CE 815 - Secure Software Systems

Lecture 1

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Acknowledgments: Some of the slides are fully or partially obtained from other sources. Reference is noted on the bottom of each slide, when the content is fully obtained from another source. Otherwise a full list of references is provided on the last slide.

Software Faults

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- Are all software faults security bugs?

Software Insecurity

Software Insecurity

- A software bug or software fault may be a security bug or vulnerability
  - When the bug is triggered or exploited it compromises the security of the software system

Software Security

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  - Is that actually enough?

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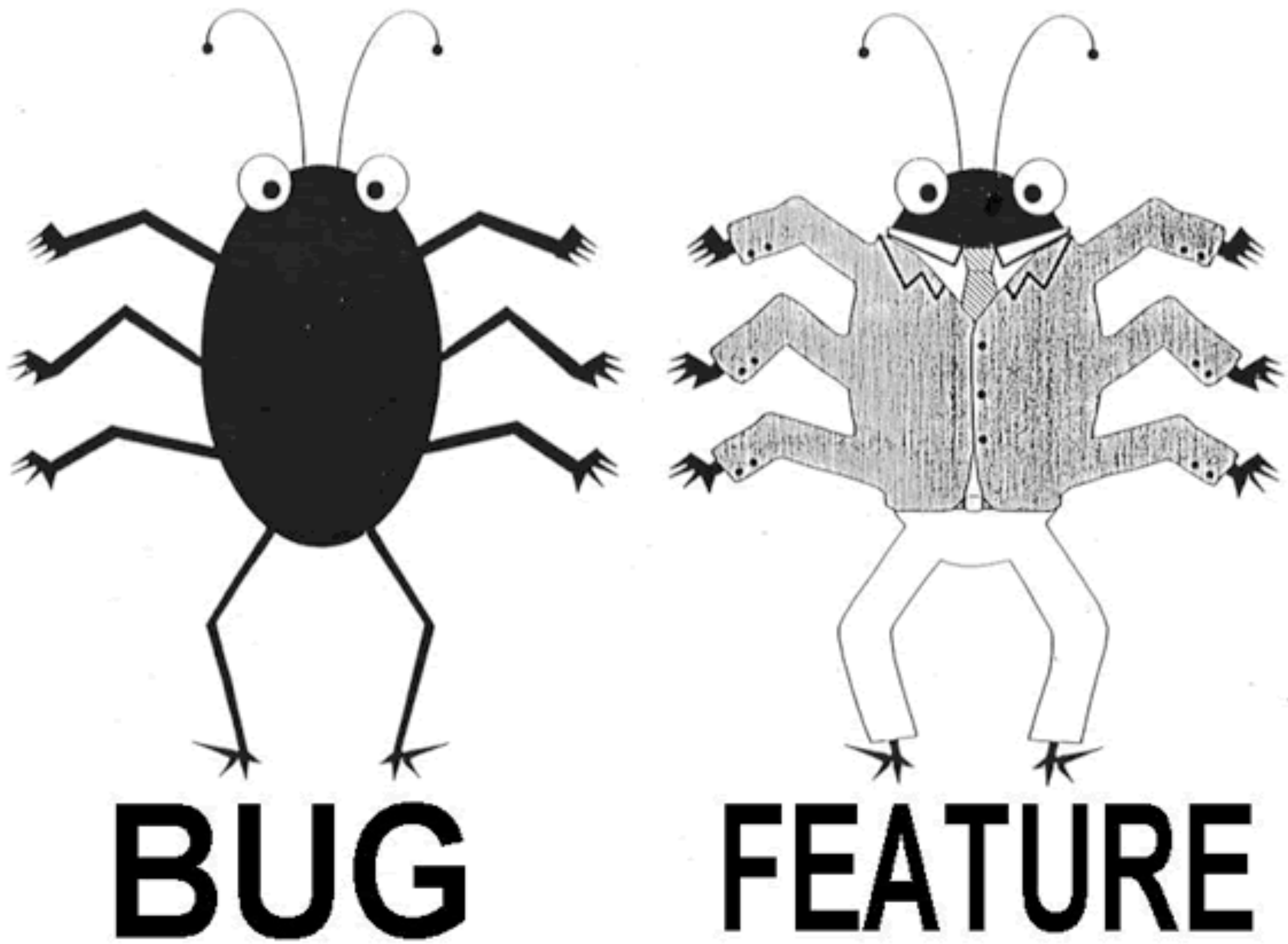
Software Security

Software Security

- Easy, just write perfect software, have perfect users, configure software perfectly, use a perfect Operating System, use a perfect hypervisor, run on a system with perfect firmware, run on a system with perfect hardware, …

Really depend on how you look at it



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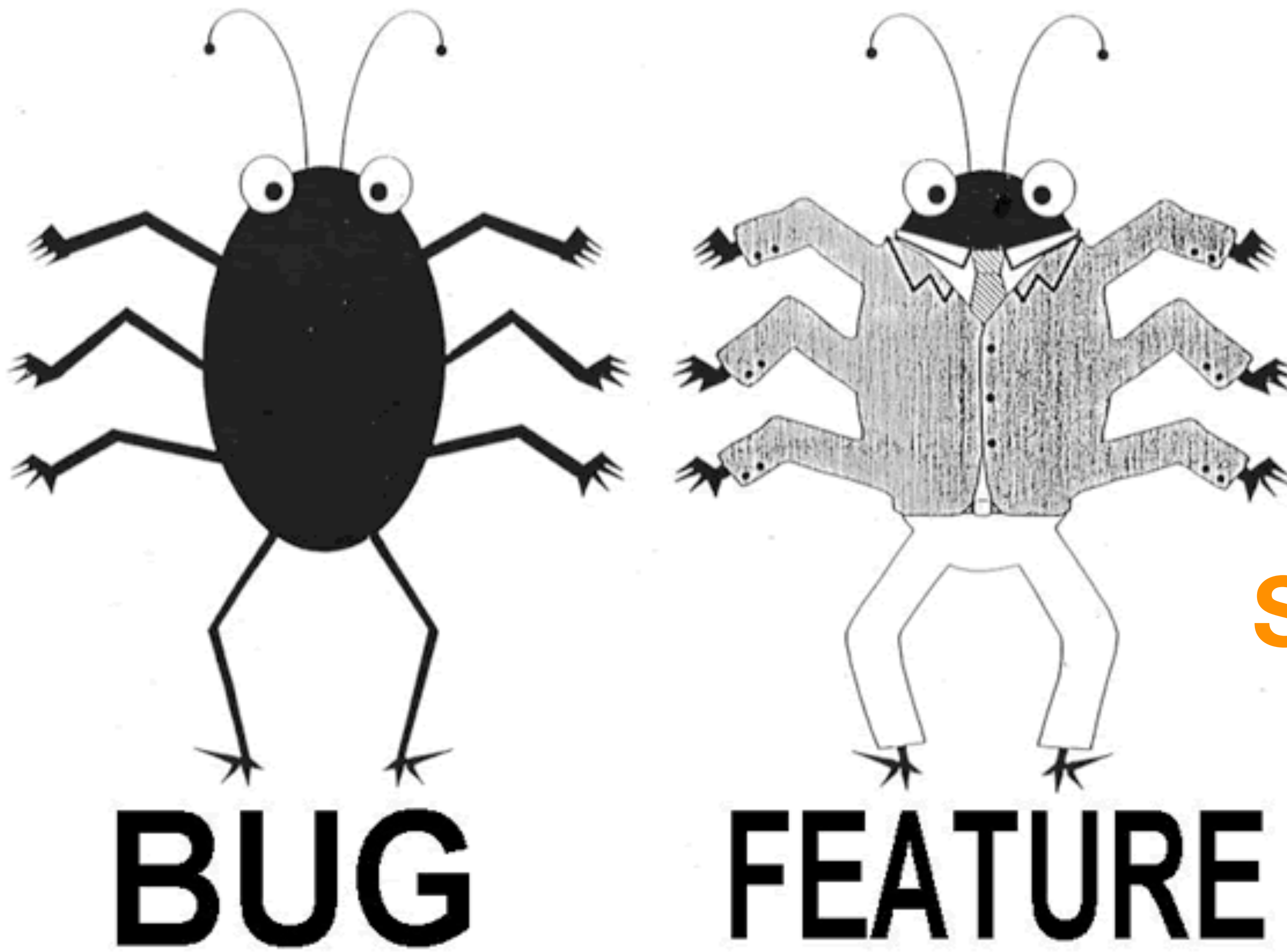

Speculative Execution

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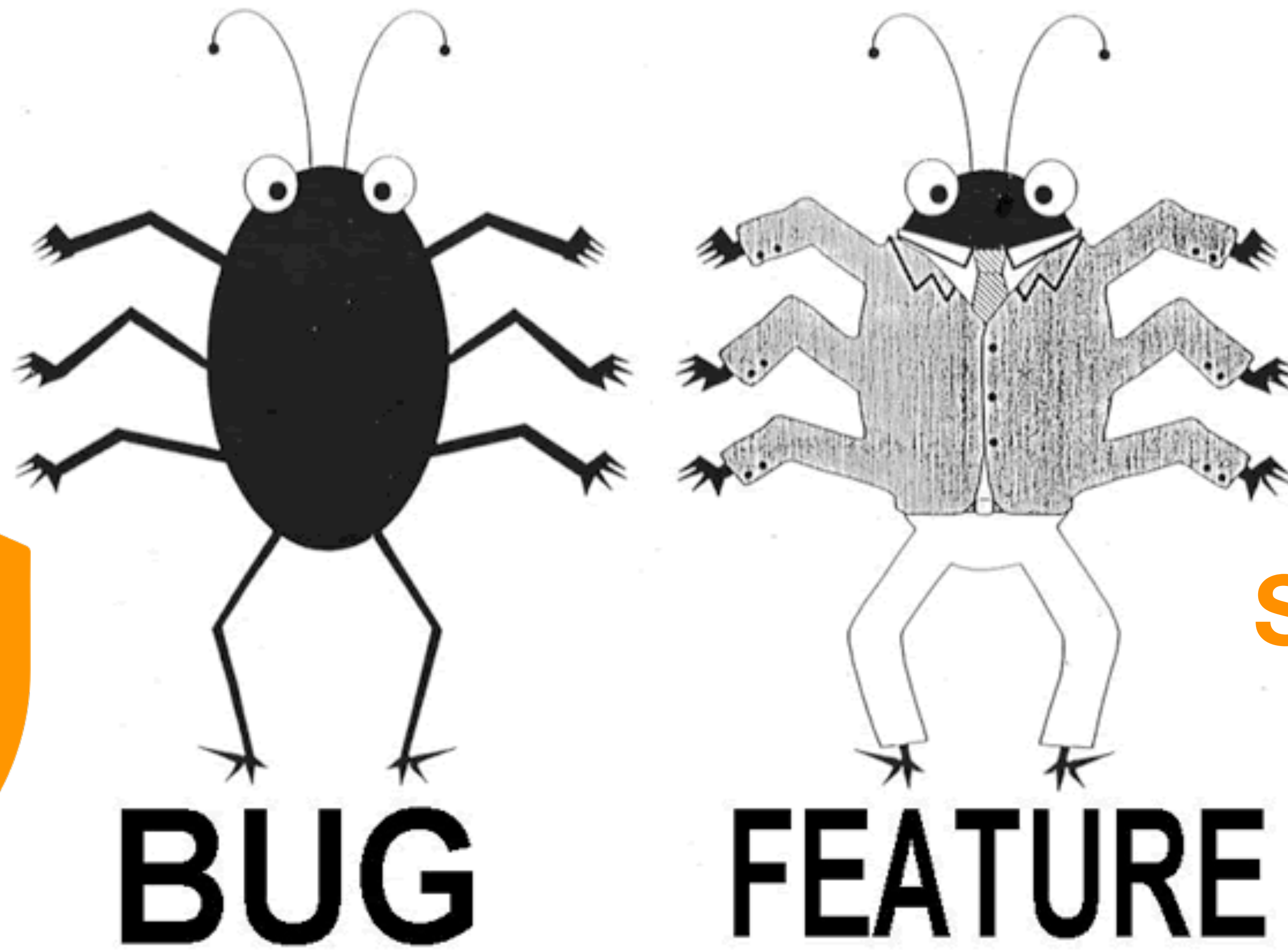

