case study

E-VOTING ANALYSIS

Kohno et al., IEEE S&P 2004

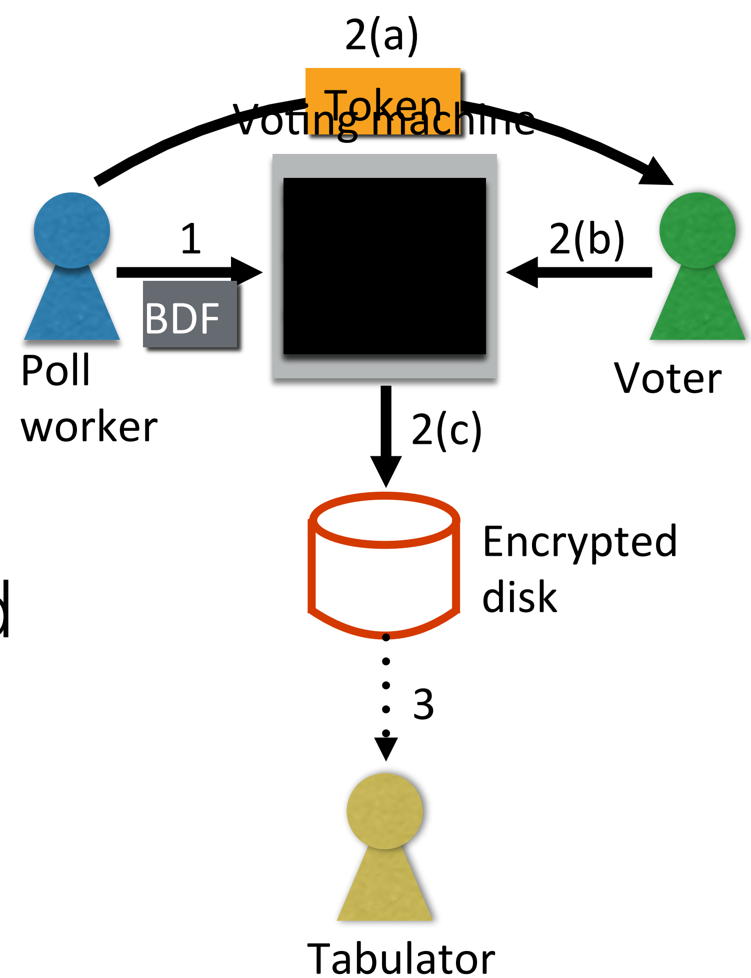
Halderman, 2016

“Security mindset”

- Consider a complex system:
  - Potential security threats?
  - Hidden and explicit assumptions
  - How to mitigate the risks?
  - What are different players’ incentives?

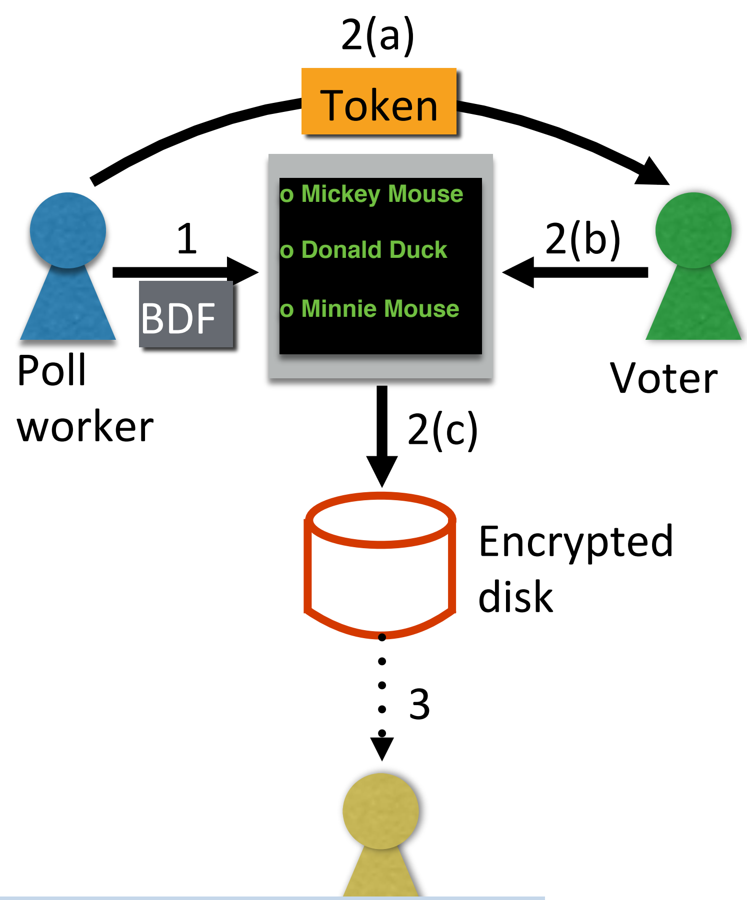
1. Summarize the system

1. Pre-election: Poll worker loads "ballot definition" via e.g. USB
2. Voting: Voter obtains single-use smartcard, votes, vote stored encrypted, card canceled
3. Post-election: Votes decrypted and sent to tabulator, who counts



2. Identify goals/requirements

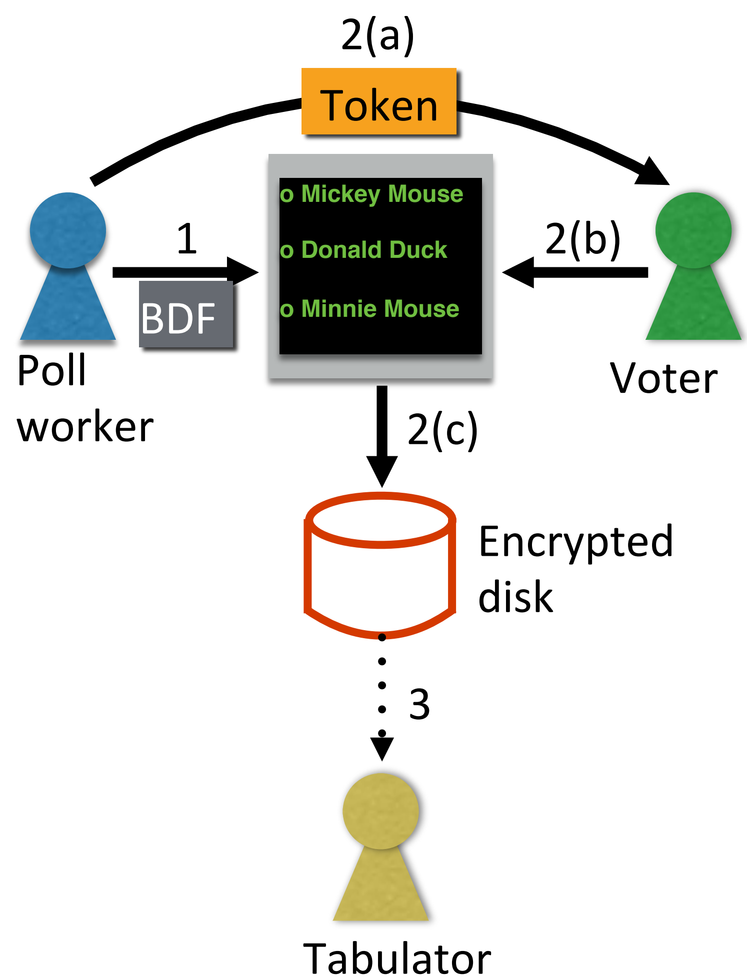
- **Confidentiality**: Can't find out who I voted for
- **Integrity**: Can't alter votes
- **Availability**: Can't deny opportunity to vote
- **Usability**: General public can vote correctly without undue b[urden]



What if the attacker can violate these, but you catch him/her?

3. Identify adversaries/threats

- Poll worker, voter, outsider
- Display one vote / count a different vote
- Vote multiple times
- End election early (DOS)
- Tamper with stored data
- Reveal who voted for whom



Diebold Accuvote TS

- Used in 37 states! (in 2004)
- No cryptography protects smartcards, ballot definition file
- “Protected counter” in single, mutable file
- Pose as voting machine, send to tabulator
- Homebrew crypto protects vote logs
  - Hardcoded key since at least 1998
- Read the paper for more

Follow-up

- More researchers confirmed these bugs and found others (got real hardware)
- State investigations: MD, CA, OH
  - Similar problems from other manufacturers
  - Sequoia AVC: designed 1980, used in NJ 2009
- "By the 2014 general election, 70% of American voters were casting ballots on paper"

Takeaways

- Adversarial thinking
- Whole-systems view
  - Hardware, software, network, users, economics
- Only as strong as weakest link
  - Break into building vs. sniff unencrypted traffic
  - You have to be right always, adversary once
- Never homebrew crypto!
- Security through obscurity DOESN'T WORK!

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

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”

Don't unlock pretty
plz

Locked by dml
press ctrl-c to logout

screensaver --prompt=“Don’t unlock plz ${}^{S}{}_{P}$ ${}^{S}{}_{P}$ ${}^{S}{}_{P}$ \
${}^{S}{}_{P}$ ${}^{S}{}_{P}$”

