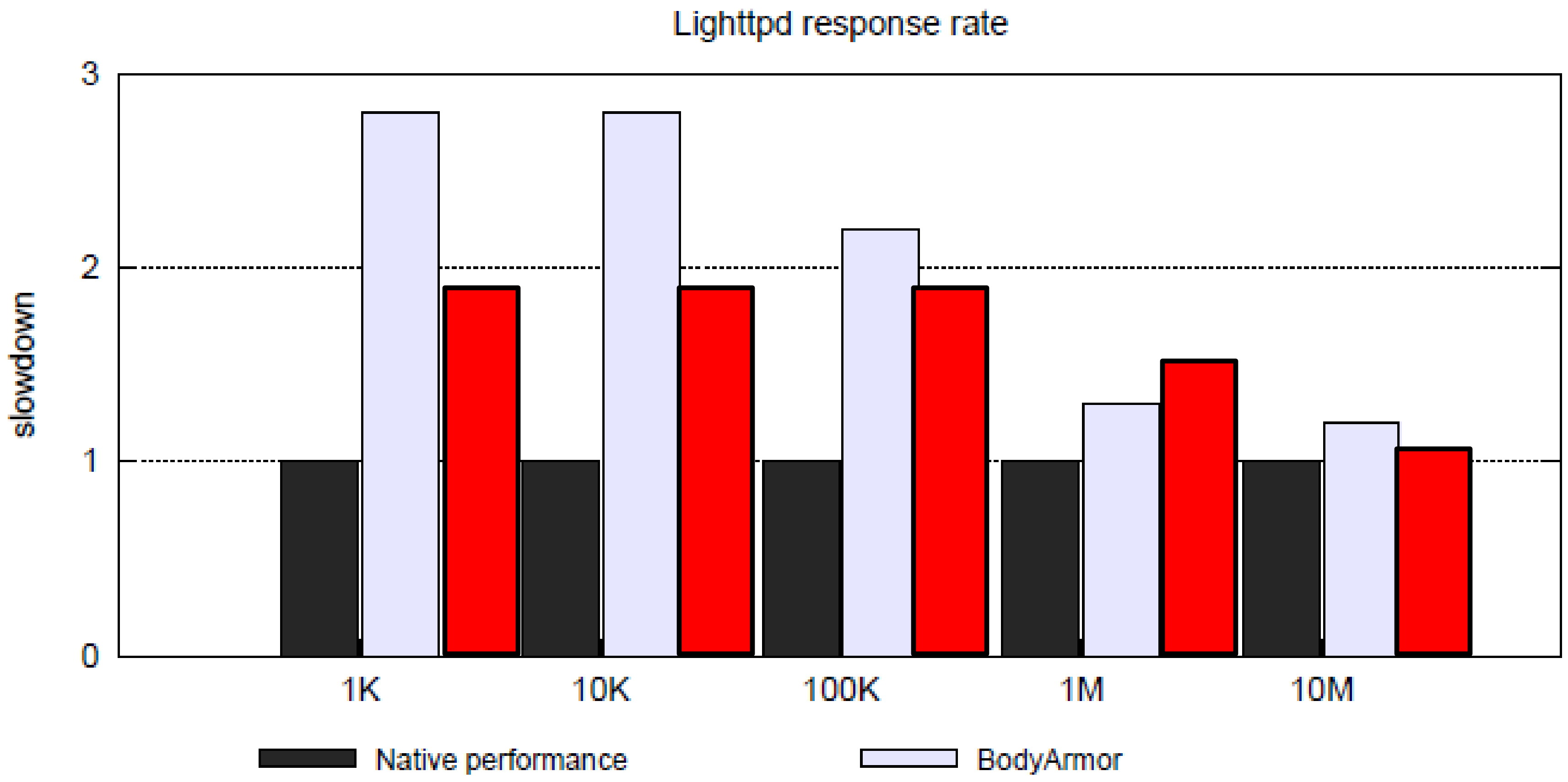


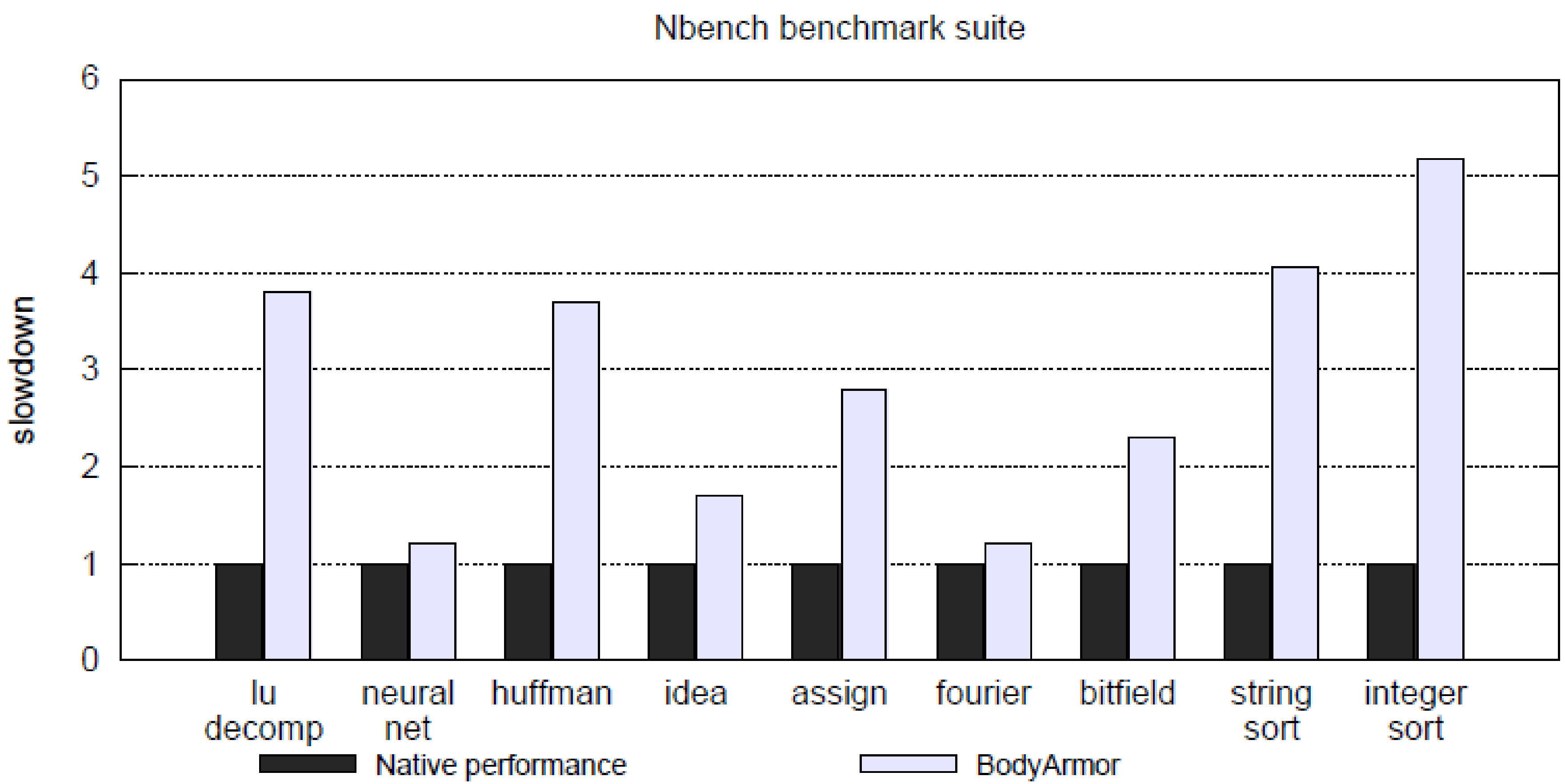
Performance?



Performance?



Performance?



overall: 2.9

1 2 3

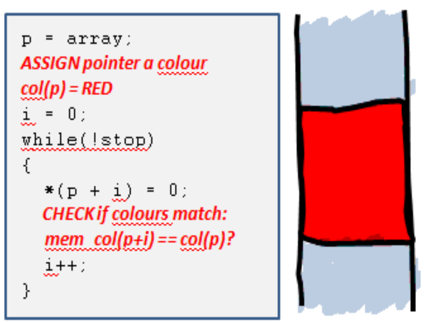
Effectiveness?

Application	Type of vulnerability	Security advisory
Proftpd 1.3.3a	Stack overflow	CVE-2010-4221
Htget 0.93 (1)	Stack overflow	CVE-2004-0852
Htget 0.93 (2)	Stack overflow	
Aspell 0.50.5	Stack overflow	CVE-2004-0548
Iwconfig v.26	Stack overflow	CVE-2003-0947
Aeon 0.2a	Stack overflow	CVE-2005-1019

Application	Type of vulnerability	Security advisory
Exim 4.41	Heap overflow, non-control data	CVE-2010-4344
bc-1.06 (1)	Heap overflow	Bugbench [27]
bc-1.06 (2)	Heap overflow	Bugbench [27]
Nullhttpd-0.5.1	Heap overflow, reproduced	CVE-2002-1496
Squid-2.3	Heap overflow, reproduced	Bugbench [27]
Ncompress 4.2.4	Stack overflow	CVE-2001-1413

Conclusions

- Memory errors
  - are not going to go away
- BinArmor
  - protect against attacks on non-control data
  - few (if any) FPs
  - expensive
  - not fully optimised yet!



http://www.cs.vu.nl/~herbertb/

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