Speculative Execution

MELTDOWN

Examples (CVE- 2009-4307)

```
groups_per_flex = 1 << sbi->s_log_groups_per_flex;
  /* There are some situations, after shift the value of 'groups_per_flex' can
  become zero and division with 0 will result in fixpoint divide exception */
if (groups_per_flex == 0)
  return 1;
flex_group_count = ... / groups_per_flex;
```

- X86 32bit, shift inst. truncates the shift amount to 5 bits. (32 shift becomes 0)
- PowerPC 32bit, shift inst. truncates the shift amount to 6 bits. (32 shift becomes 1)
- In C, shifting an n-bit integer by n or more bits is undefined behavior.
- Compiler thinks, groups_per_flex will never be zero
  - removed the check when compiling to optimize code

 [Regehr 2017]

Buffer overflow

- Suppose a web server contains a function:

```
void func(char *str) {
    char buf[128];

    strcpy(buf, str);
     do-something(buf);
}
```

- When func() is called stack looks like:

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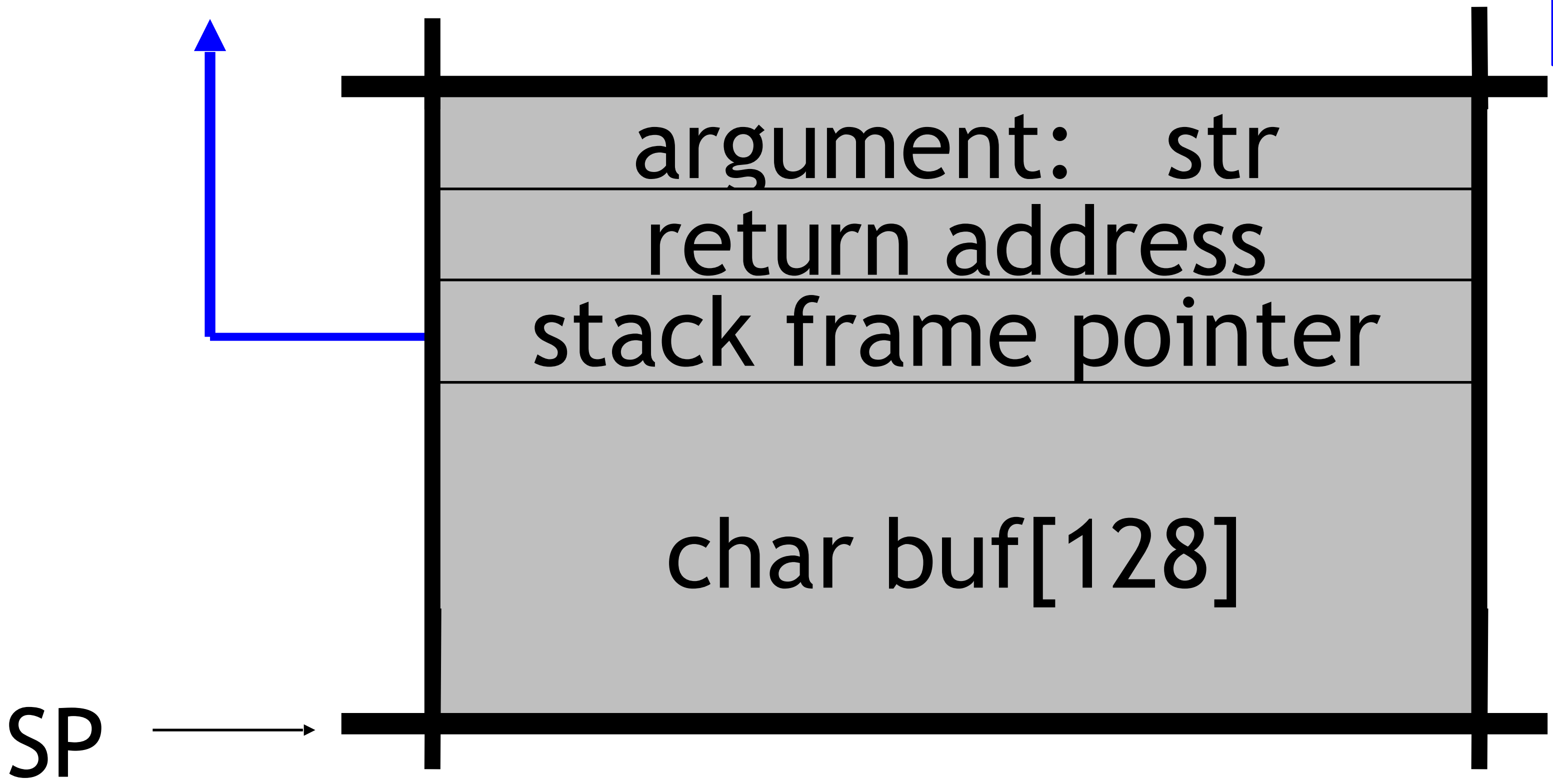

Buffer overflow

- What if *str is 136 bytes long?
- After strcpy:

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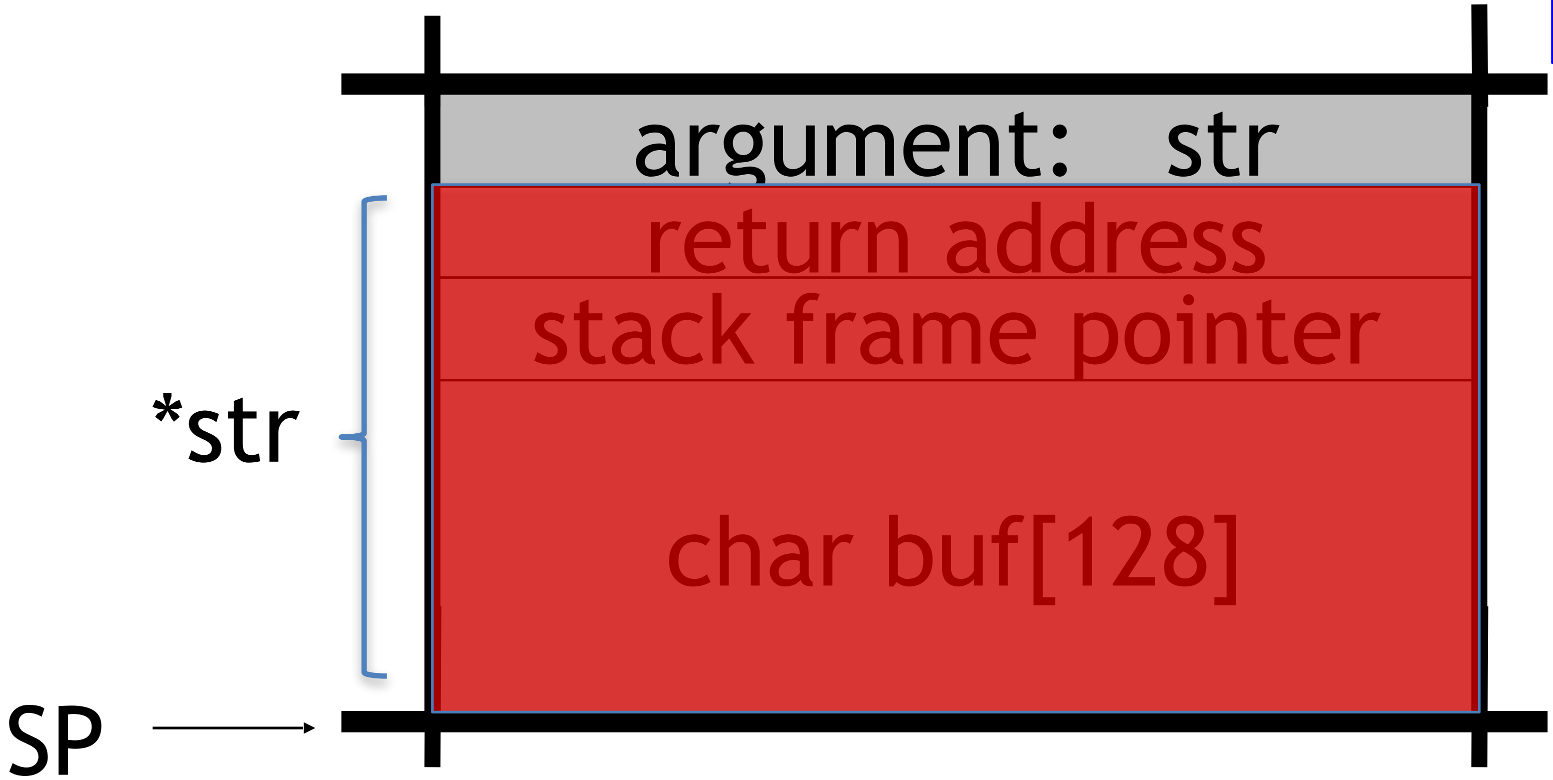