Don't unlock plz

Locked by dml

press ctrl-c to logout

```
screensaver –prompt=“Under maintenance;\
Do not interrupt␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠\
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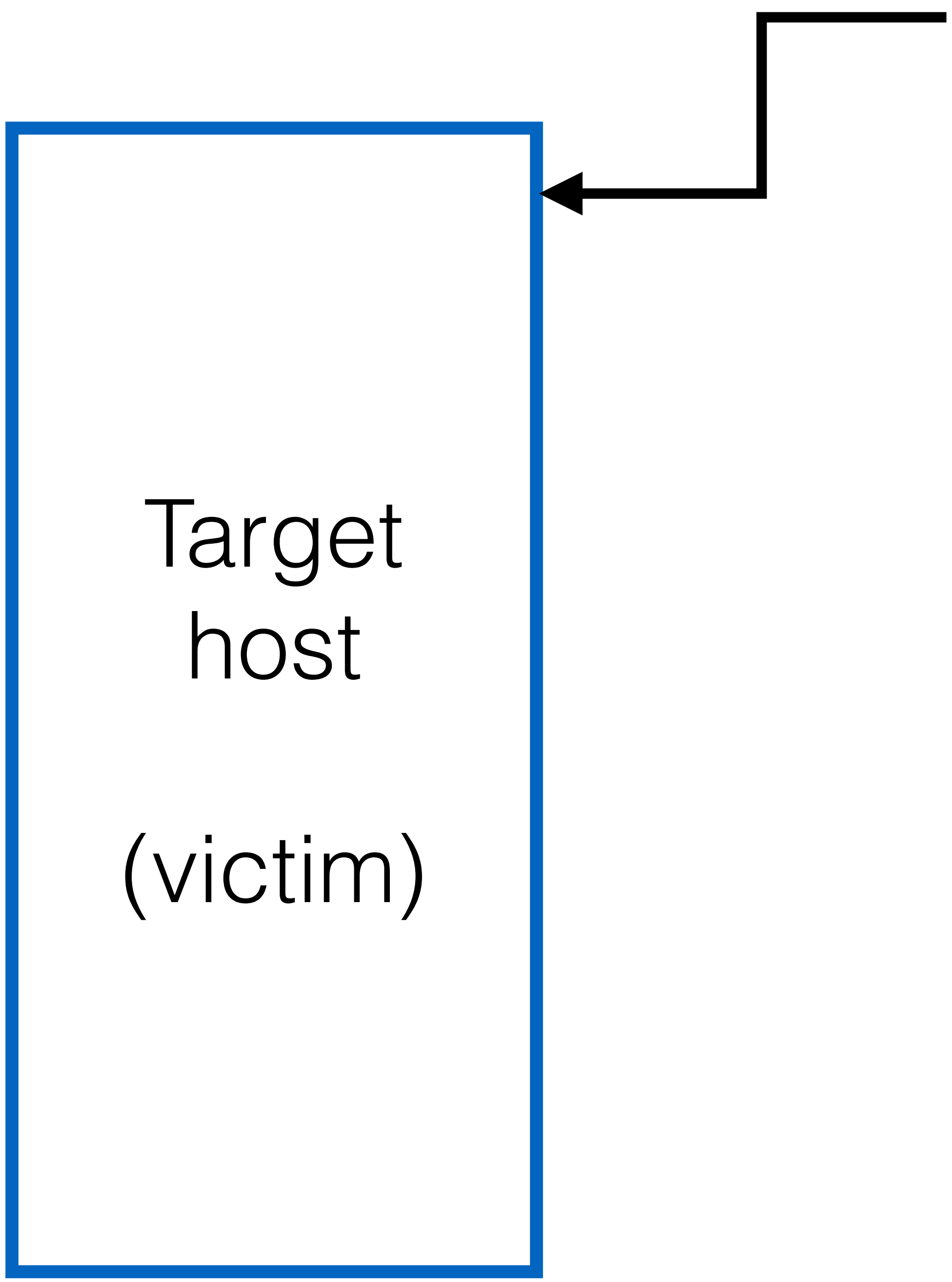
Most (interesting) software takes input



Direct user interaction
- command line interface (stdin)
- user opens a document

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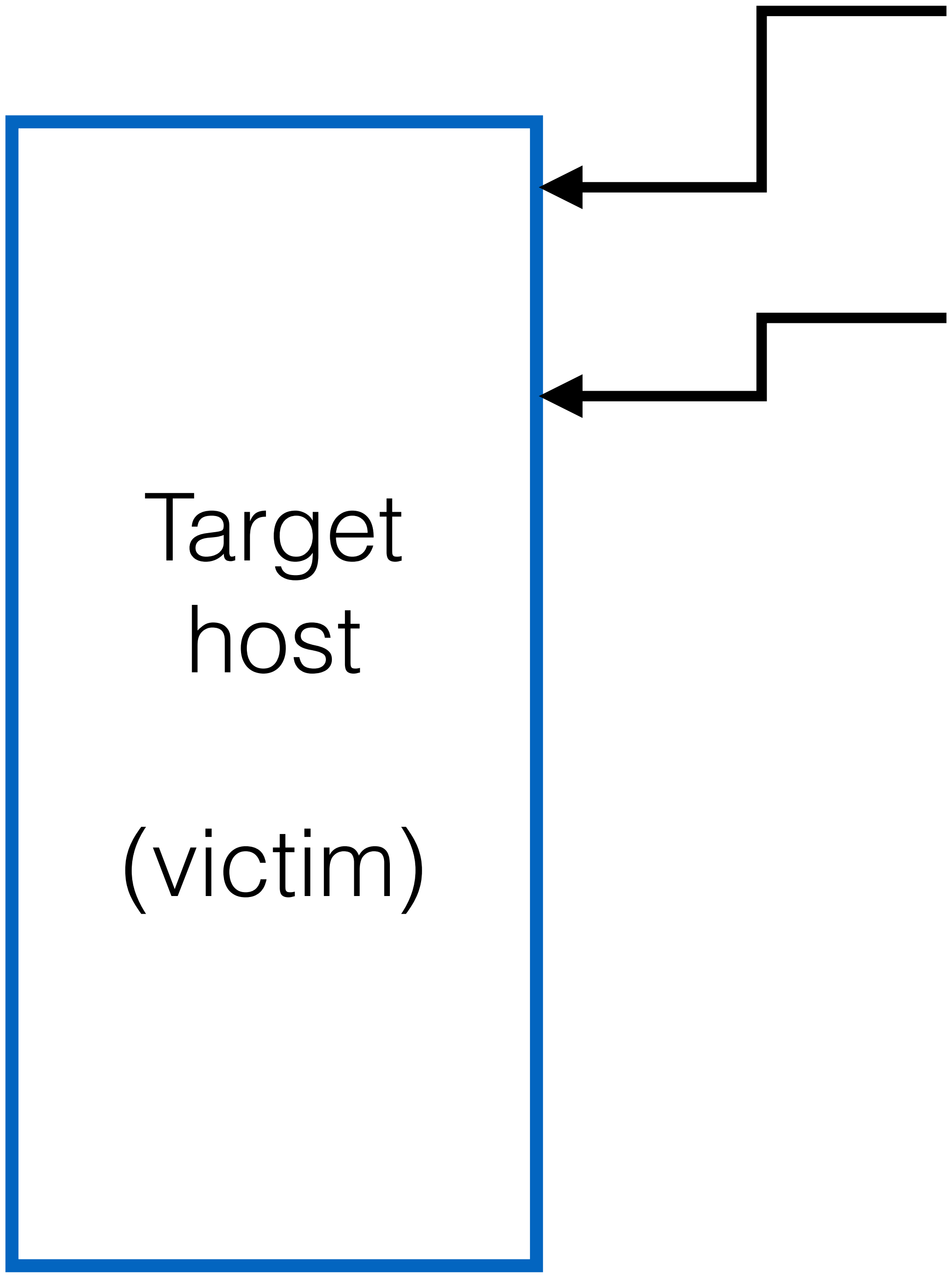

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Network communication

- emails
- various protocols

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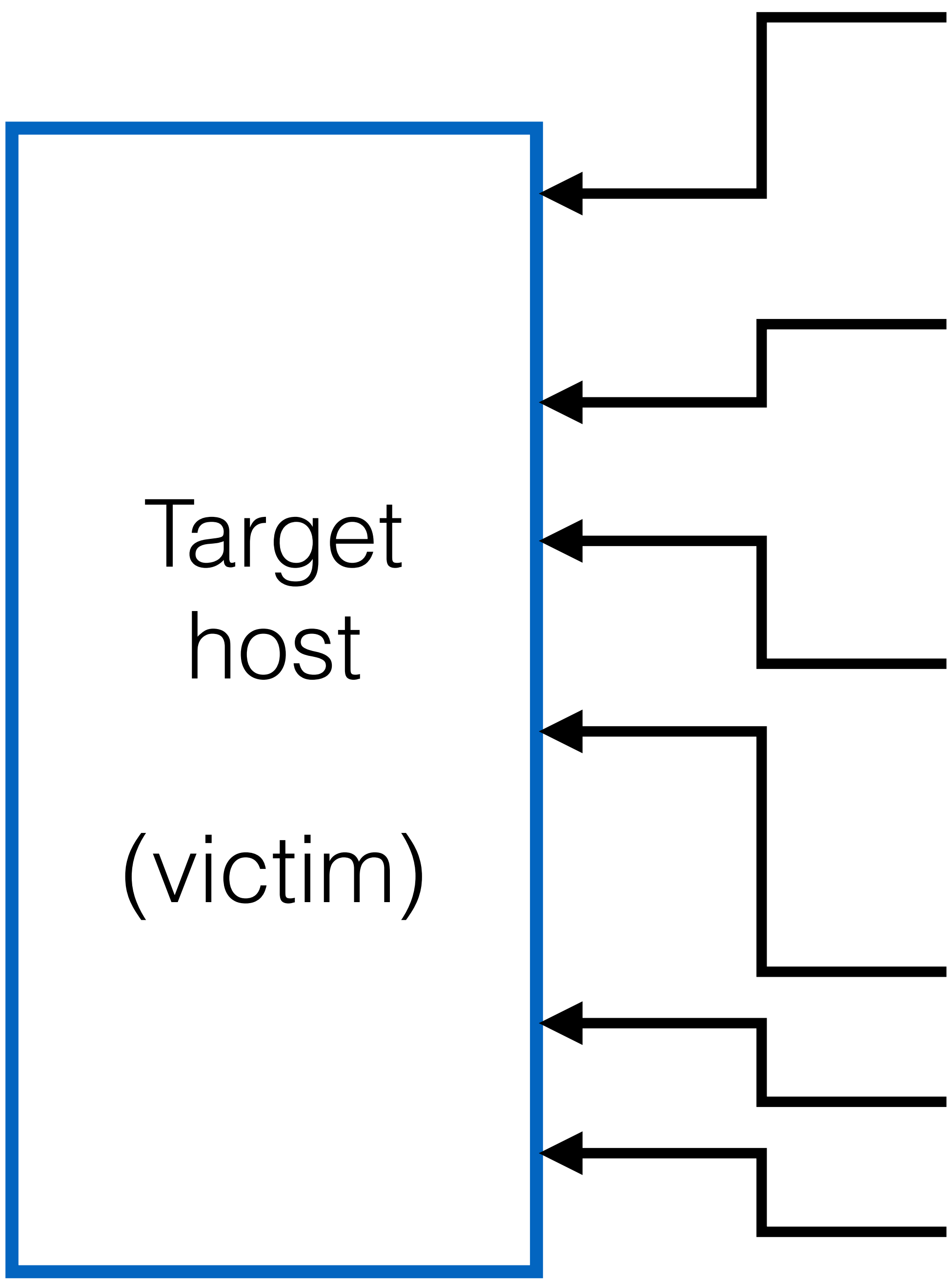


Direct user interaction
- command line interface (stdin)
- user opens a document

Network communication
- emails
- various protocols

Sensing the outside world
- QR codes (to link w/ malware)
- sound recordings

Third-party libraries

Future code updates

Others…

Goal: Correct operation despite malicious inputs

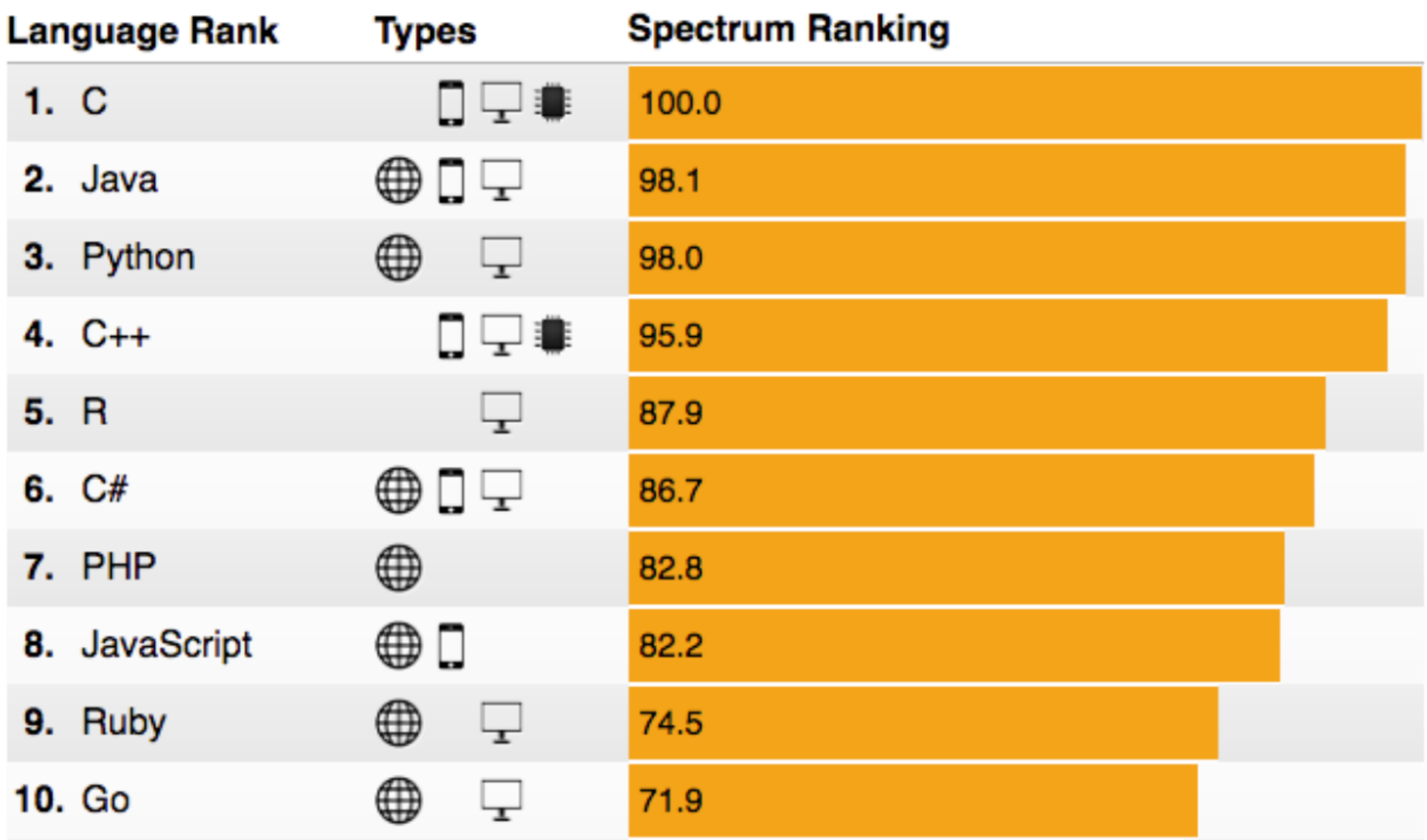
What is a buffer overflow?

- A **low-level** bug, typically in **C/C++**
  - Significant security implications!
- If accidentally triggered, causes a crash
- If maliciously triggered, can be **much worse**
  - **Steal** private info
  - **Corrupt** important info
  - **Run** arbitrary code

Why study them?

- Buffer overflows are still **relevant** today
  - C and C++ are still popular
  - Buffer overflows still occur with regularity
- They have a **long history**
  - Many different approaches developed to defend against them, and bugs like them
- They share **common features** with other bugs we will study
  - In **how the attack works**
  - In **how to defend against it**

C and C++ still very popular



http://spectrum.ieee.org/computing/software/the-2016-top-programming-languages

Critical systems in C/C++

- Most **OS kernels** and utilities
  - fingerd, X windows server, shell
