This time

We will begin our 1st section:

Software Security

By investigating

Buffer overflows

and other memory safety vulnerabilities

- History
- Memory layouts
- Buffer overflow fundamentals

Analyzing security

“Security mindset”

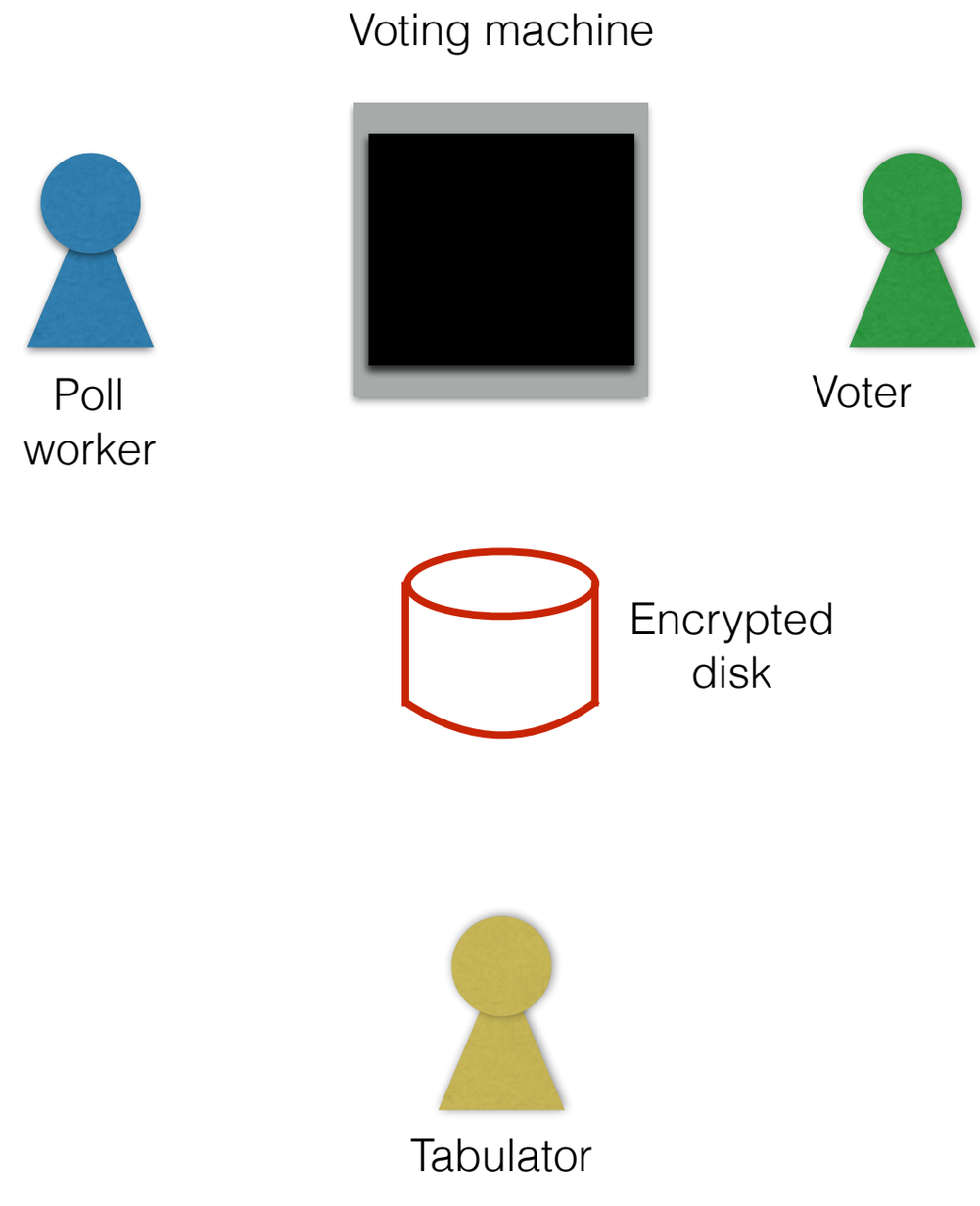
- One of the goals for this course is to develop a “security mindset”

- That is, the ability to view a potentially large, complex system and be able to reason about:
  - What are some of the **potential security threats**?
  - What are the **hidden assumptions**? (and are the explicit assumptions likely to be true?)
  - How can we **mitigate the risks** of the system?

- Be creative! (attackers will be)

E-voting analysis

1. Summarize the system as clearly and concisely as possible



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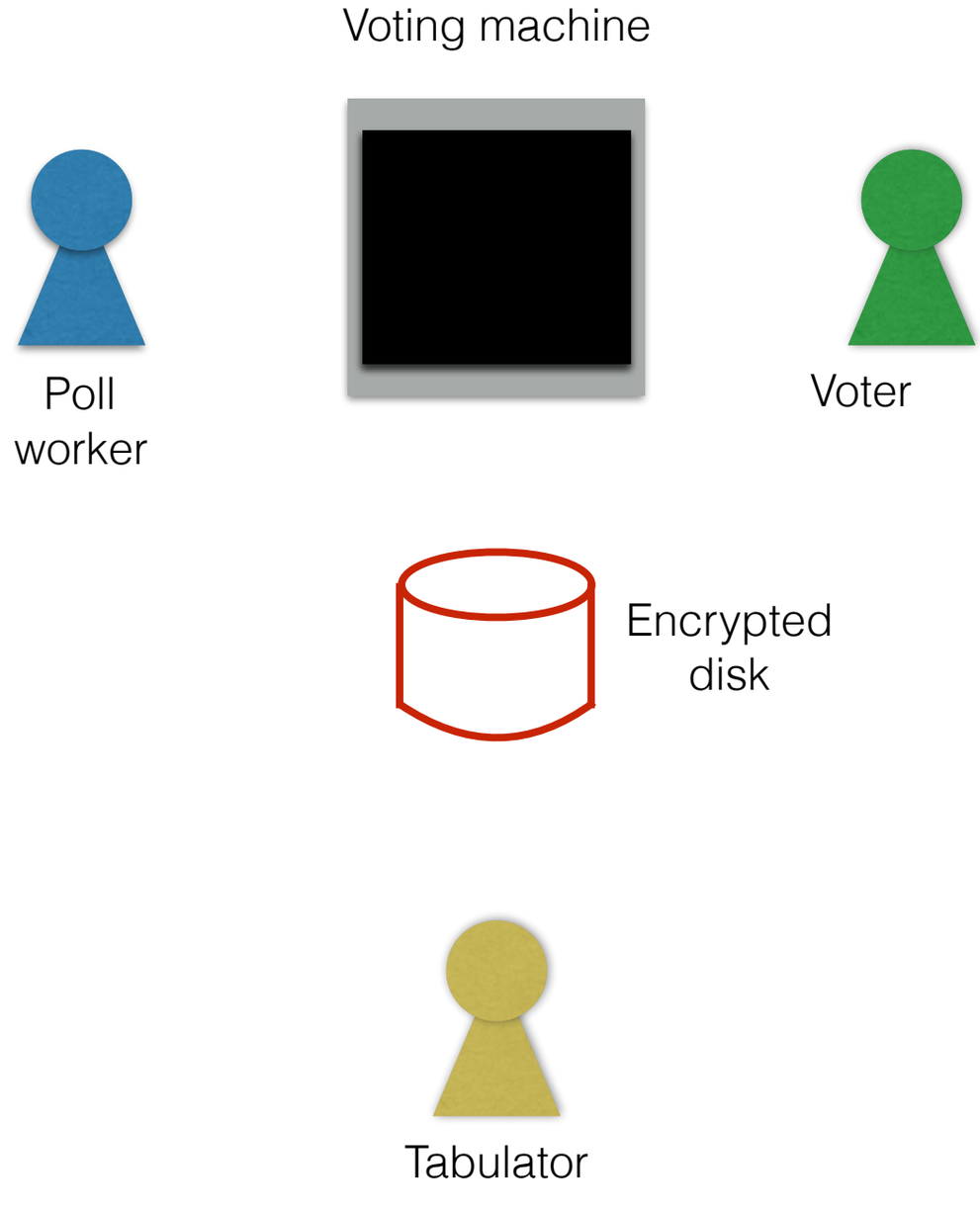

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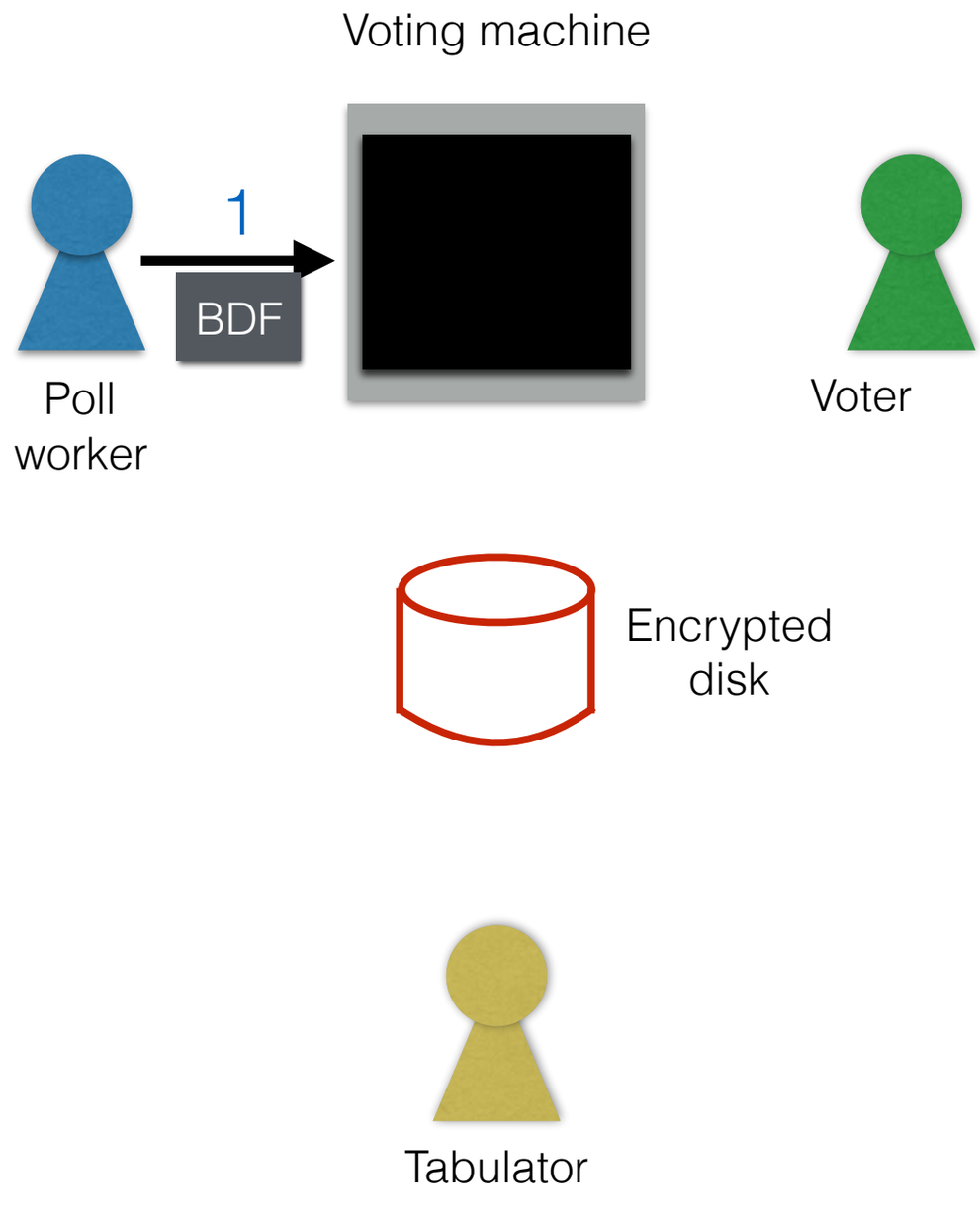

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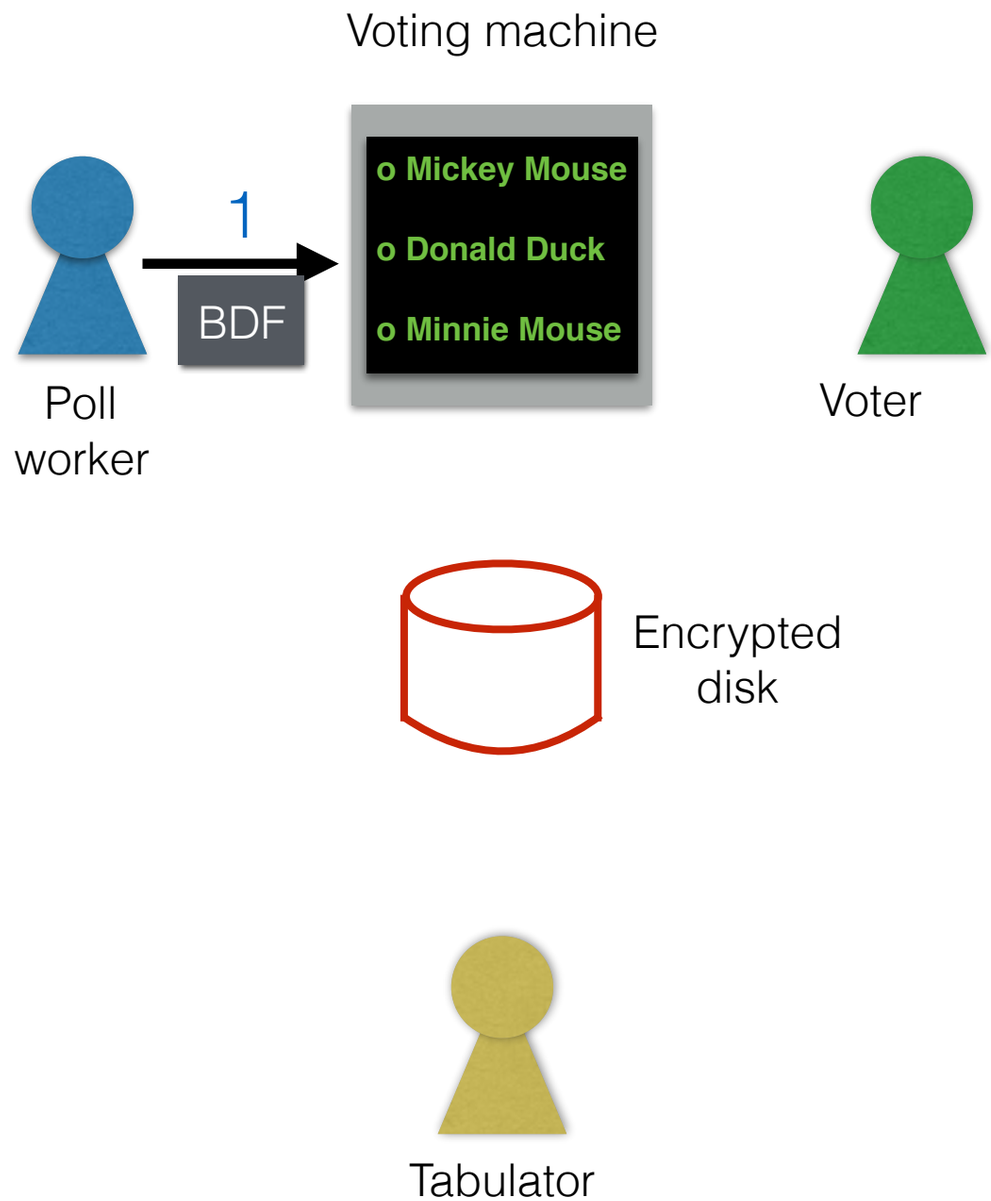

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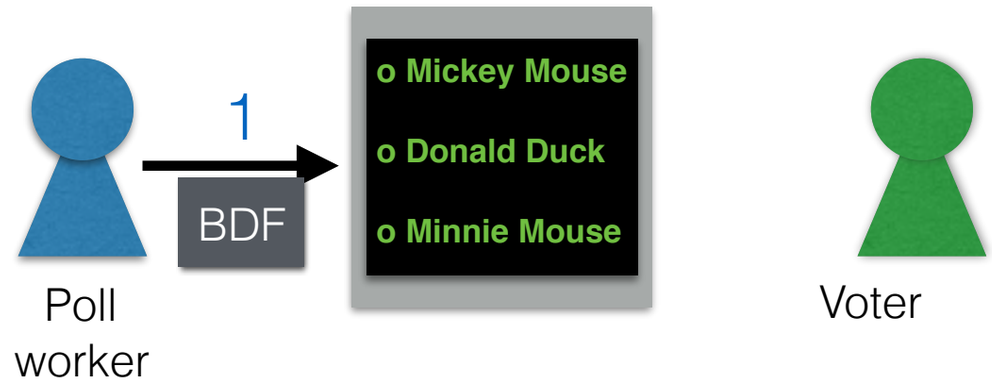

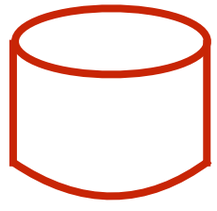

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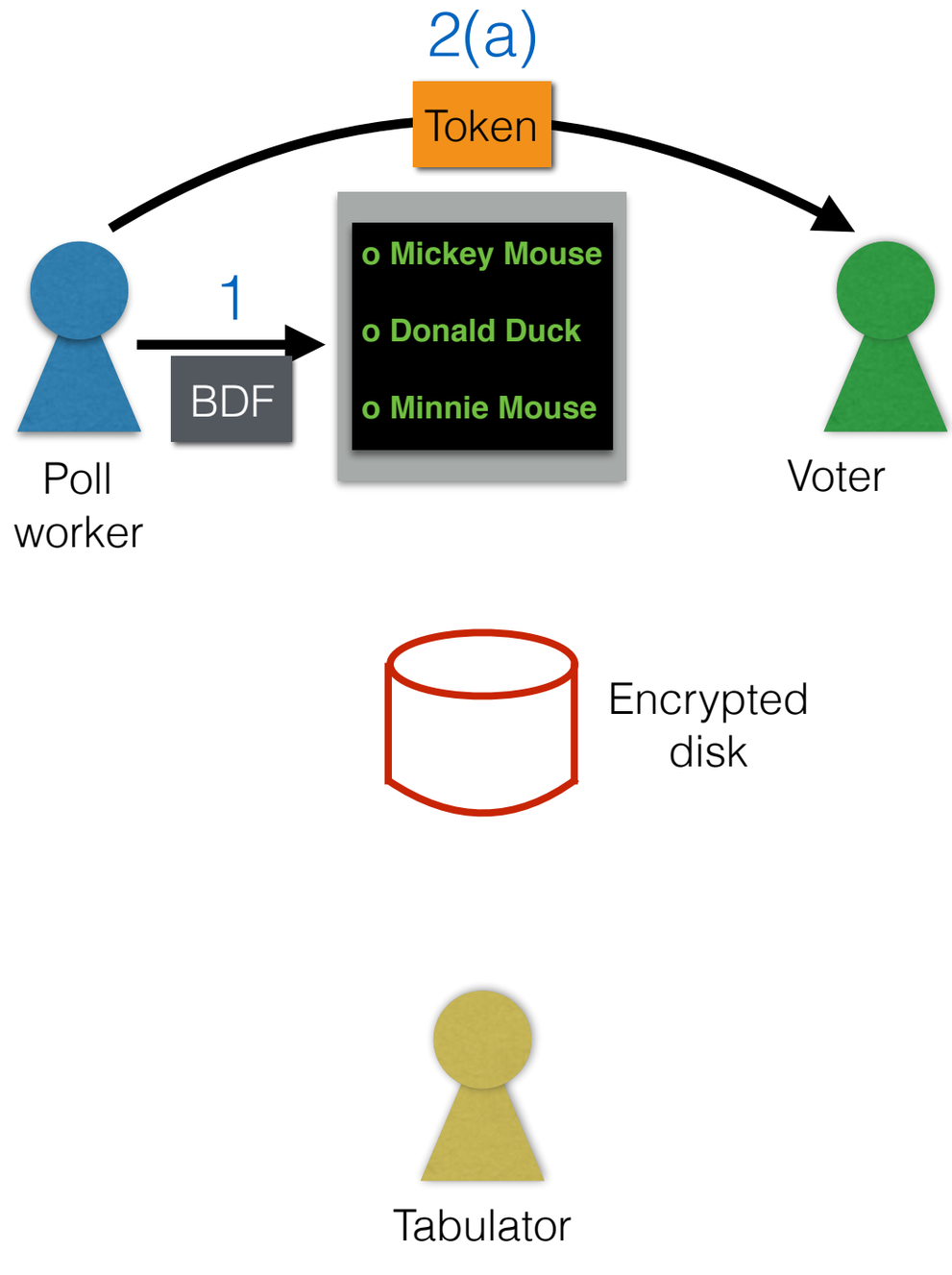

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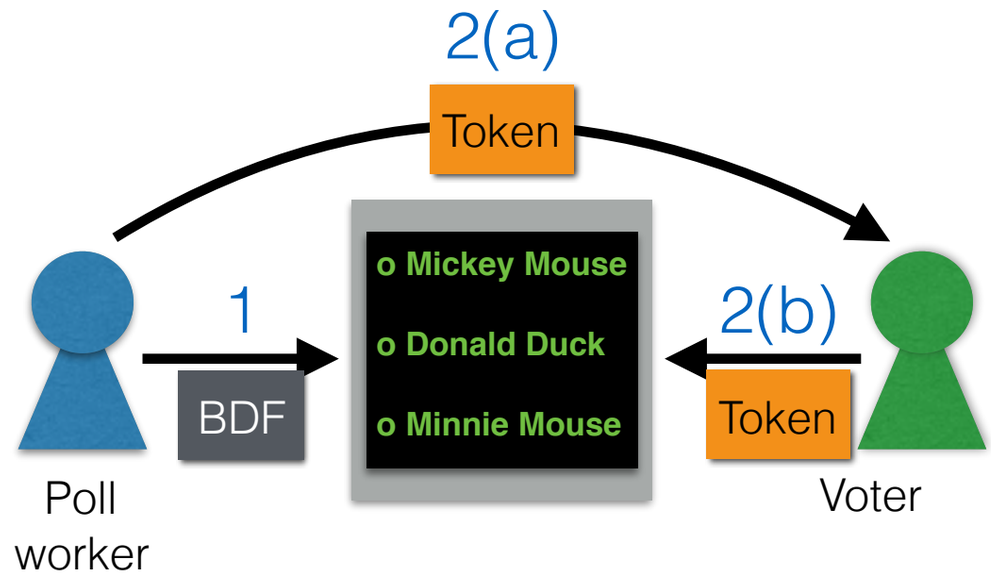

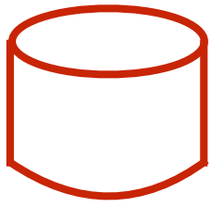
Encrypted disk


Tabulator

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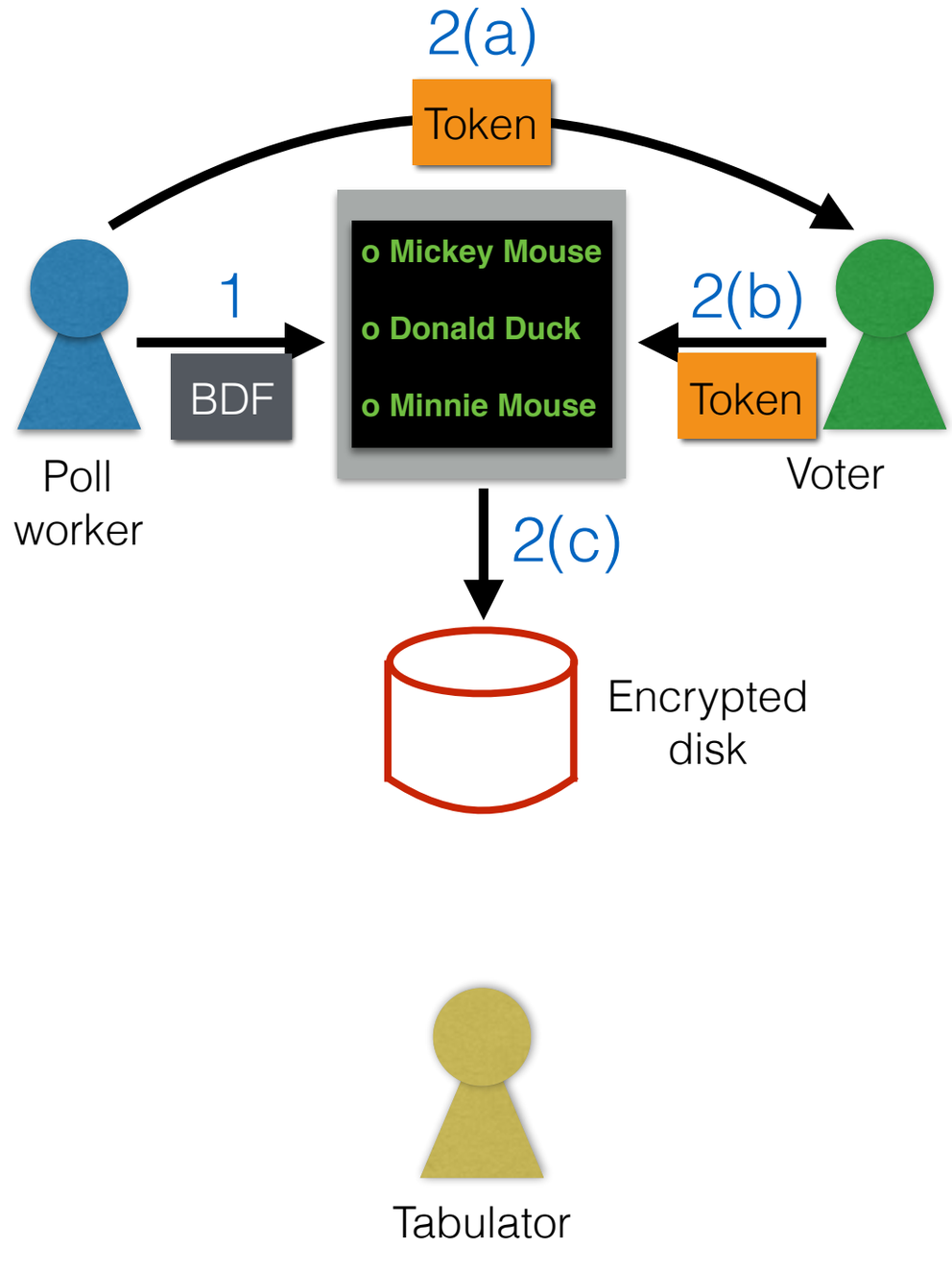