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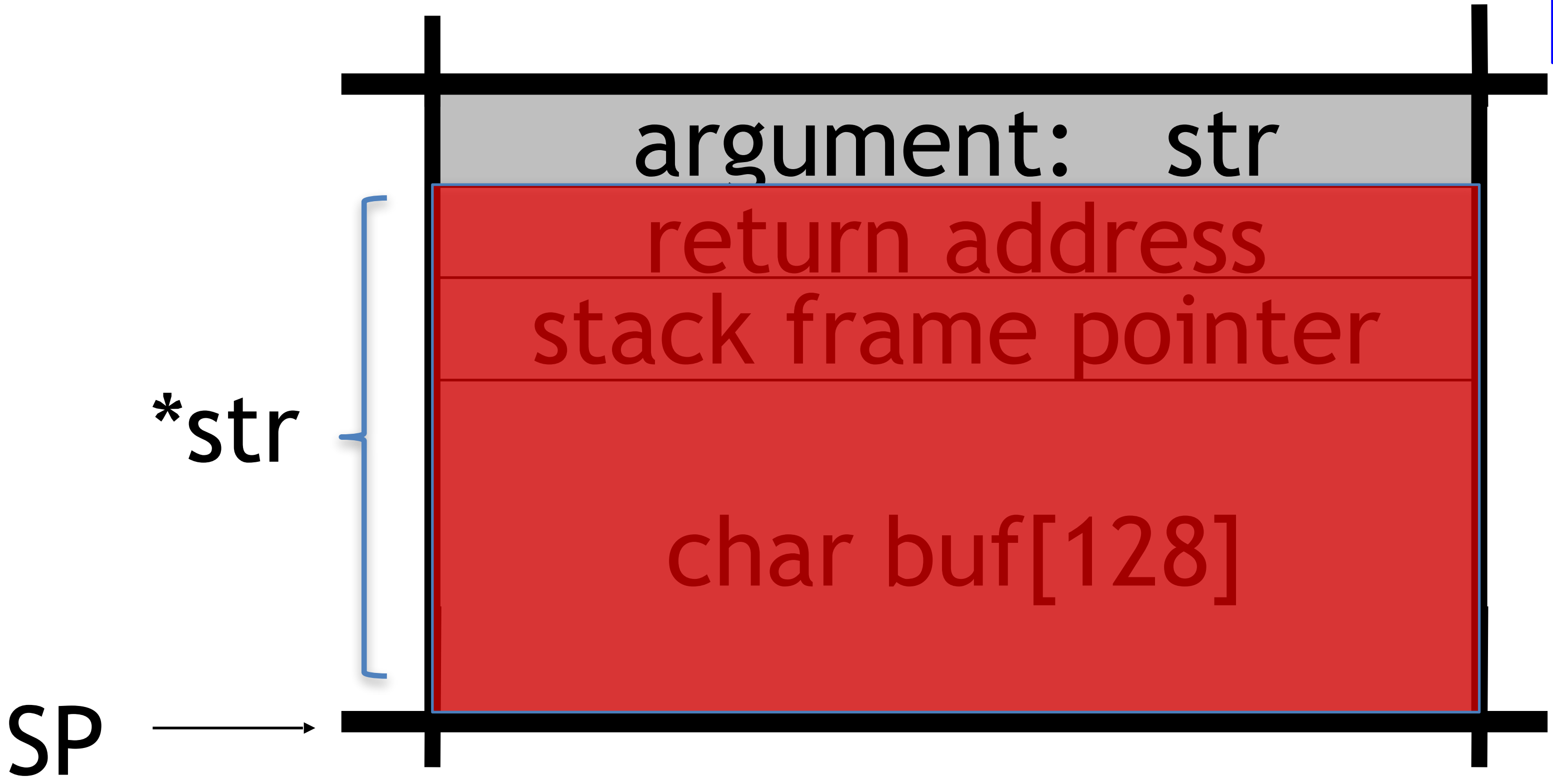
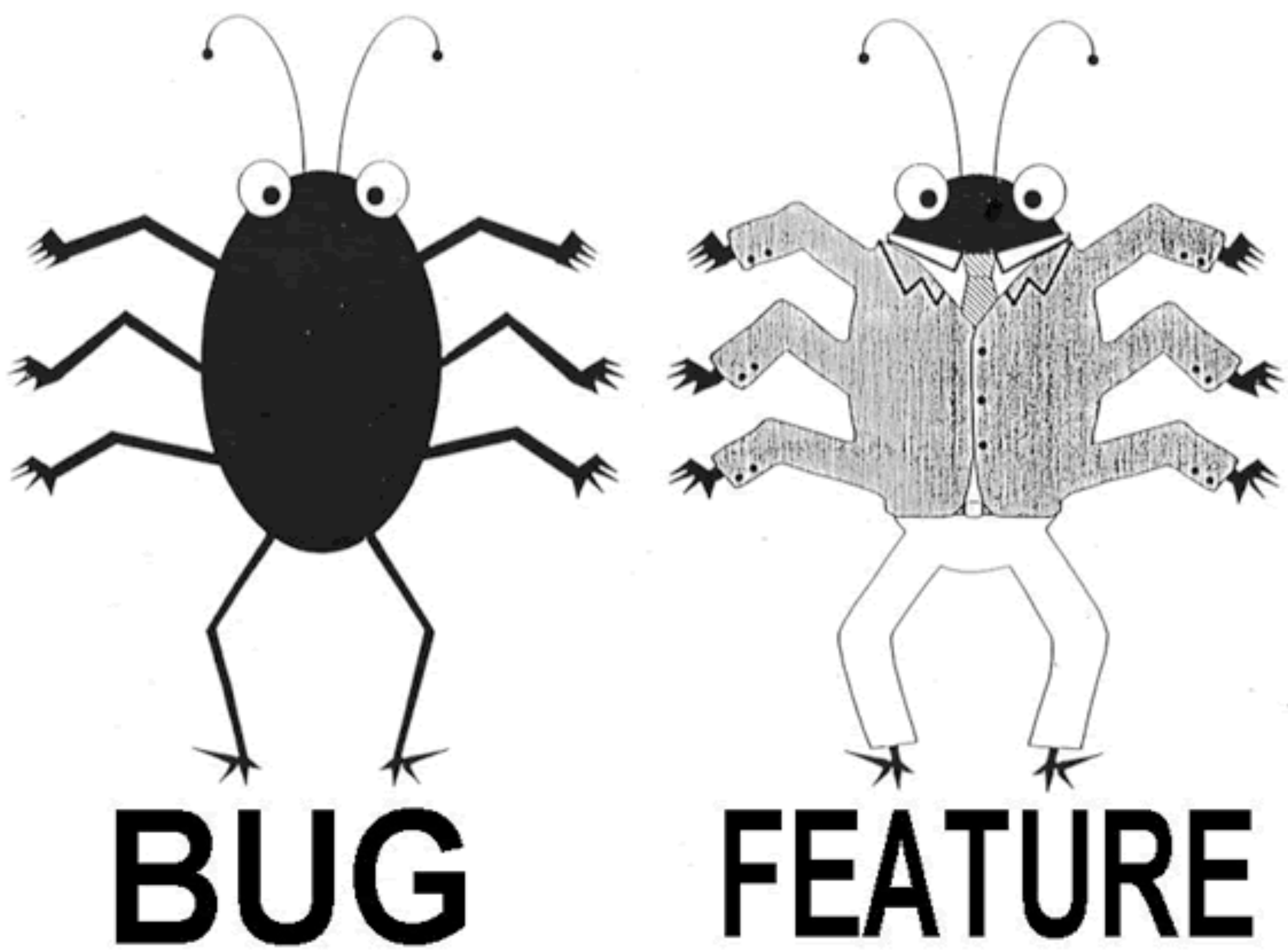


Problem:
no length checking in strcpy()

Other Examples

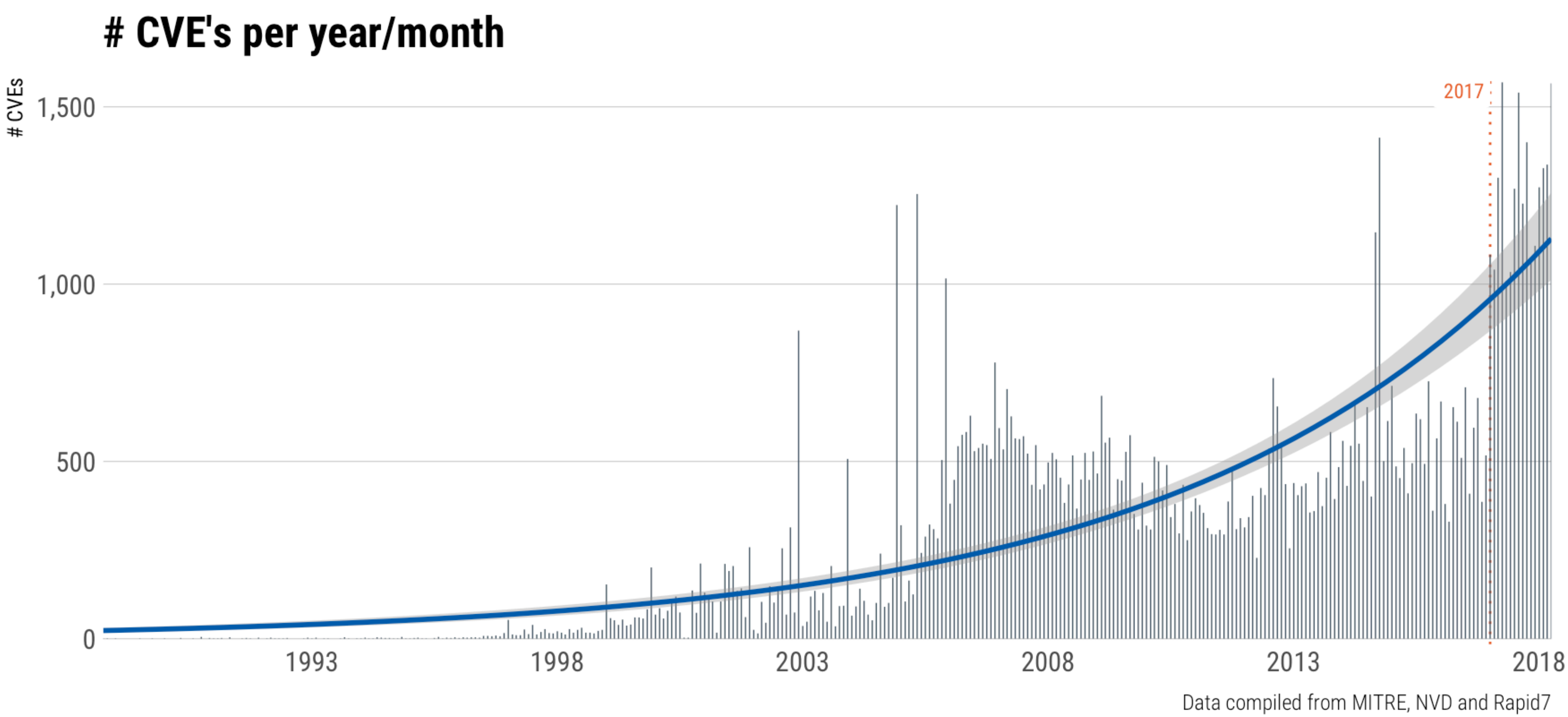
- Out of bound memory access
- Temporal Memory Safety Violations
- Integer overflow
- …..


BUG
FEATURE

Vulnerabilities ….

HeartBleed	CVE-2014-0160	Affected over 600,000 websites
Shellshock	CVE-2014-6271	The impact is anywhere from 20 to 50% of global servers
Dirty COW	CVE-2016-5195	Affects all Linux-based operating systems including Android
VNOM	CVE-2015-3456	Affected all version of XEN and KVM
glib GHOST	CVE-2015-0235	A core component used in most Linux distributions

CVE Growth

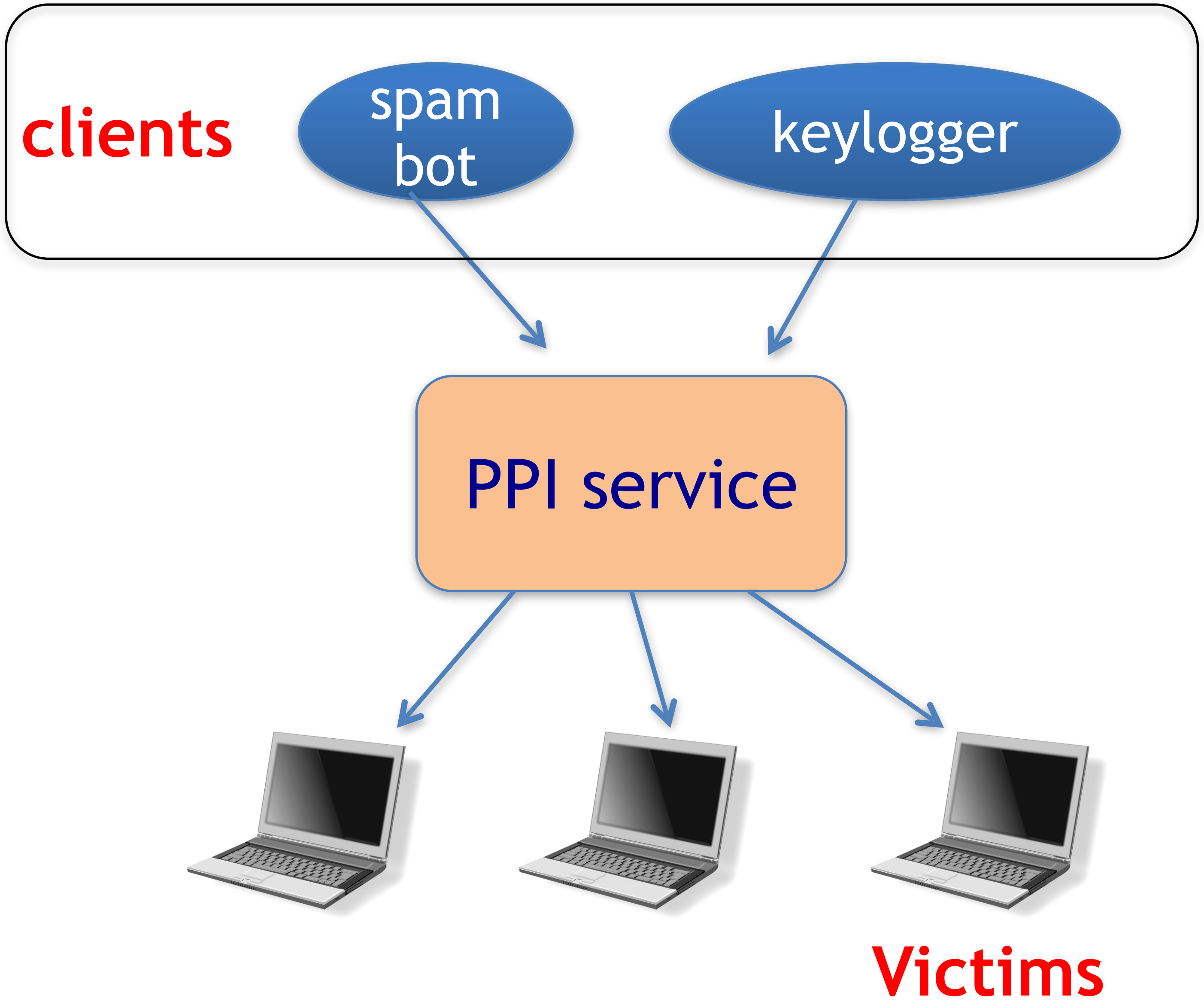


CVE's per year/month
CVEs
1,500
1,000
500
0
2017
1993
1998
2003
2008
2013
2018
Data compiled from MITRE, NVD and Rapid7

Who cares if there are vulnerabilities???