- Many **high-performance servers**
  - Microsoft IIS, Apache httpd, nginx
  - Microsoft SQL server, MySQL, redis, memcached
- Ma
  - Mars rover, industrial control systems, automobiles, healthcare devices

A successful attack on these systems is particularly dangerous!

We're going to focus on C

A breeding ground for *buffer overflow attacks*

1988 1999 2000 2001 2002 2003

- 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

(Robert Morris is now a professor at MIT)

We’re going to focus on C

A breeding ground for *buffer overflow attacks*

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

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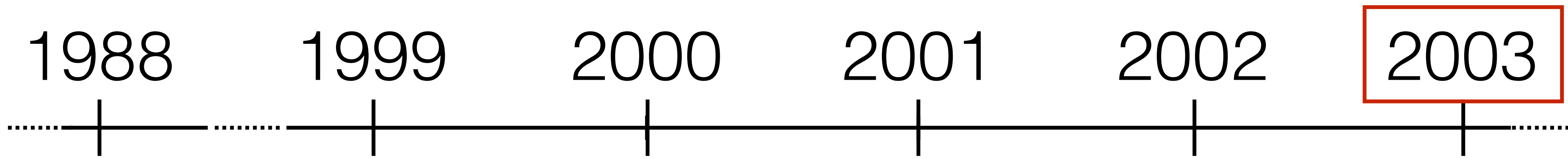

- SQL Slammer
  - Exploited an **overflow** in the MS-SQL server
  - 75,000 machines infected in 10 *minutes*

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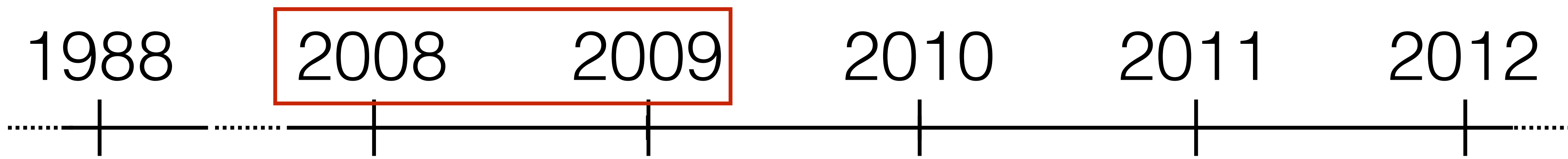

- Conficker worm
  - Exploited an **overflow** in Windows RPC
  - ~10 million machines infected

We're going to focus on C

A breeding ground for *buffer overflow attacks*

1988 2008 2009 2010 2011 2012

- 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*)

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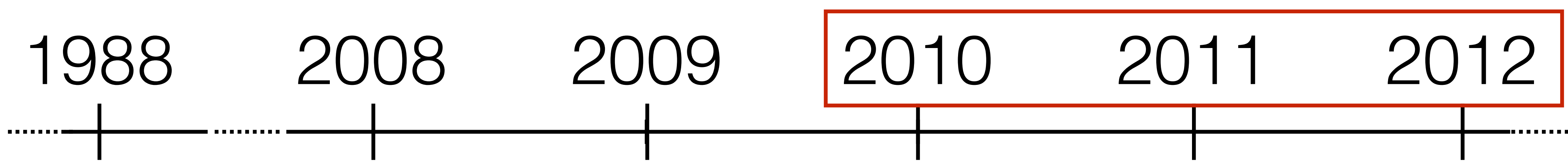
A breeding ground for *buffer overflow attacks*



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

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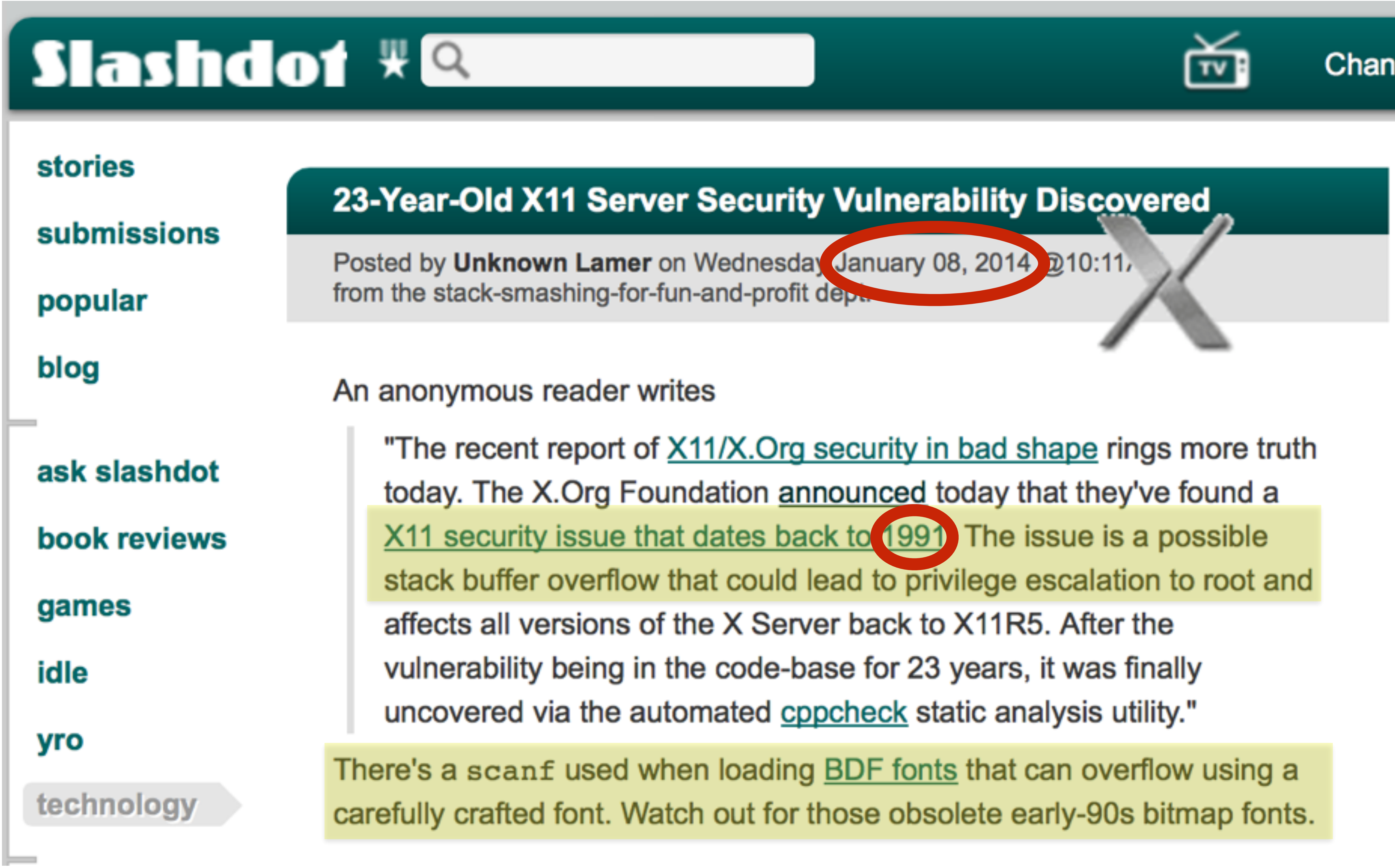
23-Year-Old X11 Server Security Vulnerability Discovered

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
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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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```

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

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Buffer too small

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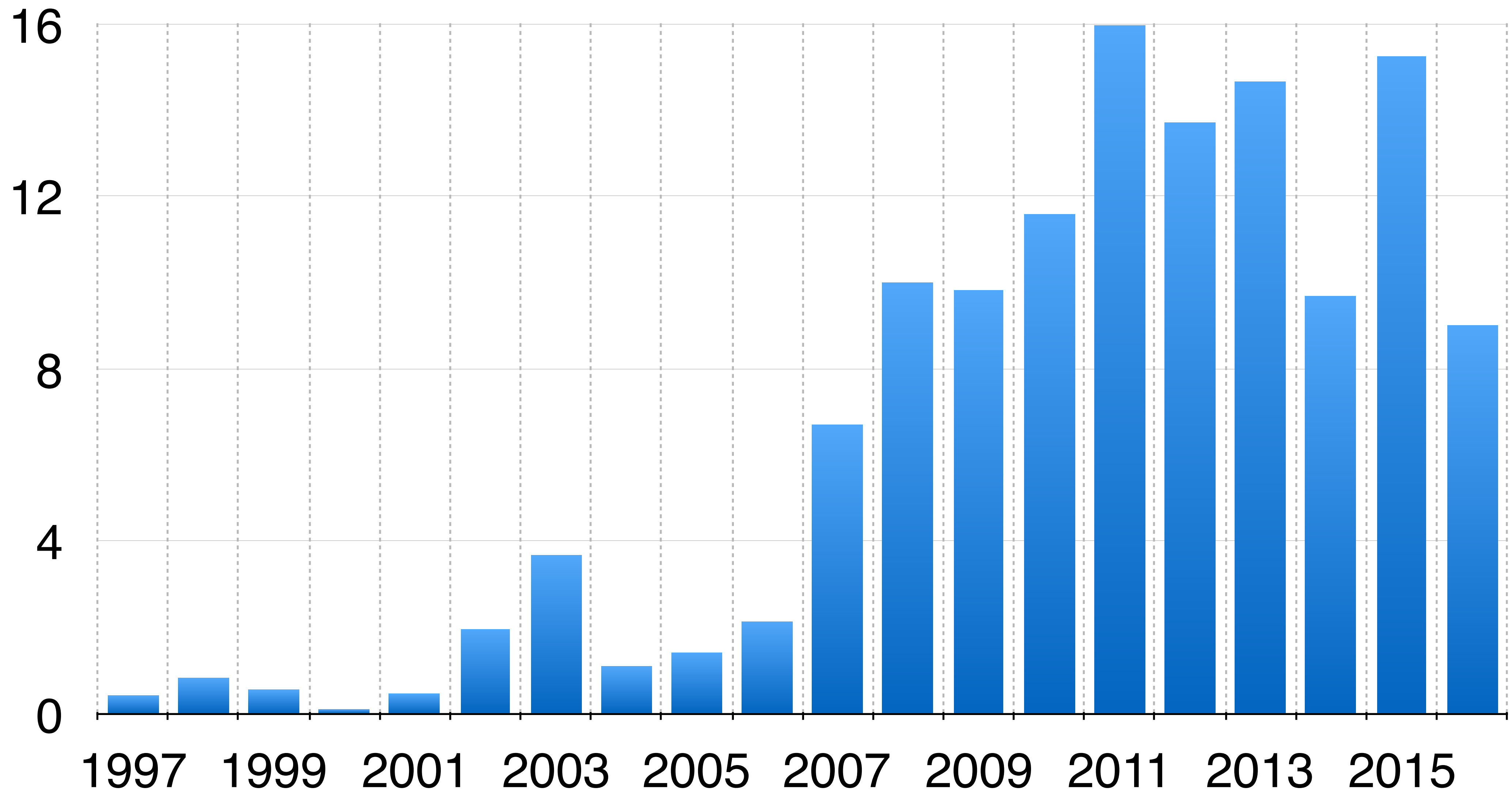