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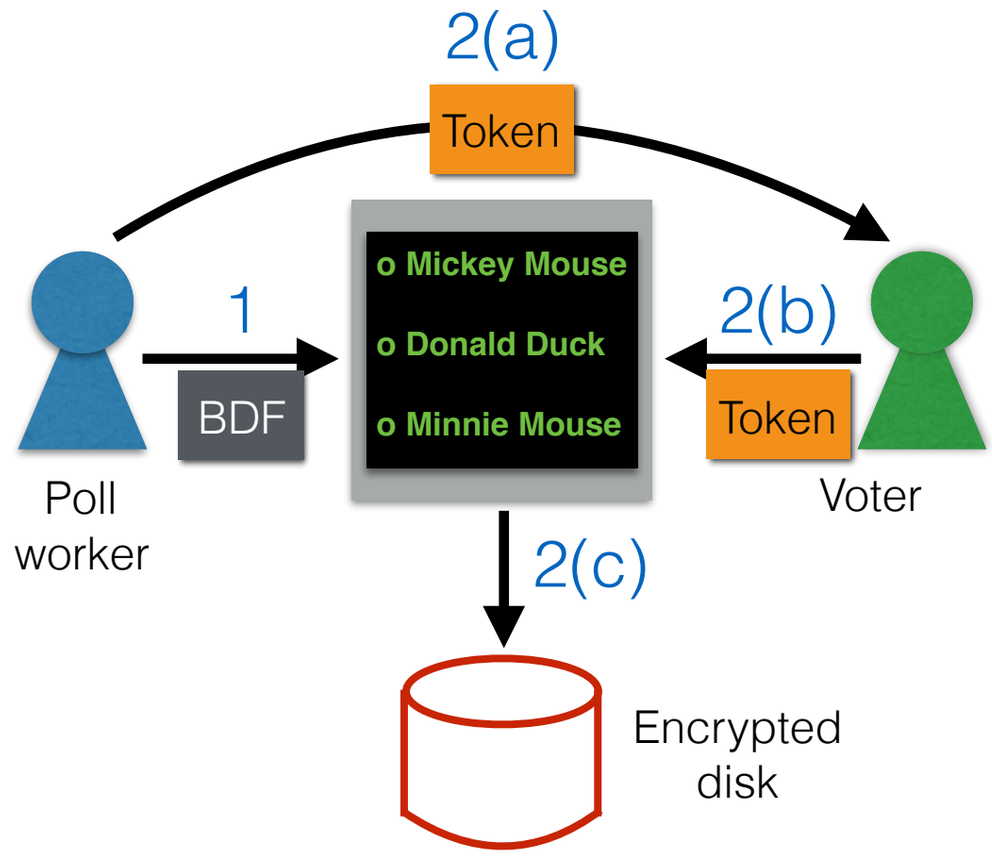


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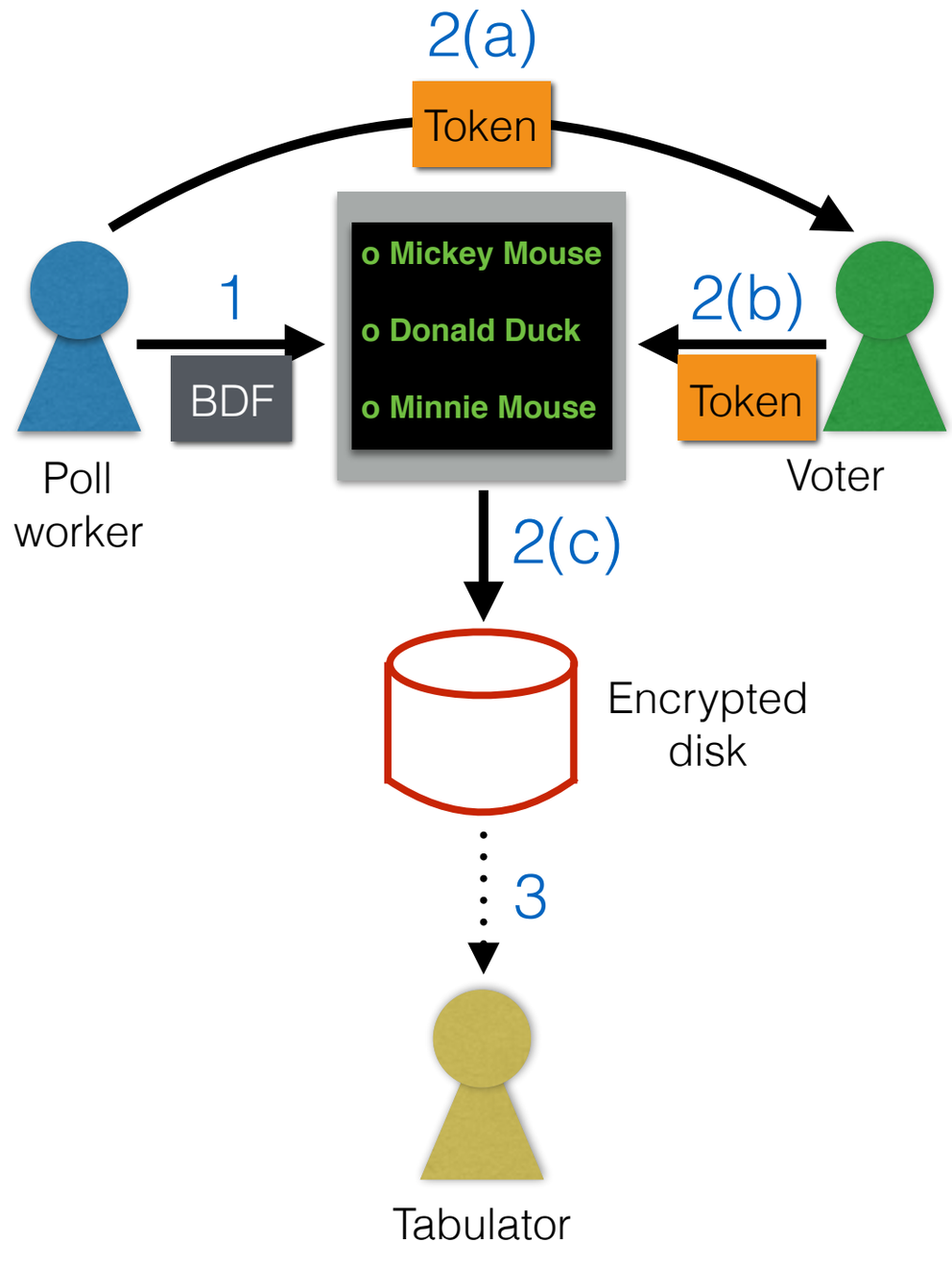
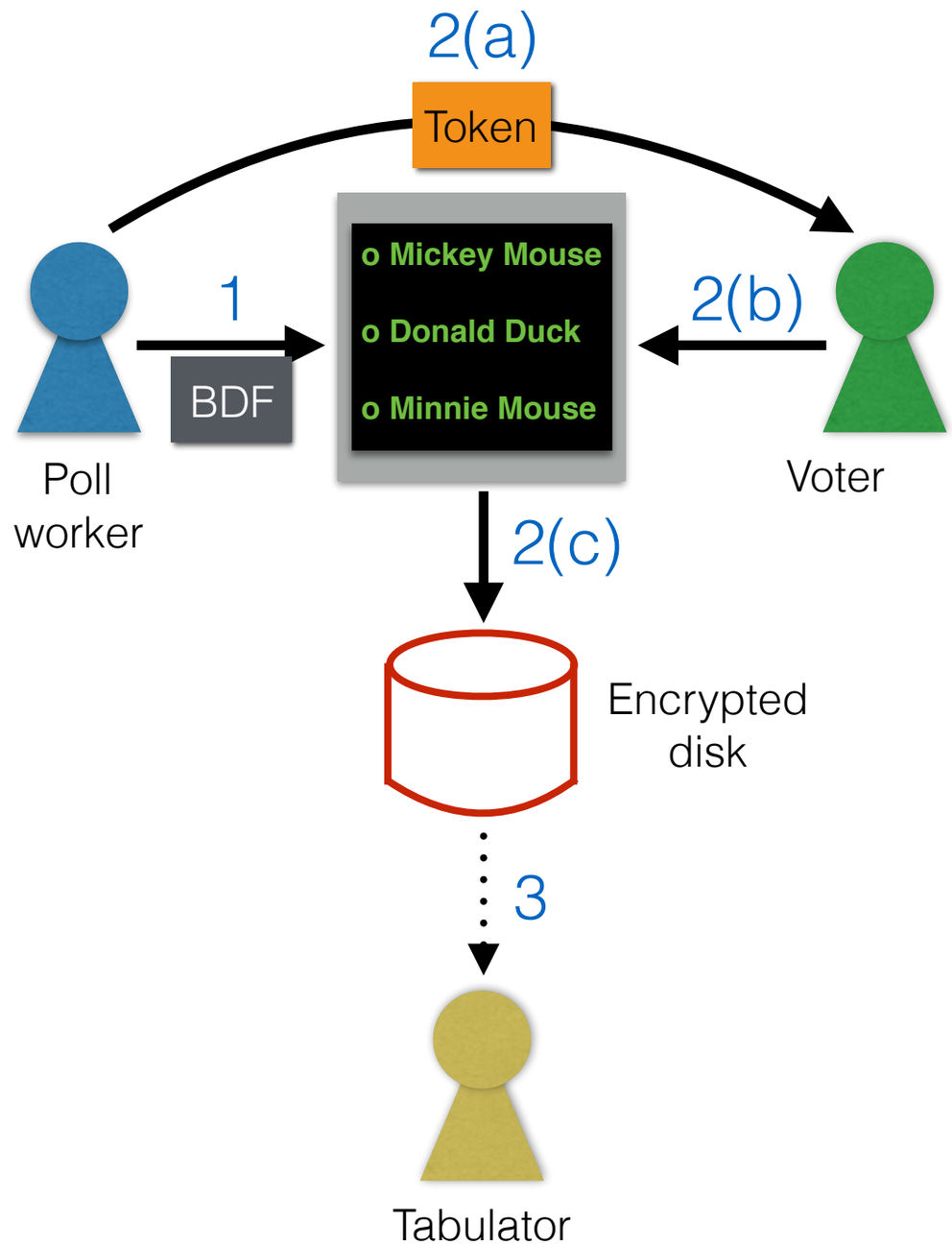


E-voting analysis

2. Identify the assets / goals of the system

- Confidentiality (can't steal data)
- Integrity (can't modify data)
- Availability (system stays up)
- Usability (no undue burden on users)



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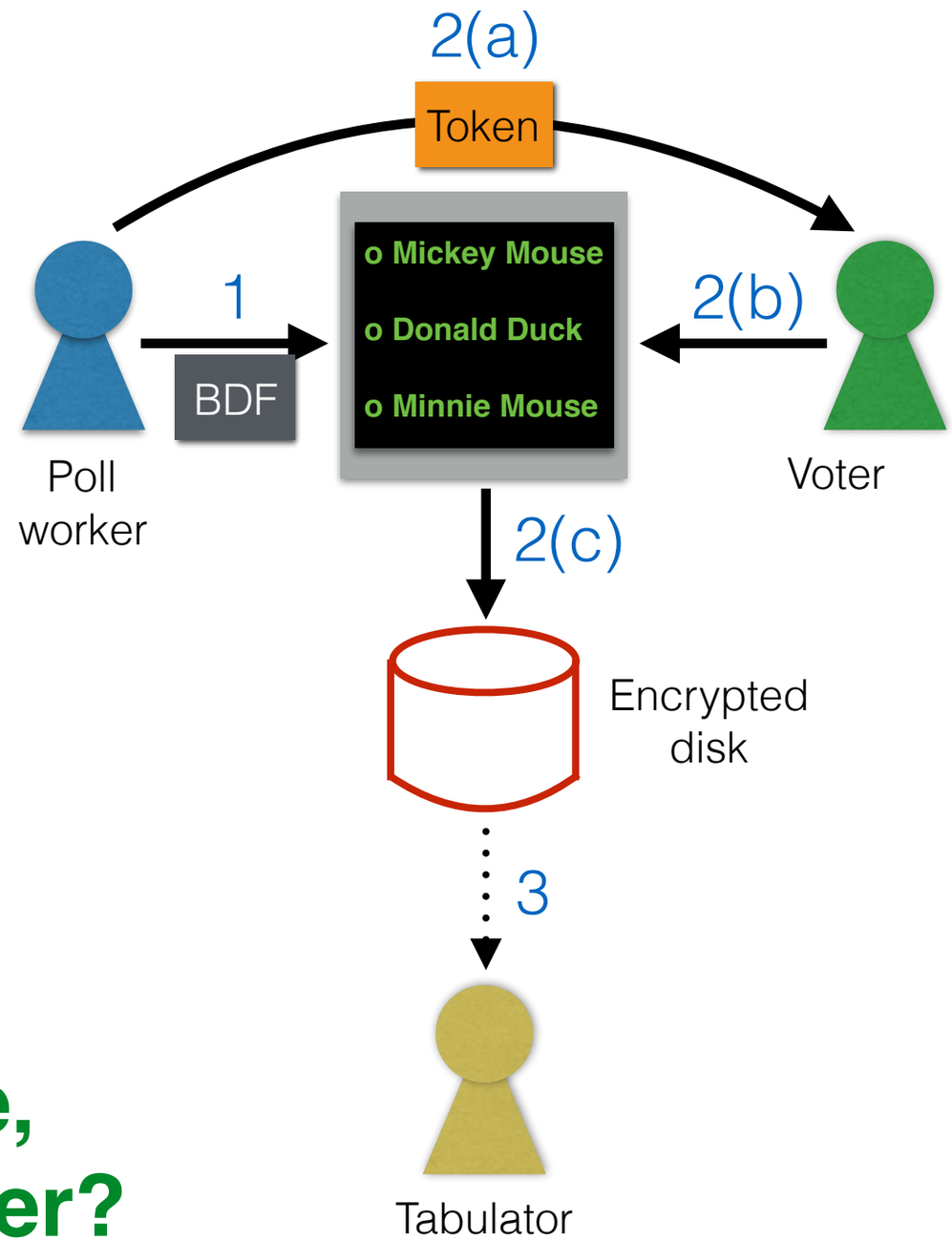
Is it ok if the attacker *can* do these, so long as you can *catch* him or her?



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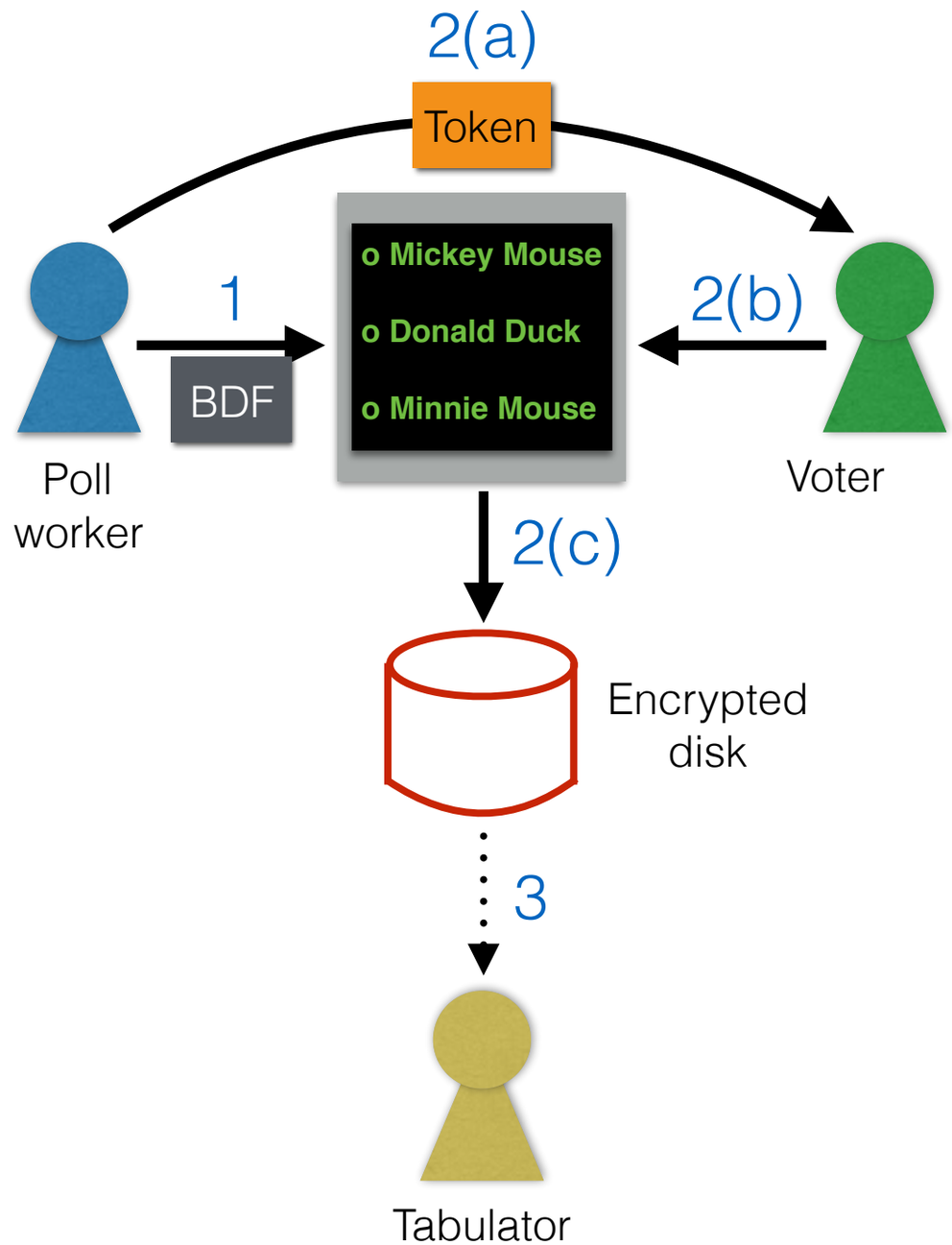

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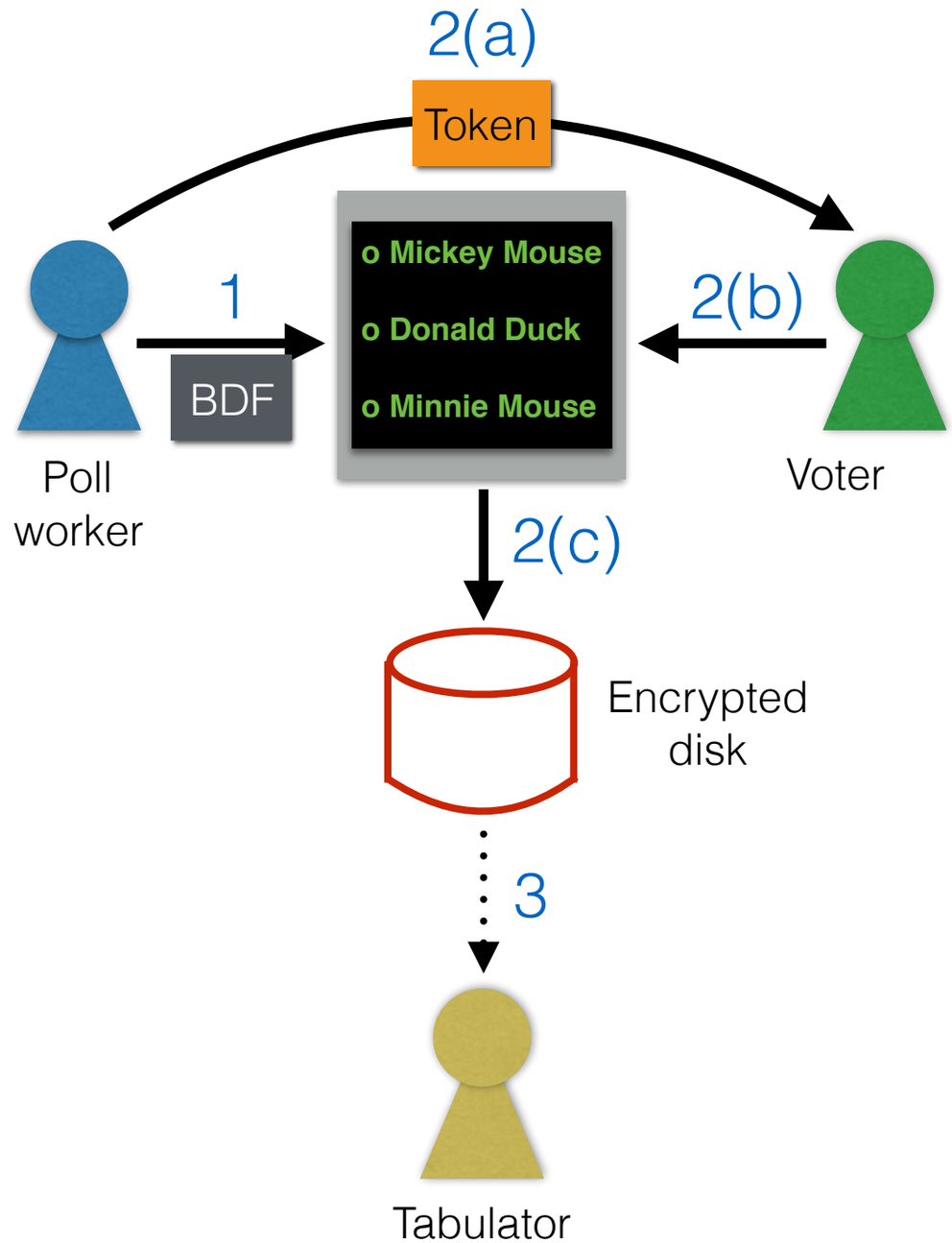

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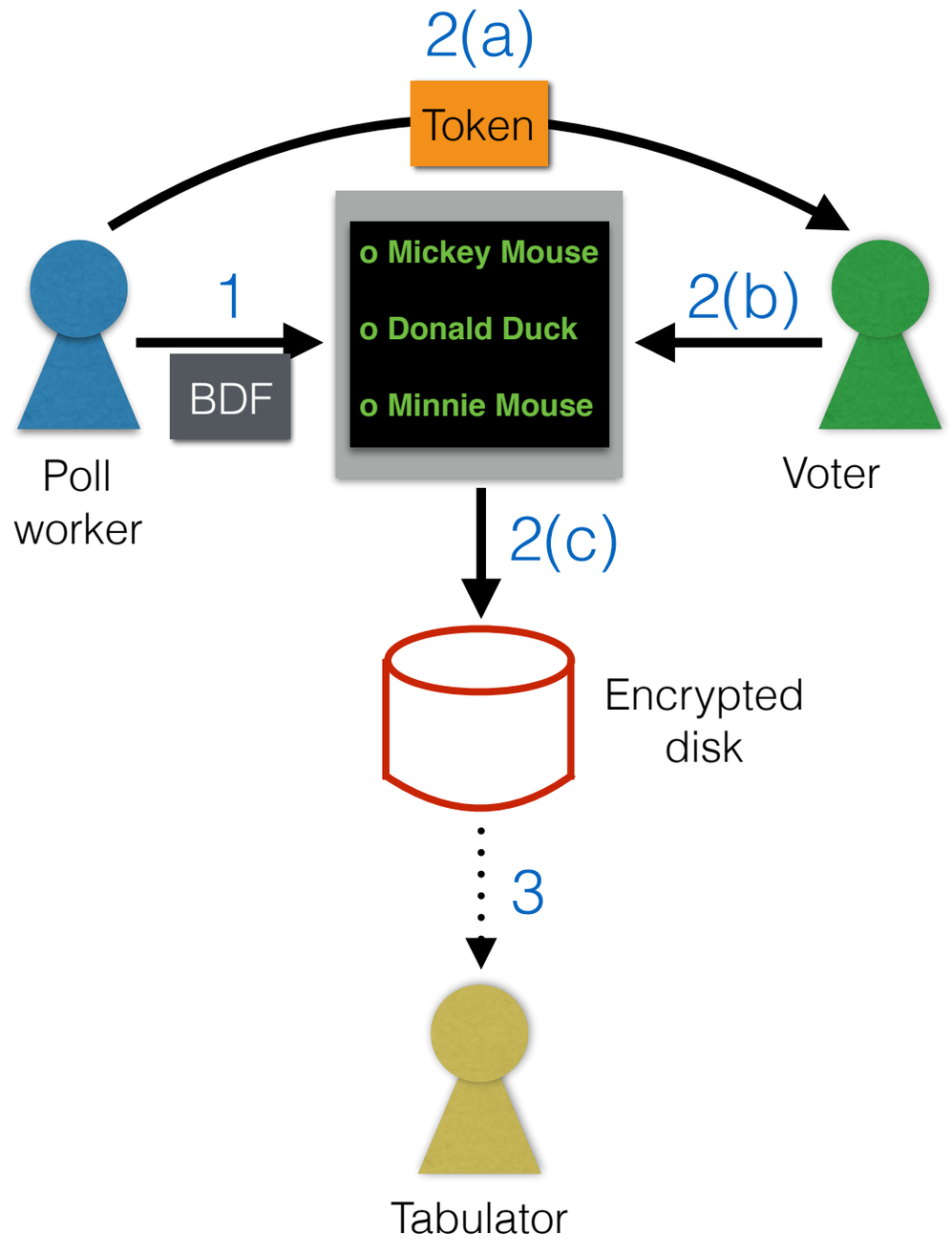

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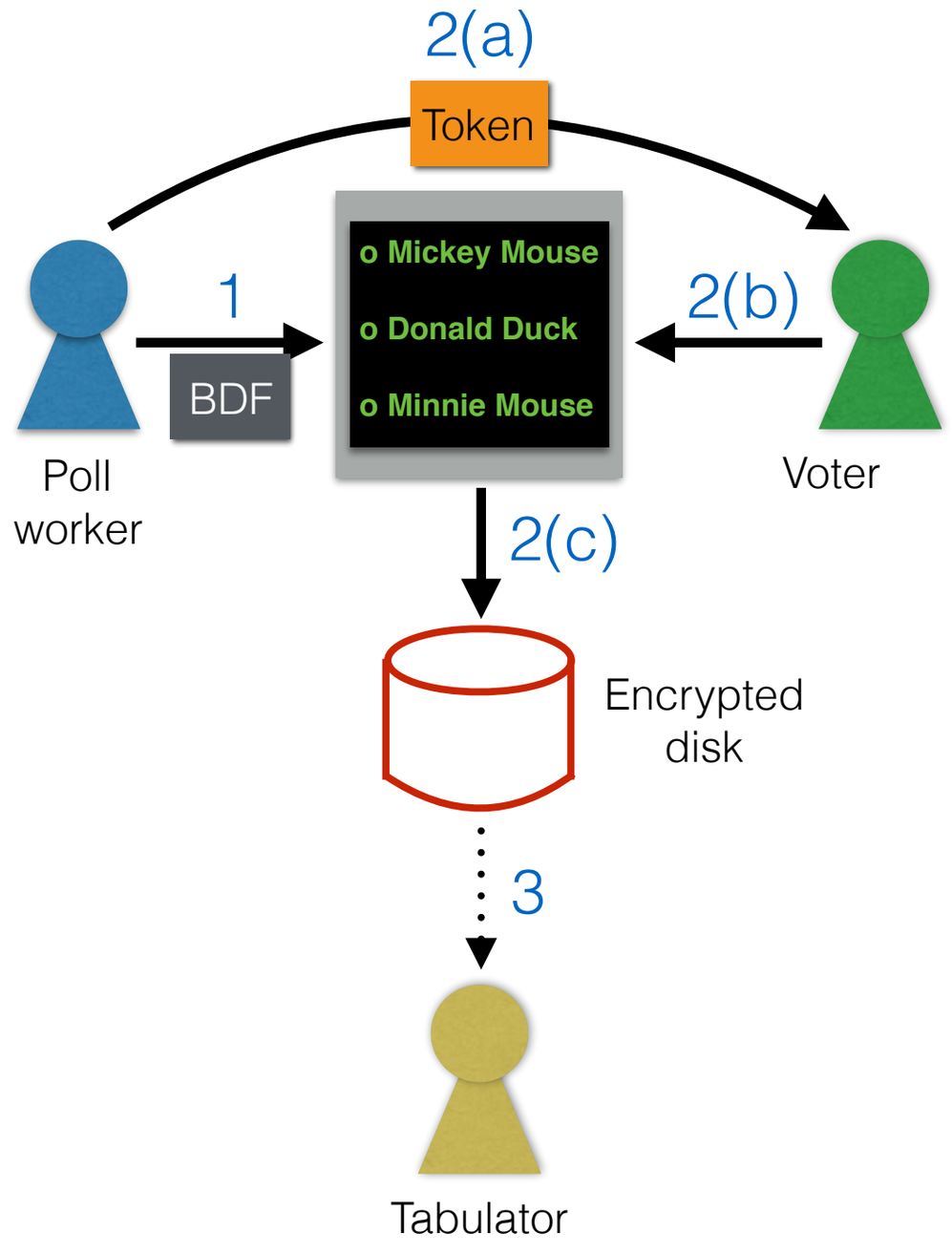