Marketplace for owned machines

Pay-per-install (PPI) services



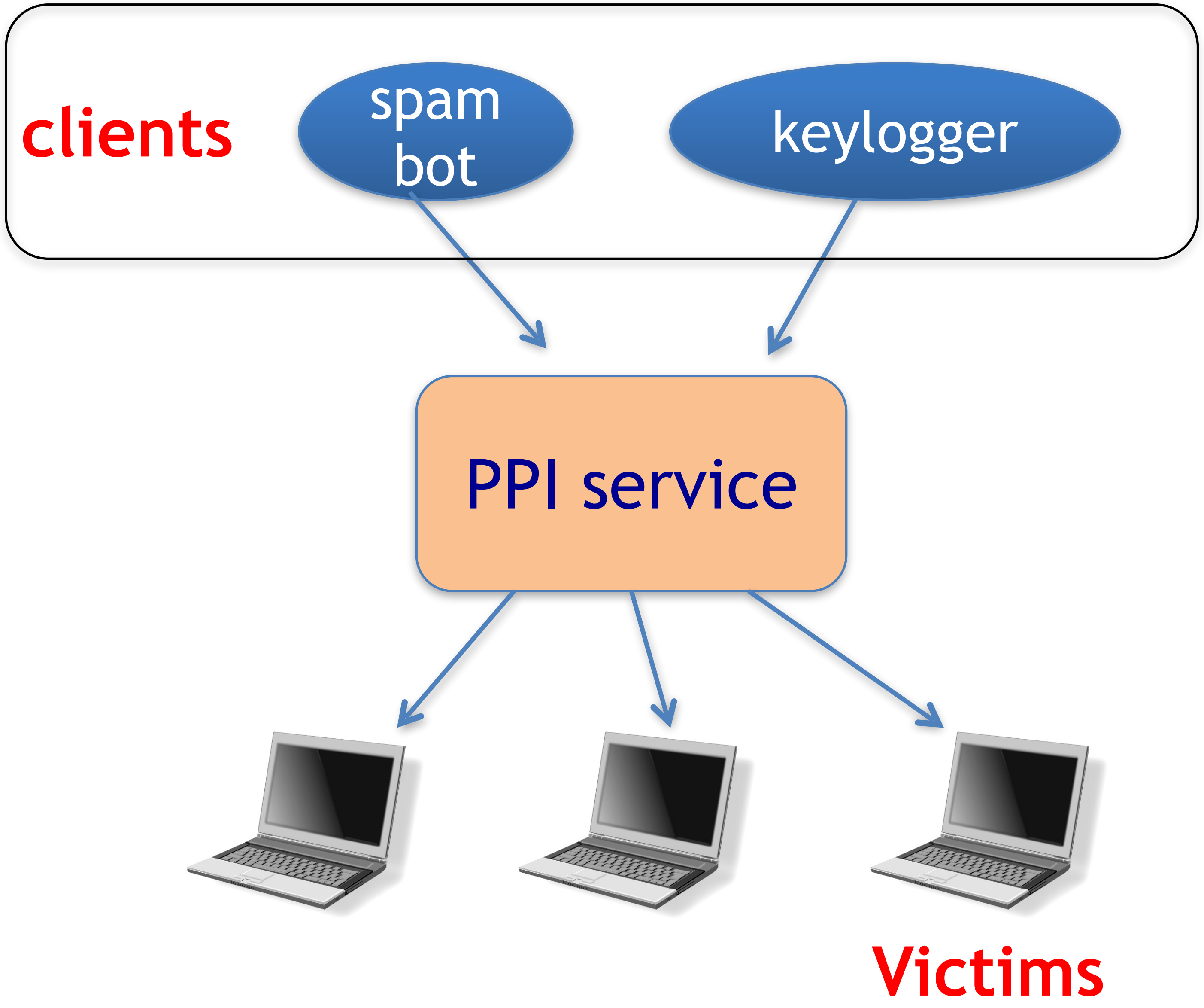
Source: Cabalerro et al. (www.icir.org/vern/papers/ppi-usesec11.pdf)

Marketplace for owned machines

Pay-per-install (PPI) services

PPI operation:

1. Own victim's machine
2. Download and install client's code
3. Charge client



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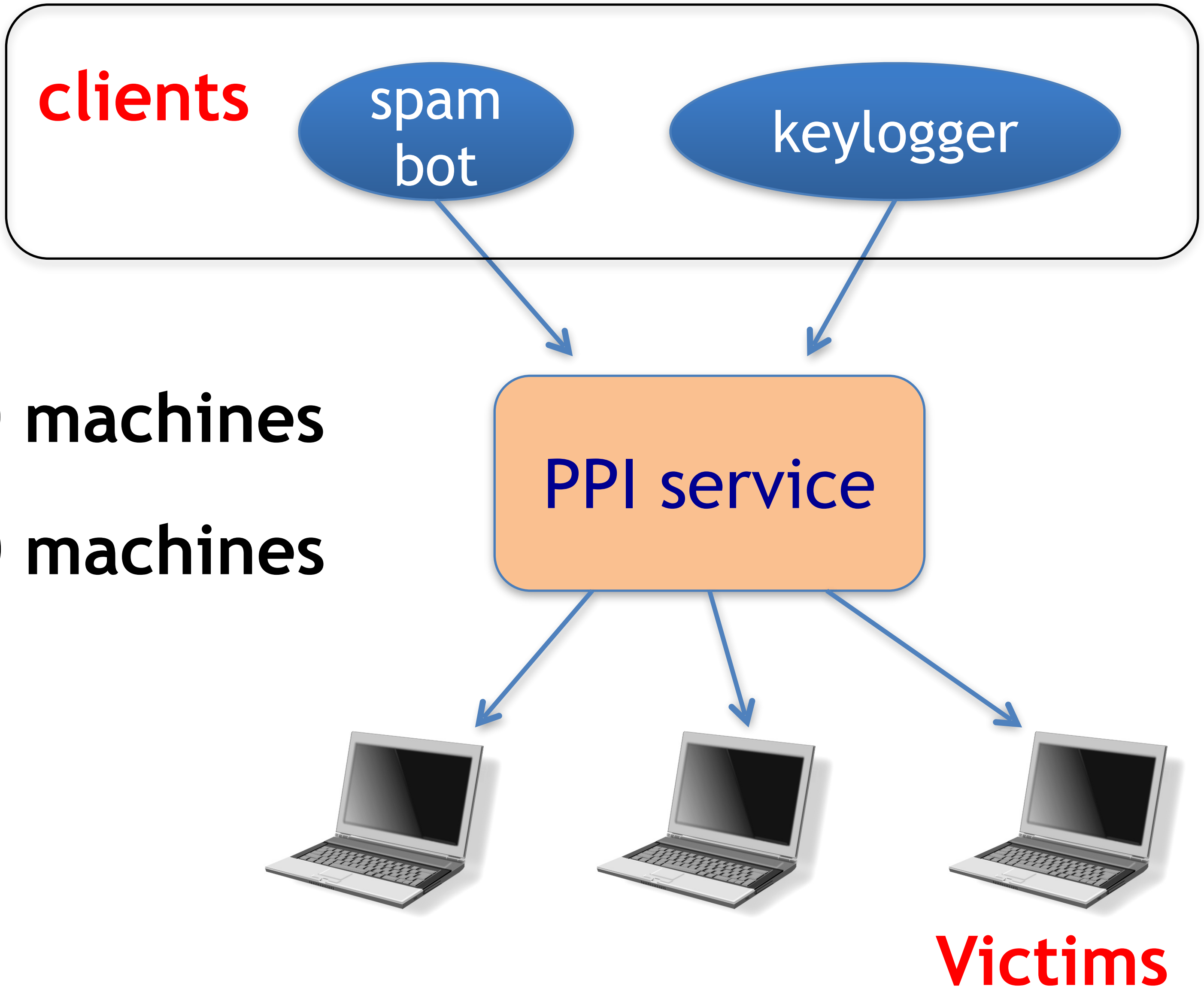


Cost: **US - 100-180$ / 1000 machines**

Asia - 7-8$ / 1000 machines

Source: Cabalerro et al. (www.icir.org/vern/papers/ppi-usesec11.pdf)

Marketplace for Vulnerabilities

Option 1: bug bounty programs (many)

- Google Vulnerability Reward Program: up to $20K
- Microsoft Bounty Program: up to $100K
- Mozilla Bug Bounty program: $7500
- Pwn2Own competition: $15K

Option 2:

- Zero day initiative (ZDI), iDefense: $2K – $25K

Example: Mozilla

Novel vulnerability and exploit, new form of exploitation or an exceptional vulnerability	High quality bug report with clearly exploitable critical vulnerability[1]	High quality bug report of a critical or high vulnerability[2]	Minimum for a high or critical vulnerability[3]	Medium vulnerability
$10,000+	$7,500	$5,000	$3,000	$500 - $2500

Marketplace for Vulnerabilities

Option 3: black market

ADOBE READER	$5,000–$30,000
MAC OSX	$20,000–$50,000
ANDROID	$30,000–$60,000
FLASH OR JAVA BROWSER PLUG-INS	$40,000–$100,000
MICROSOFT WORD	$50,000–$100,000
WINDOWS	$60,000–$120,000
FIREFOX OR SAFARI	$60,000–$150,000
CHROME OR INTERNET EXPLORER	$80,000–$200,000
IOS	$100,000–$250,000

Source: Andy Greenberg (Forbes, 3/23/2012)

Ok, Important. How we find them?

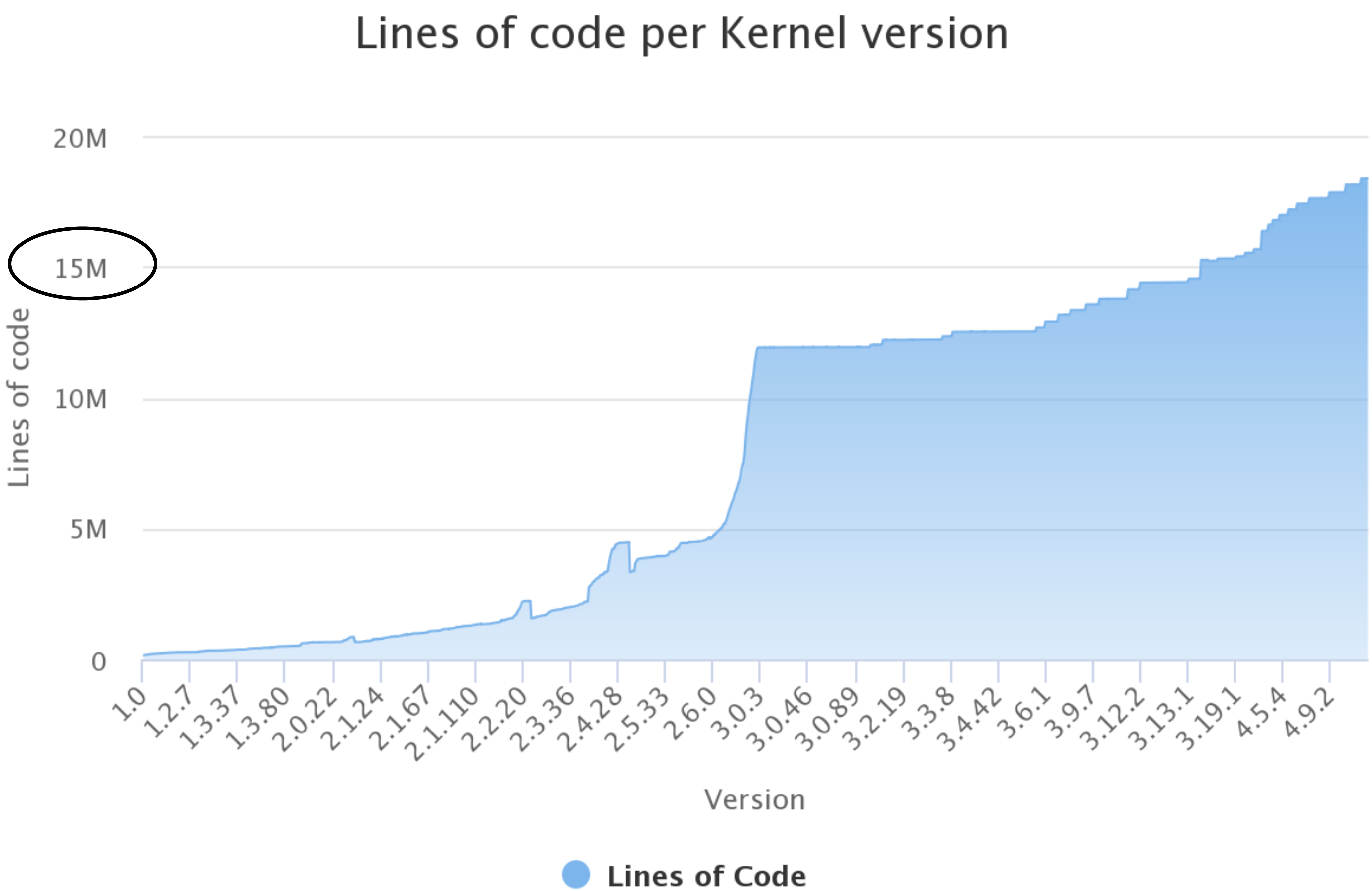
Audit it

- How much does it take to audit all available programs?