Buffer too small

Writes beyond the buffer

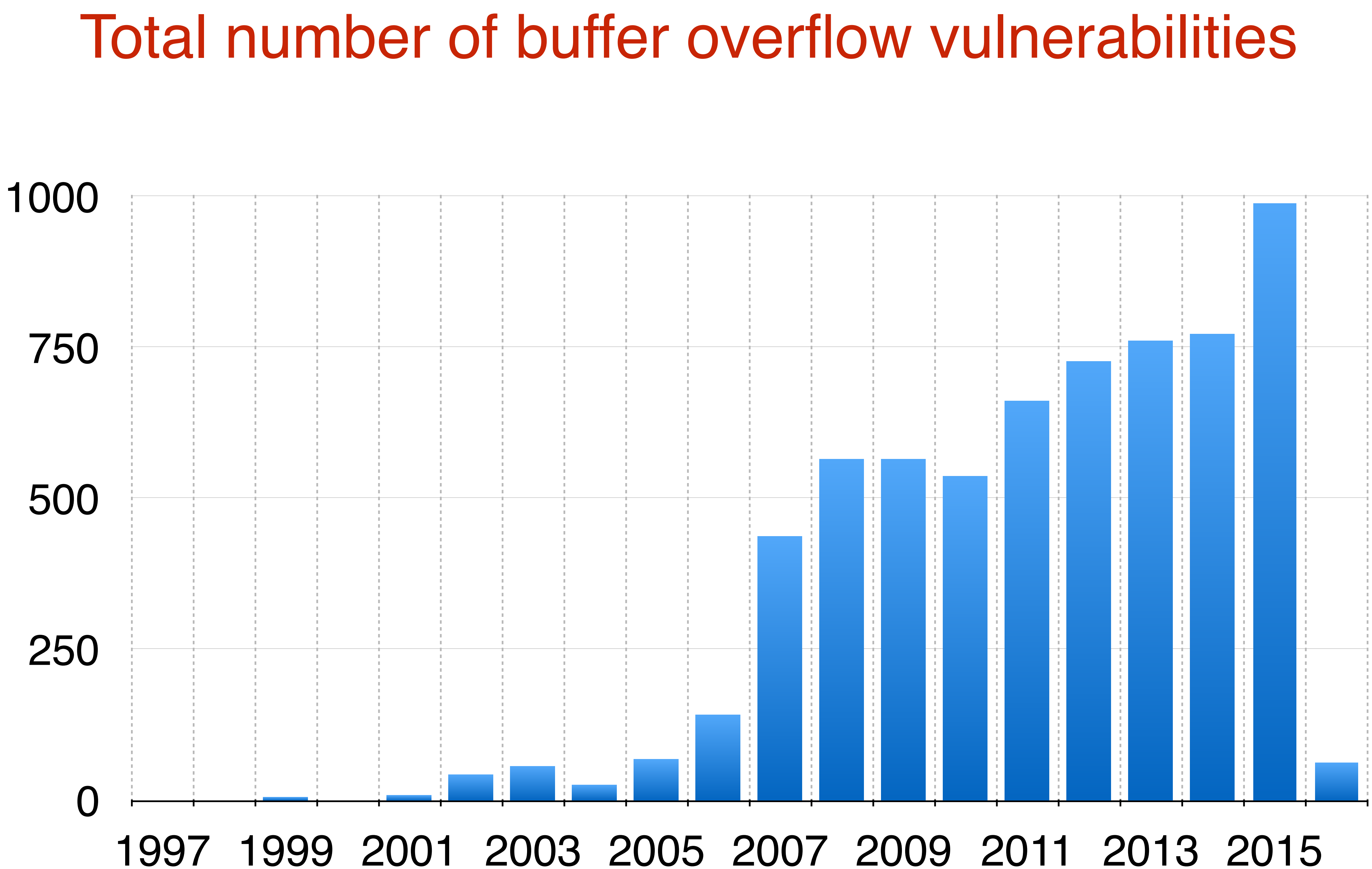
Buffer overflows are prevalent

Significant percent of *all* vulnerabilities



[Data from the National Vulnerability Database]

Buffer overflows are prevalent



Data from the National Vulnerability Database

Buffer overflows are impactful

Rank	Score	ID	Name
[1]	93.8	CWE-89	Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')
[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')
[5]	76.9	CWE-306	Missing Authentication for Critical Function
[6]	76.8	CWE-862	Missing Authorization
[7]	75.0	CWE-798	Use of Hard-coded Credentials
[8]	75.0	CWE-311	Missing Encryption of Sensitive Data
[9]	74.0	CWE-434	Unrestricted Upload of File with Dangerous Type
[10]	73.8	CWE-807	Reliance on Untrusted Inputs in a Security Decision
[11]	73.1	CWE-250	Execution with Unnecessary Privileges
[12]	70.1	CWE-352	Cross-Site Request Forgery (CSRF)

This class

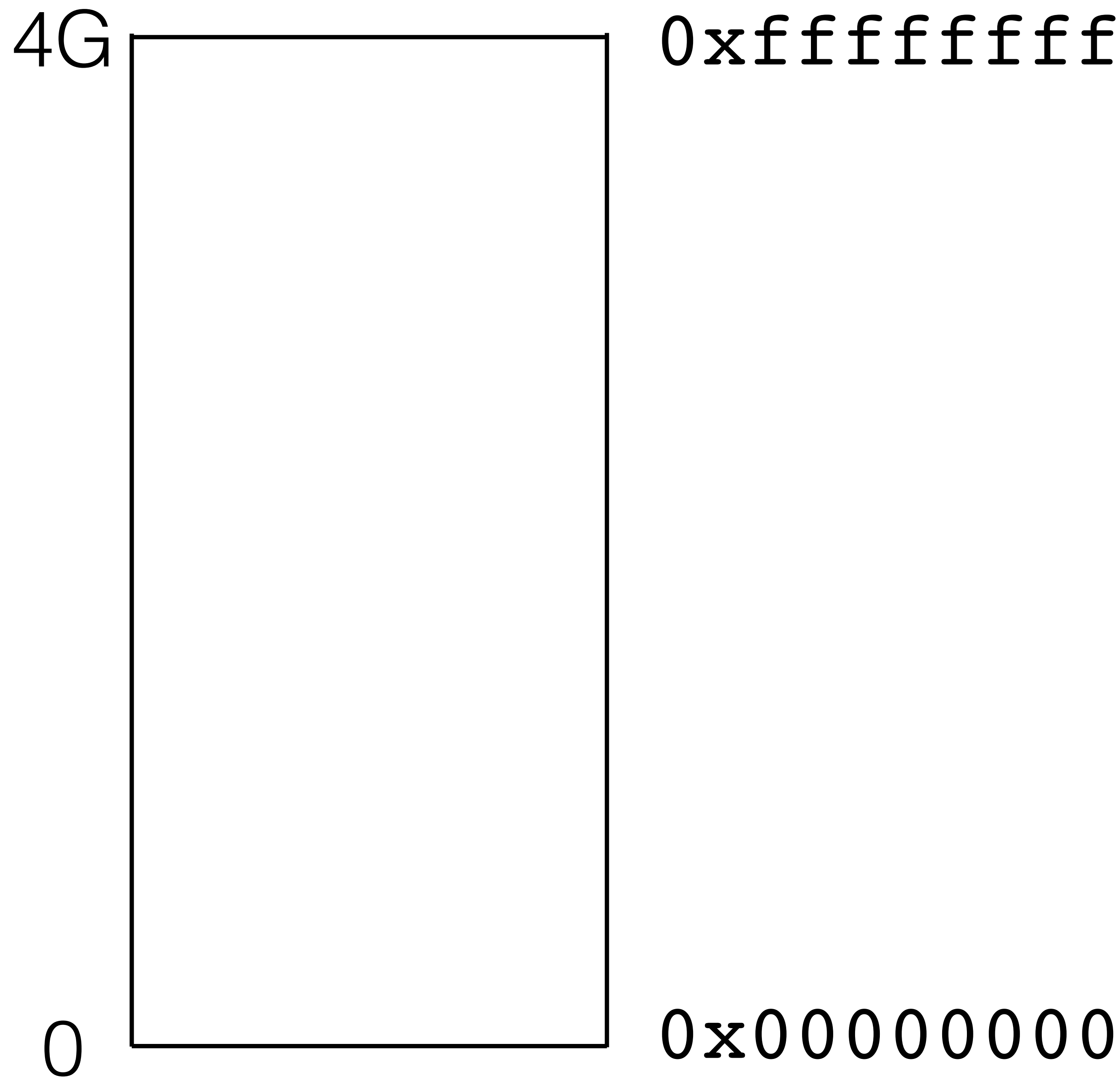
[MITRE's top-25 most dangerous software errors (from 2011)]

Note about terminology

- We will use **buffer overflow** to mean ***any access of a buffer outside of its allotted bounds***
  - An over-*read*, or an over-*write*
  - During *iteration* (“running off the end”) or by *direct access*
  - Could be to addresses that *precede* or *follow* the buffer
- Other terms you may hear (more specific)
  - *Underflow*, *over-read*, *out-of-bounds access*, etc.
  - Some use *buffer overflow* only for writing off the end

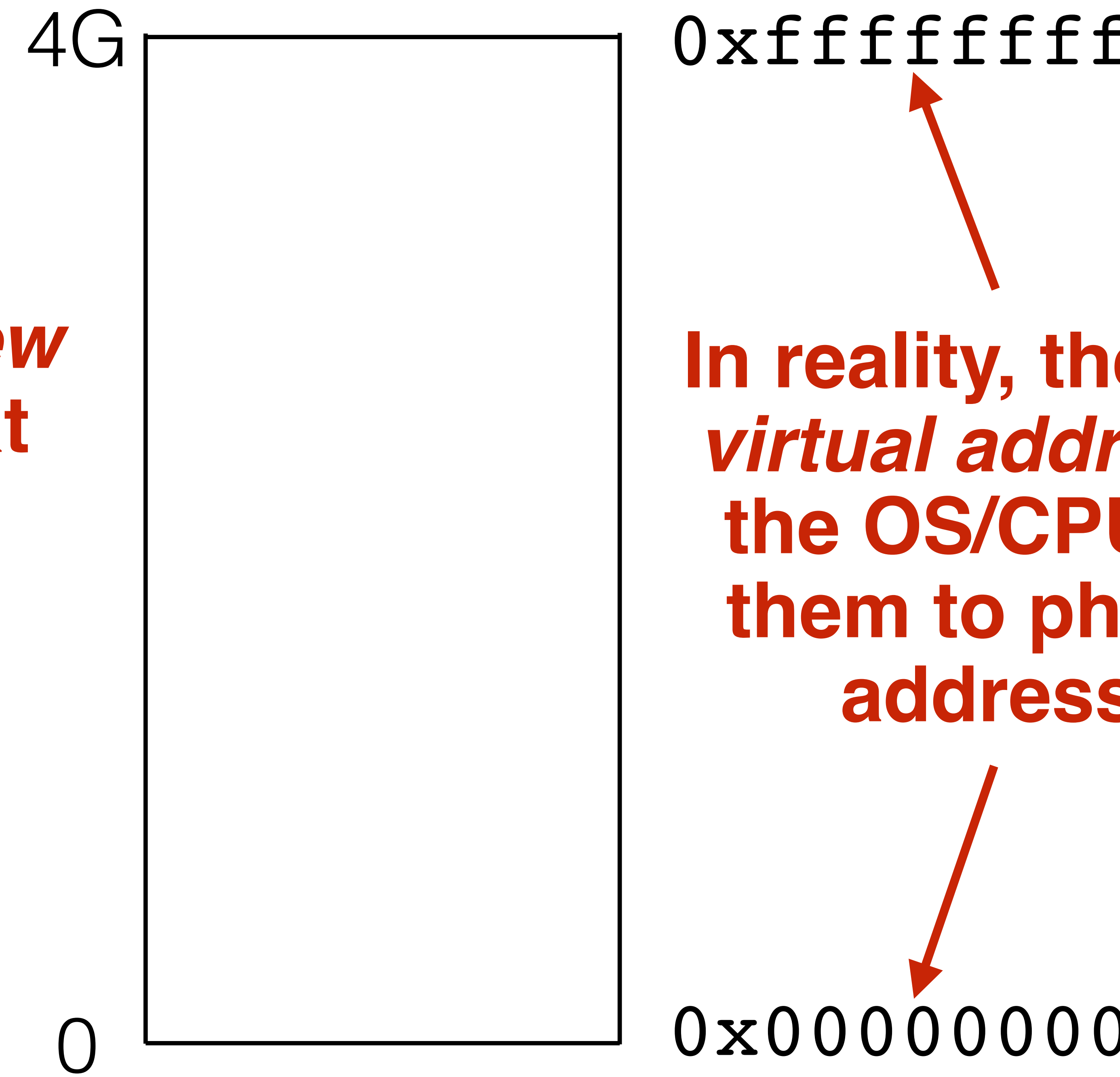
Memory layout

All programs are stored in memory



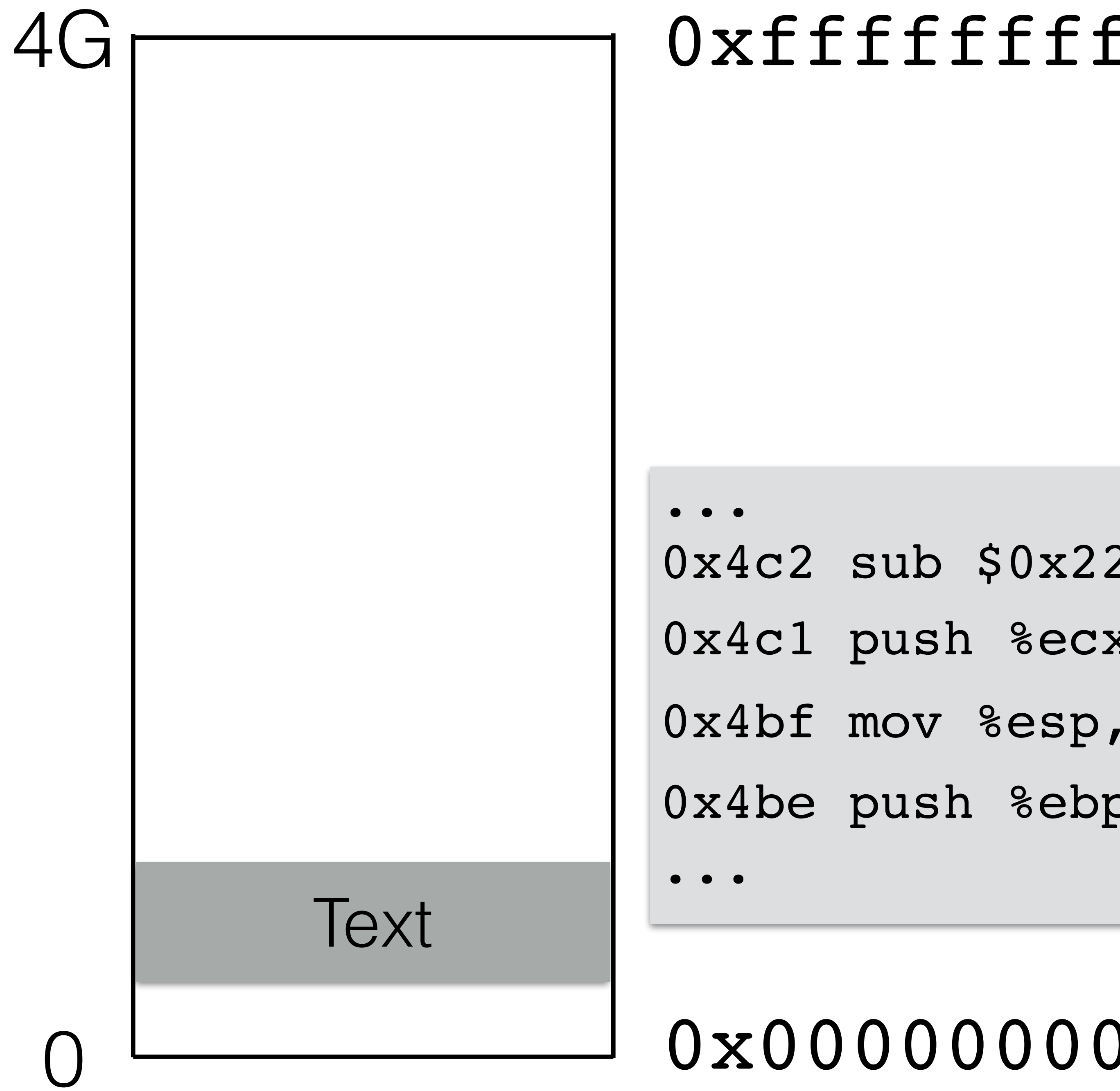
All programs are stored in memory

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



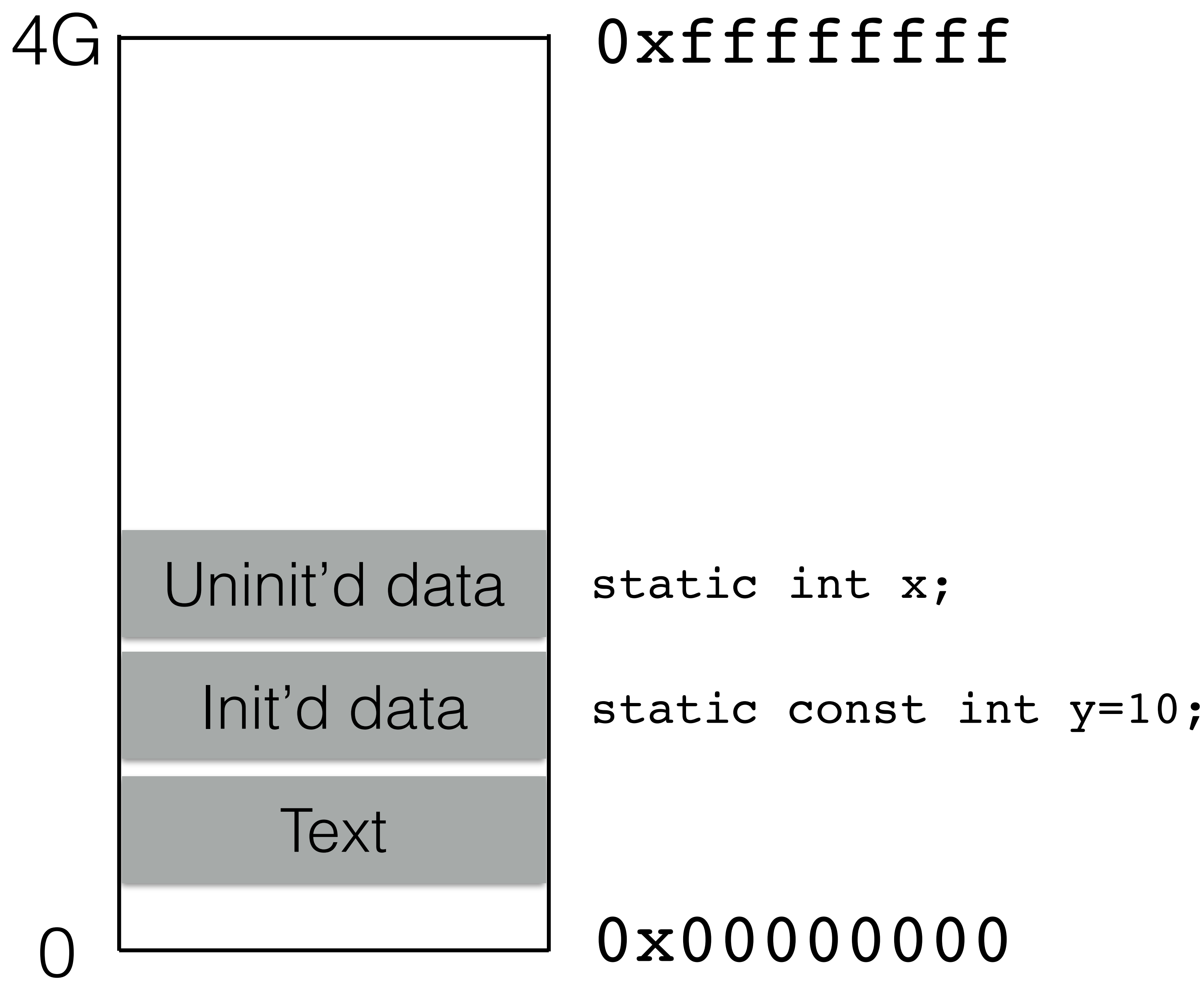
In reality, these are *virtual addresses*; the OS/CPU map them to physical addresses

The instructions themselves are in memory