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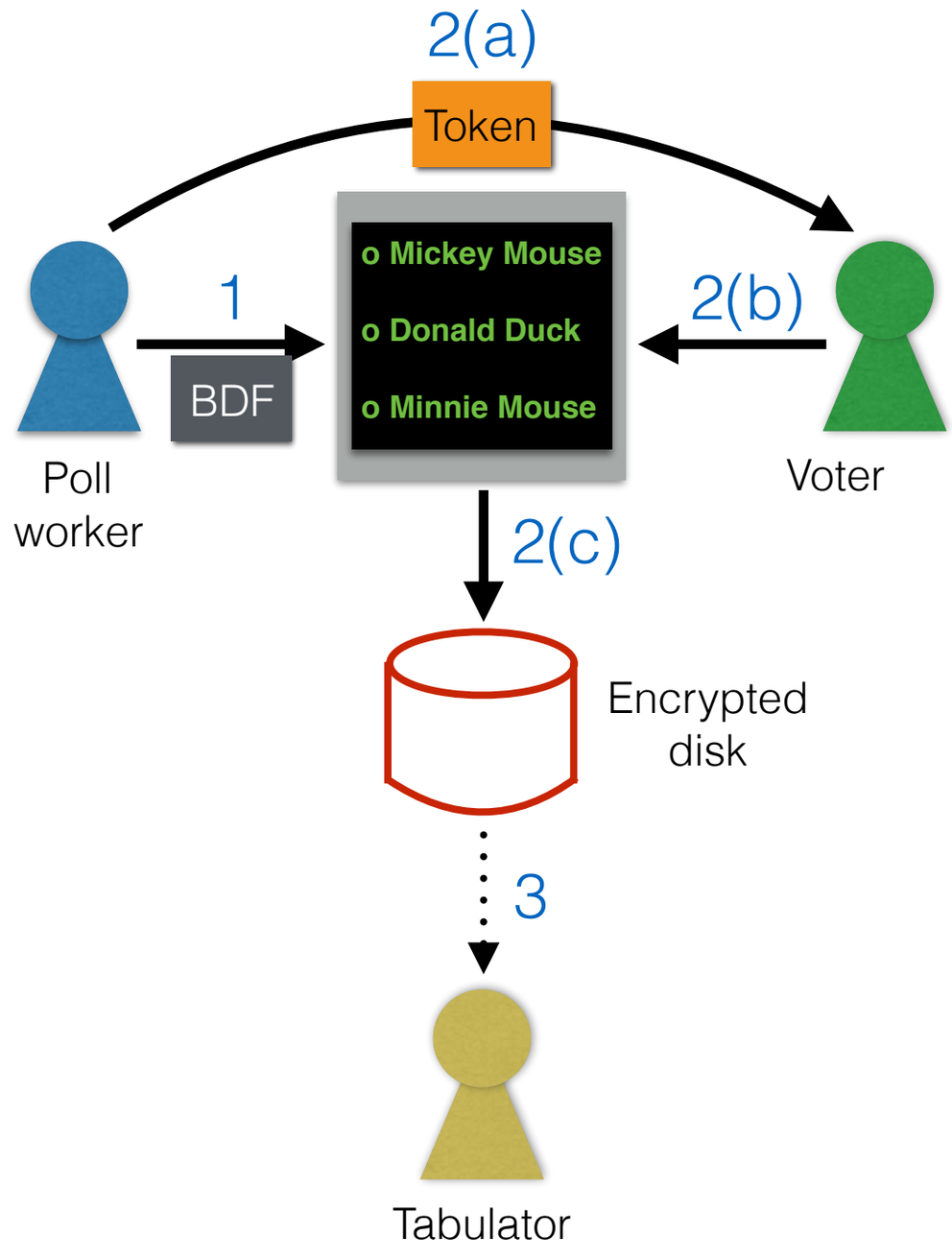
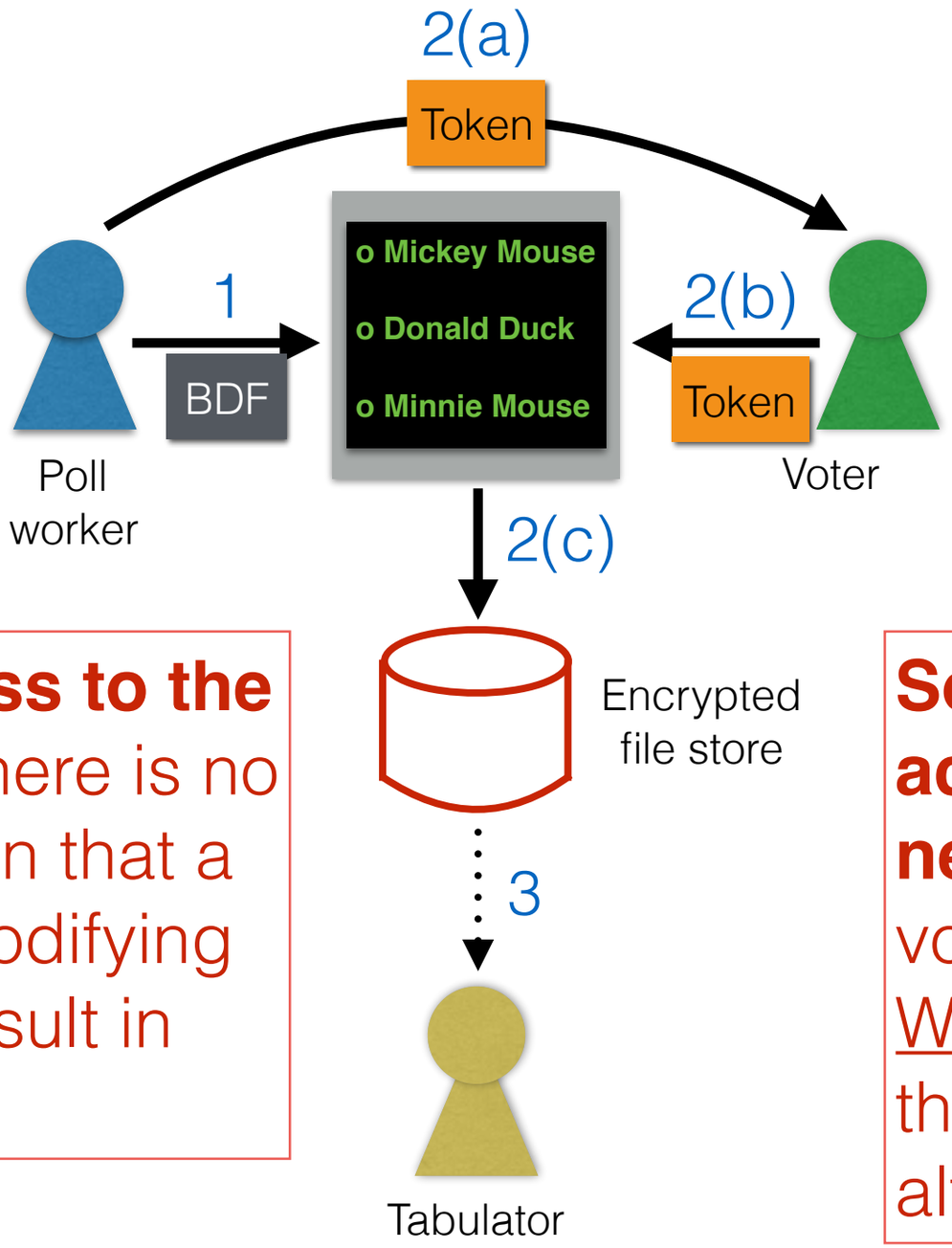
- Usability (no undue burden on users)
  - Easy for the voter to vote (correct language, good UI)
  - Easy for the tabulator to count votes



E-voting analysis

3. Identify the adversaries and threats

Poll worker could set BDF to print "Mickey Mouse" but record as "Minnie Mouse"



Voter could attempt to generate their own tokens & get ≥2 votes

Someone with access to the machine: Because there is no end-to-end verification that a vote was counted, modifying the software could result in complete control

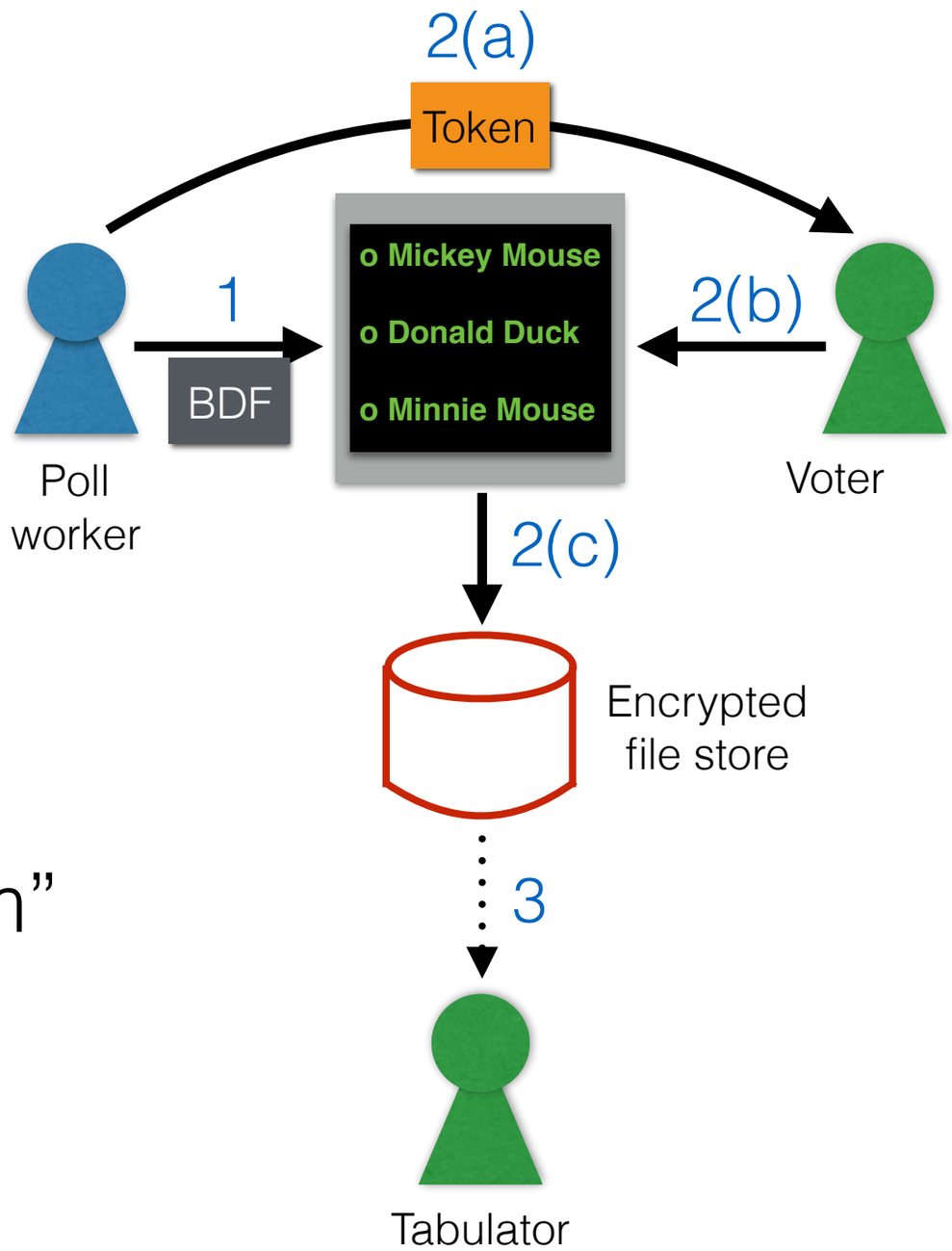
Someone with access to the disk or network: Read who voted for whom. Writing could change the outcome altogether

E-voting analysis

4. Identify the vulnerabilities

Not a theoretical system:

Diebold AccuVote-TS
Used in 37 states at time of study



Optional reading

"Analysis of an Electronic Voting System"
Kohno et al.

E-voting analysis

4. Identify the vulnerabilities

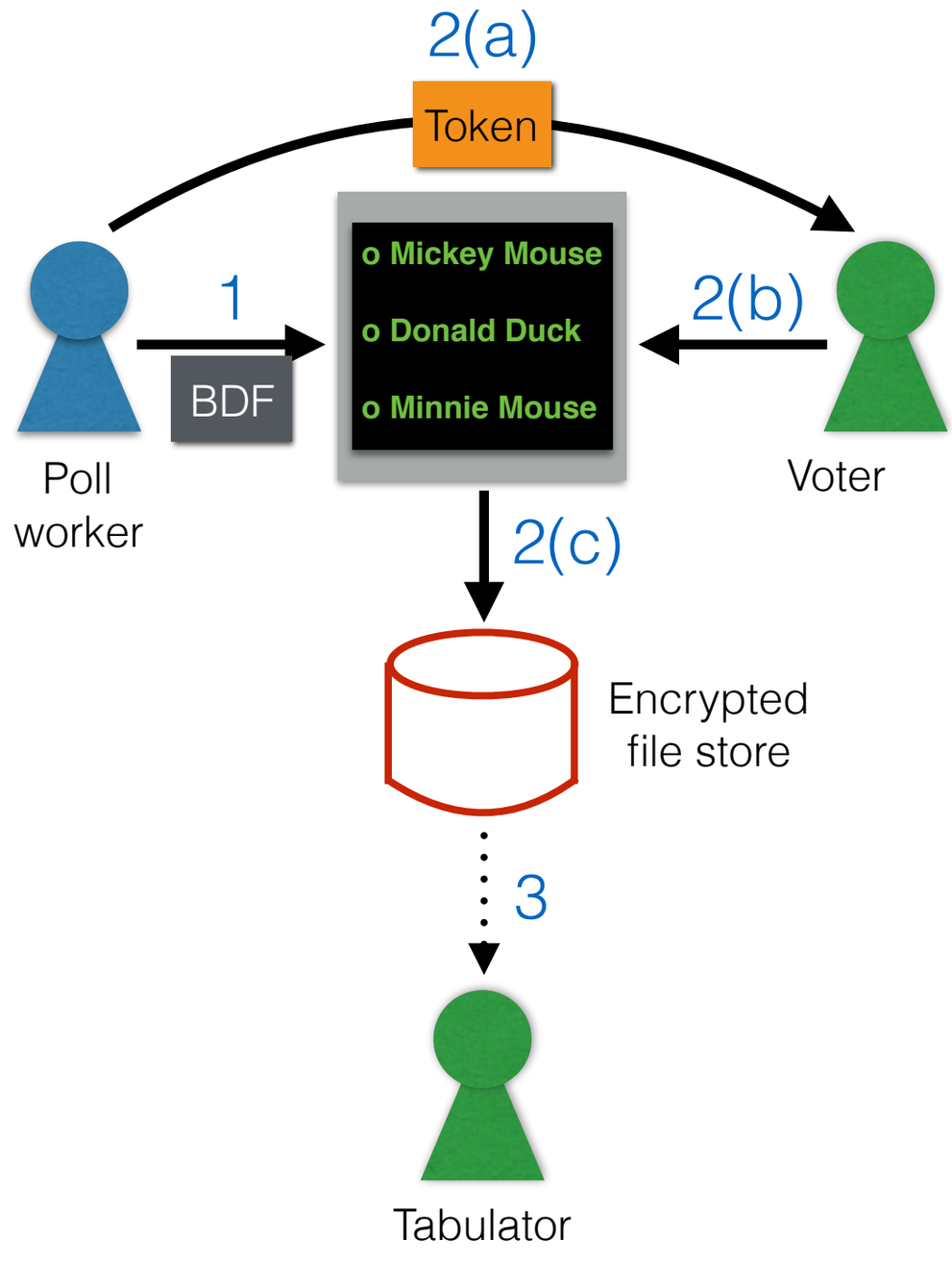
- Ballot definition files are not authenticated
  - How do we know they're from the election board?
  - Can redefine "Candidate A" as "Candidate B"
  - Viruses

- Smartcards are not authenticated
  - How do we know they're not user-generated?
  - Possible to make your own and vote multiple times.

- Specific software vulnerabilities
  - Every machine has the same encryption key!
  - Break one, and they all fall

- Votes are shipped unencrypted!

- Votes are stored in the order cast
  - If one can view the data unencrypted, this violates our confidentiality goal



Analyzing security

Takeaway points

- Analyzing security requires a whole-systems view
  - Hardware, software, users, economics, ….

- Security is only as strong as the weakest link
  - May have been difficult to break into the building
  - But if the data is sent unencrypted…

- Securing a system can be difficult
  - Interdisciplinary (software, hardware, UI design)
  - Humans are in the loop

- Security through obscurity does not work
  - Especially for high-value assets
  - It's only a matter of time until someone finds out

The Goals of CMSC 414

Be able to eliminate bugs and design flaws
and/or make them harder to exploit.

Be able to think like attackers.

Develop a foundation for deeply understanding
the systems we use and build.

Software **Hardware** **Protocols**

Users **Law** **Economics**

Software security

- Security is a form of dependability
  - Does the code do “what it should”
  - To this end, we follow the software lifecycle

- Distinguishing factor: an *active, malicious* attacker

- Attack model
  - The developer is trusted
  - But the attacker can provide any inputs
    - Malformed strings
    - Malformed packets
    - etc.

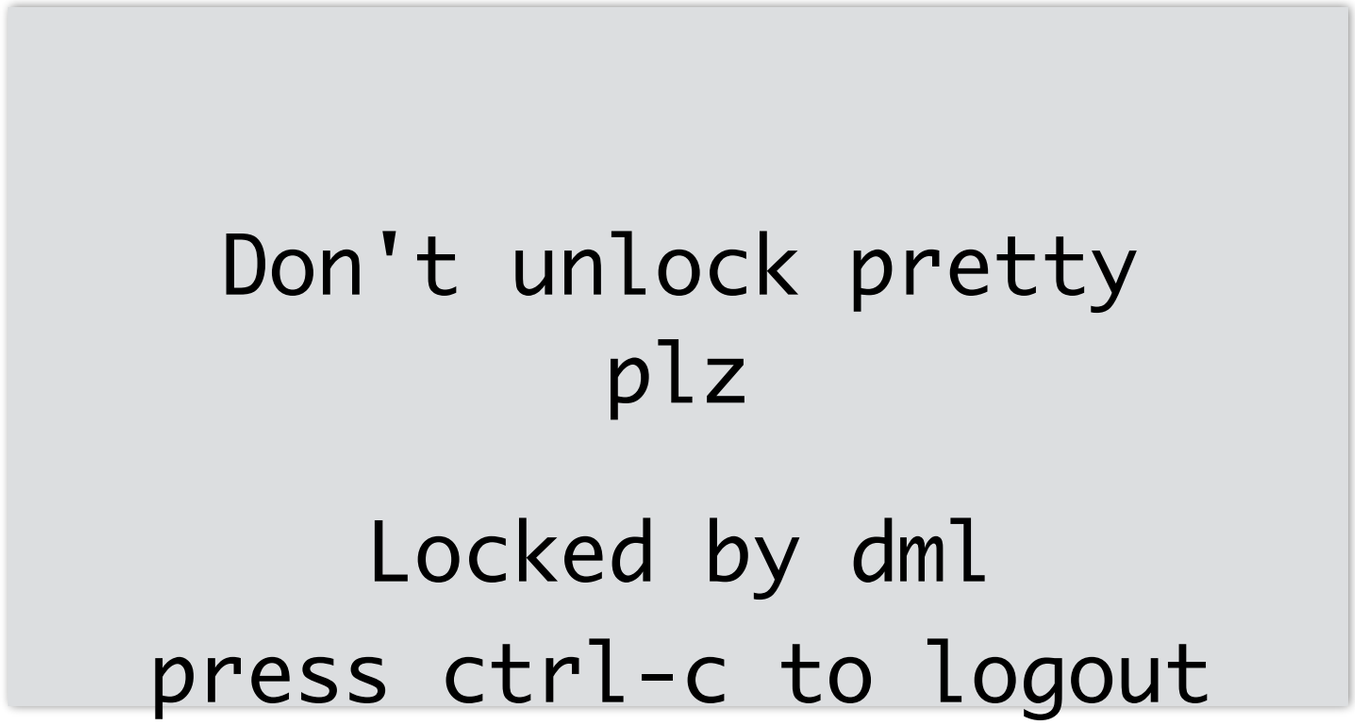
What harm could an attacker possibly cause?

```
screensaver --prompt="Don't unlock plz"
```

```
Don't unlock plz

Locked by dml
press ctrl-c to logout
```

screensaver --prompt=“Don’t unlock pretty plz”



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screensaver --prompt="Don't unlock plz SP SP SP \
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screensaver –prompt="Under maintenance;\
Do not interrupt␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠\
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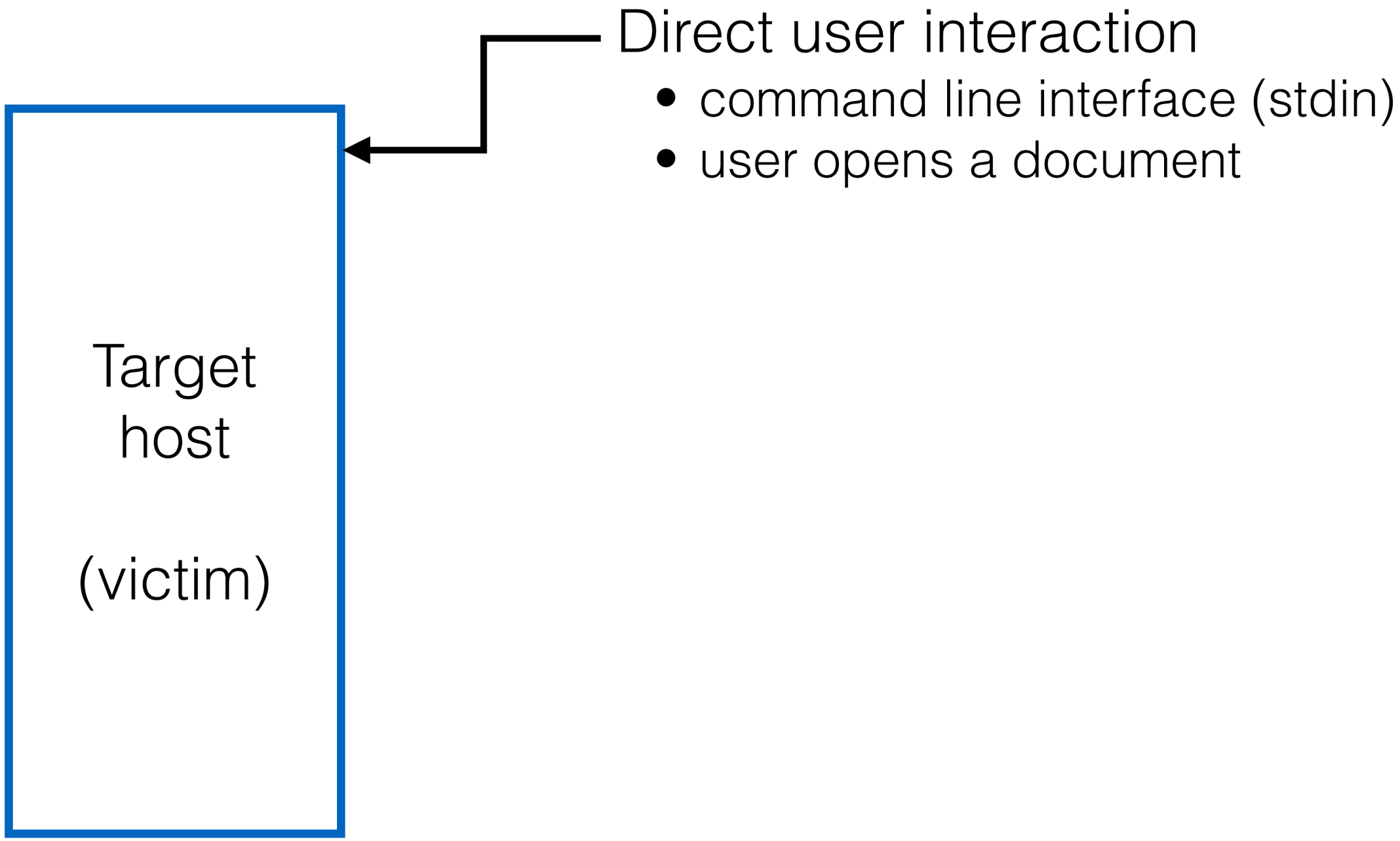
Most (interesting) software takes input