Language	files	blank	comment	code
C	53	12066	3945	46676
C++	28	2027	328	7189
C/C++ Header	114	1775	1351	6891

- It took 2 years to audit TrueCrypt (2013-2015)
- German Government + Cryptographers and Security researchers conducted the audit
- Audit finished April 2015
- CVE-2015-7358 and CVE-2015-7359 discovered September 2015 by Google Zero Project!

Too much code !



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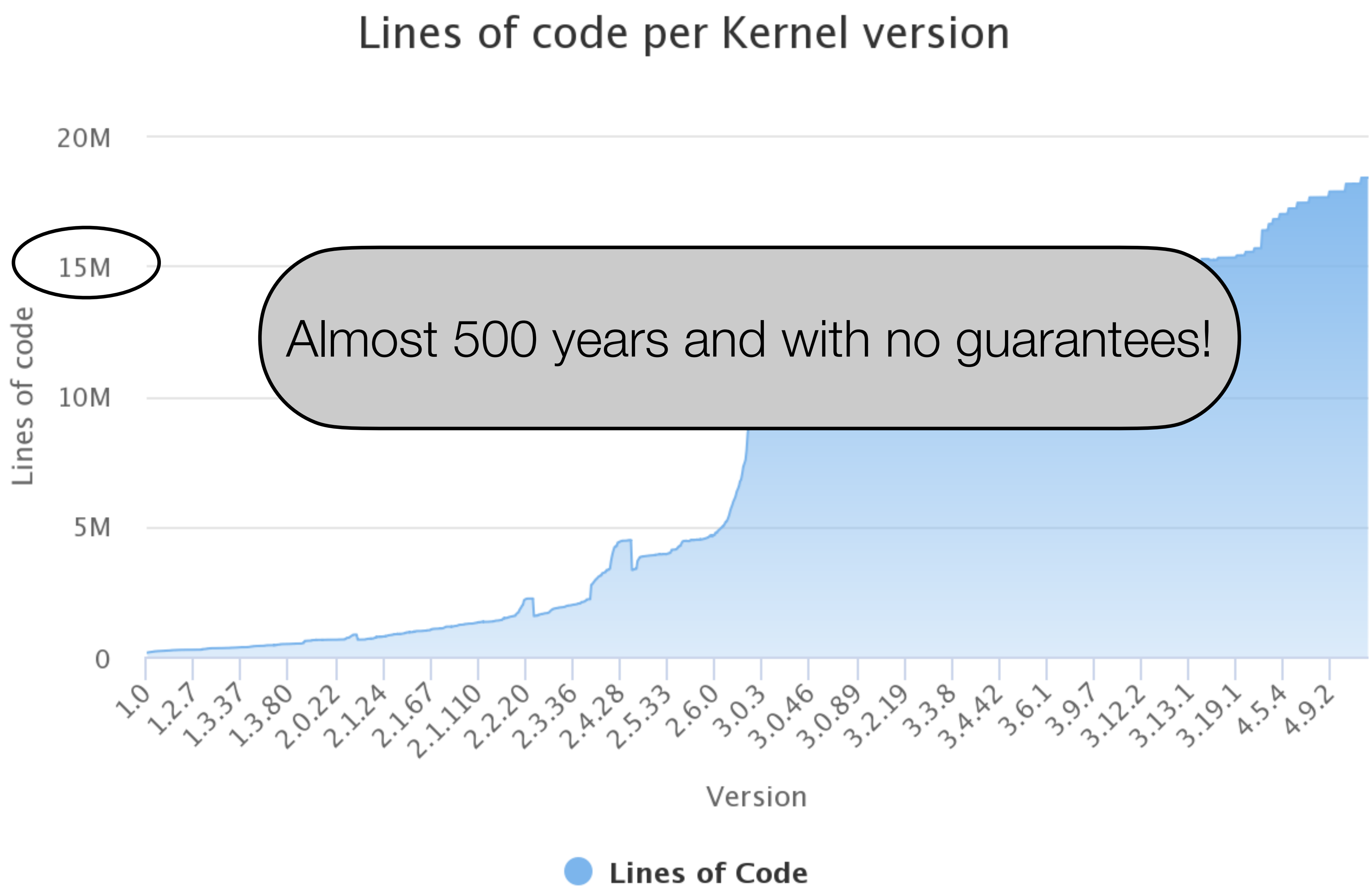
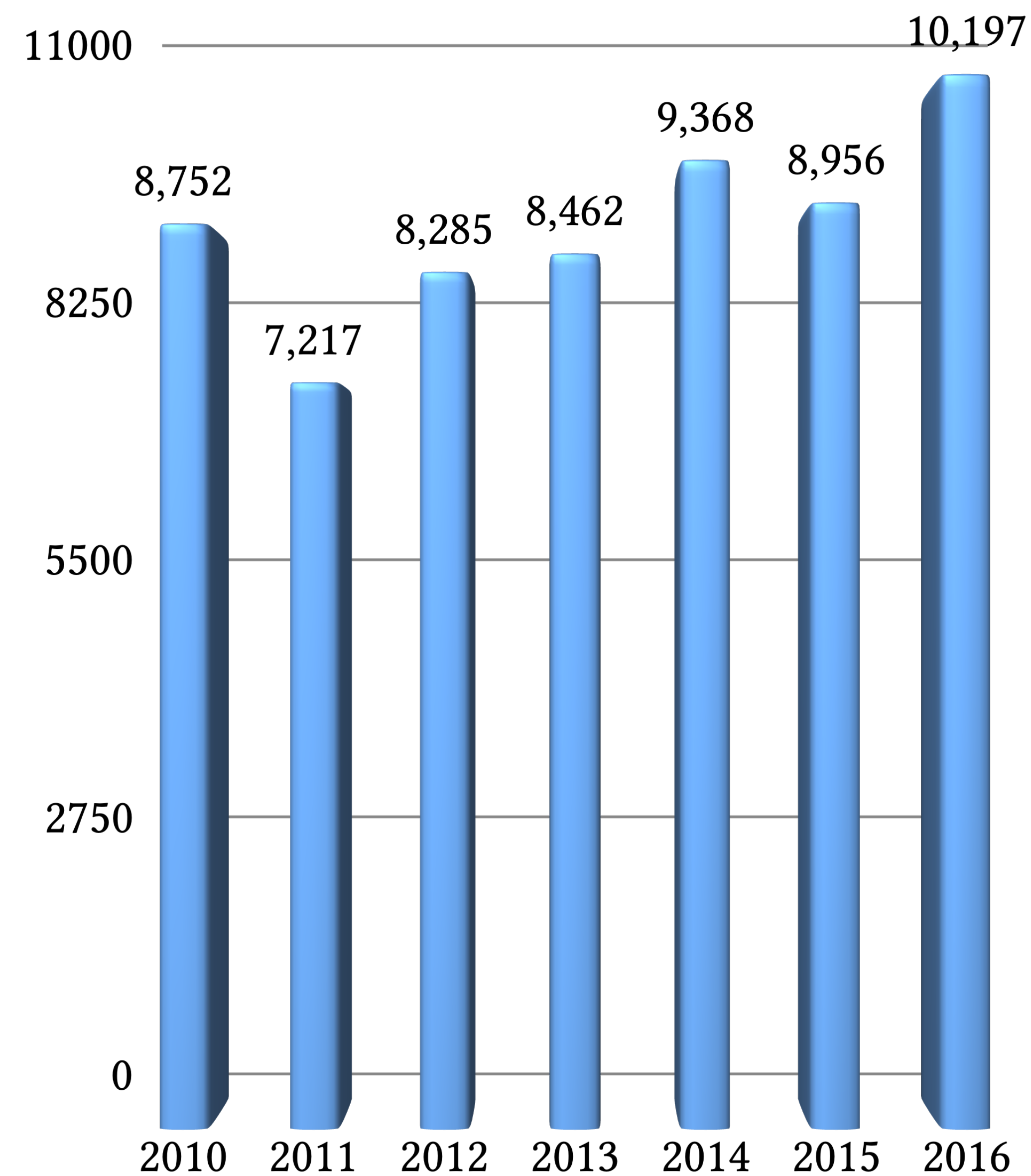


Too much code !!!

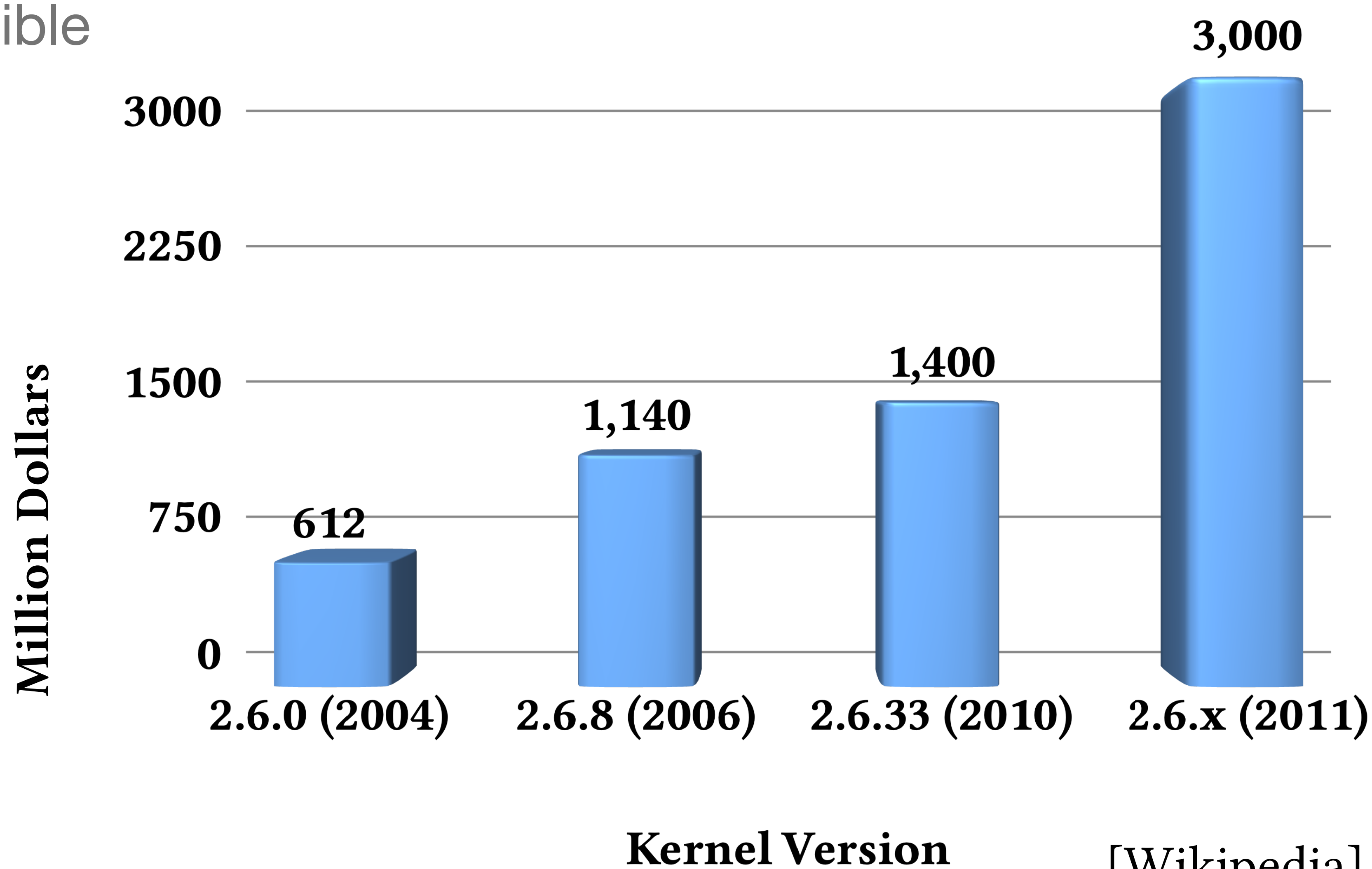
- 111 billion lines of new software code is created every year
- Each bug found by hackers first, will lead to a disaster
- Hackers are interested in Exploitable bugs!