```
...
0x4c2 sub $0x224,%esp
0x4c1 push %ecx
0x4bf mov %esp,%ebp
0x4be push %ebp
...
```

Data's location depends on how it's created



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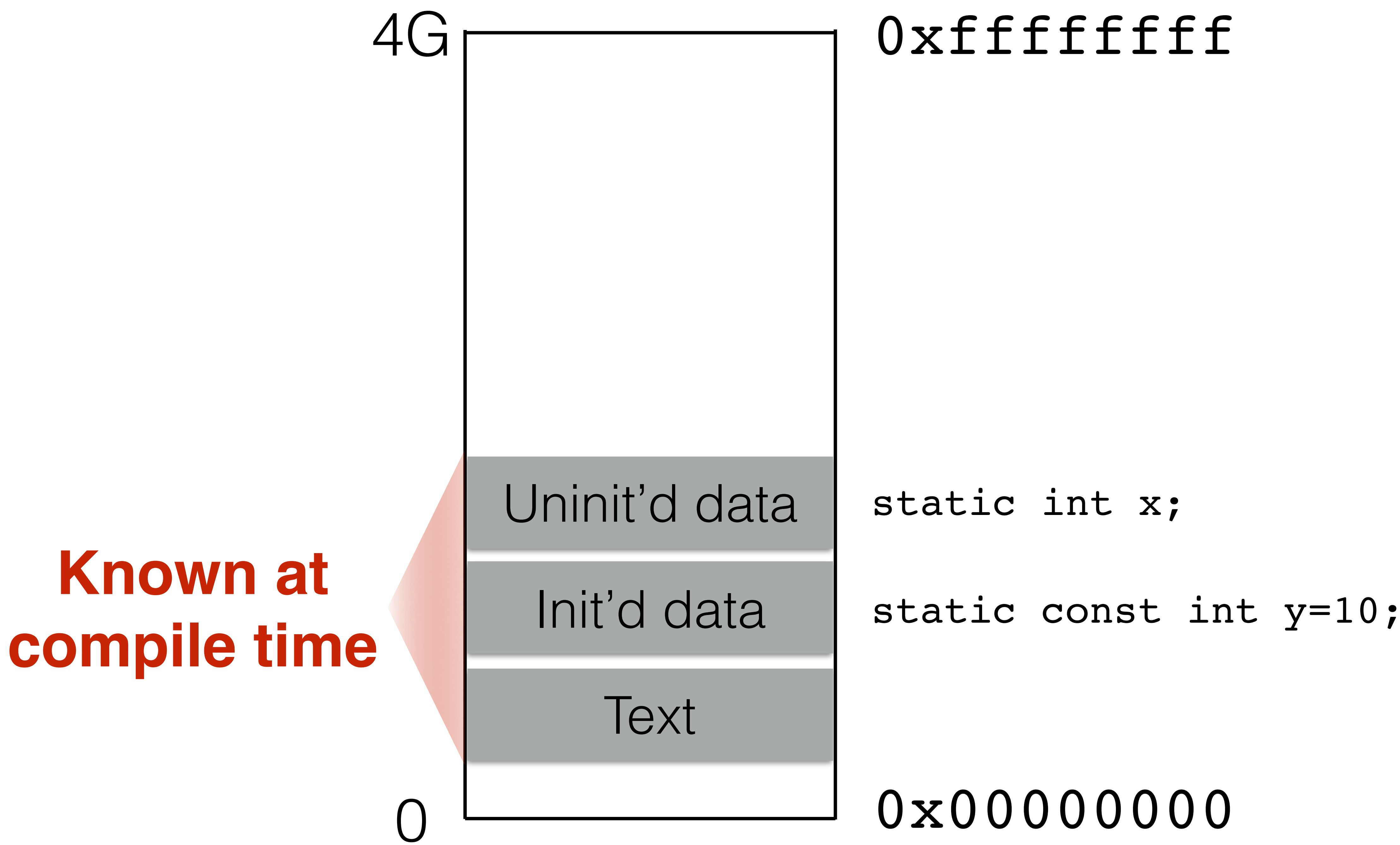

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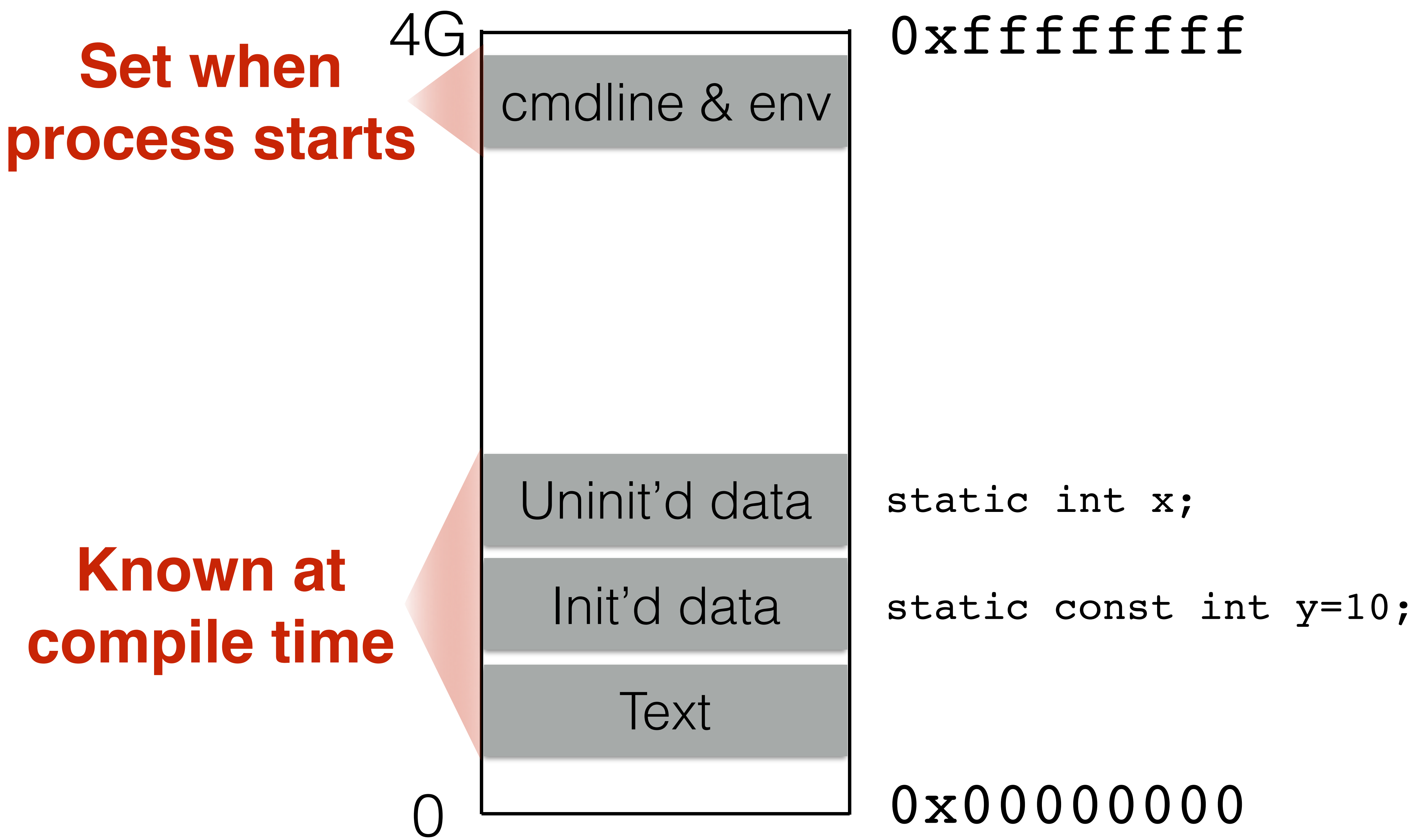

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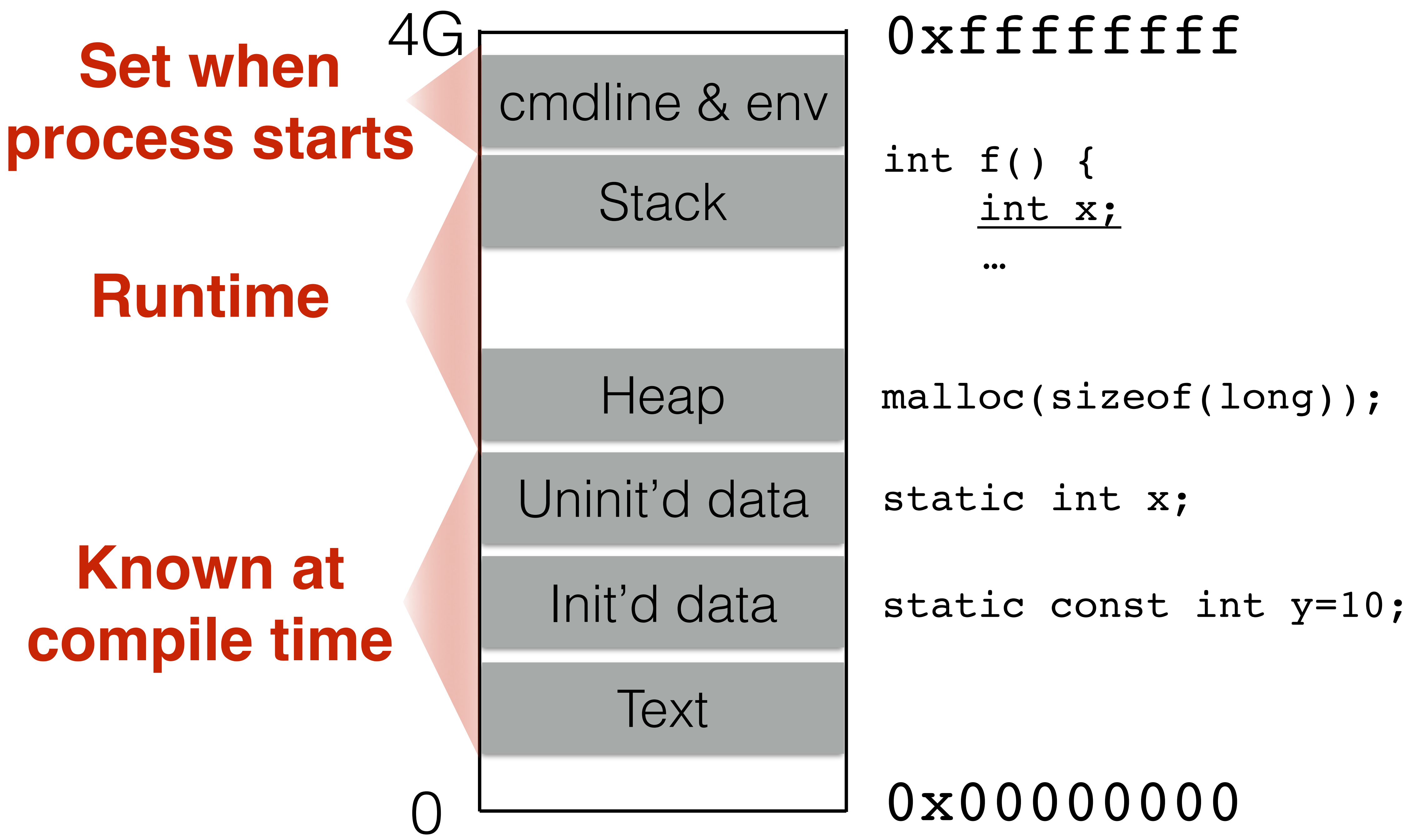
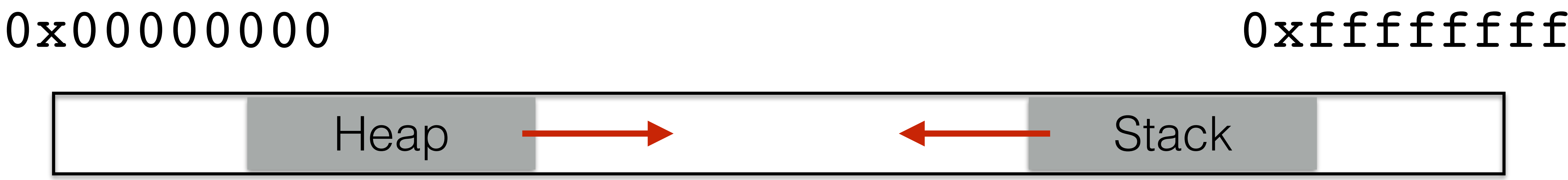


We are going to focus on runtime attacks

Stack and heap grow in opposite directions



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Compiler provides instructions that
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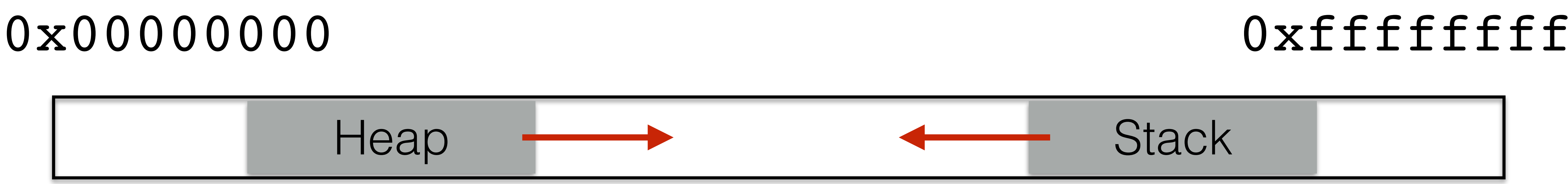

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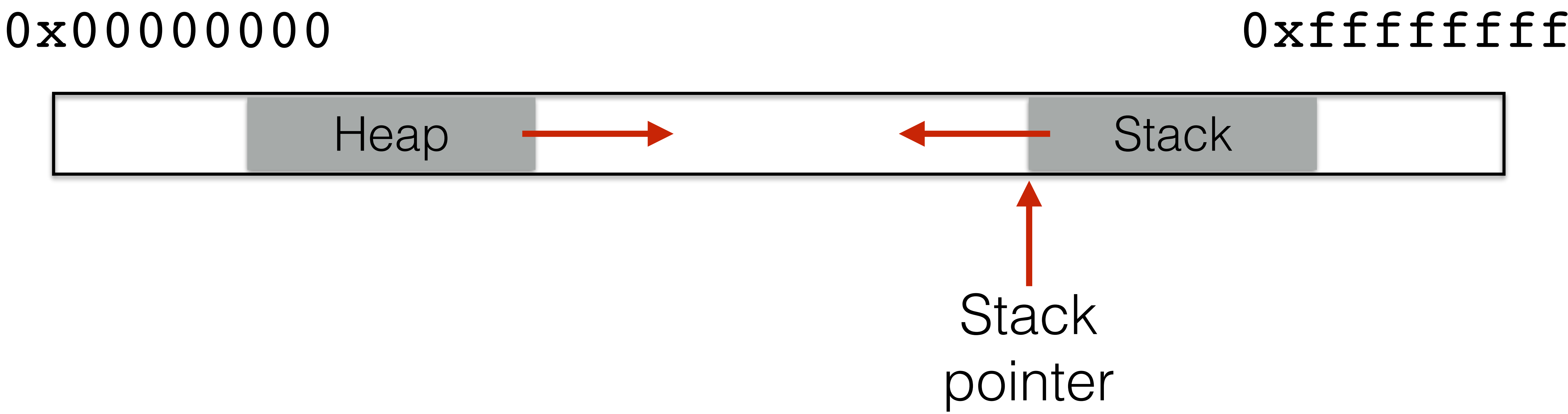

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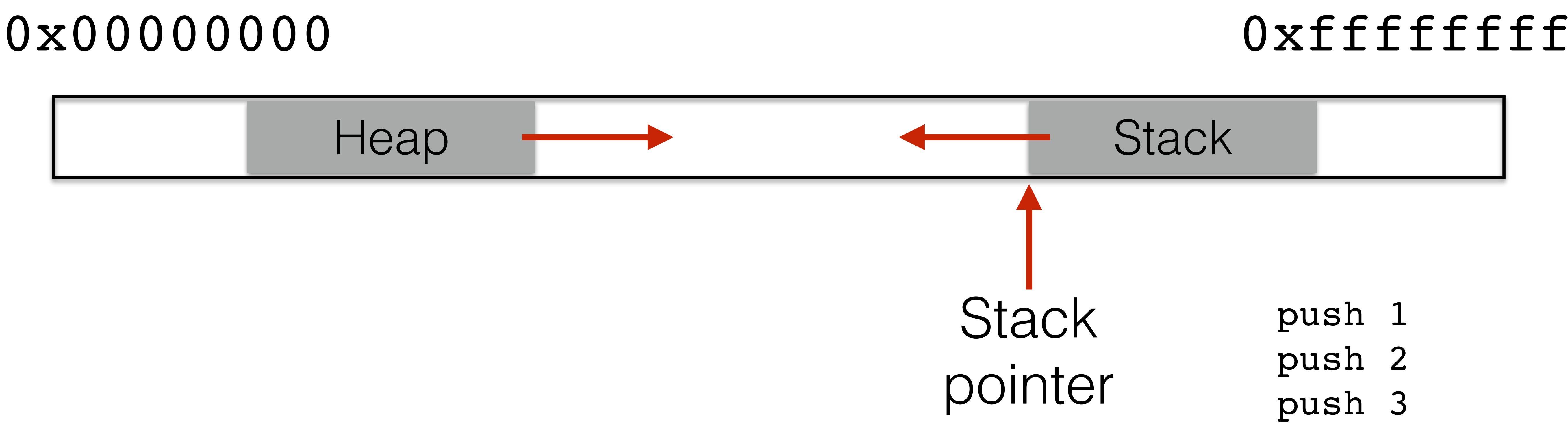

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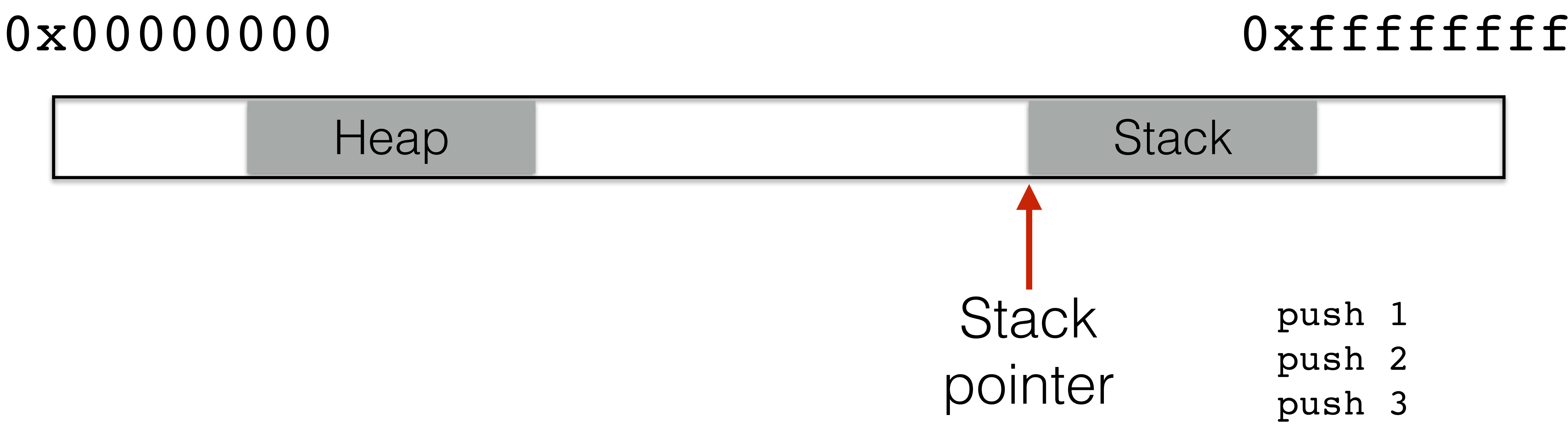

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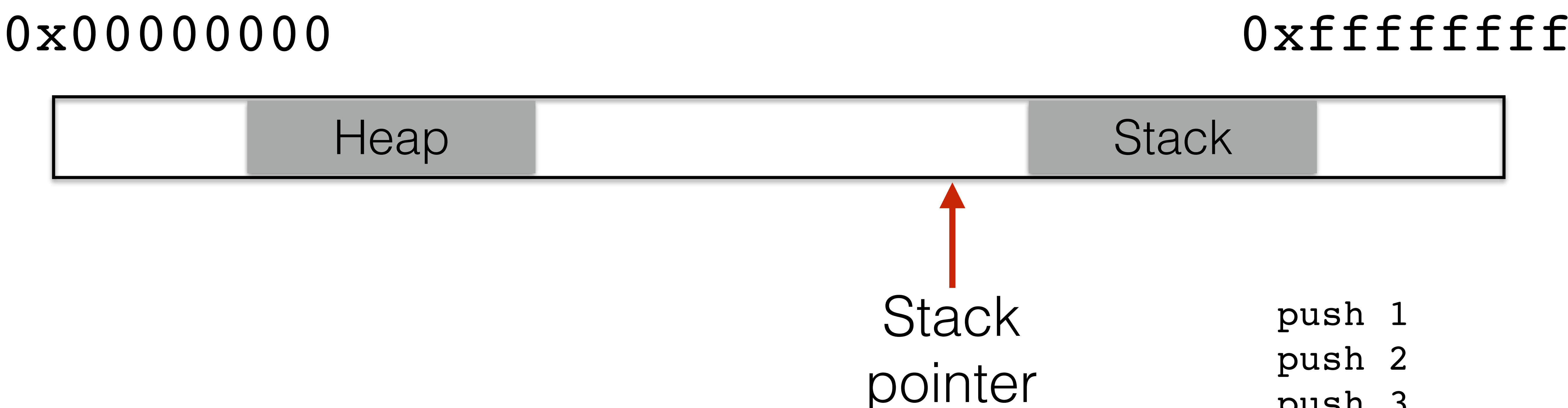