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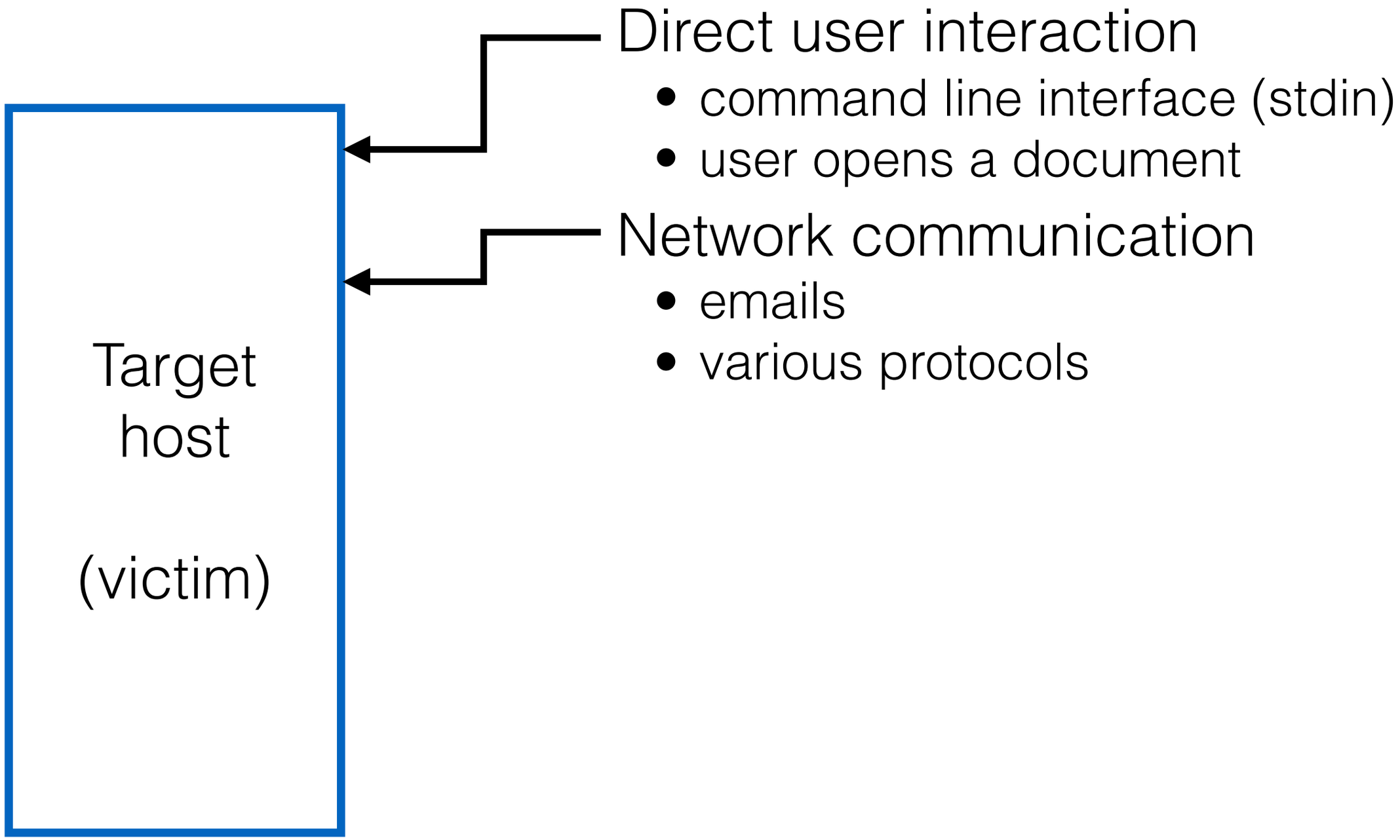

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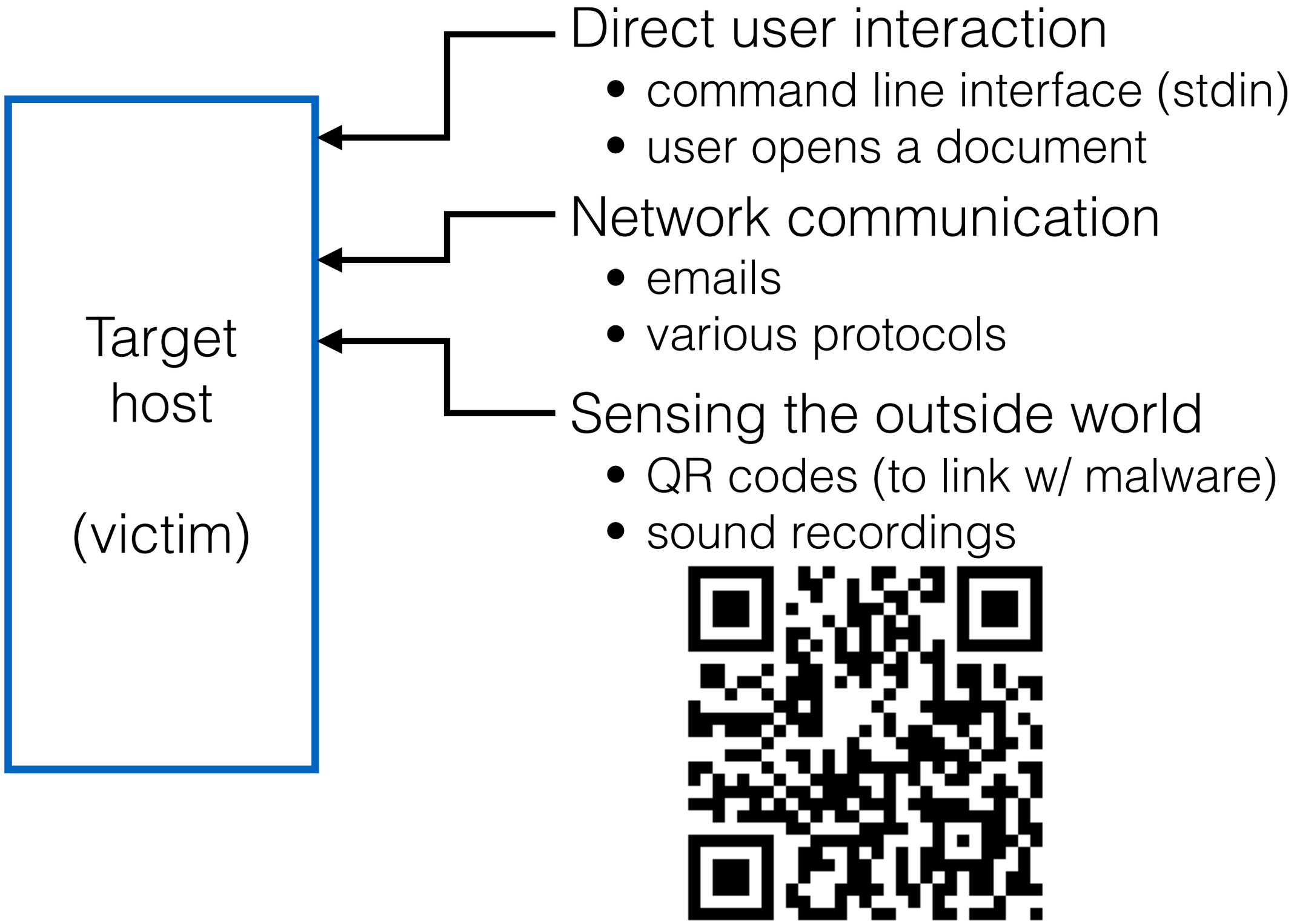

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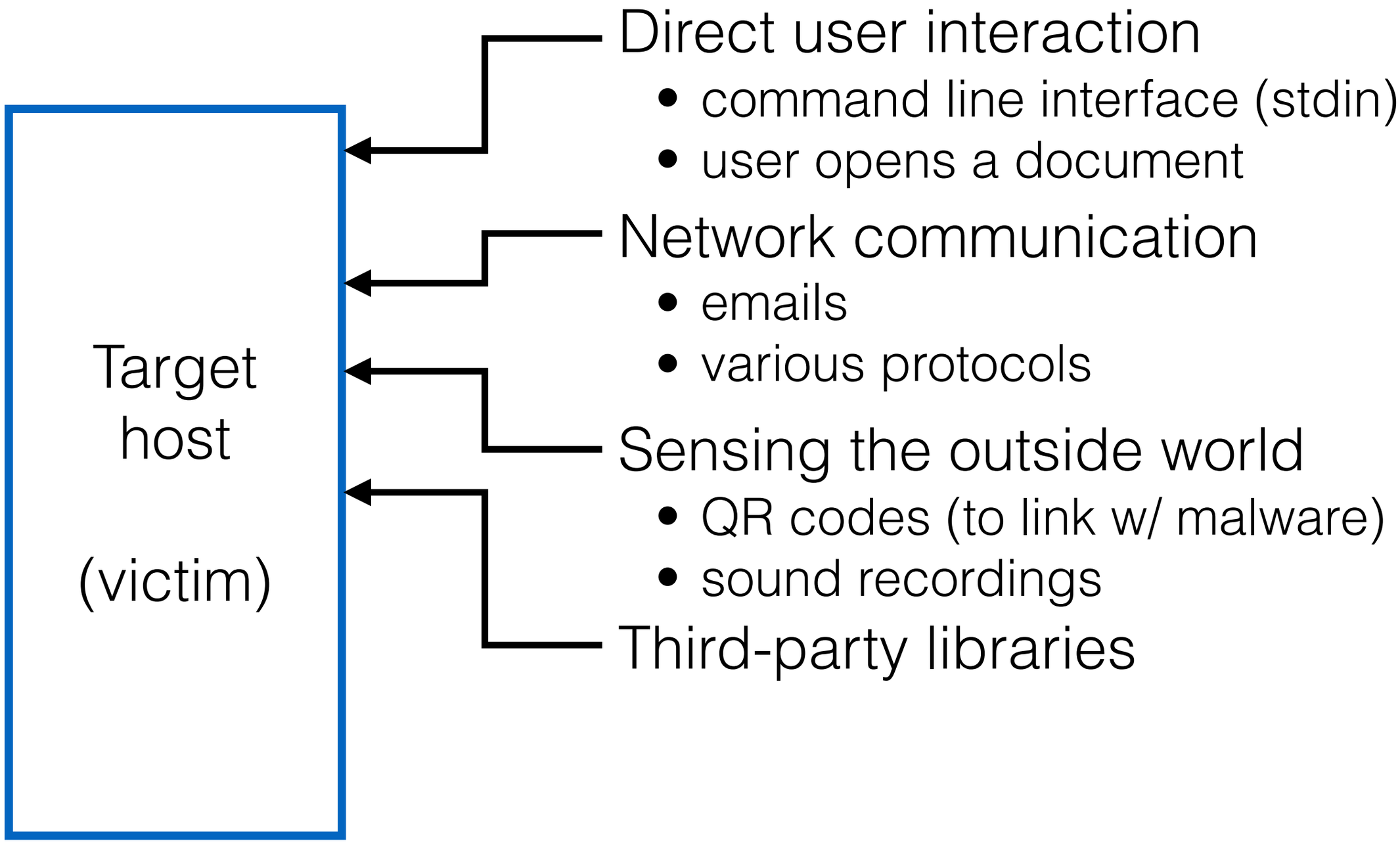

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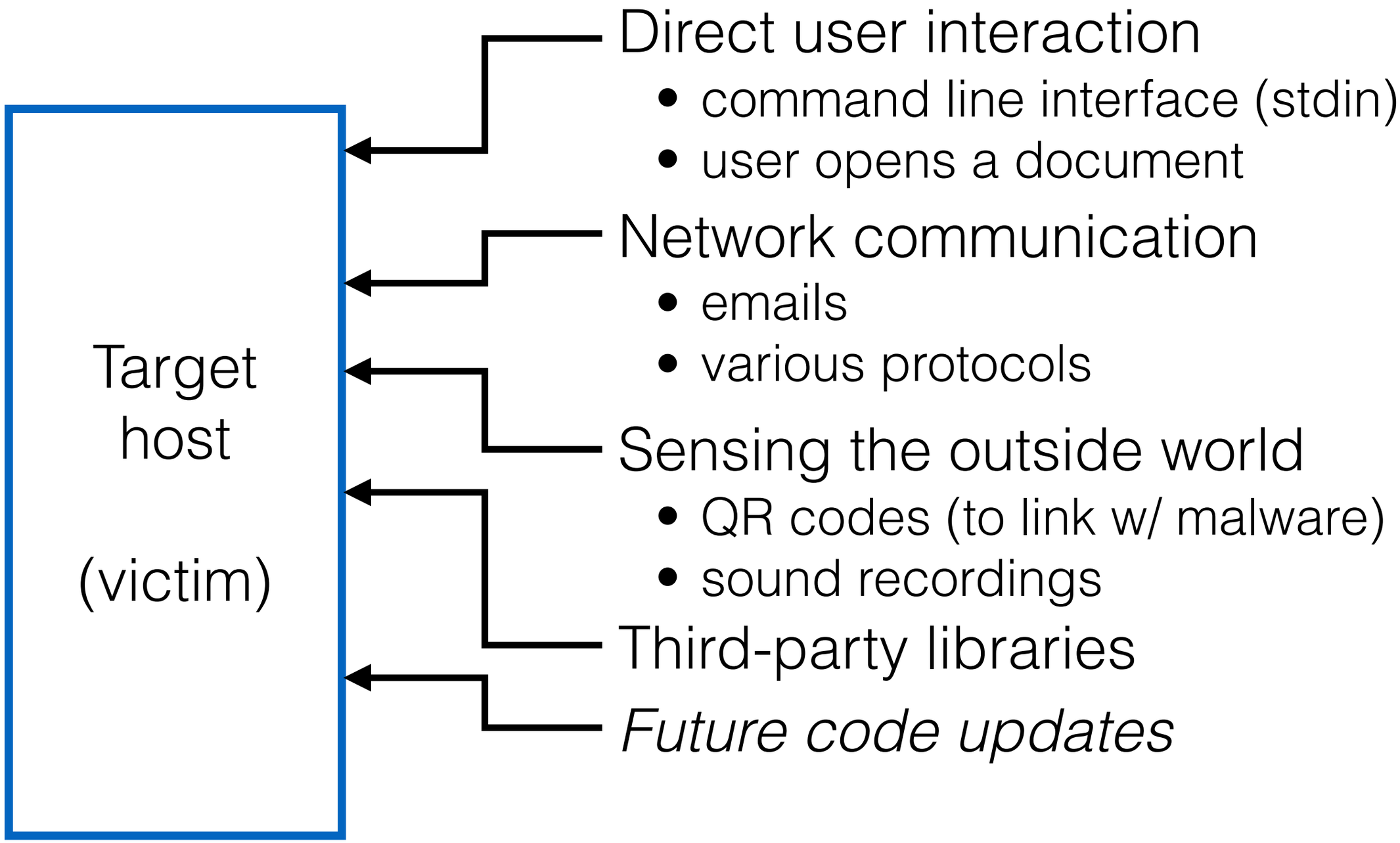

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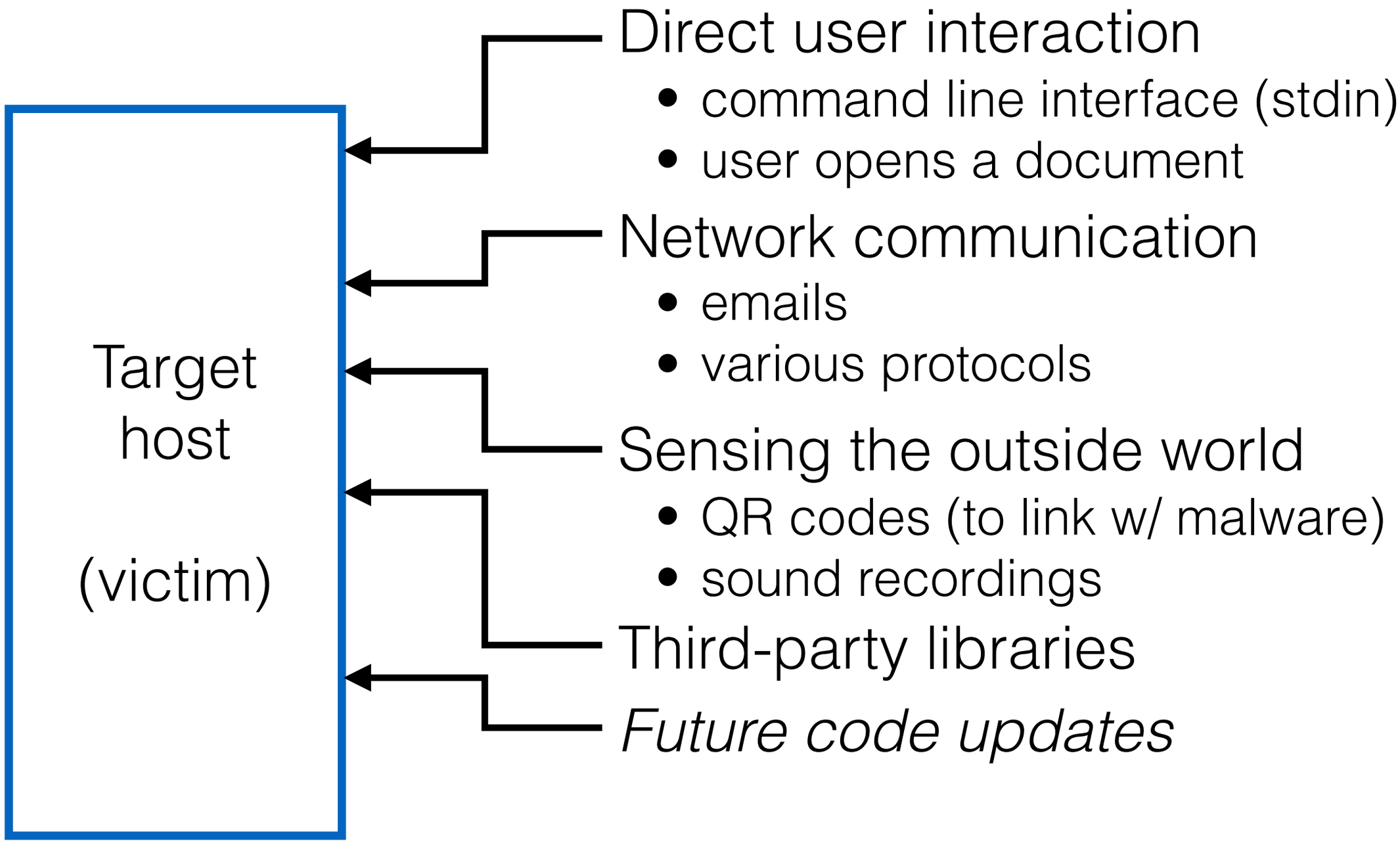

Goal: Correct operation despite malicious inputs

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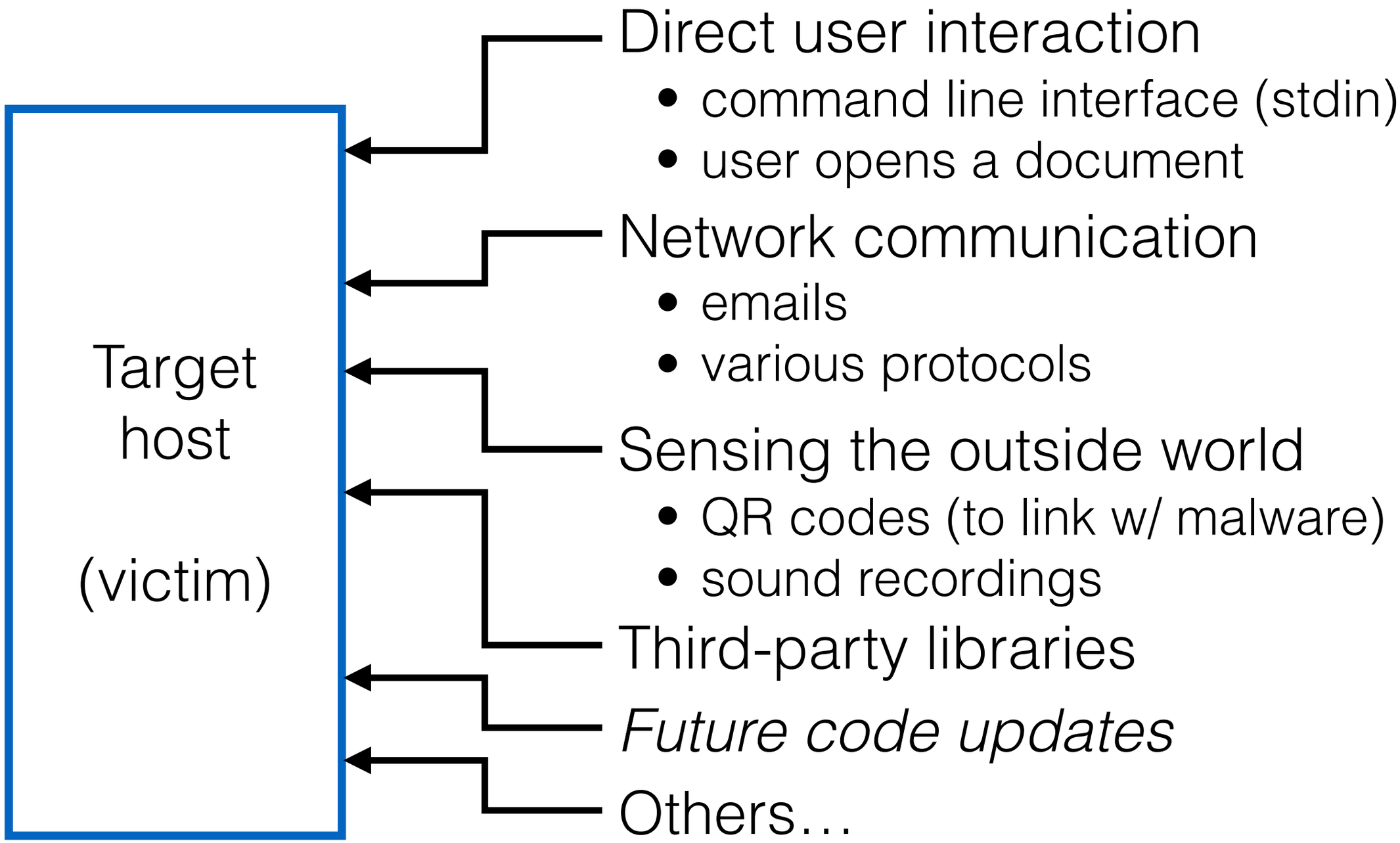
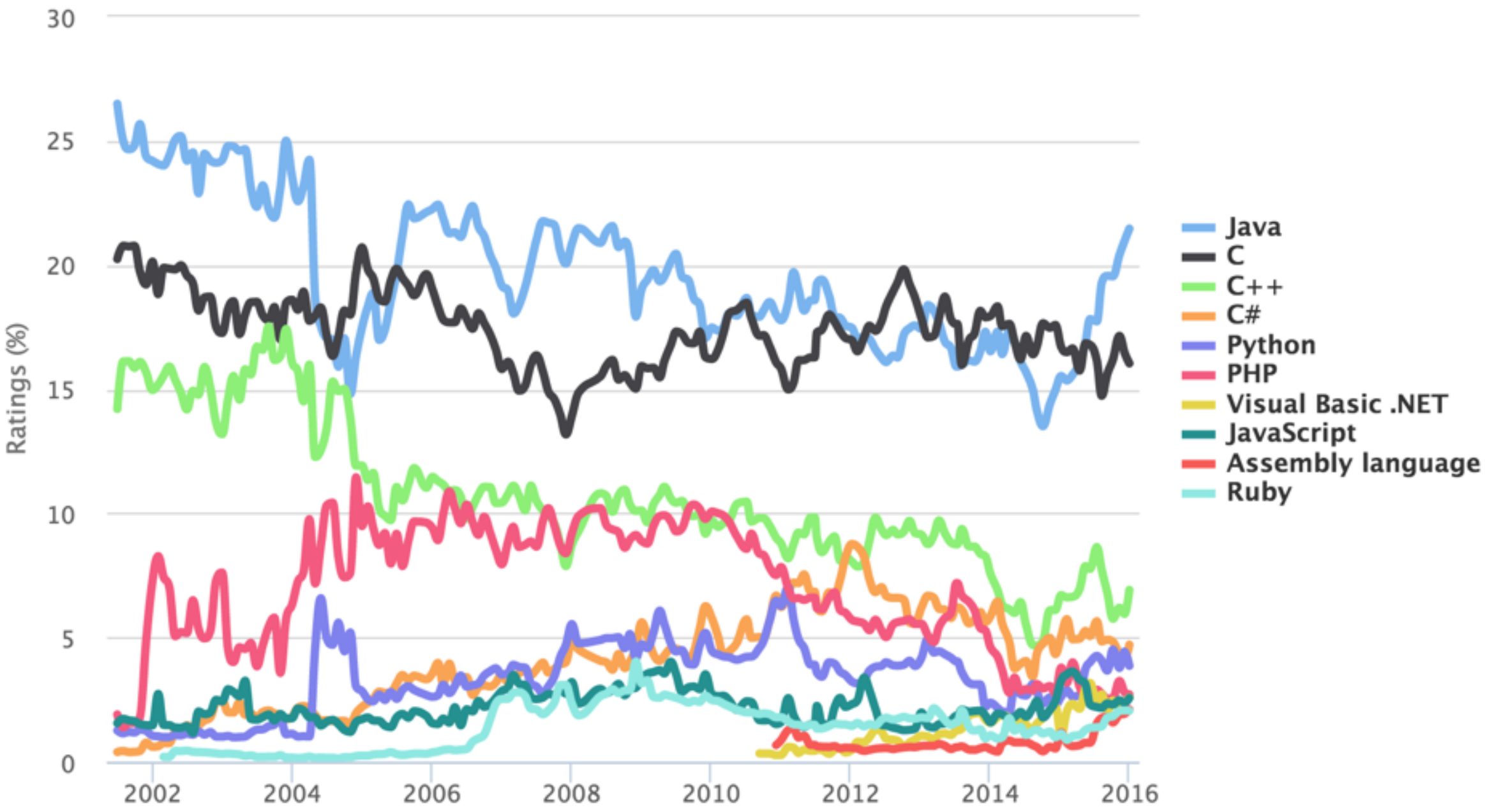


Goal: Correct operation despite malicious inputs

We’re going to focus on C

C is consistently in wide use



http://www.tiobe.com

We're going to focus on C

Many mission critical systems are written in C

- Most kernels & OS utilities
  - `fingerd`
  - X windows server
- Many high-performance servers
  - Microsoft IIS
  - Microsoft SQL server
- Many embedded systems
  - Mars rover
- But the techniques apply more broadly
  - Wiibrew:"Twilight Hack" exploits buffer overflow when saving the name of Link's horse, Epona

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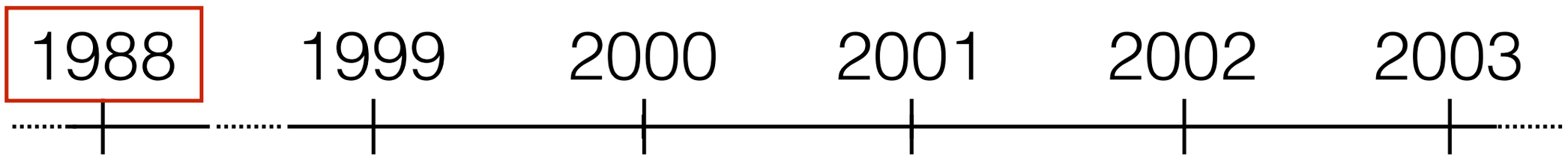
A breeding ground for *buffer overflow attacks*



- Morris worm
  - Propagated across machines (too aggressively, thanks to a bug)
  - One way it propagated was a **buffer overflow attack** against a vulnerable version of `fingerd` on VAXes
    - Sent a special string to the finger daemon, which caused it to execute code that created a new worm copy
    - Didn't check OS: caused Suns running BSD to crash
  - End result: $10-100M in damages, probation, community service

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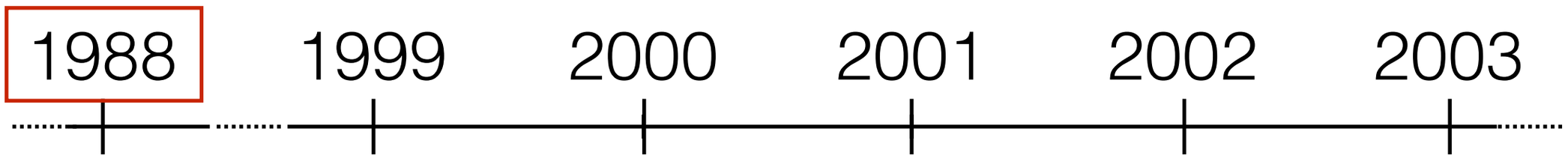

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(Robert Morris is now a professor at MIT)