- **Number of Vulnerabilities per year; IBM Report 2017**

Solutions

- Redevelop Linux Kernel and all other programs
  - Not feasible



[Wikipedia]

DARPA Cyber Grand Challenge

- “Cyber Grand Challenge (CGC) is a contest to build high-performance computers capable of Finding and Fixing Vulnerabilities
- Announced in 2013, and Final Contest held in 2016

CYBER
GRAND_CHALLENGE

- Teams build “Cyber Reasoning Systems” (CRS)
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Who participated in CGC?

- 104 teams originally registered in 2014
- 28 teams made it through to CGC Qualifying Event
- 7 teams headed to CGC finals.

- **CodeJitsu: University of California, Berkeley**
- **ForAllSecure: ForAllSecure startup from Carnegie Mellon University**
- **TECHx: GrammaTech, Inc. and University of Virginia**
- **CSDS: University of Idaho**
- **DeepRed: Raytheon Company**
- **disekt: CTF Team**
- **Shellphish: University of California, Santa Barbara**

Who participated in CGC?

What happens if we don’t find them all?

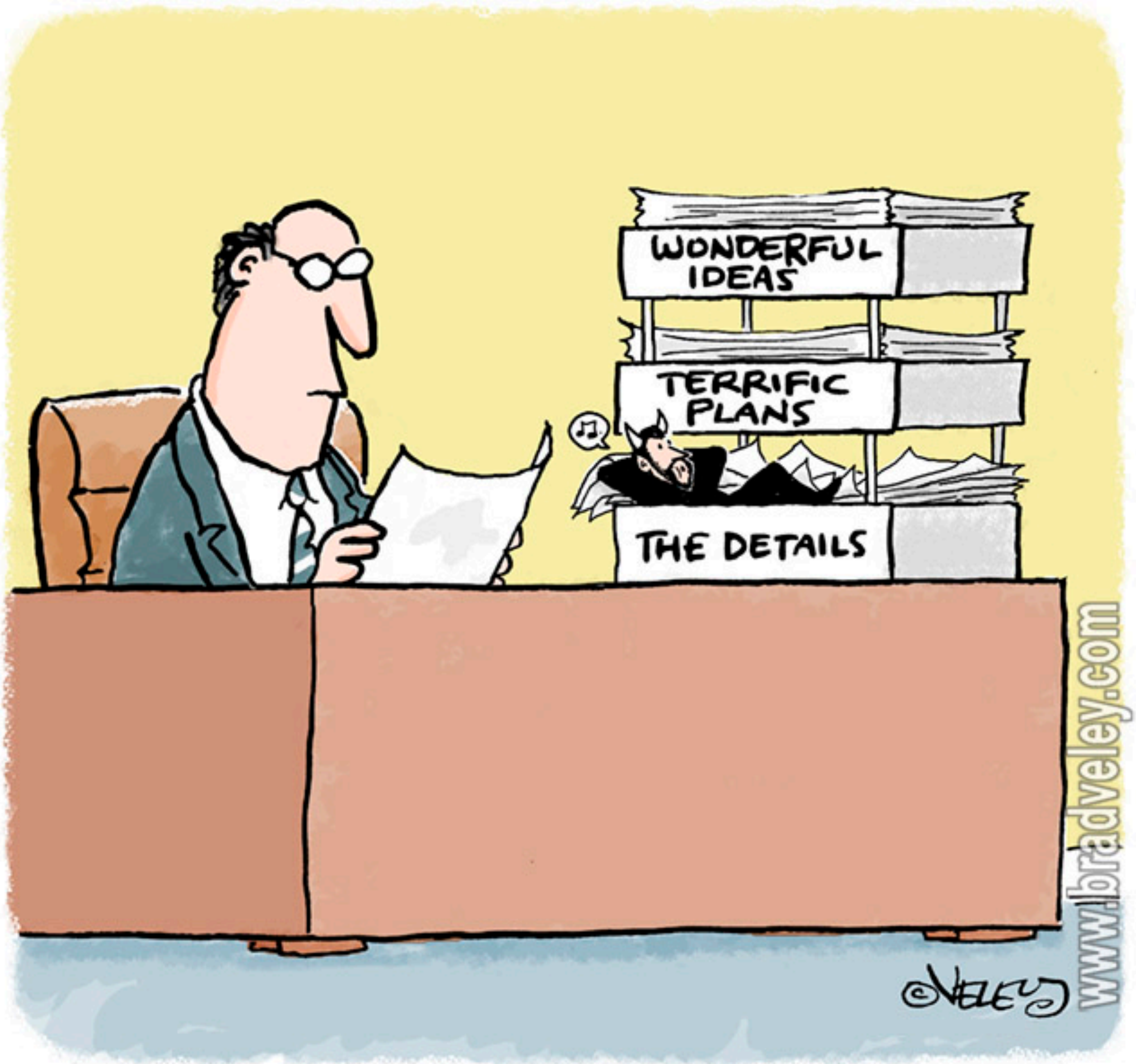
Multiple layers of defense

- How to mitigate the vulnerabilities?
  - run-time protection
- How do we look for vulnerabilities?
  - Program analysis
- How do we refrain from one vulnerabilities causing another one?
  - Better Architectures
- How do we refrain from future vulnerabilities?
  - Better programming languages

High level course view

- Classic attacks
  - Buffer Overflow, Format String, ROP, etc.
- Run-time protection
  - Taint tracking, CFI, etc.
- Code analysis
  - Static analysis, Symbolic execution, Fuzzing
- Architecture
  - Sandboxing, VMs, Isolation, Trusted computing
- Web
  - Native client, App isolation, WebAssembly
- Usability

A quick review of some of the very basics!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Application Model

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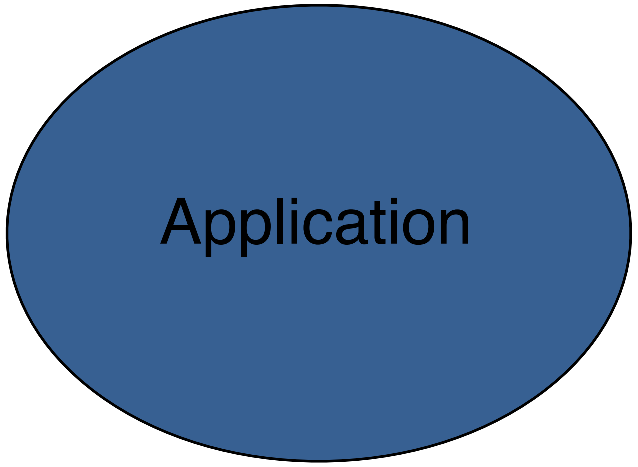

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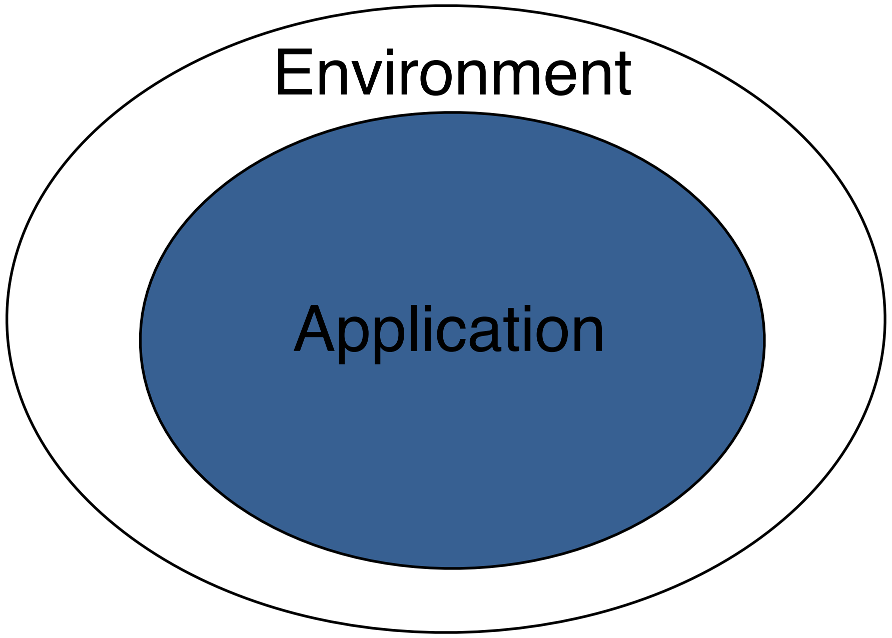

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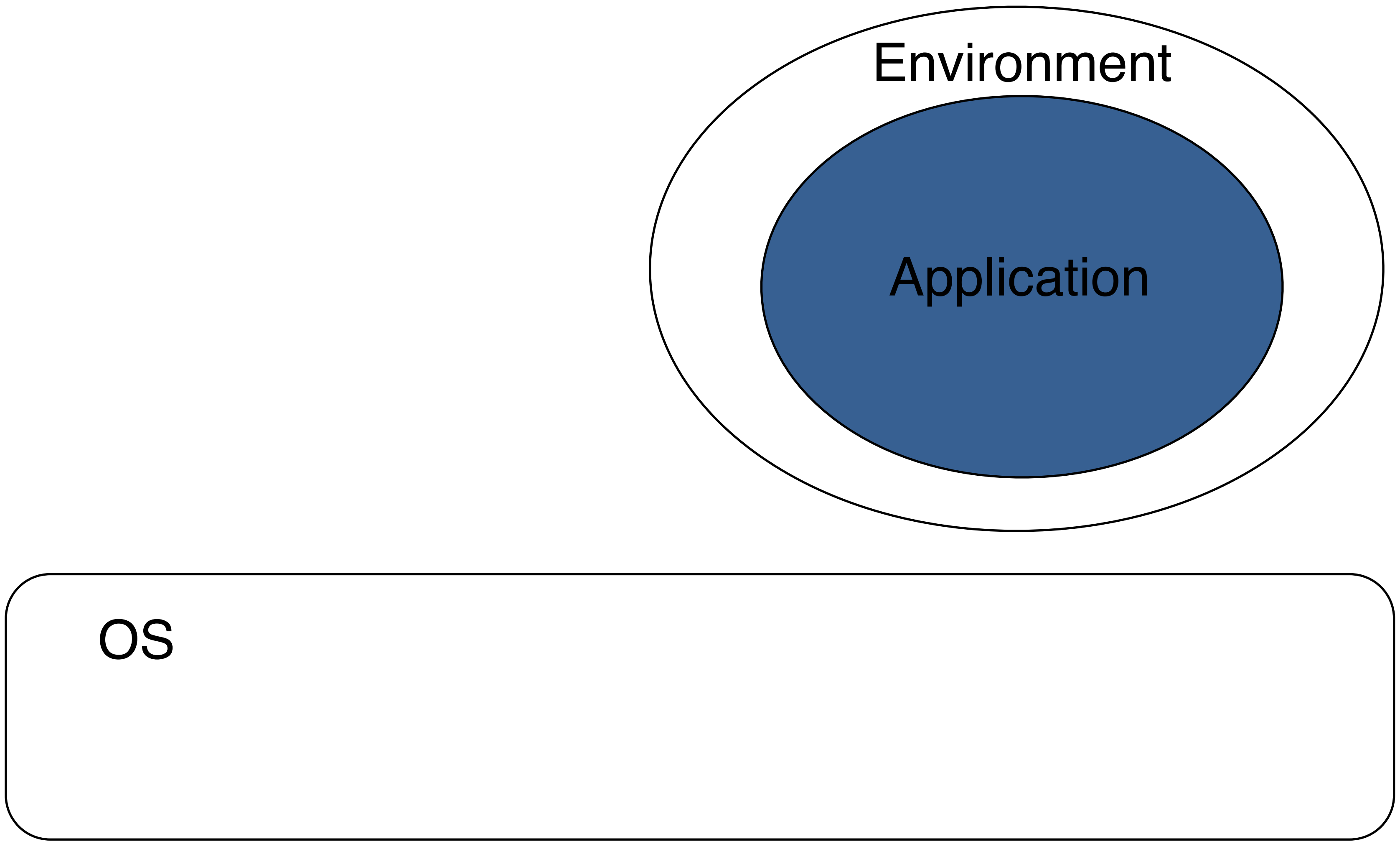