```
push 1
push 2
push 3
```

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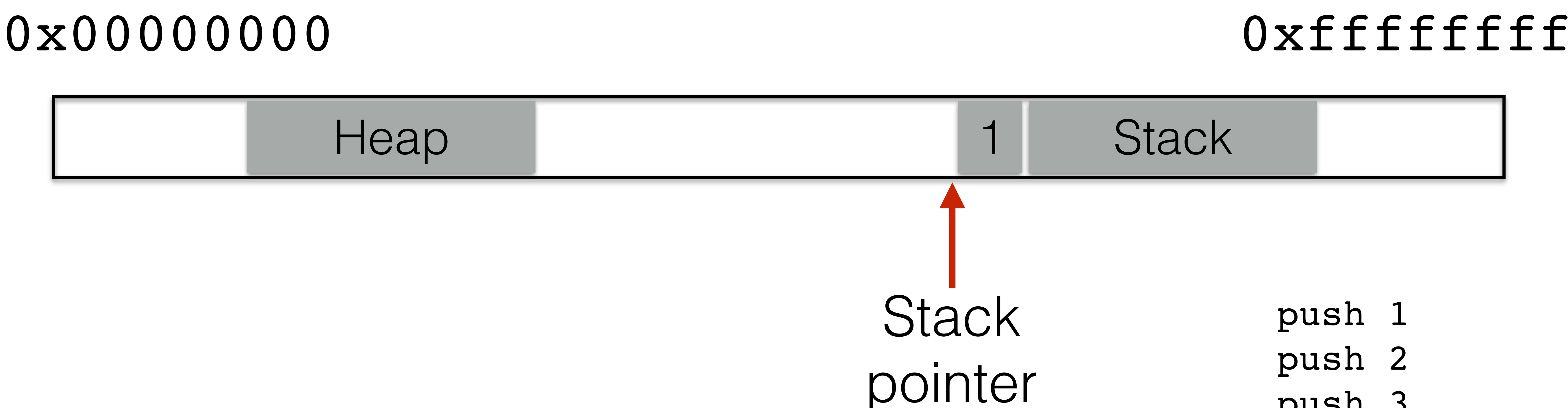
Stack and heap grow in opposite directions

Compiler provides instructions that adjusts the size of the stack at runtime