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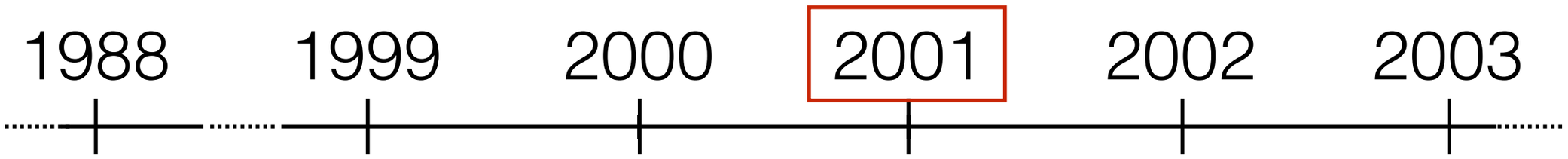
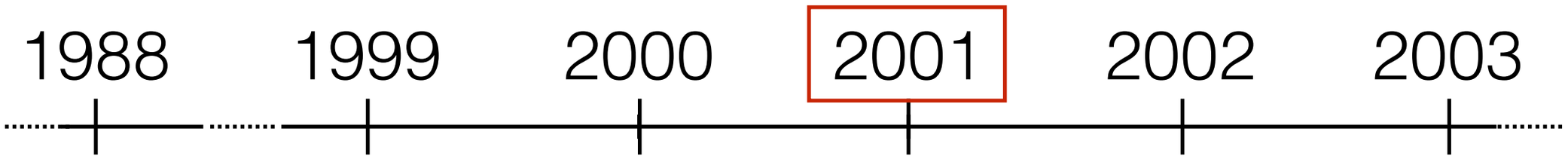


- CodeRed
  - Exploited an **overflow** in the MS-IIS server
  - 300,000 machines infected in 14 hours

We're going to focus on C

A breeding ground for *buffer overflow attacks*



- CodeRed
  - Exploited an **overflow** in the MS-IIS server
  - 300,000 machines infected in 14 hours

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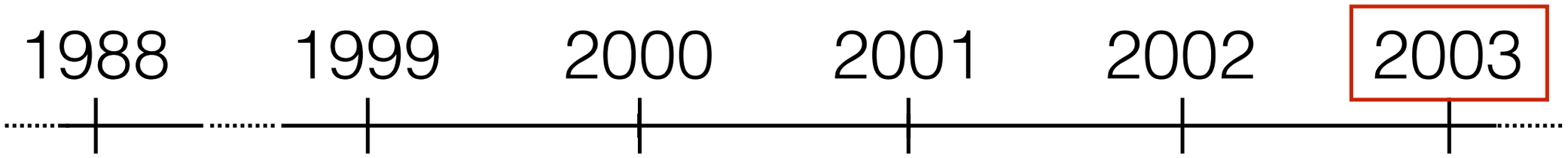

- SQL Slammer
  - Exploited an **overflow** in the MS-SQL server
  - 75,000 machines infected in 10 *minutes*

We’re going to focus on C

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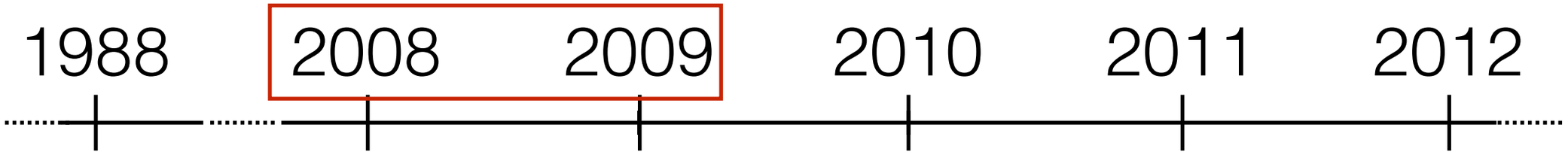

- Conficker worm
  - Exploited an **overflow** in Windows RPC
  - ~10 million machines infected

We're going to focus on C

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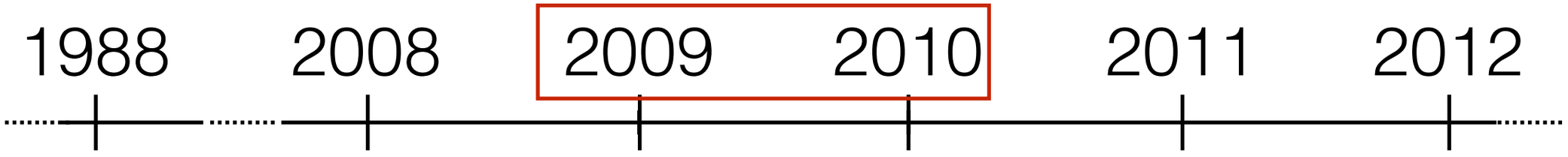
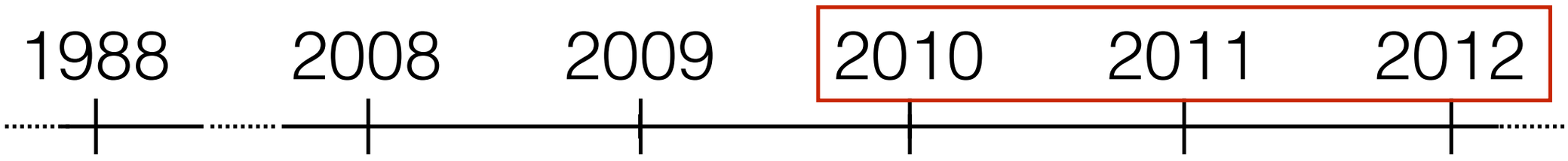


- Stuxnet
  - Exploited several **overflows** nobody had at the time known about ("zero-day")
    - Windows print spooler service
    - Windows LNK shortcut display
    - Windows task scheduler
  - Also exploited the same Windows RPC overflow as Conficker
  - Impact: legitimized cyber warfare (*more on this later*)

We’re going to focus on C

A breeding ground for *buffer overflow attacks*



- Flame
  - Same print spooler and LNK **overflows** as Stuxnet
  - Cyber-espionage virus

23-Year-Old X11 Server Security Vulnerability Discovered

Posted by **Unknown Lamer** on Wednesday January 08, 2014 @10:11
from the stack-smashing-for-fun-and-profit dept.

An anonymous reader writes

> "The recent report of X11/X.Org security in bad shape rings more truth today. The X.Org Foundation announced today that they've found a X11 security issue that dates back to 1991. The issue is a possible stack buffer overflow that could lead to privilege escalation to root and affects all versions of the X Server back to X11R5. After the vulnerability being in the code-base for 23 years, it was finally uncovered via the automated cppcheck static analysis utility."

There's a `scanf` used when loading BDF fonts that can overflow using a carefully crafted font. Watch out for those obsolete early-90s bitmap fonts.

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GHOST: glibc vulnerability introduced in 2000, only just announced last year

syslogd bug in Mac OS X & iOS

- syslog: message logging infrastructure
  - Useful: one process issues the log messages, syslogd handles storing/disseminating them

```
void
add_lockdown_session(int fd)
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        dispatch_once(&watch_init_once, ^{
                watch_queue = dispatch_queue_create("Direct Watch Queue", NULL);
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Array of **int**'s

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Had this many **int**'s

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Takes *bytes* as 2nd arg

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How many *bytes* should `global.lockdown_session_fds` be?

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```