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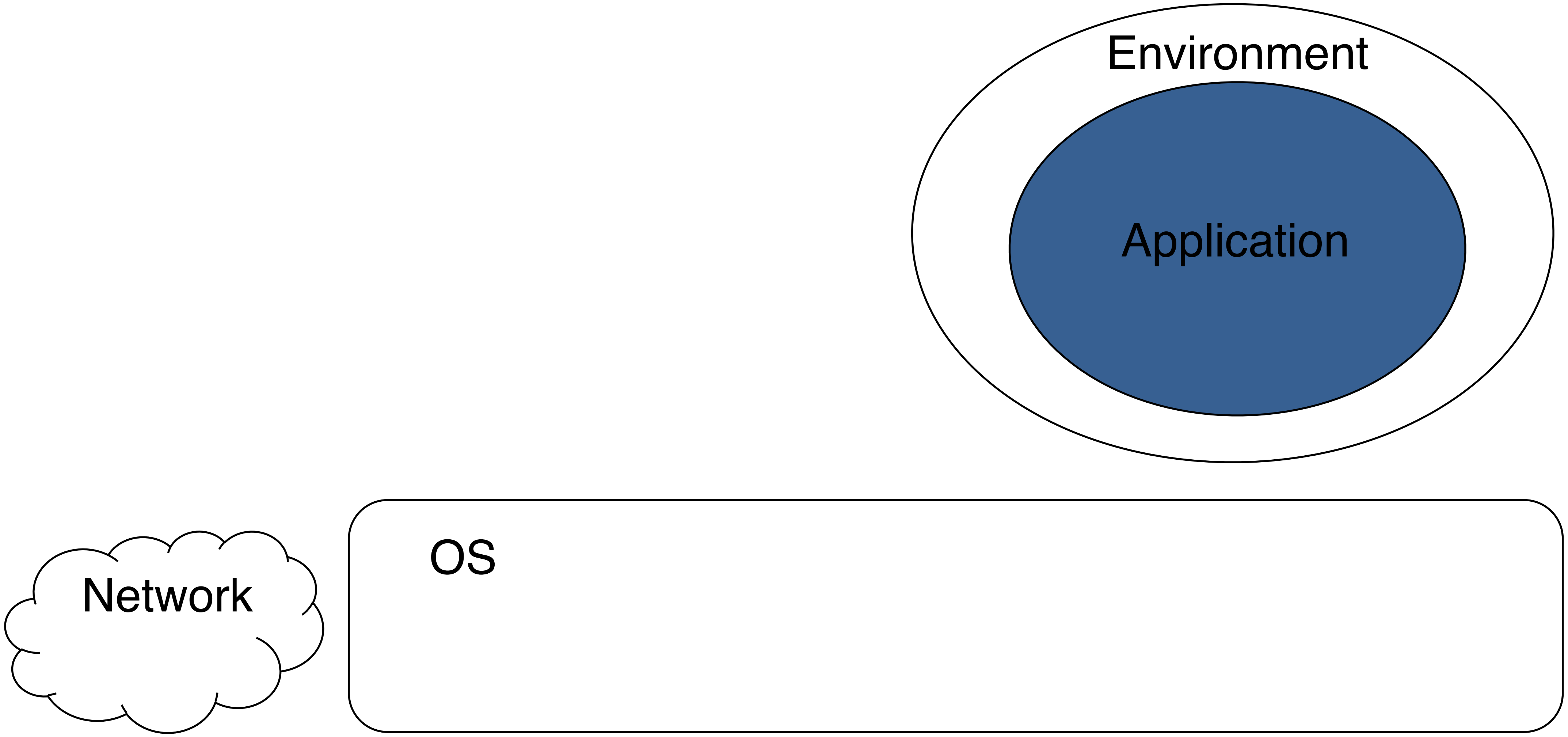

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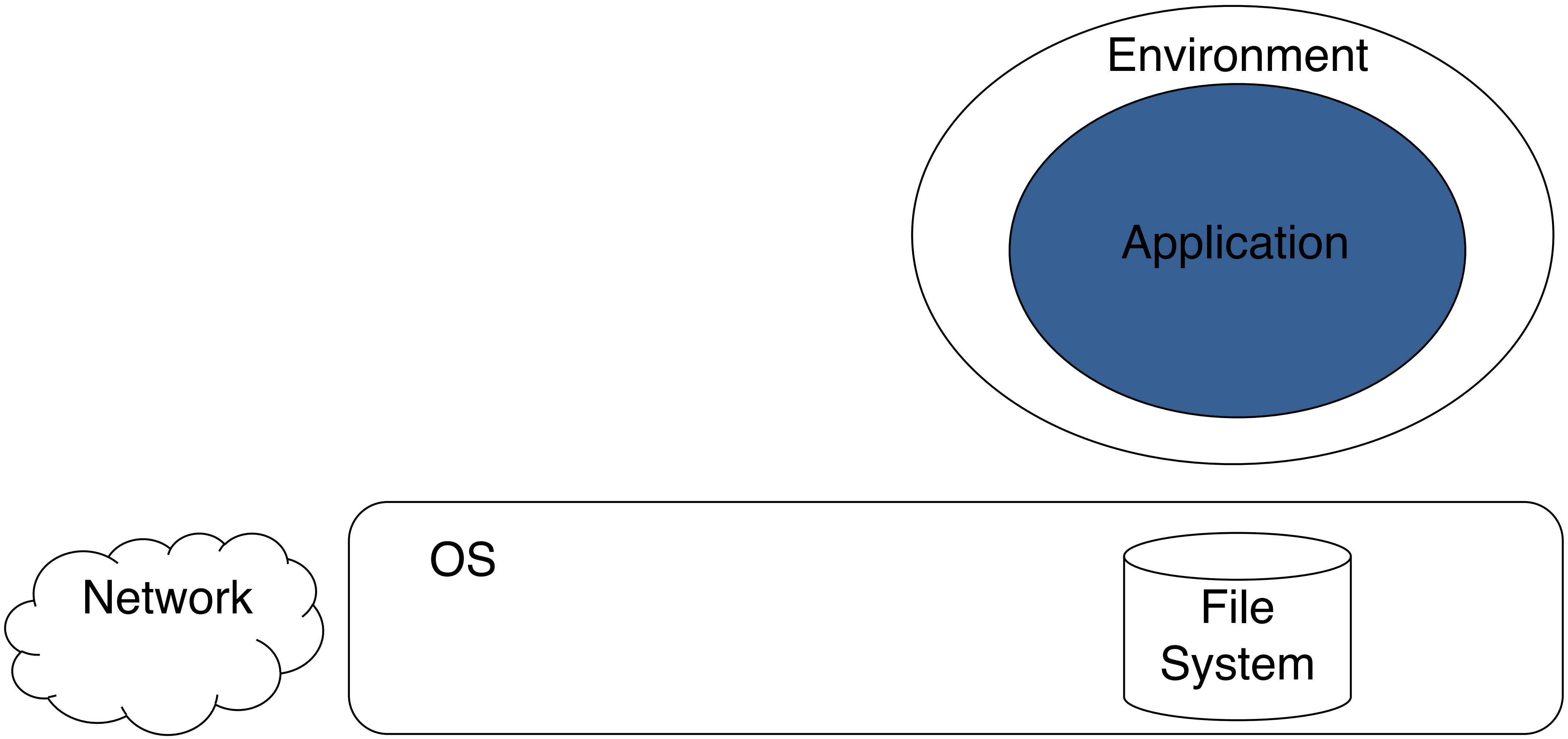

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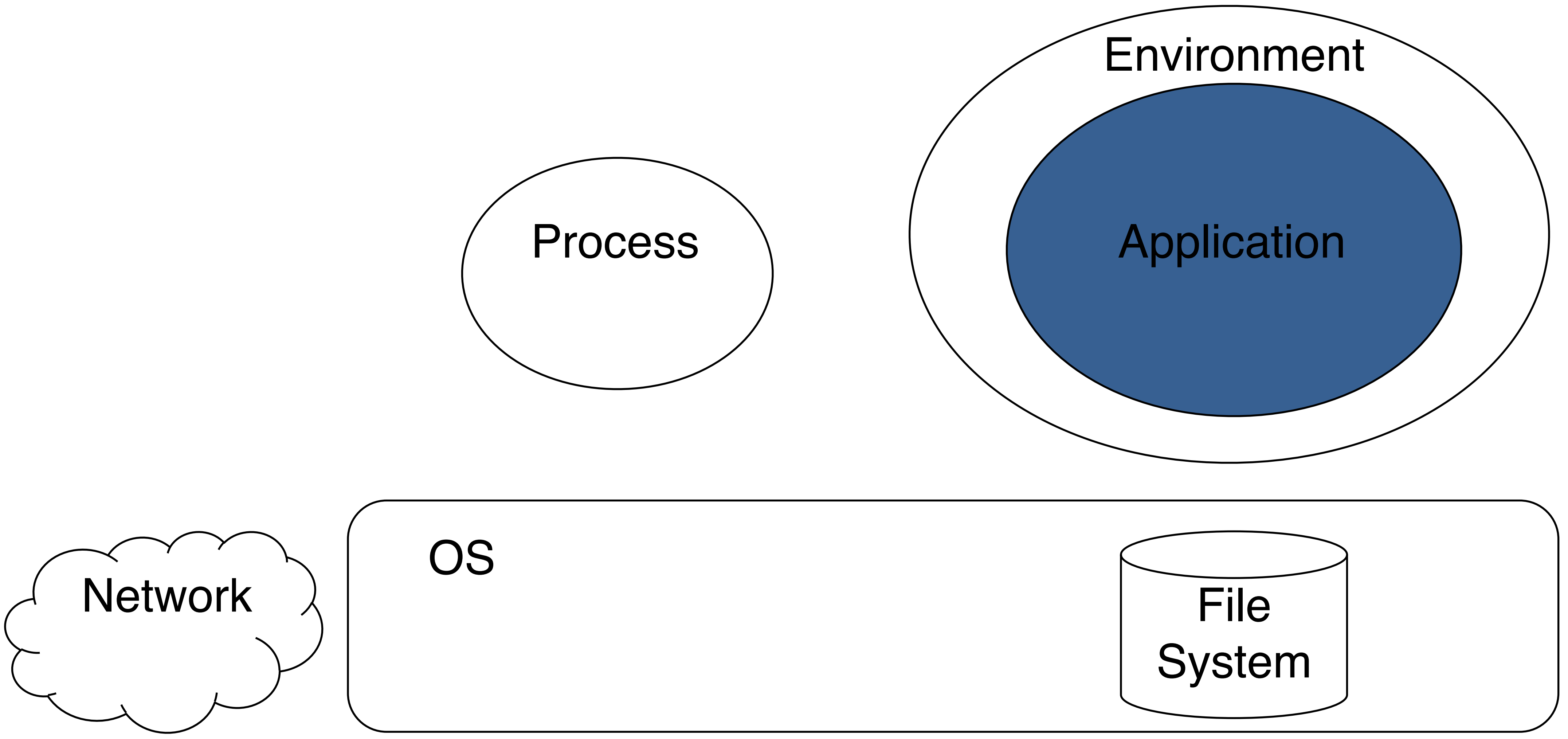