```
push 1
push 2
push 3
```

We are going to focus on runtime attacks

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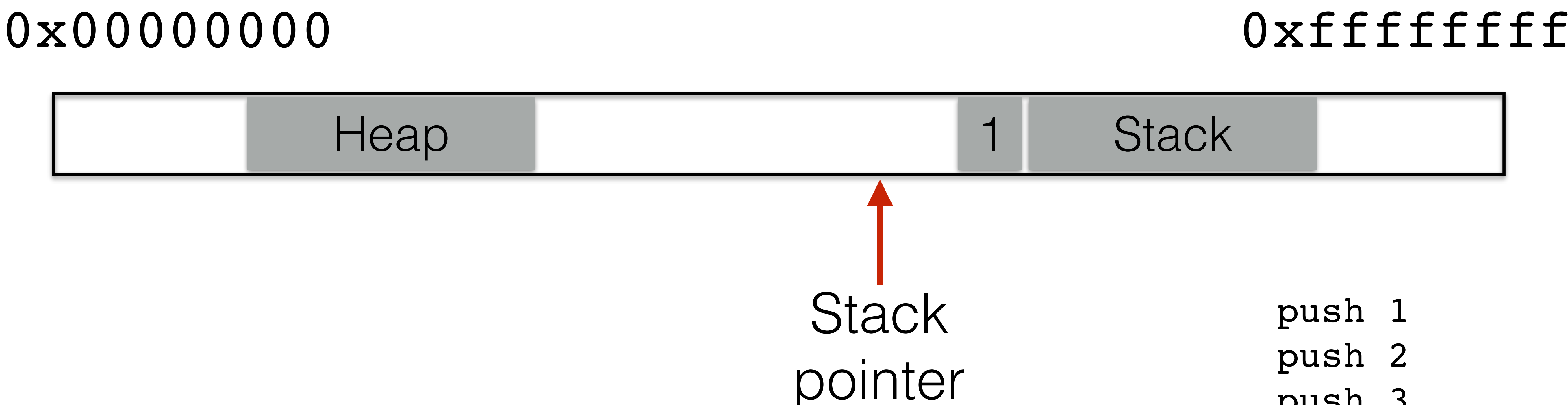


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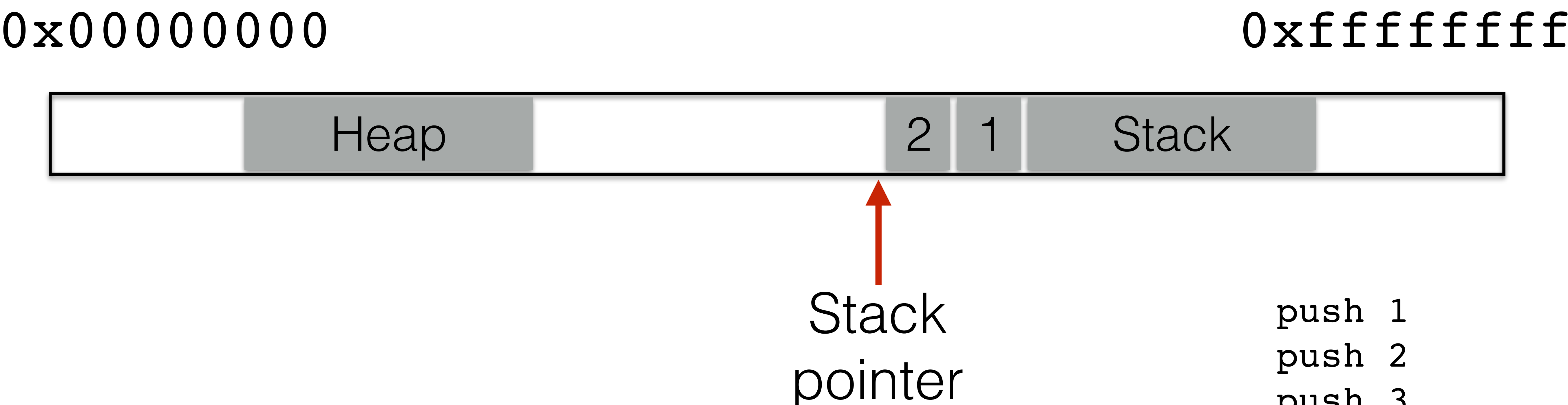


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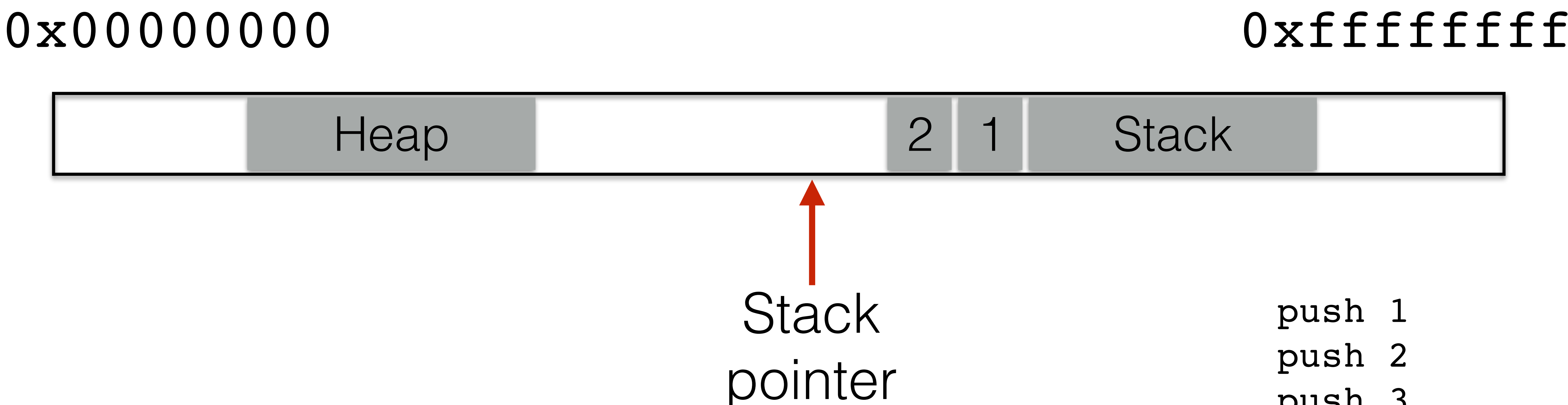


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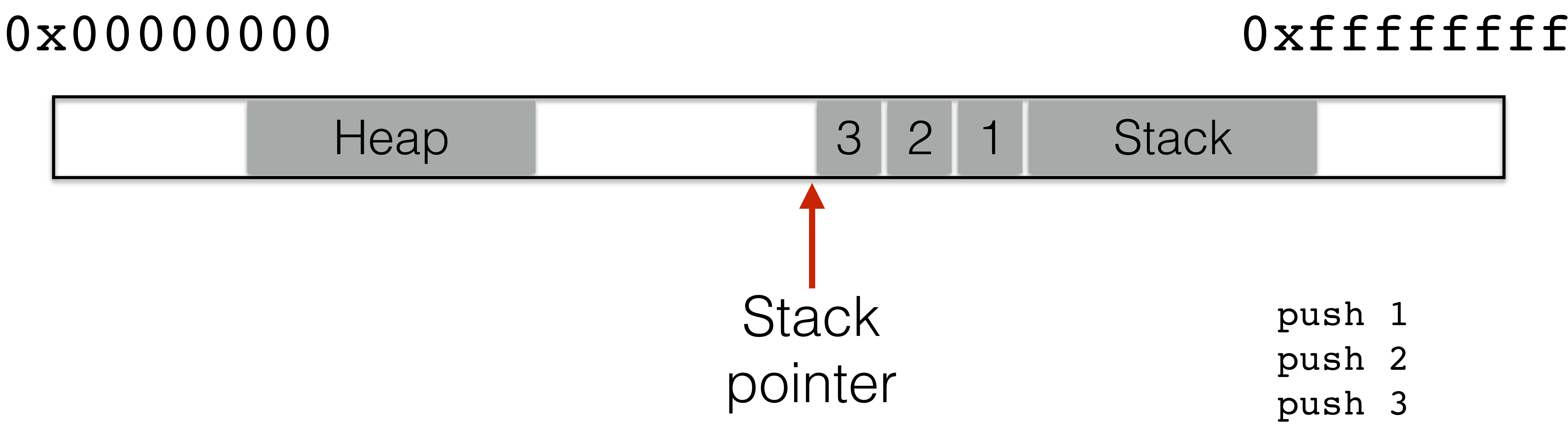

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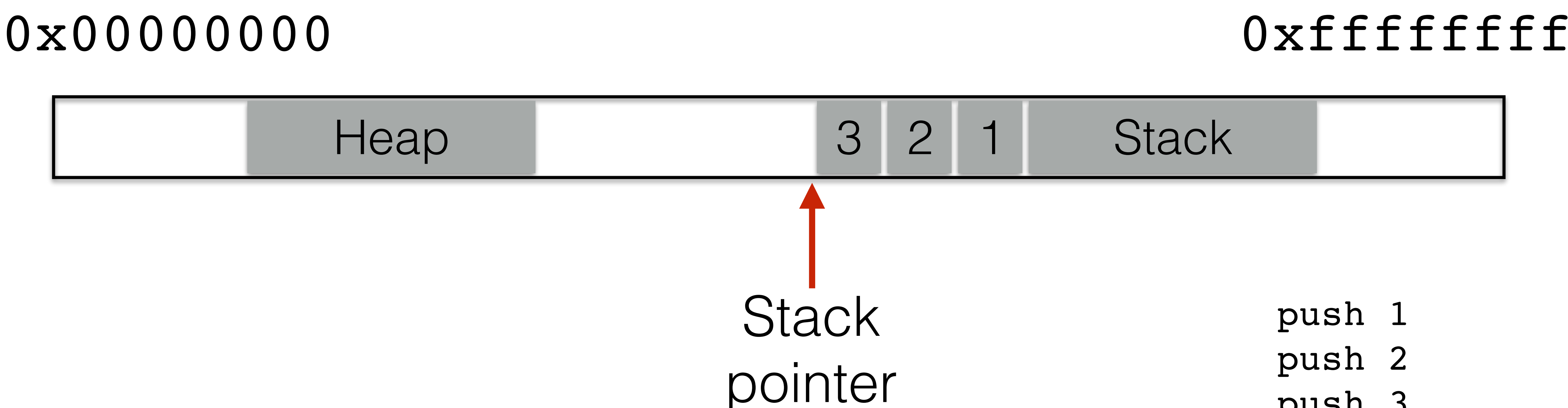