```
(global.lockdown_session_count + 1) * sizeof(int)
```

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Buffer too small

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Writes beyond the buffer

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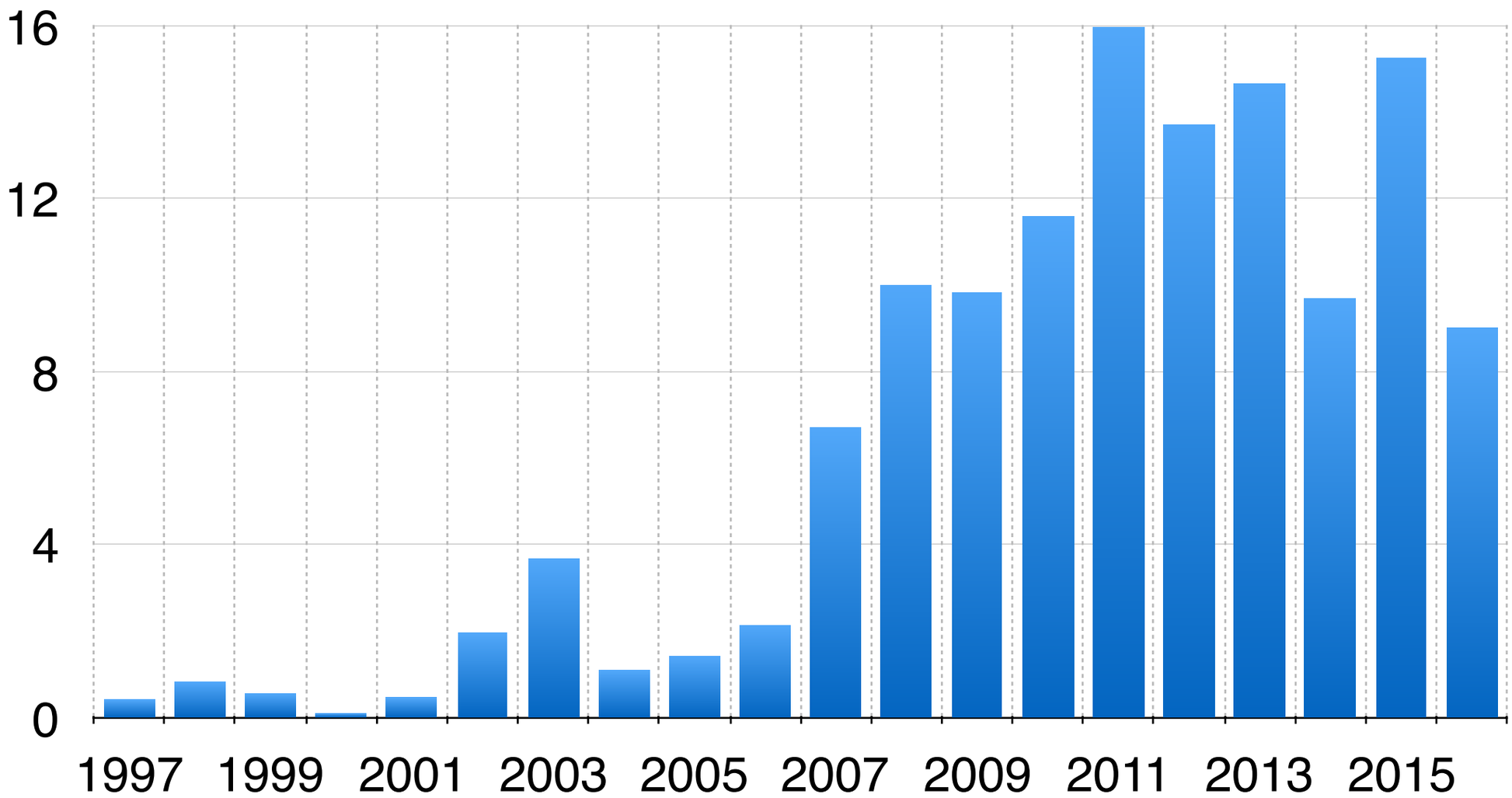
Buffer overflows are prevalent

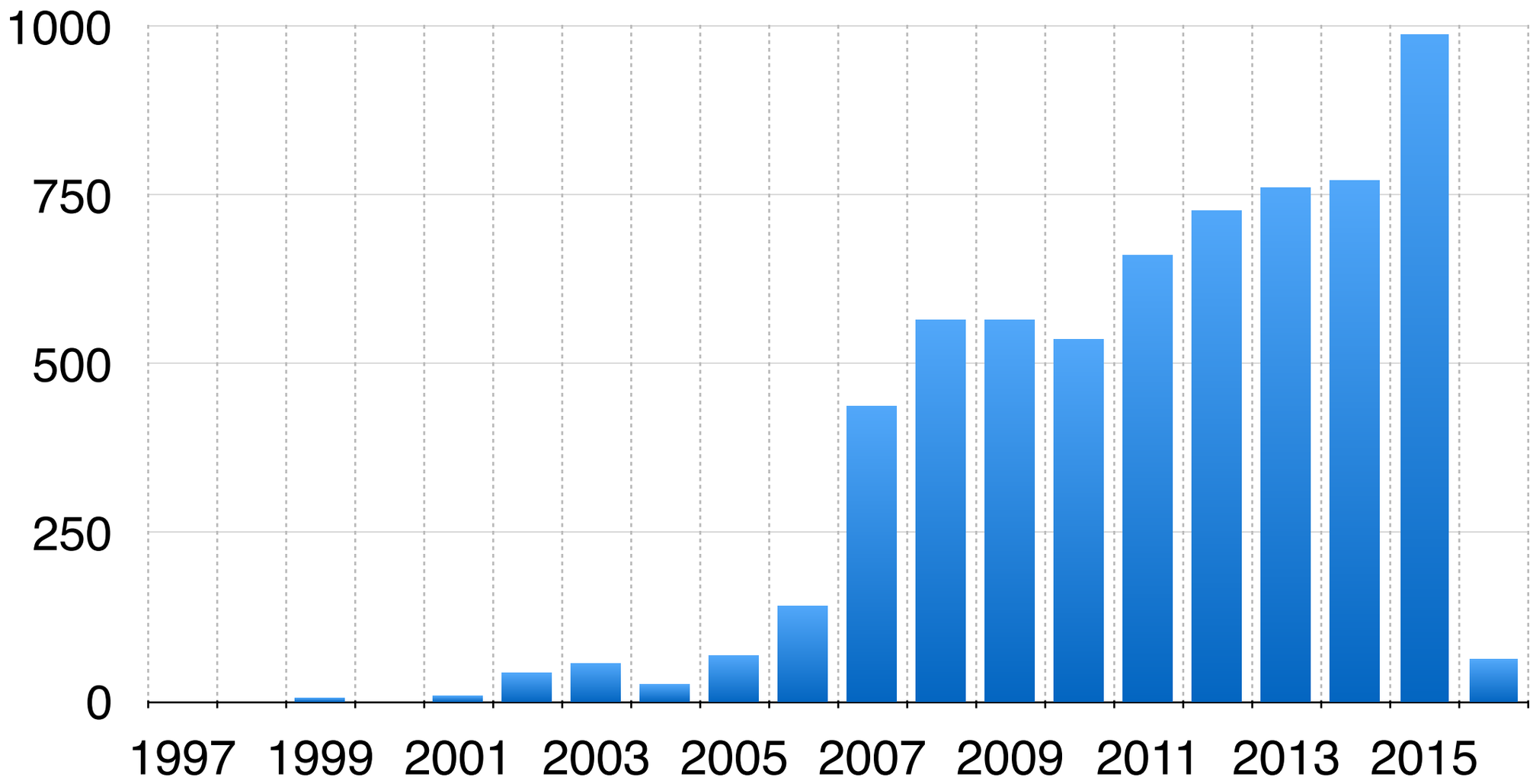
Significant percent of *all* vulnerabilities



Data from the National Vulnerability Database

Buffer overflows are prevalent

Total number of buffer overflow vulnerabilities



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Buffer overflows are impactful

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[2]	83.3	CWE-78	Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection')
[3]	79.0	CWE-120	Buffer Copy without Checking Size of Input ('Classic Buffer Overflow')
[4]	77.7	CWE-79	Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')
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This class

MITRE's top-25 most dangerous software errors (from 2011)

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Later

This class

Later

E-voting

Later

MITRE's top-25 most dangerous software errors (from 2011)

Our goals

- Understand how these attacks work, and how to defend against them

- These require knowledge about:
  - The compiler
  - The OS
  - The architecture

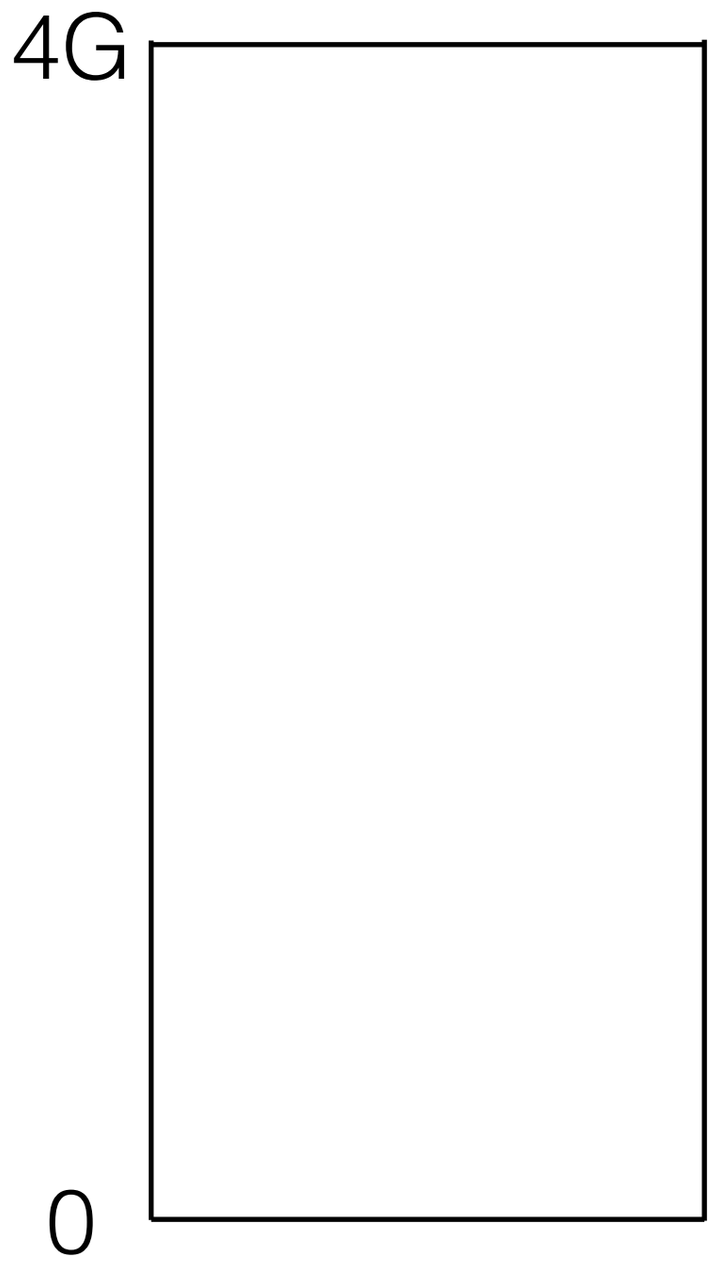
Analyzing security requires a whole-systems view

Memory layout

Refresher

- How is program data laid out in memory?
- What does the stack look like?
- What effect does calling (and returning from) a function have on memory?
- We are focusing on the Linux process model
  - Similar to other operating systems

All programs are stored in memory



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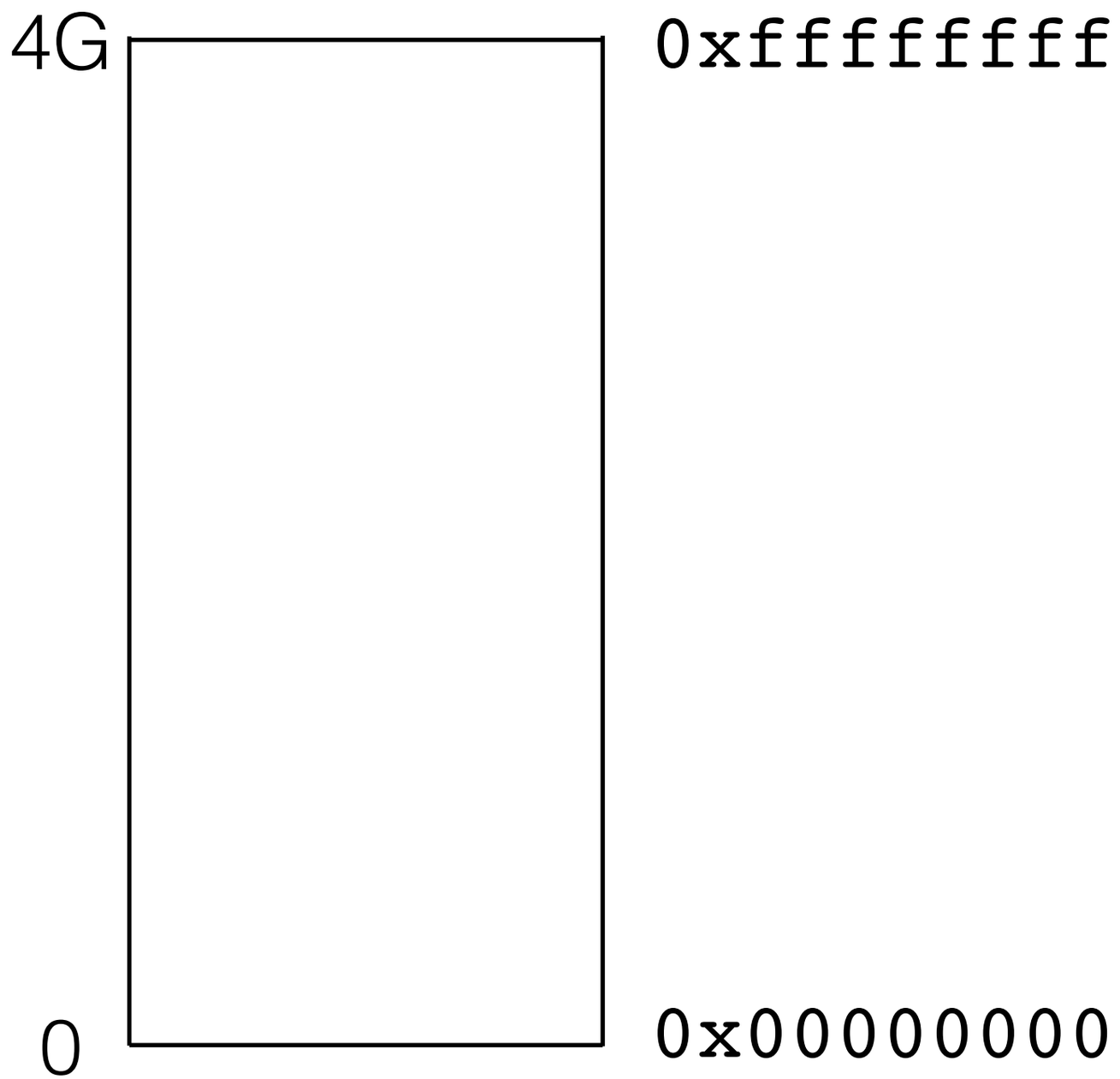

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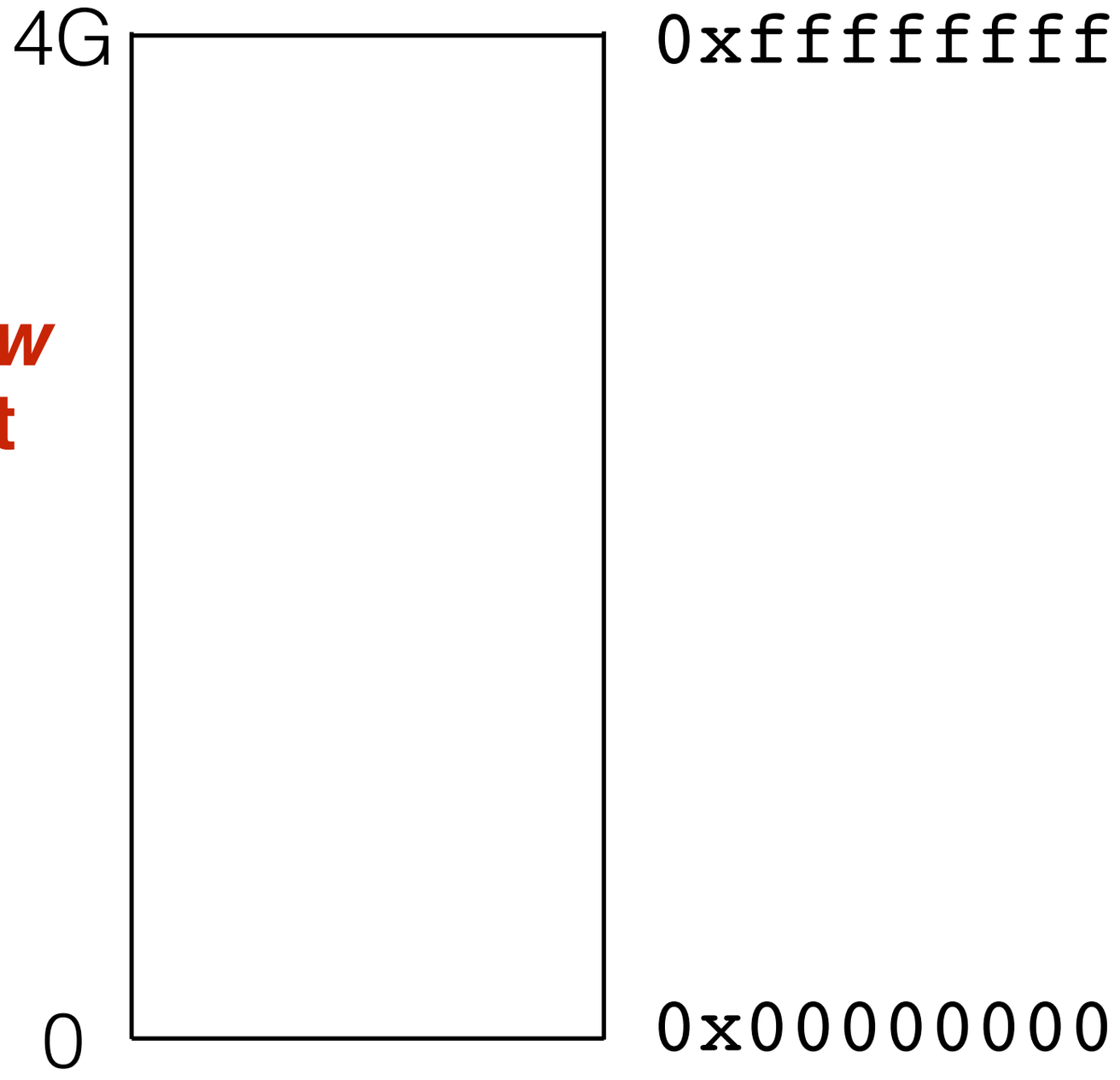
The *process's view* of memory is that it owns all of it



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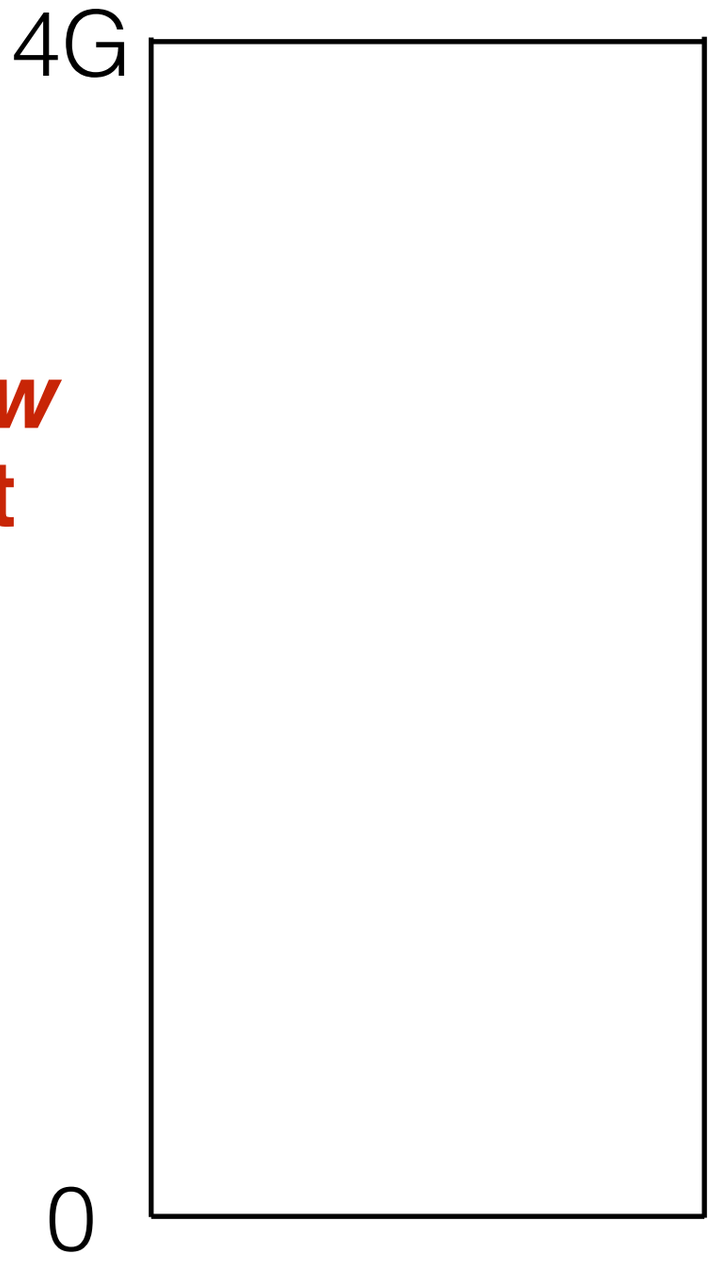
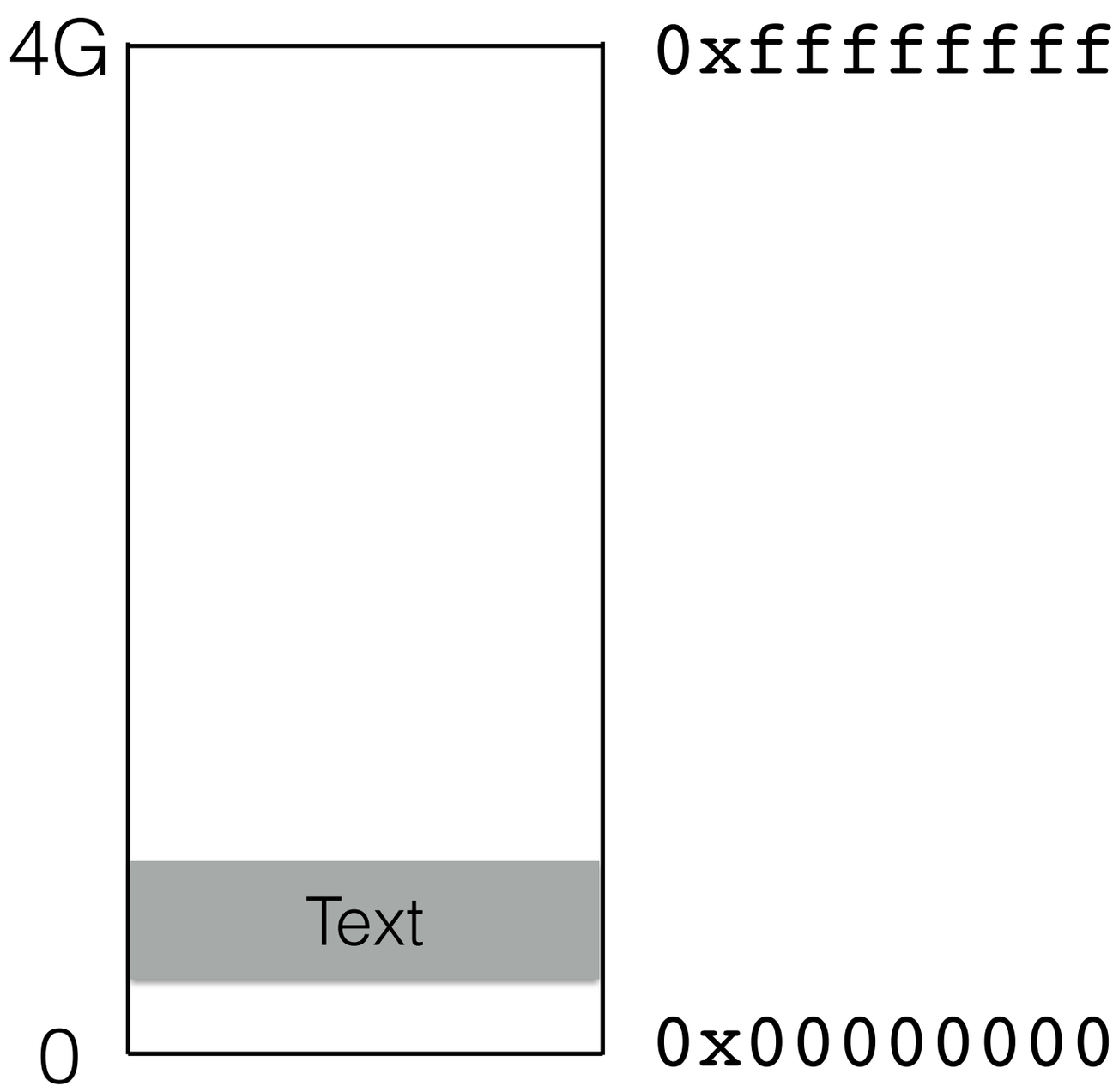


The *process's view* of memory is that it owns all of it

In reality, these are *virtual addresses*; the OS/CPU map them to physical addresses

The instructions themselves are in memory



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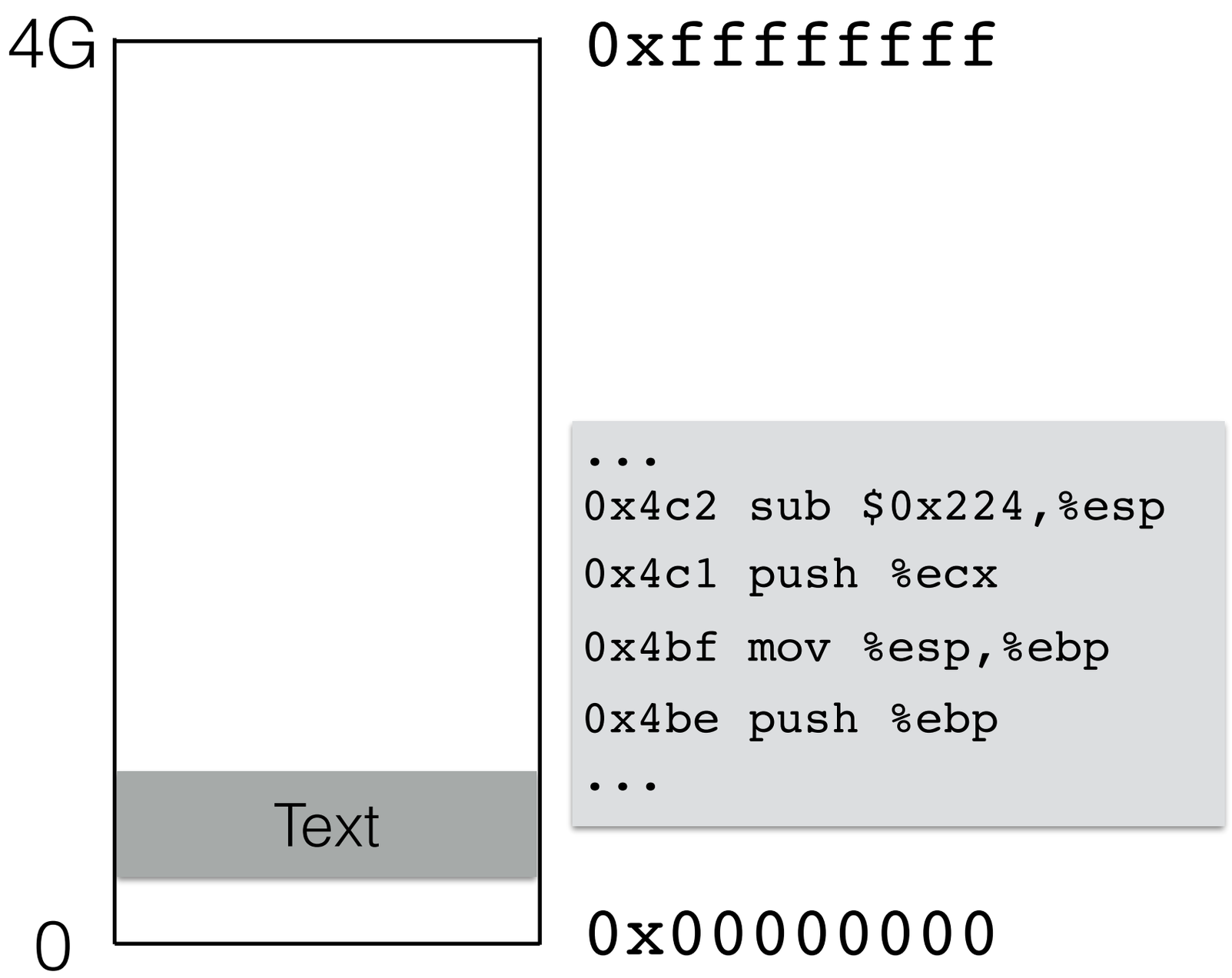
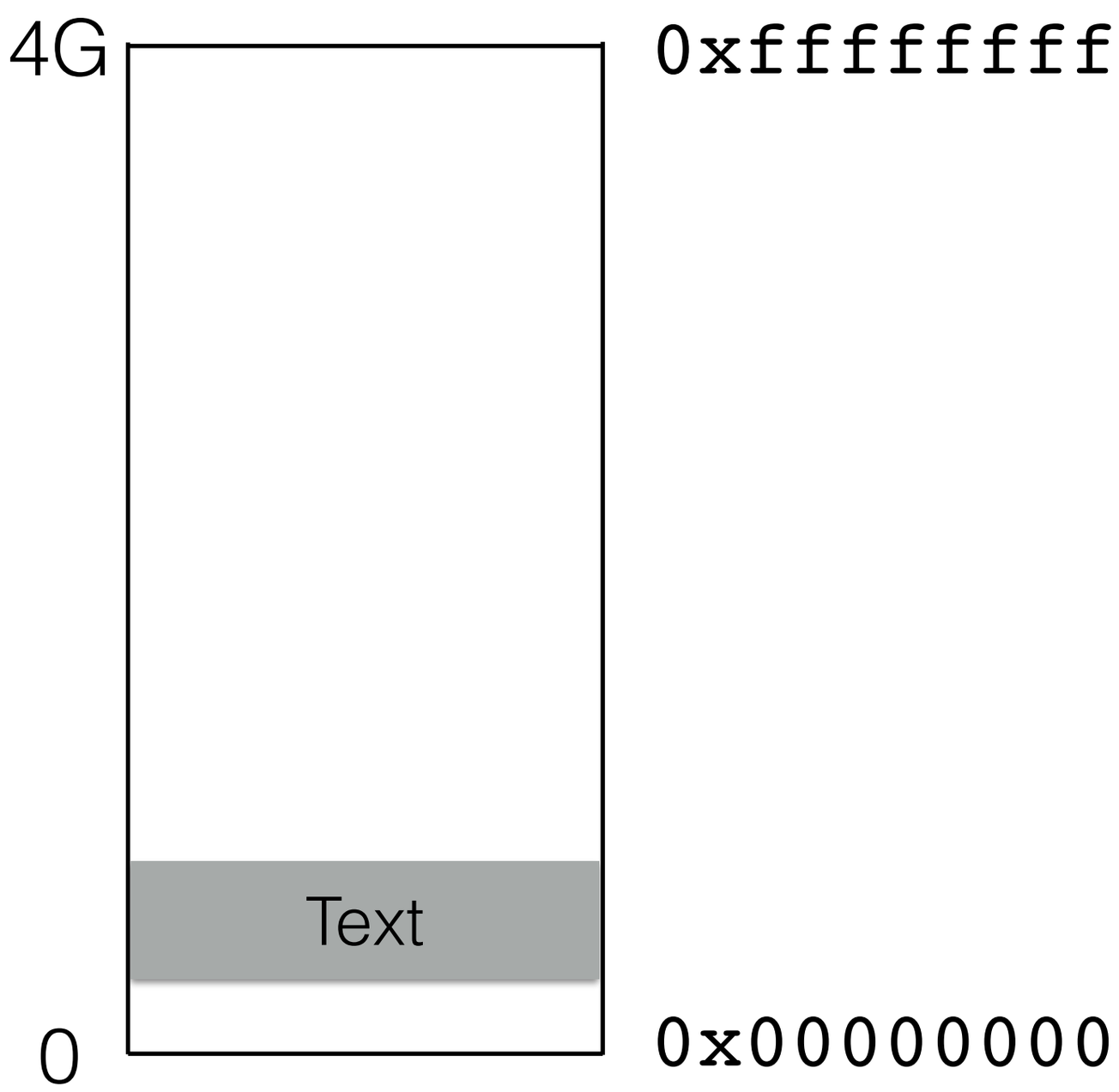


Data's location depends on how it's created



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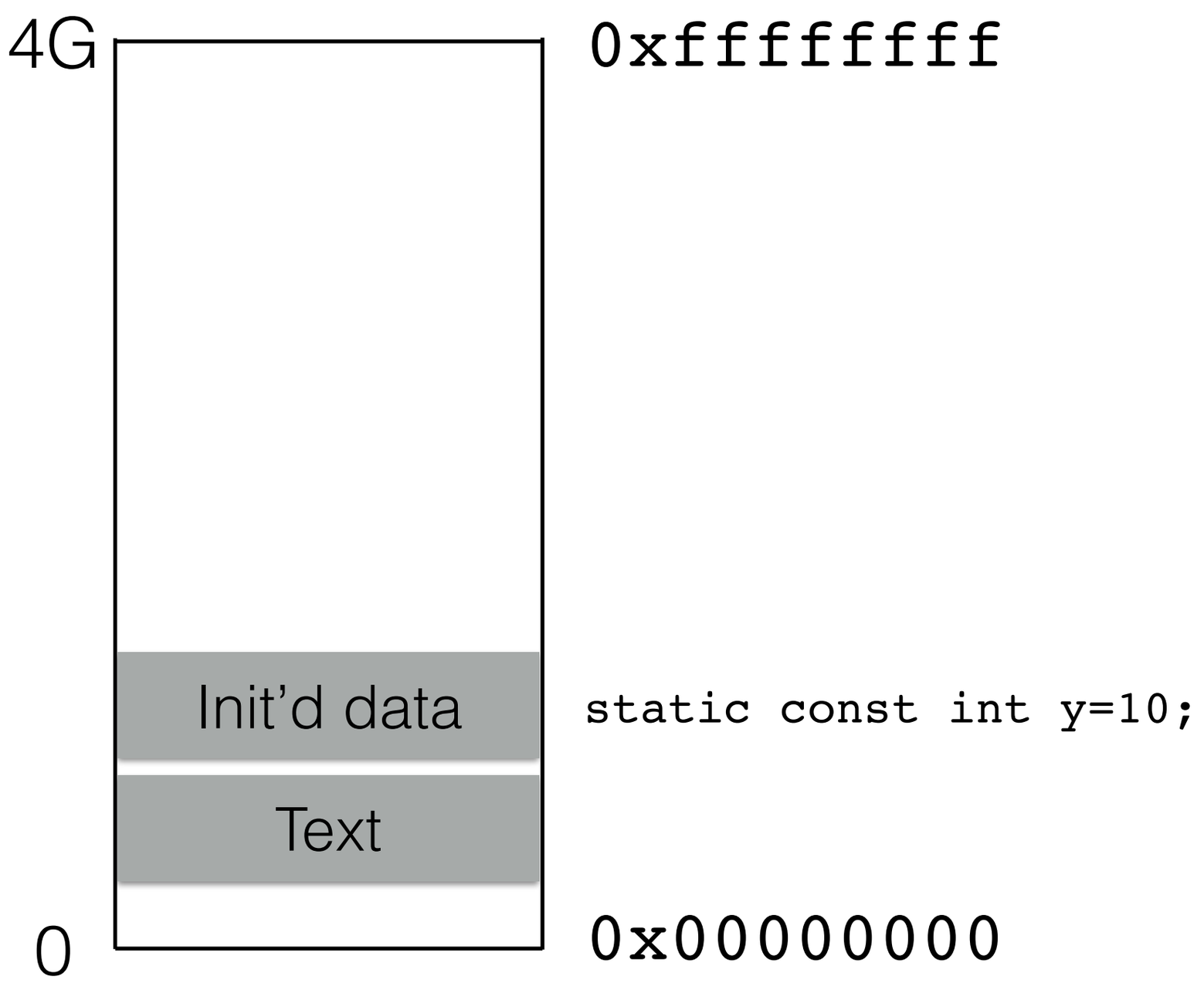

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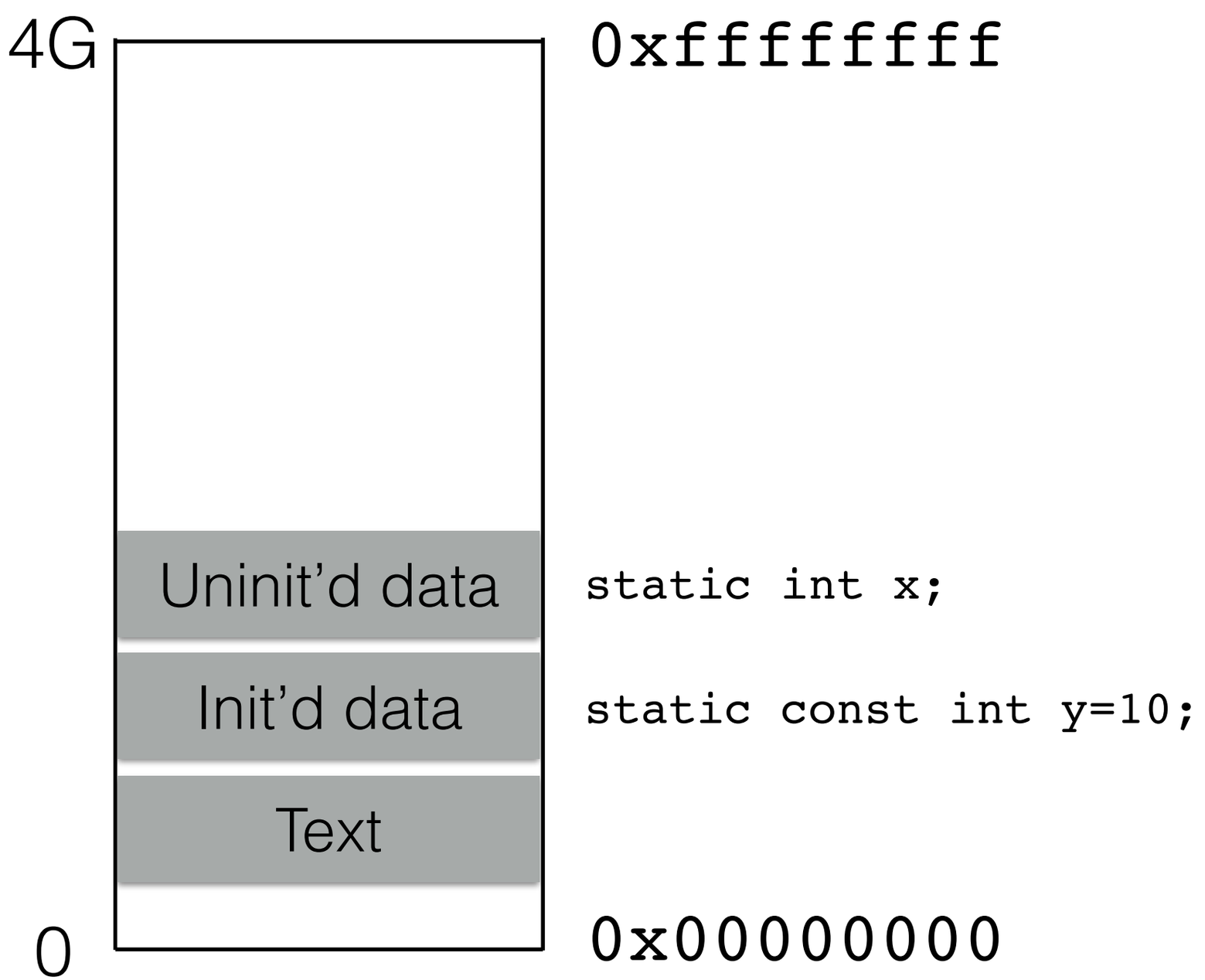

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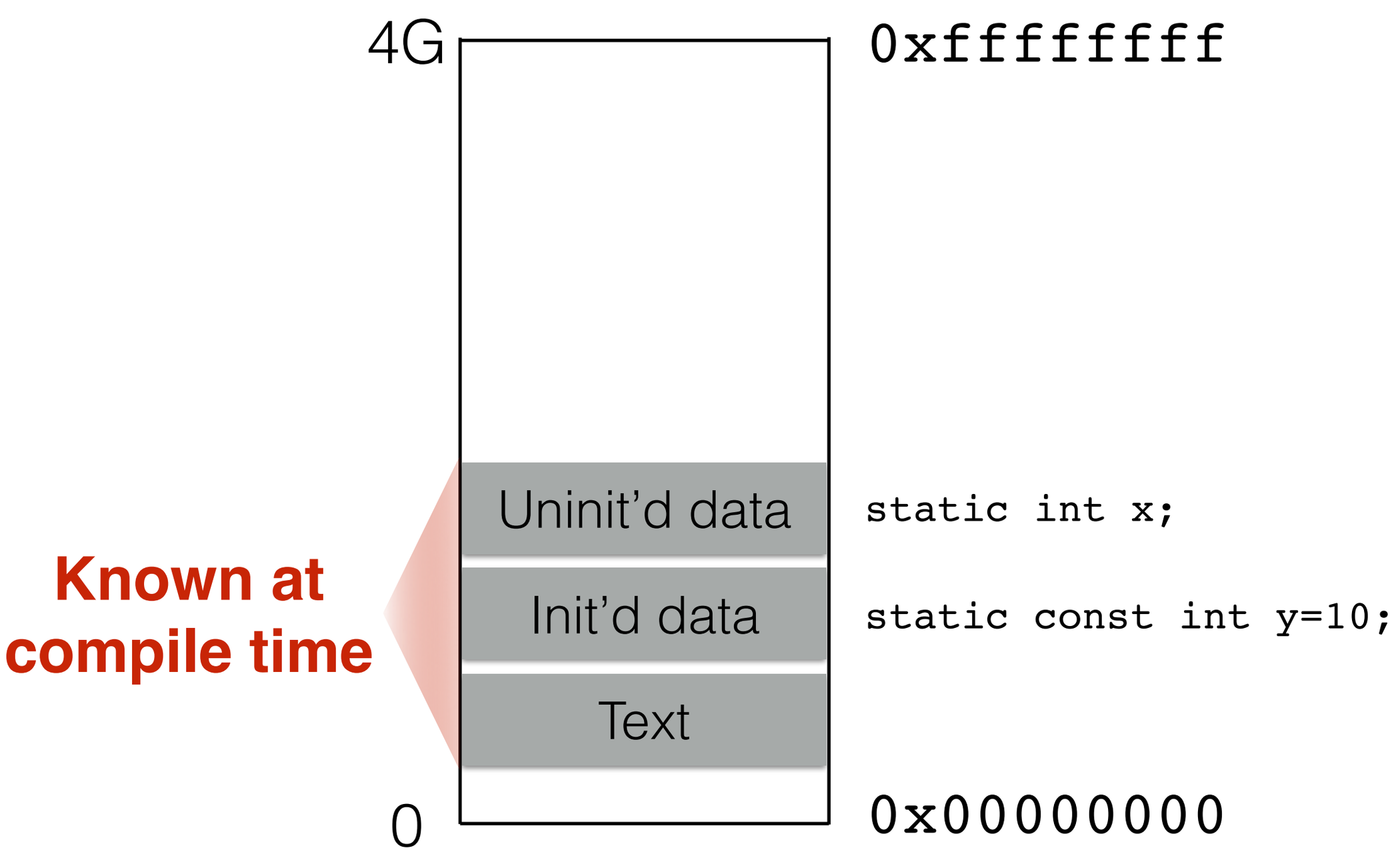

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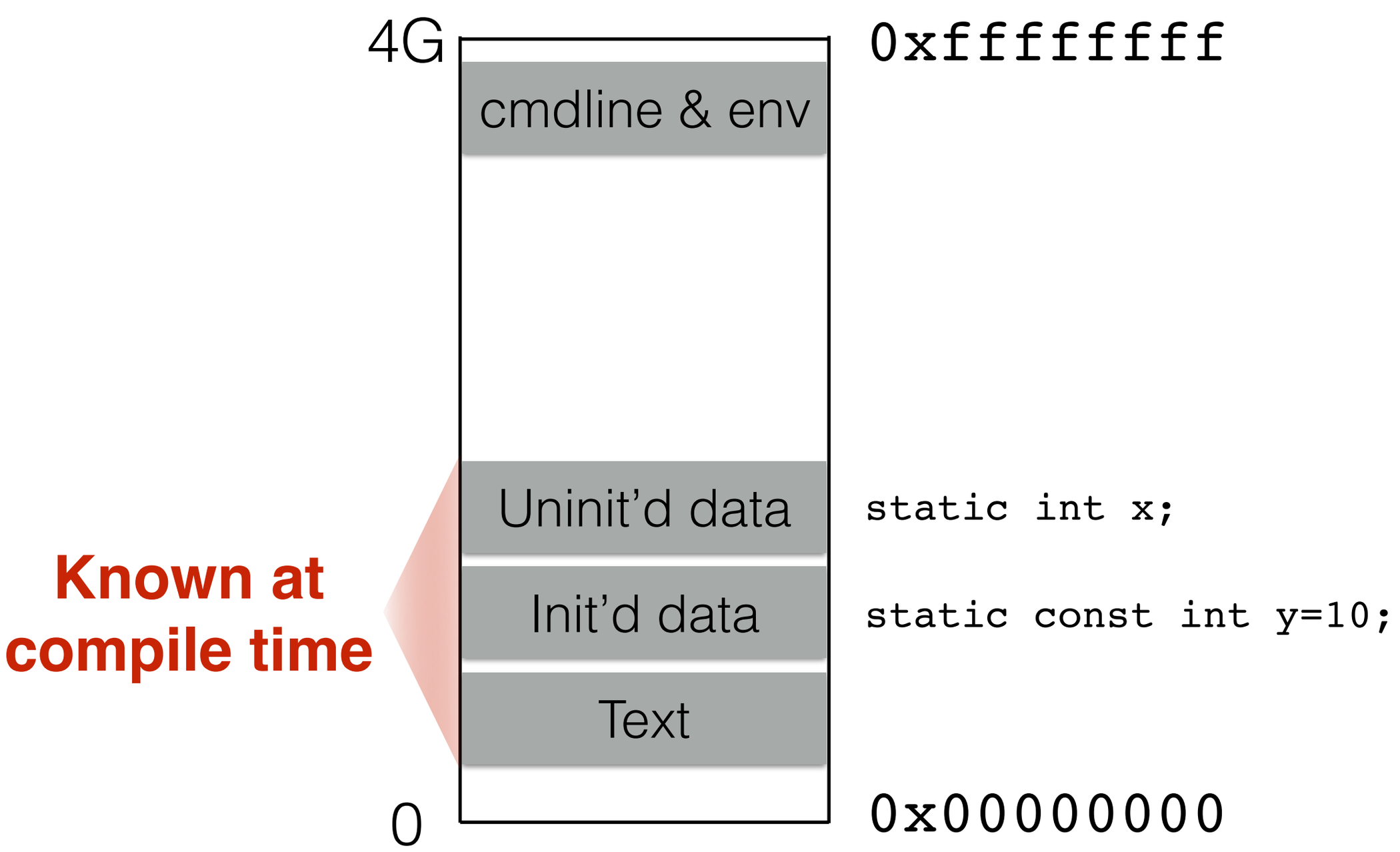

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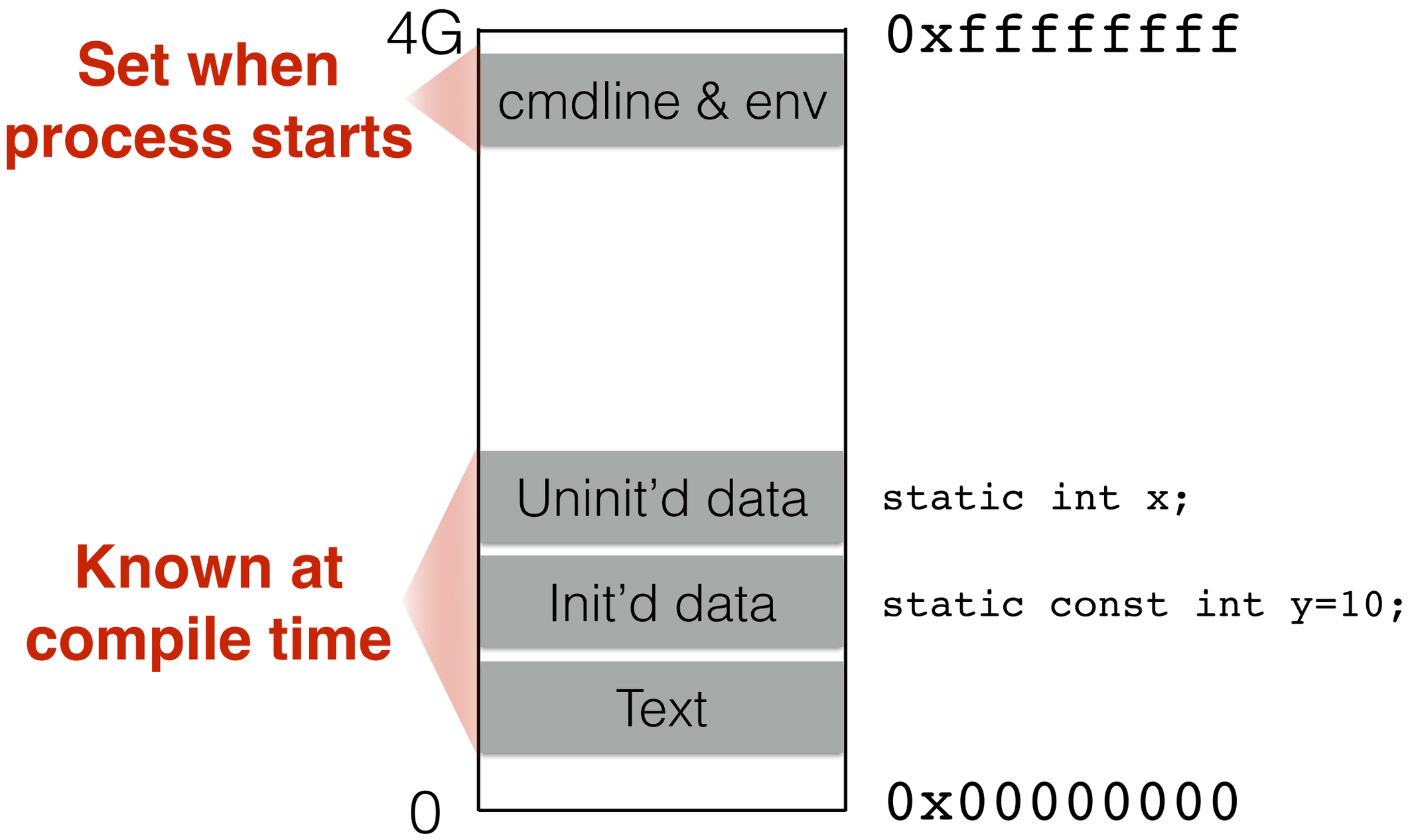
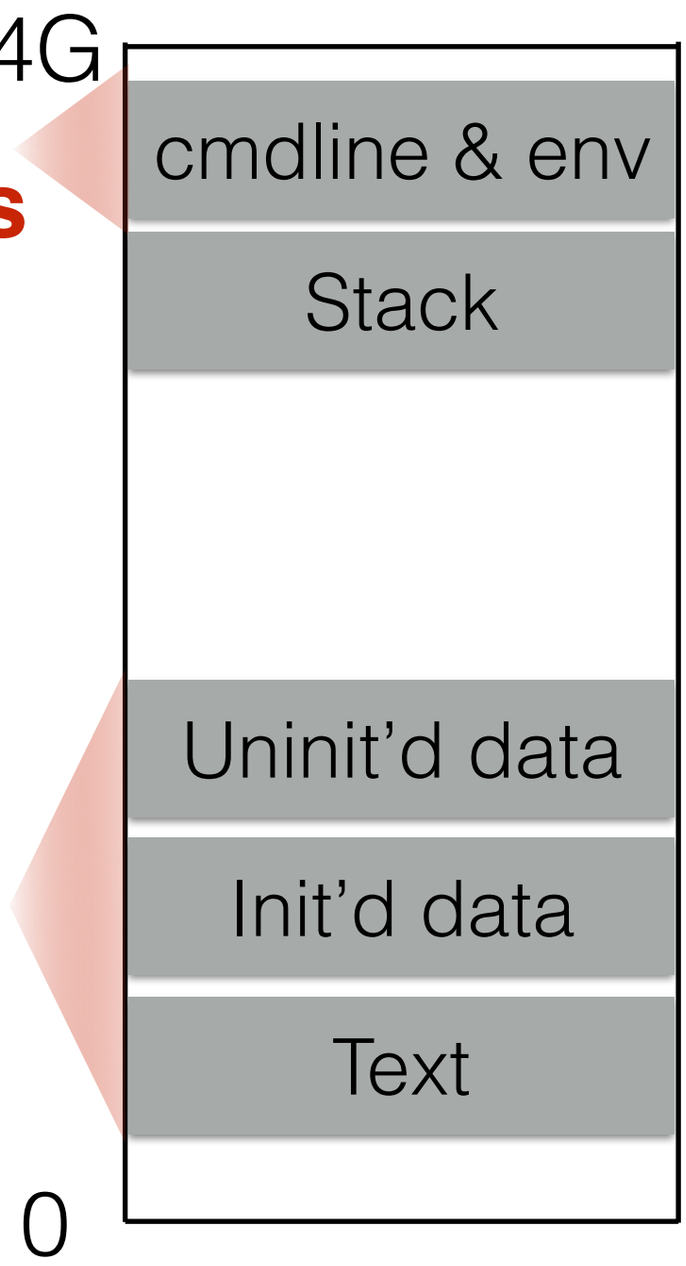


Data's location depends on how it's created

Set when process starts

Known at compile time




```
0xffffffff

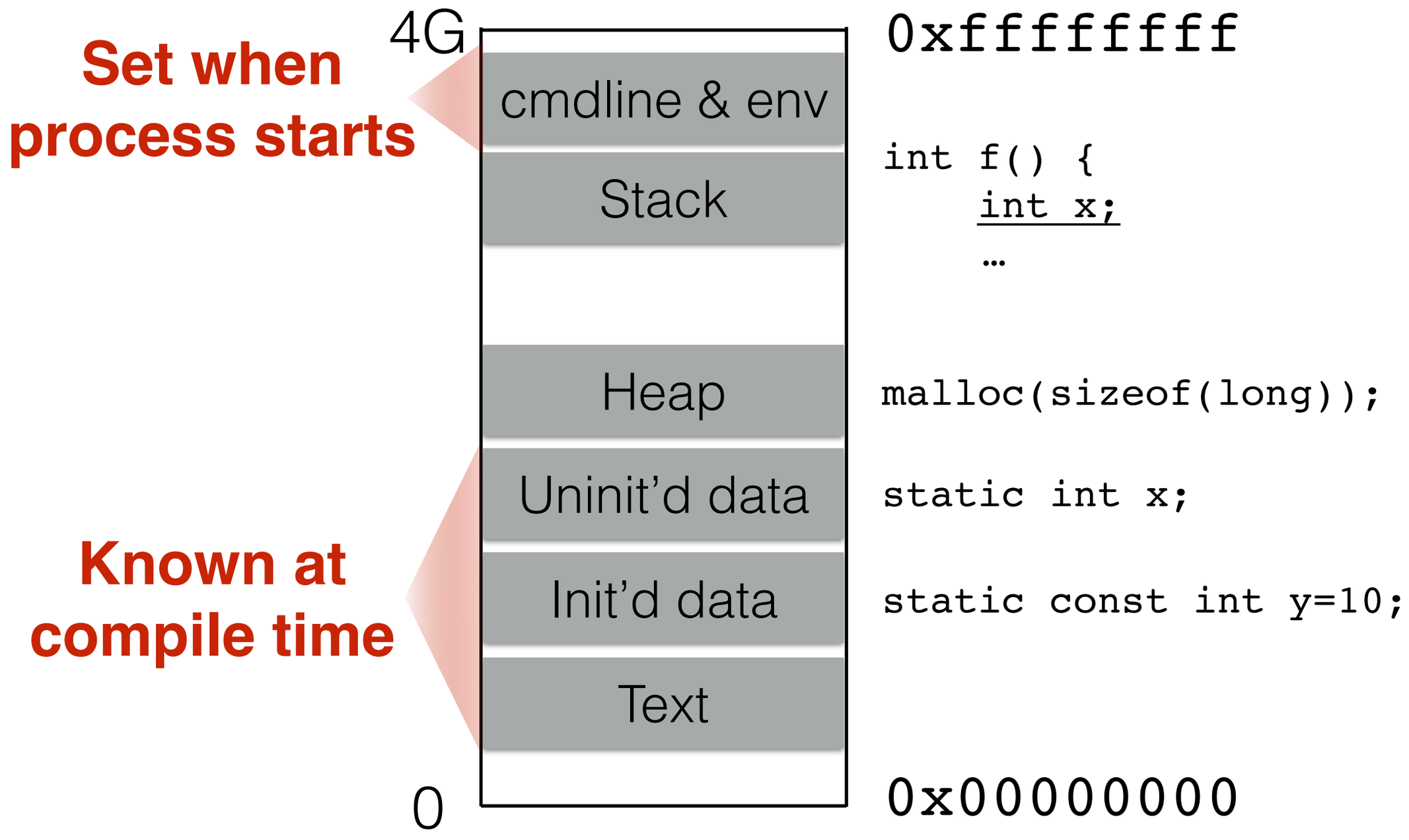
int f() {
    int x;
    …

static int x;

static const int y=10;

0x00000000
```

Data's location depends on how it's created

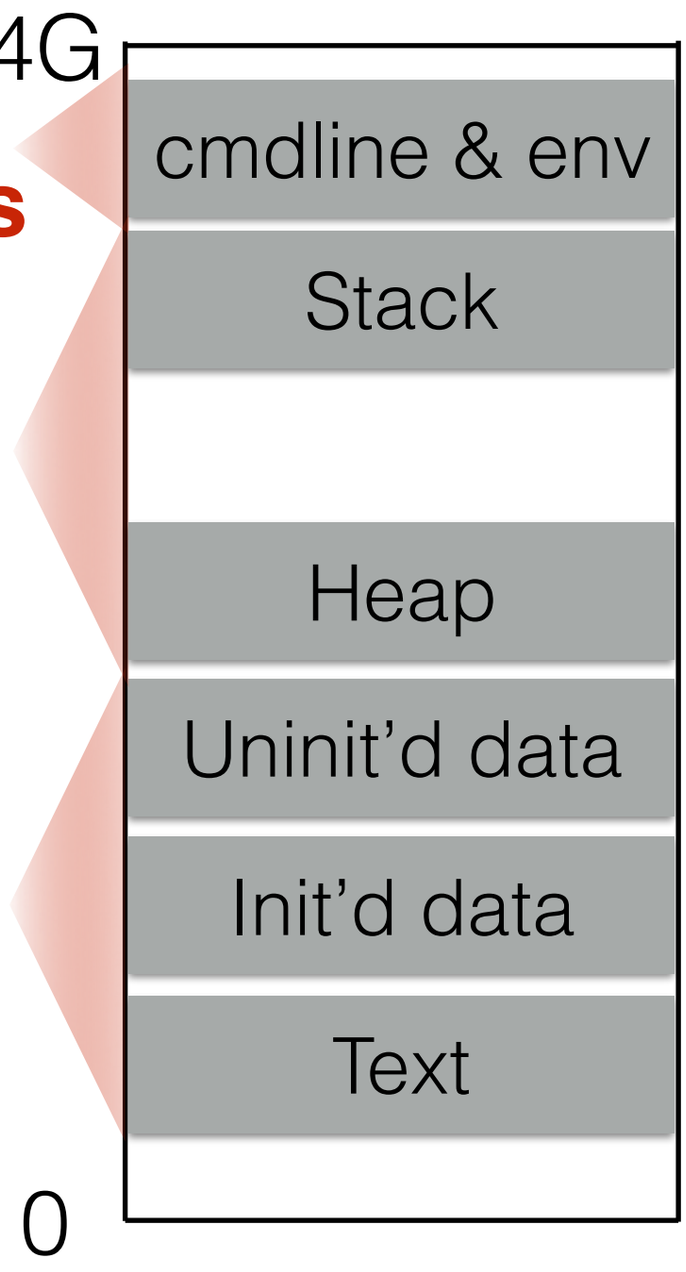


Data's location depends on how it's created

Set when process starts

Runtime

Known at compile time




```
0xffffffff

int f() {
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    …

malloc(sizeof(long));