```
push 1
push 2
push 3
return
```

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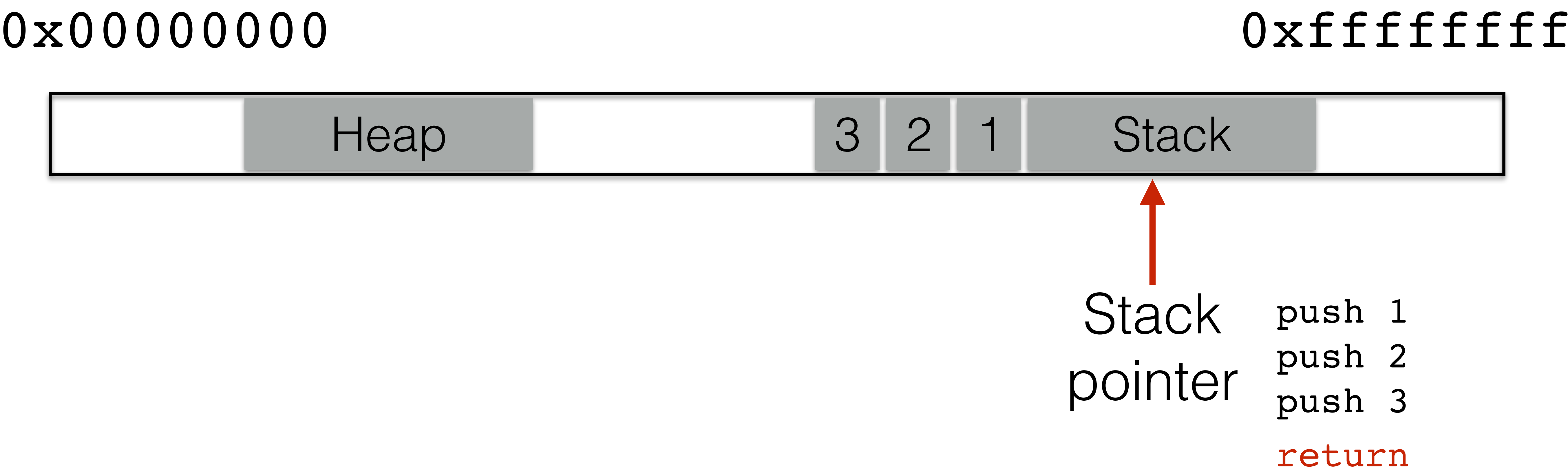

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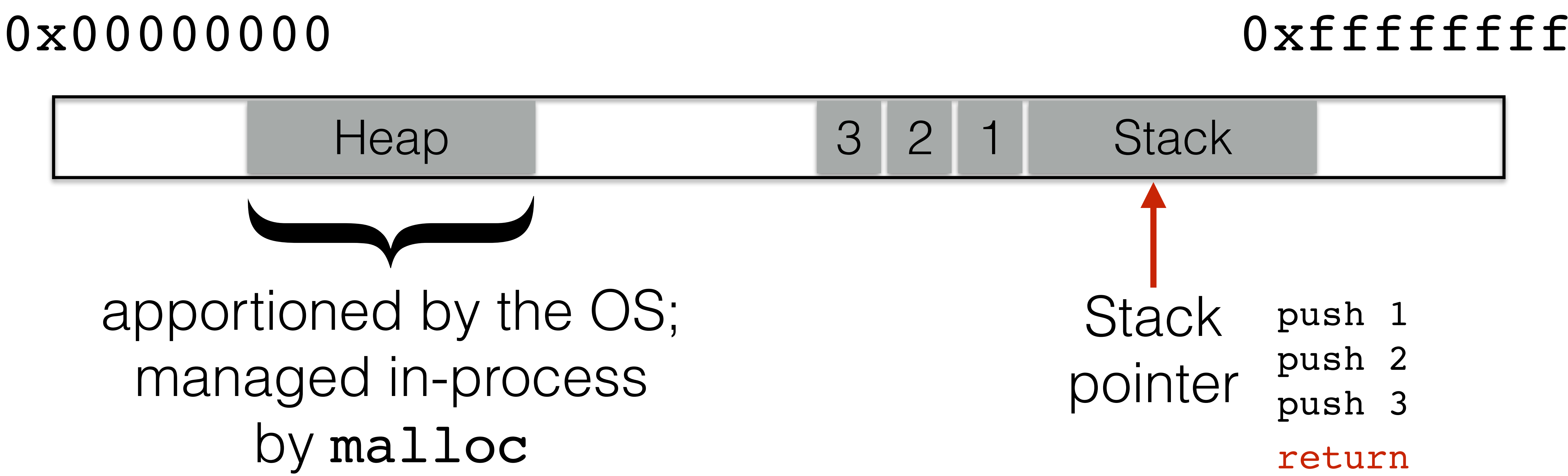

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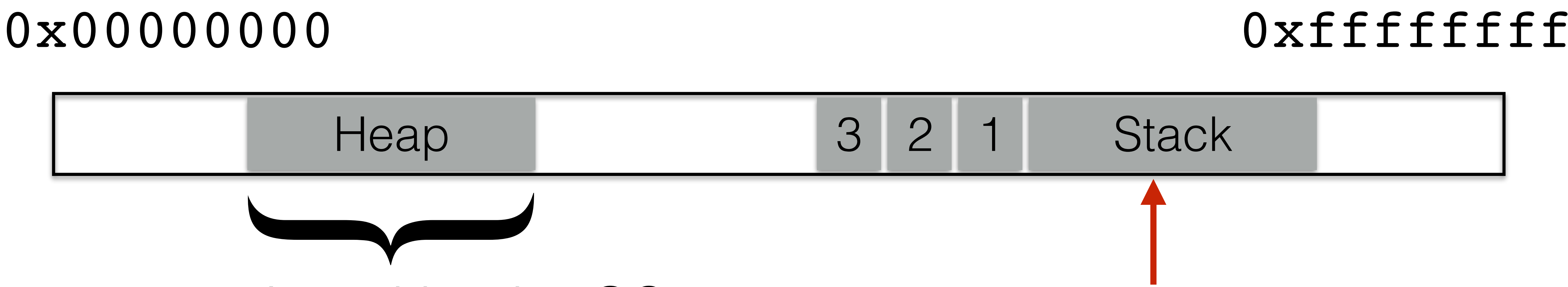

apportioned by the OS;
managed in-process
by `malloc`

Stack
pointer

```
push 1
push 2
push 3
return
```

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)