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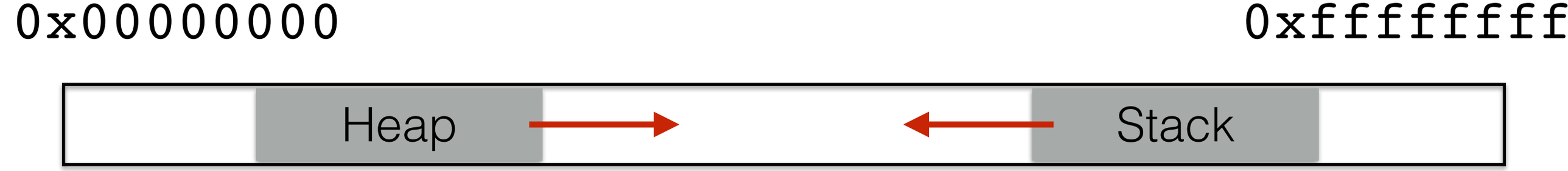
```

We are going to focus on runtime attacks

Stack and heap grow in opposite directions



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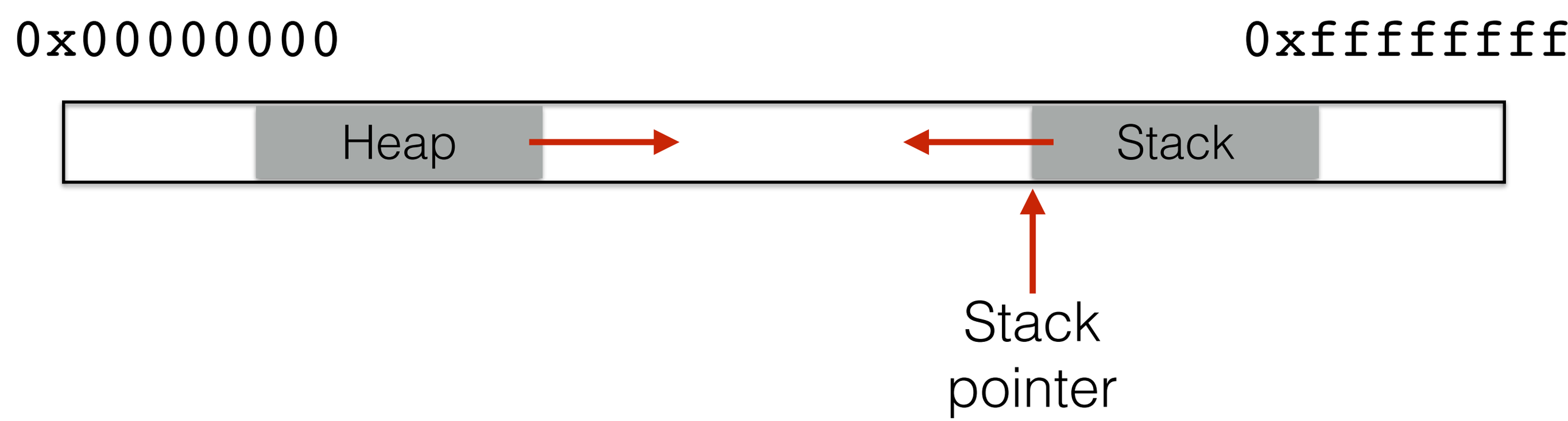

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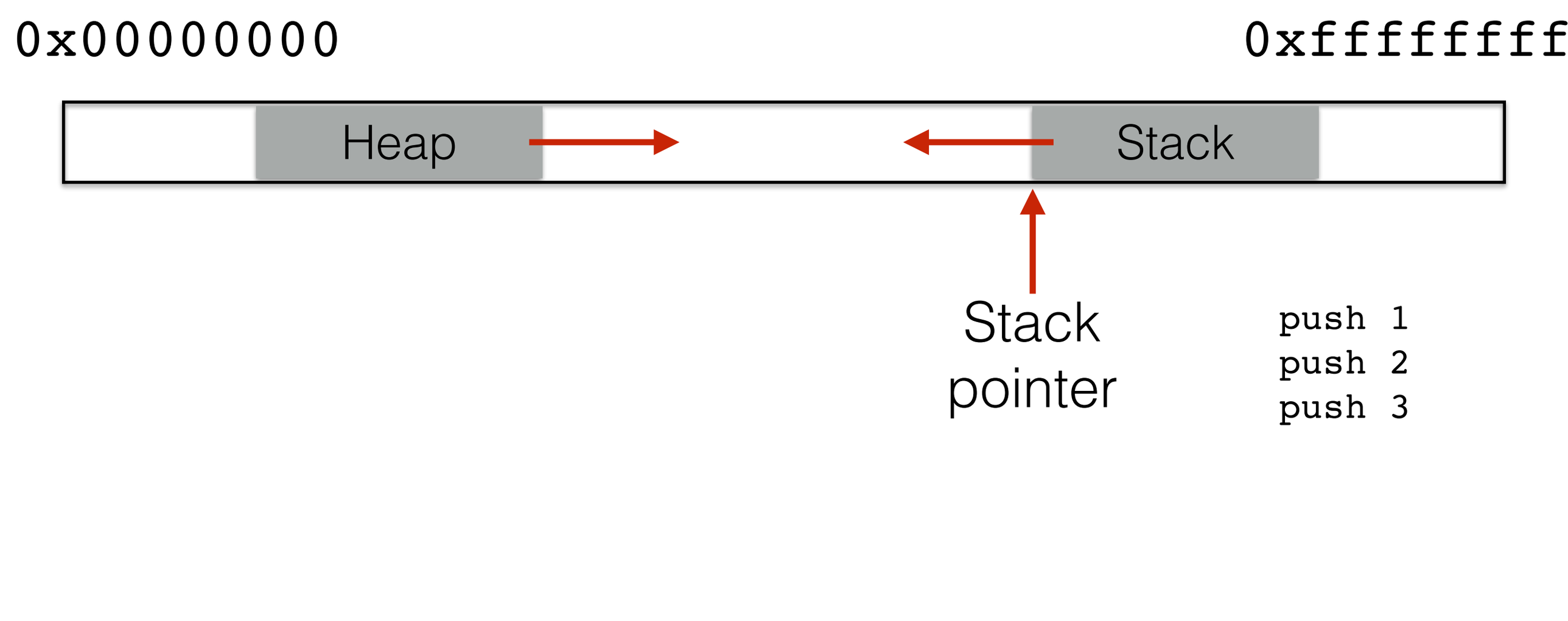

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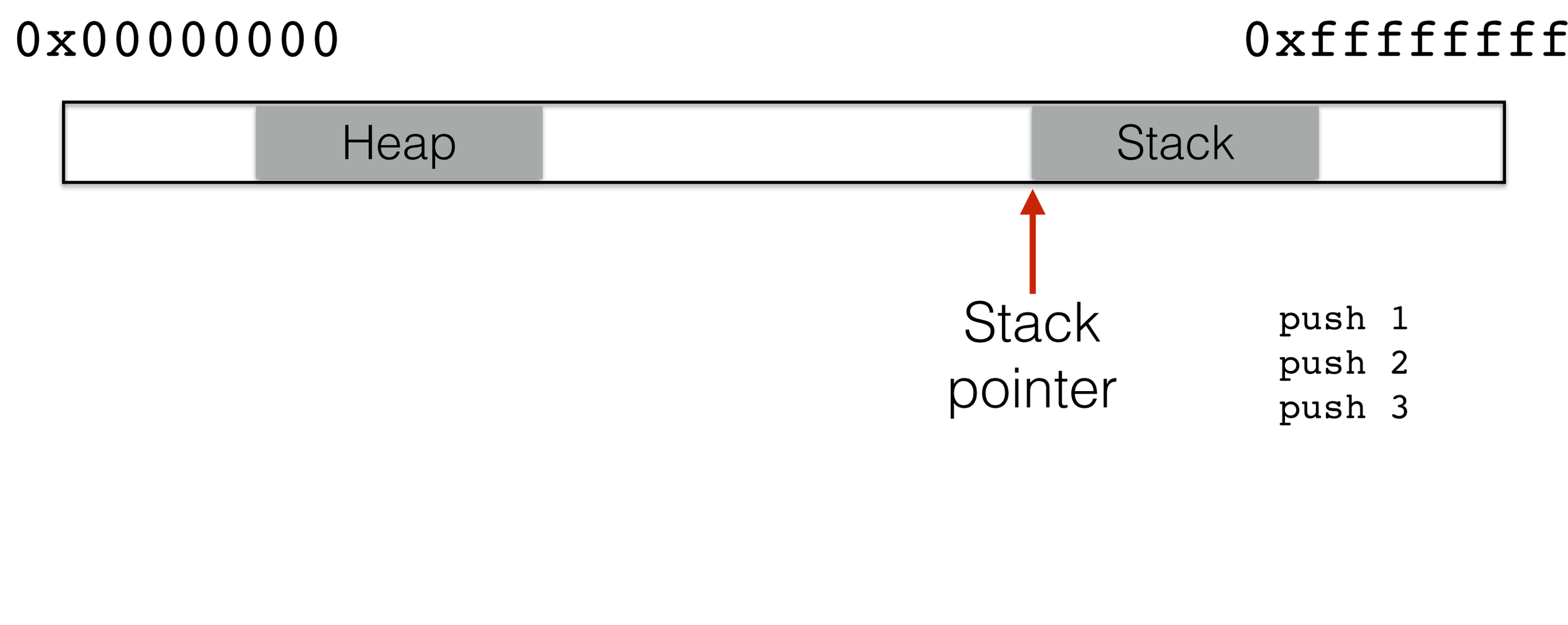

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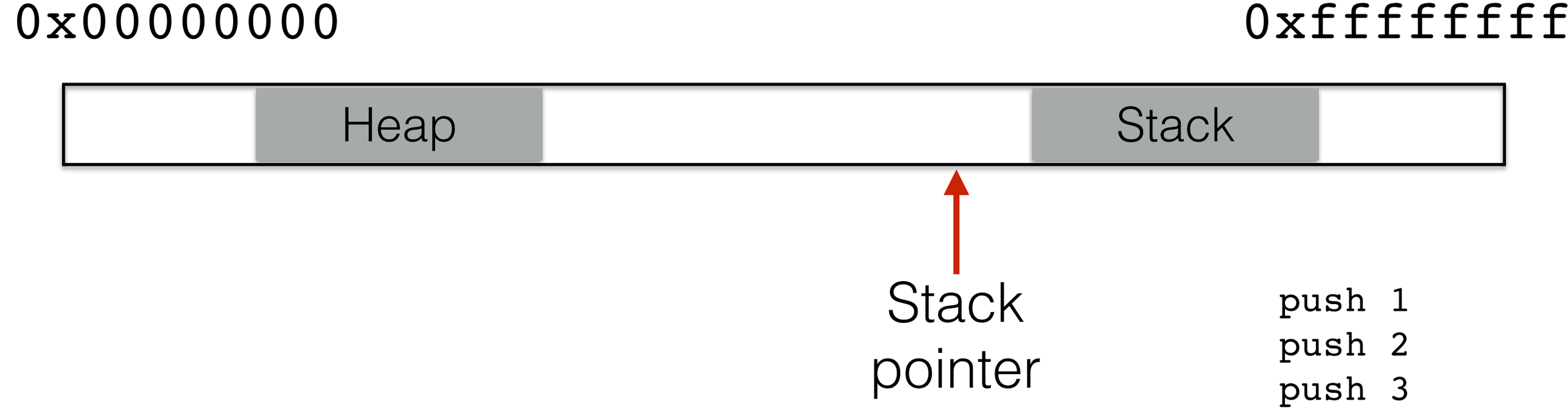

We are going to focus on runtime attacks

Stack and heap grow in opposite directions

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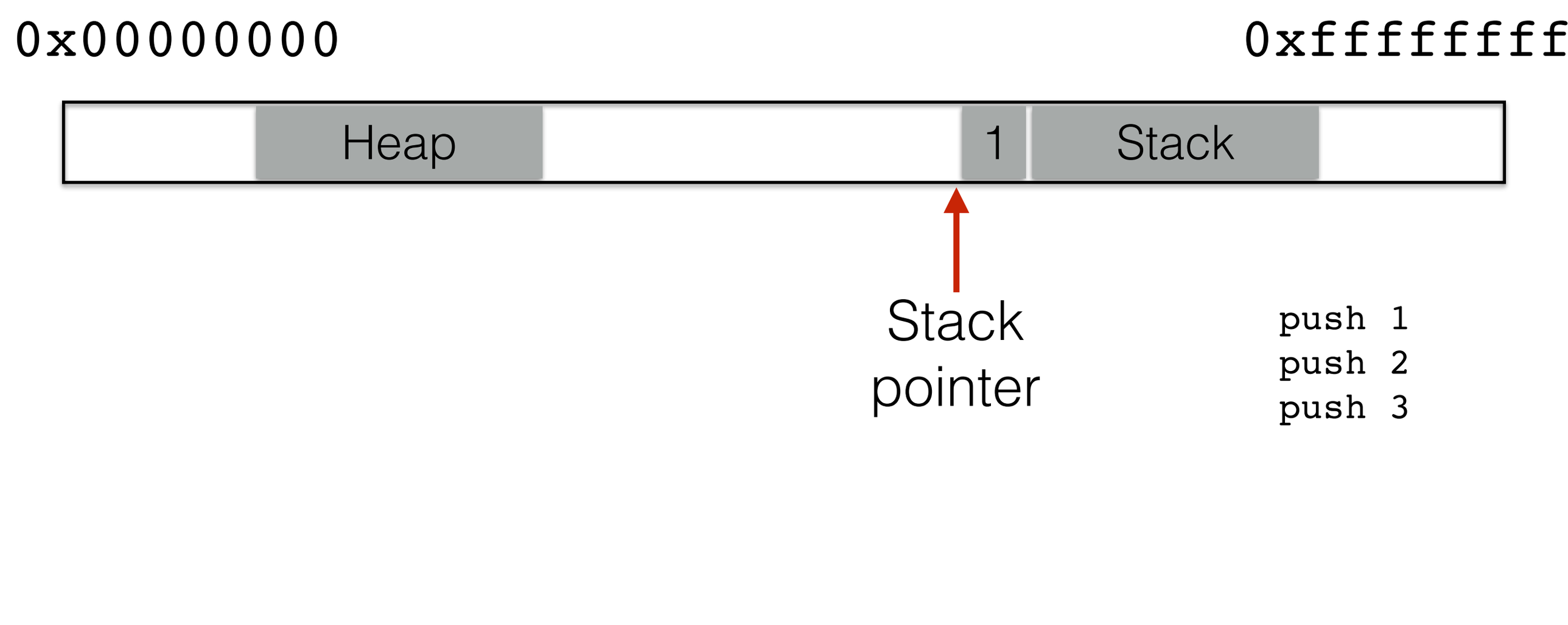

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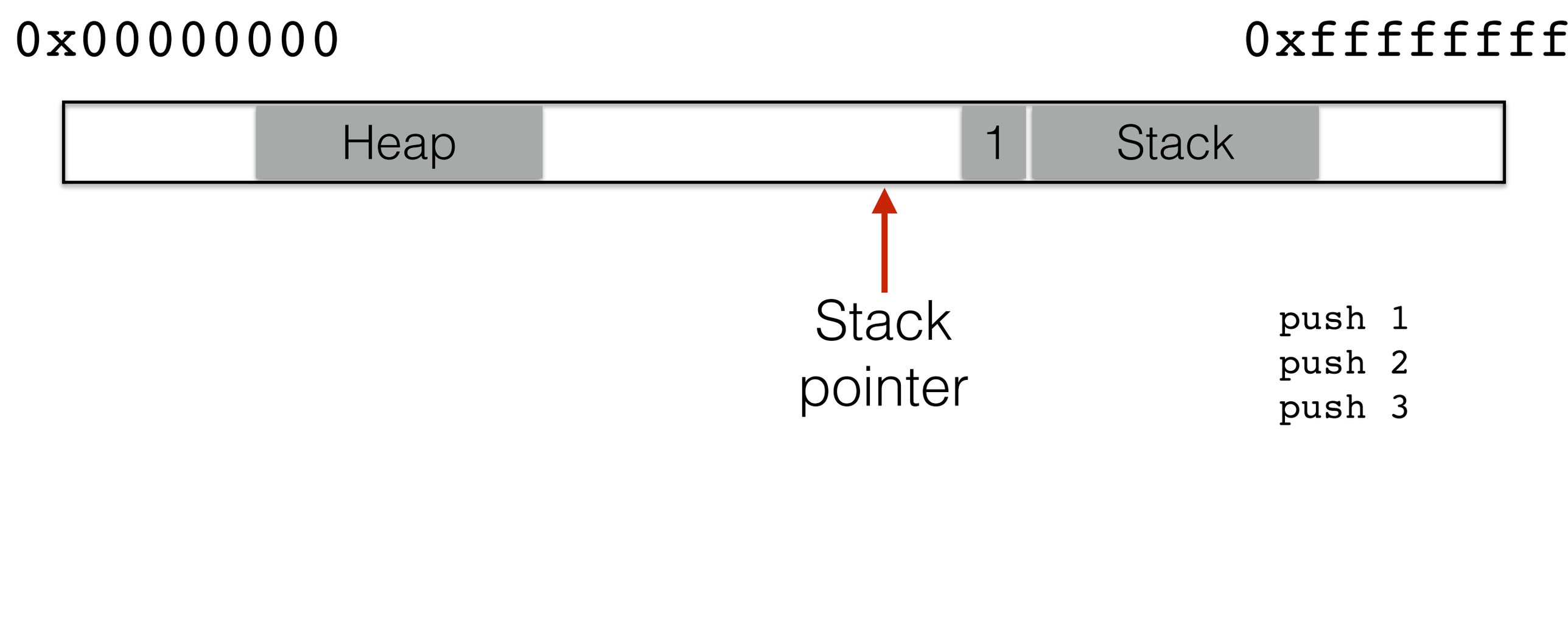

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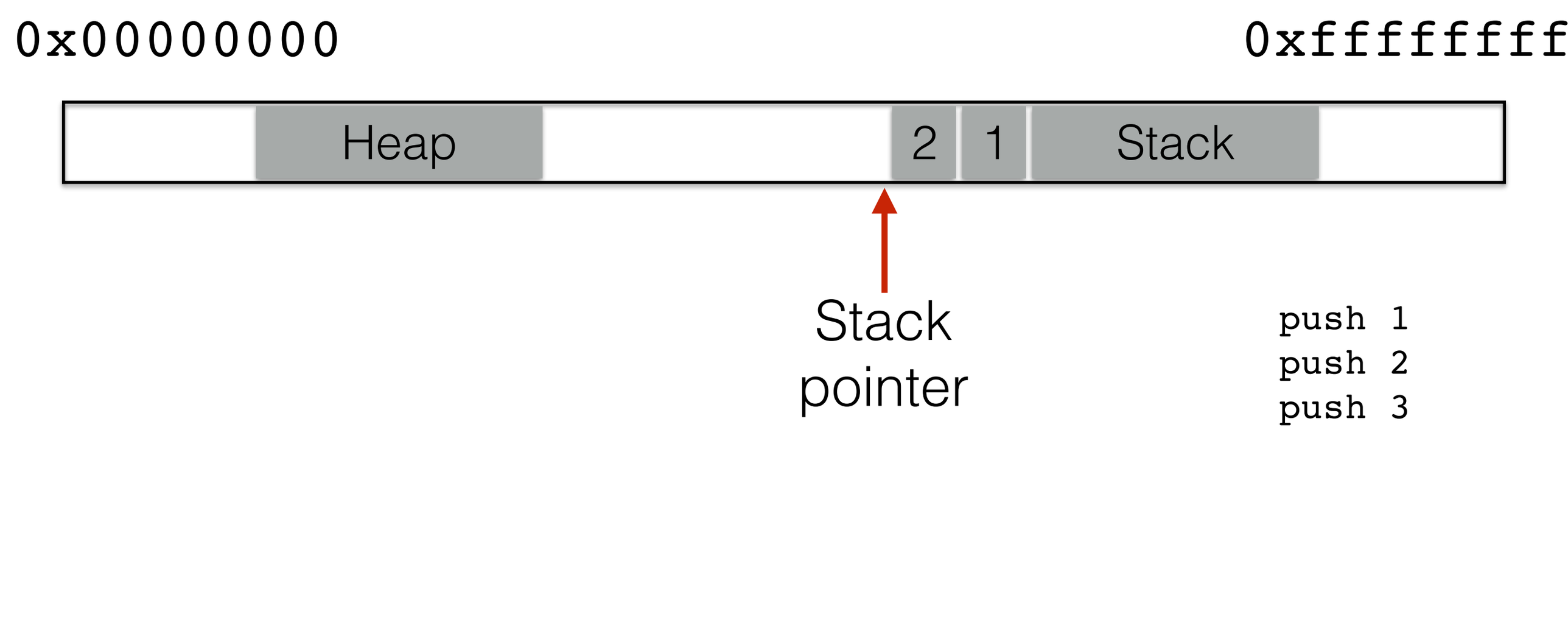

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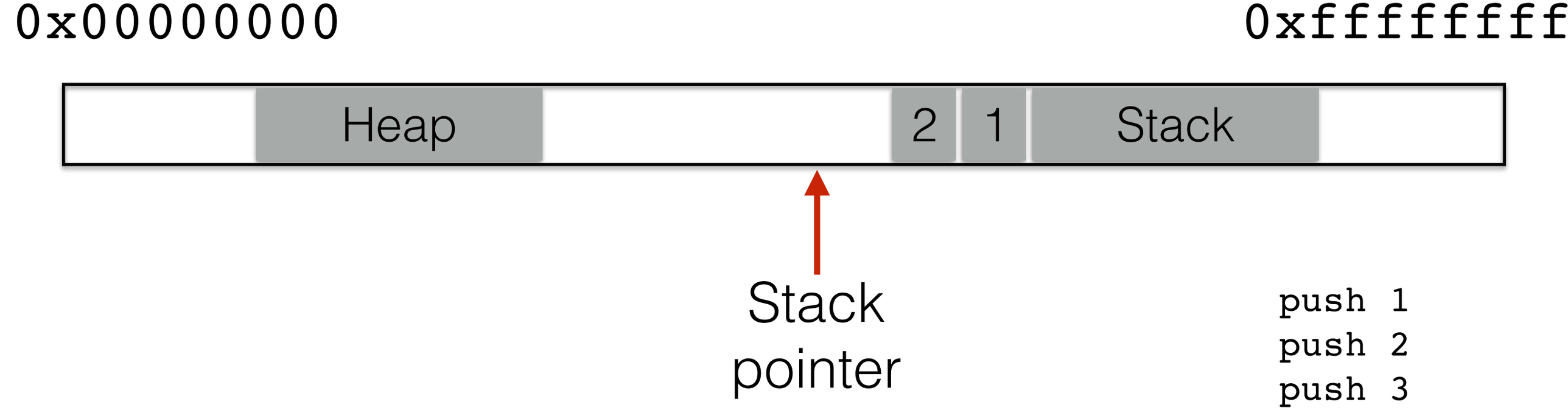

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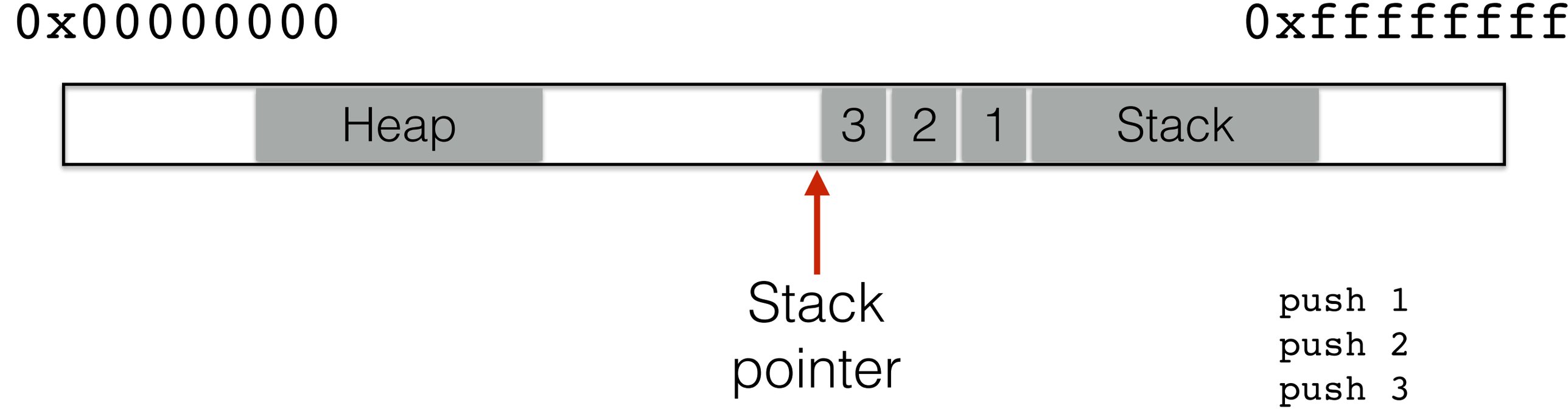

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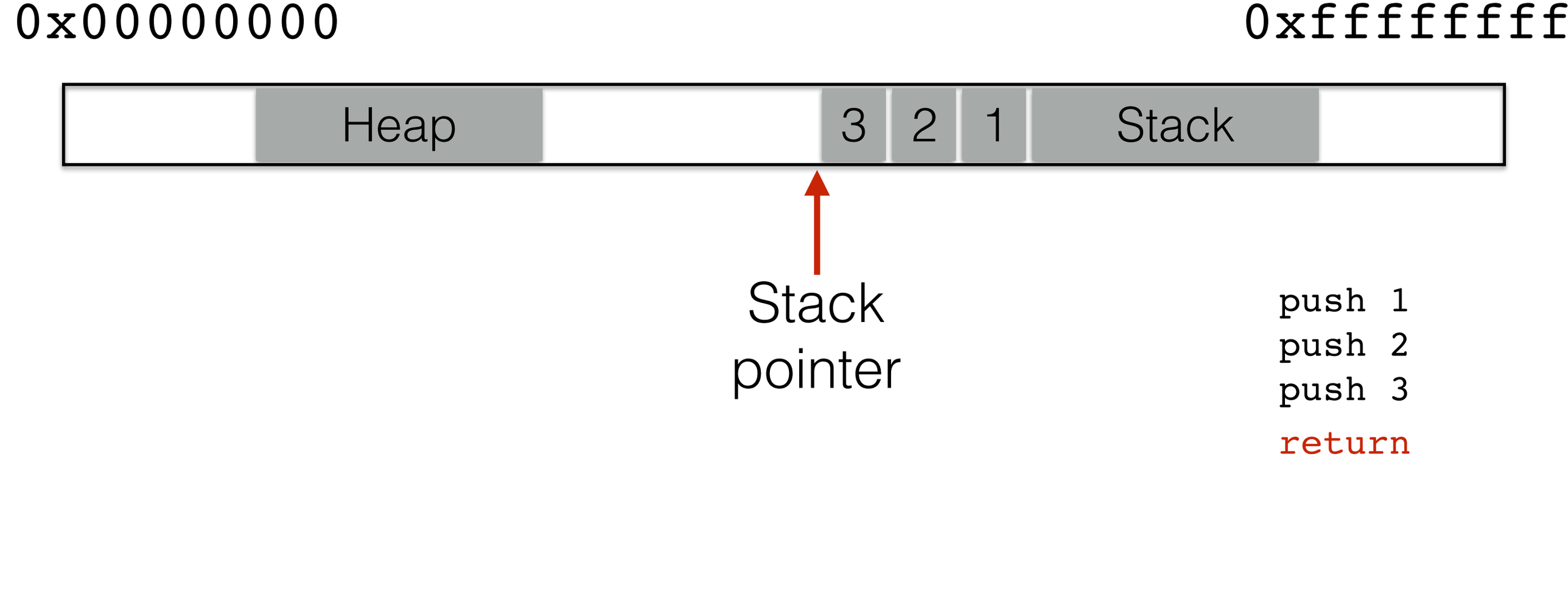

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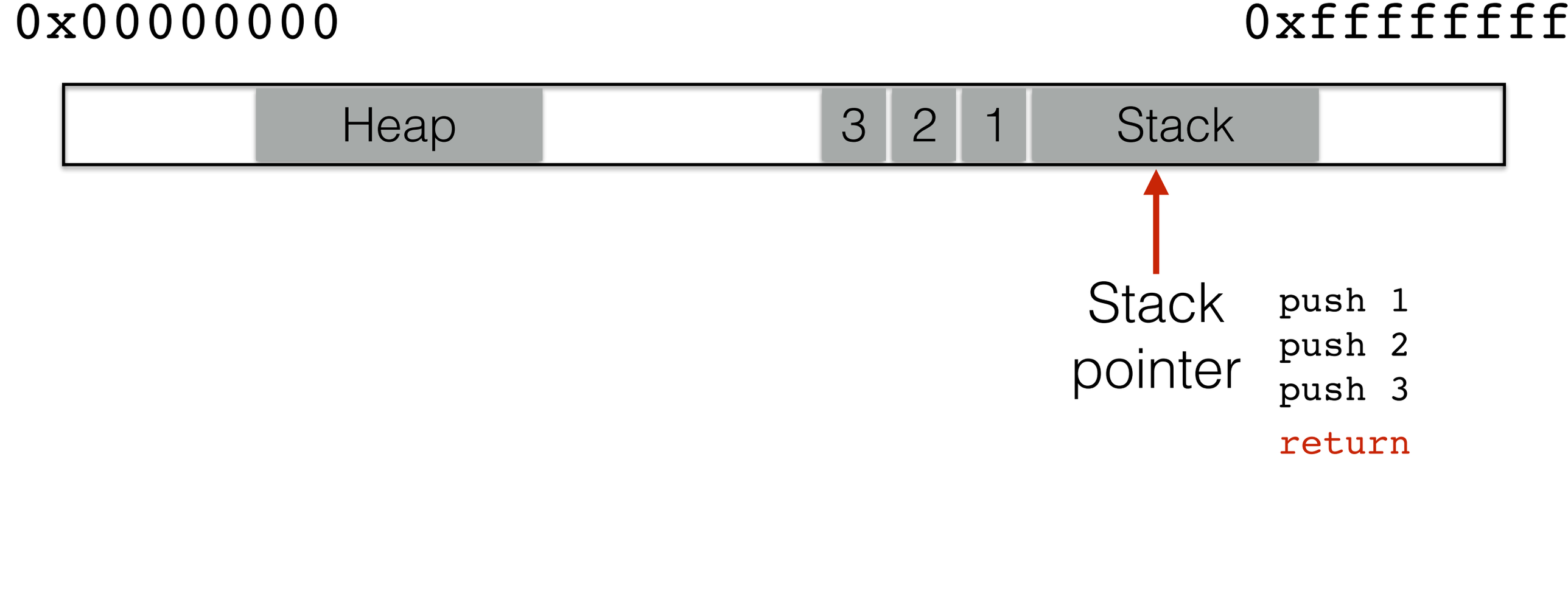

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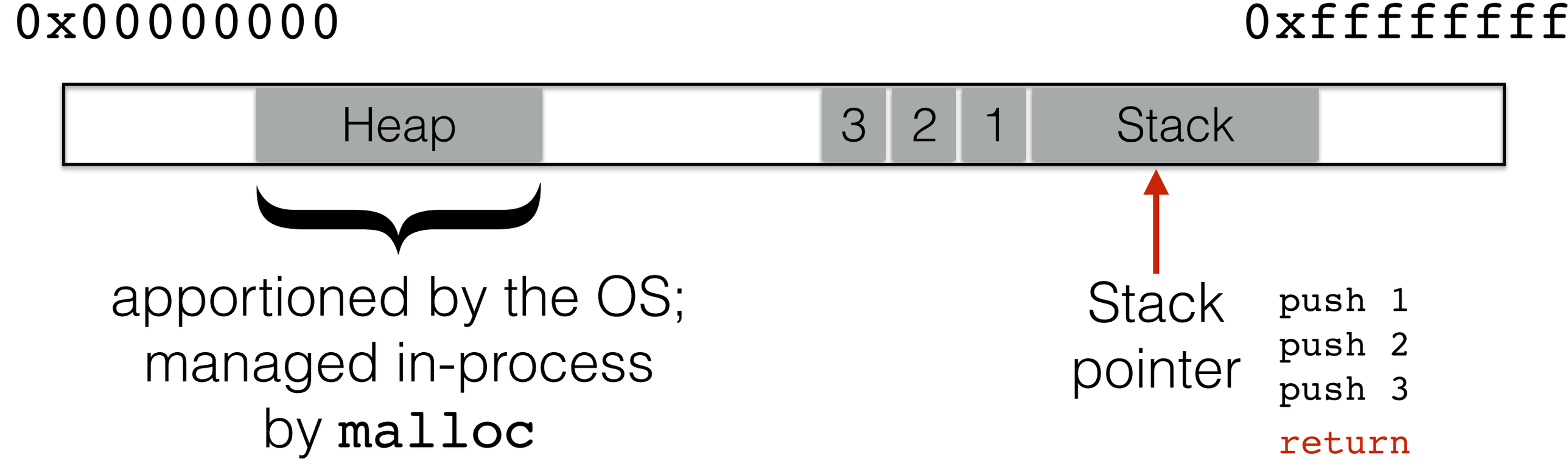

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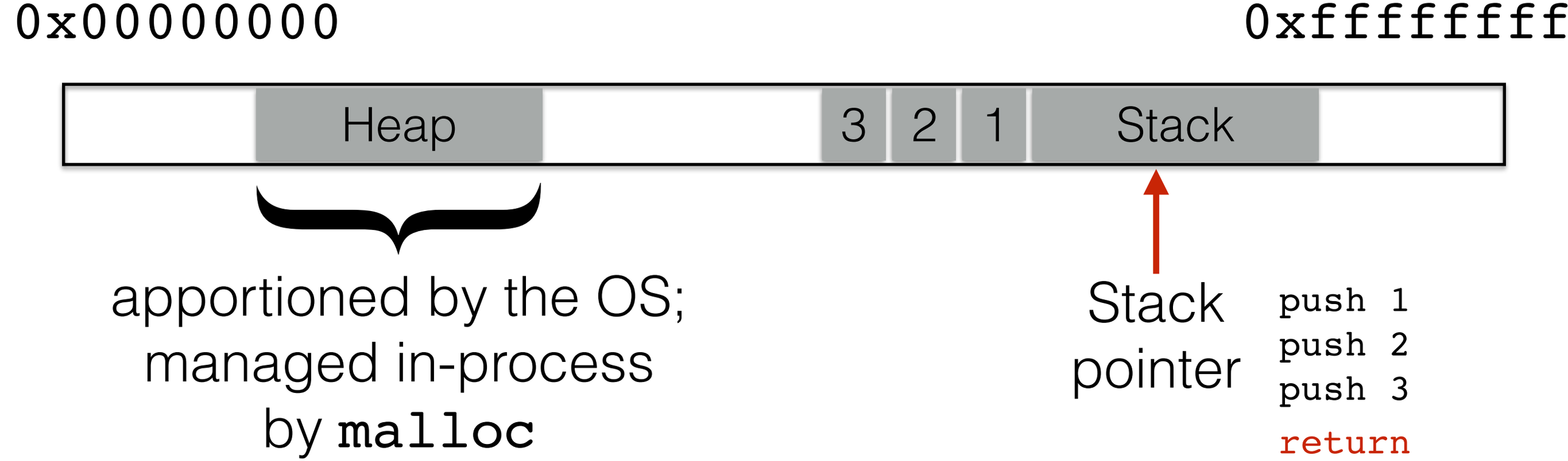

Focusing on the stack for now

Stack layout when calling functions

- What do we do when we *call* a function?
  - What data need to be stored?
  - Where do they go?

- How do we *return* from a function?
  - What data need to be *restored*?
  - Where do they come from?

Code examples

(see `~/UMD/examples/` in the VM)

Stack layout when calling functions

```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4]
    int  loc2;
    int  loc3;
}
```

0x00000000 0xffffffff

Stack layout when calling functions

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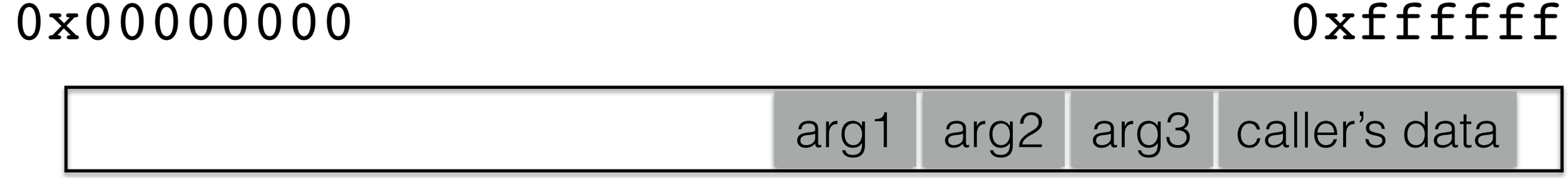

Arguments pushed in reverse order of code

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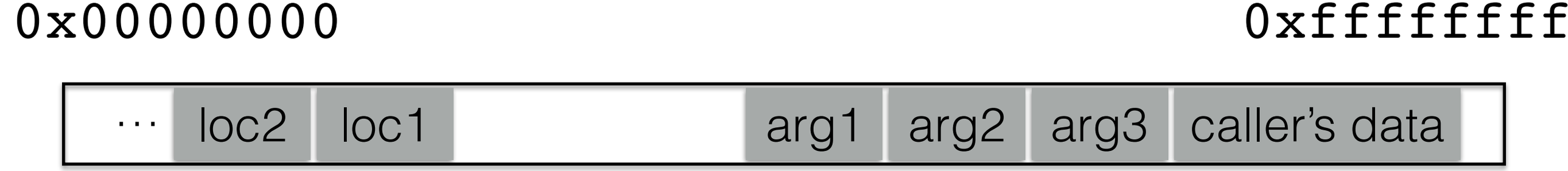

Local variables pushed in the same order as they appear in the code

Arguments pushed in reverse order of code

Stack layout when calling functions

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Stack layout when calling functions

```
void func(char *arg1, int arg2, int arg3)
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Two values between the arguments and the local variables

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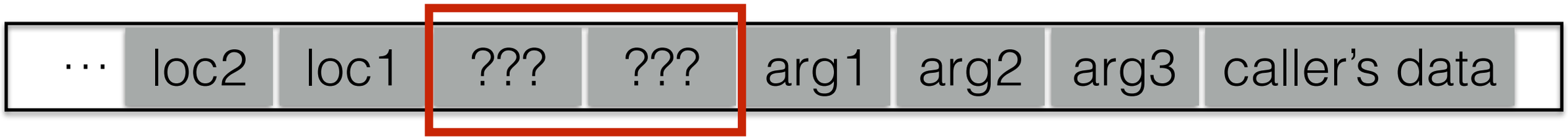

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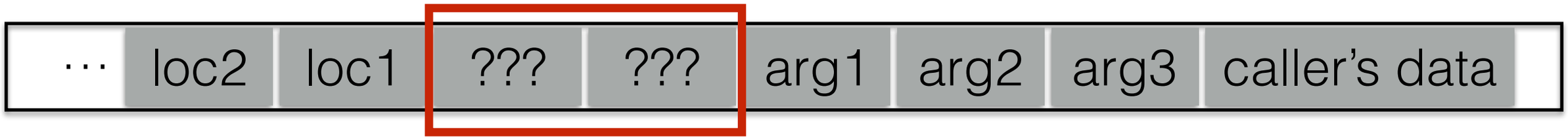

Local variables pushed in the same order as they appear in the code

Arguments pushed in reverse order of code

We will explore (and attack and defend) them *next time*.