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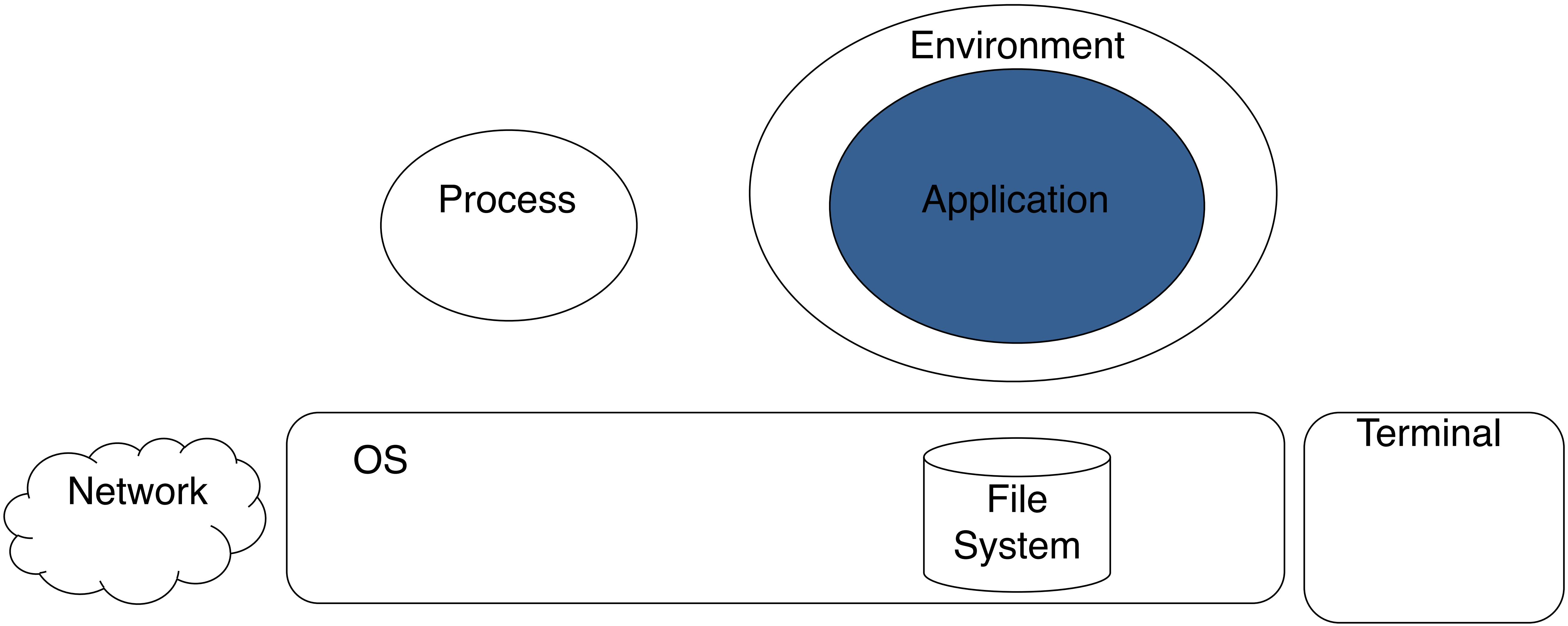

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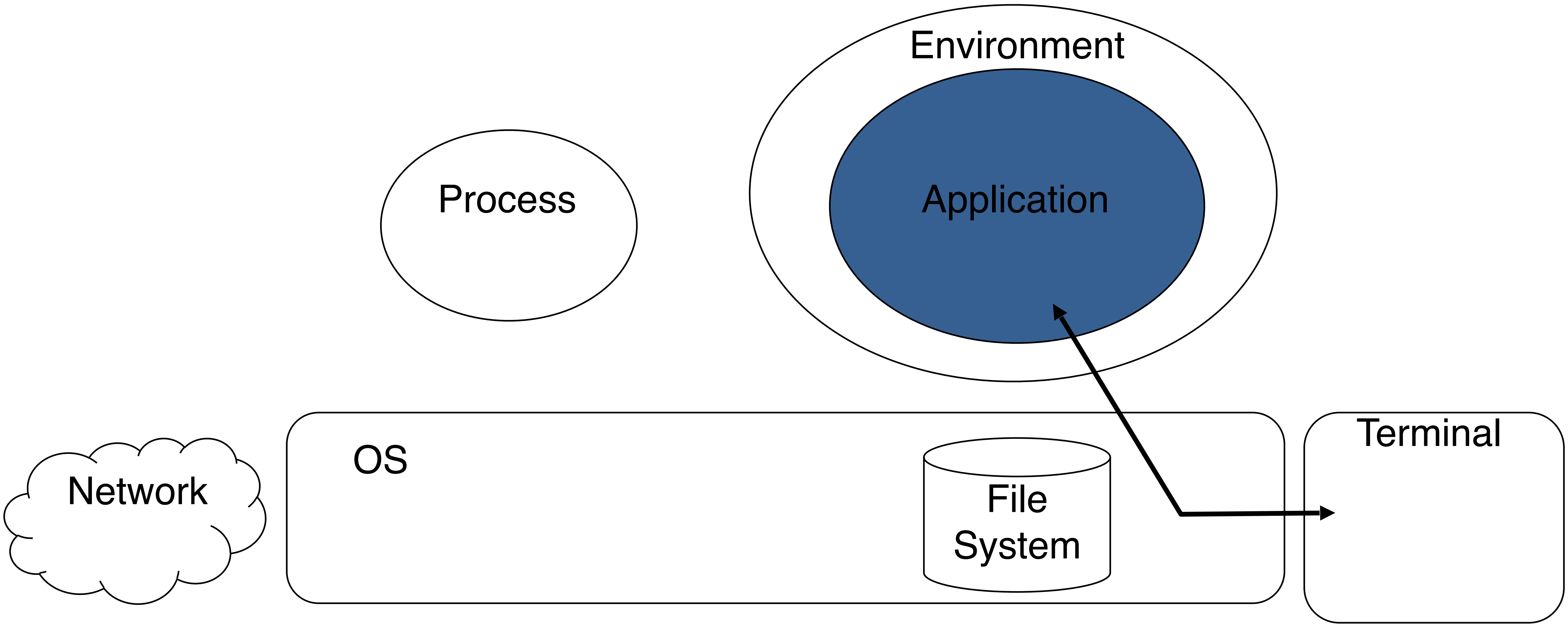

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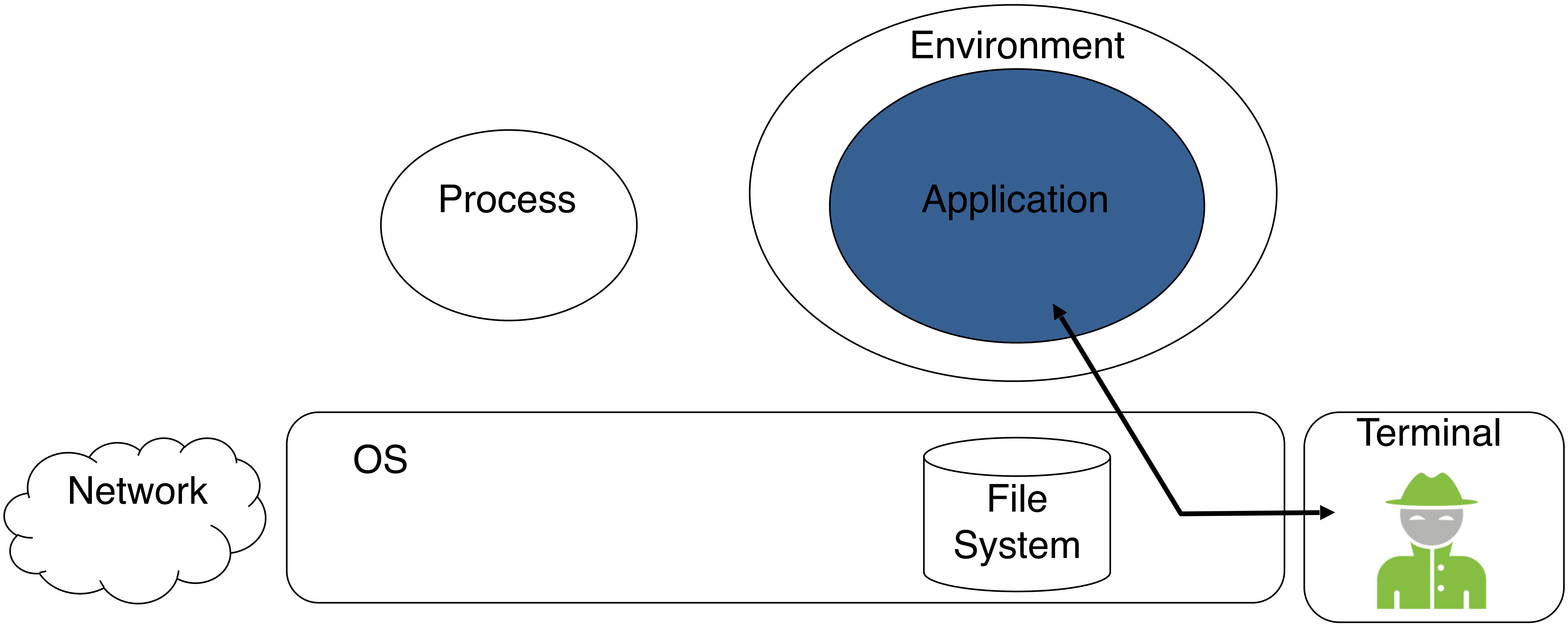

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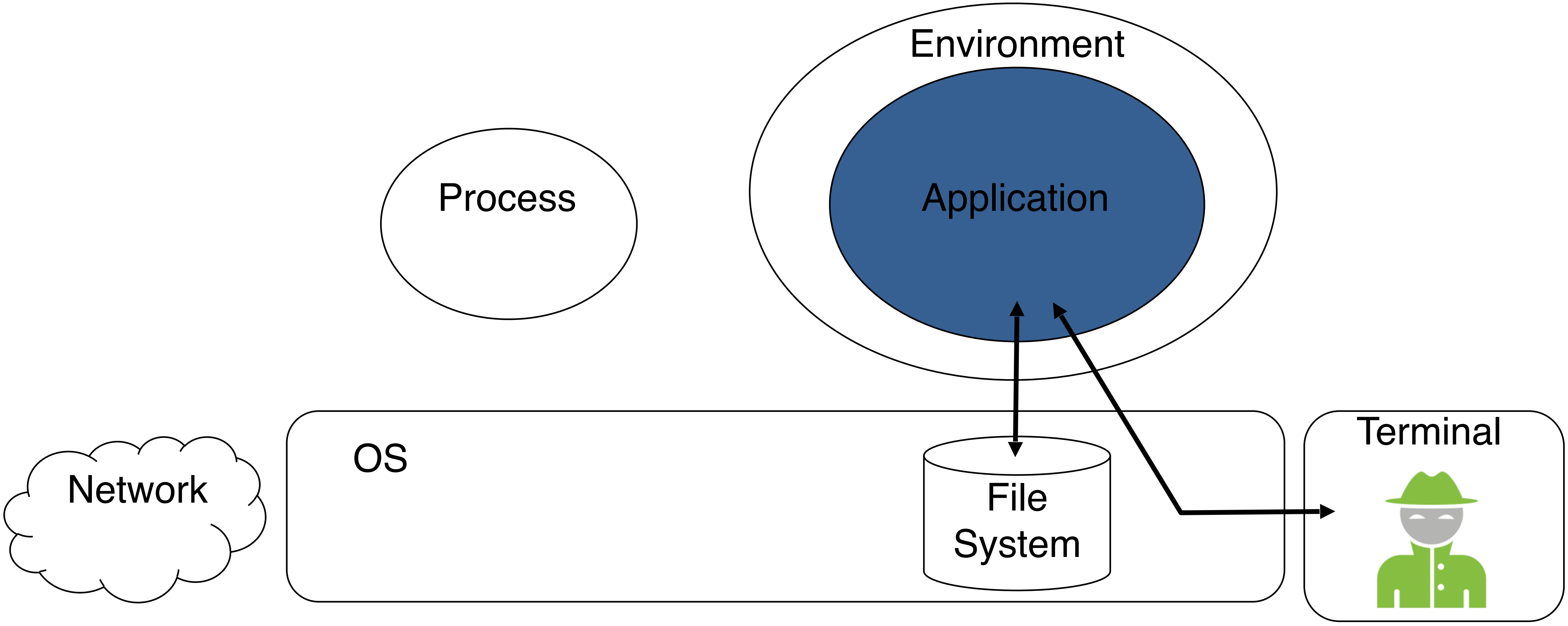

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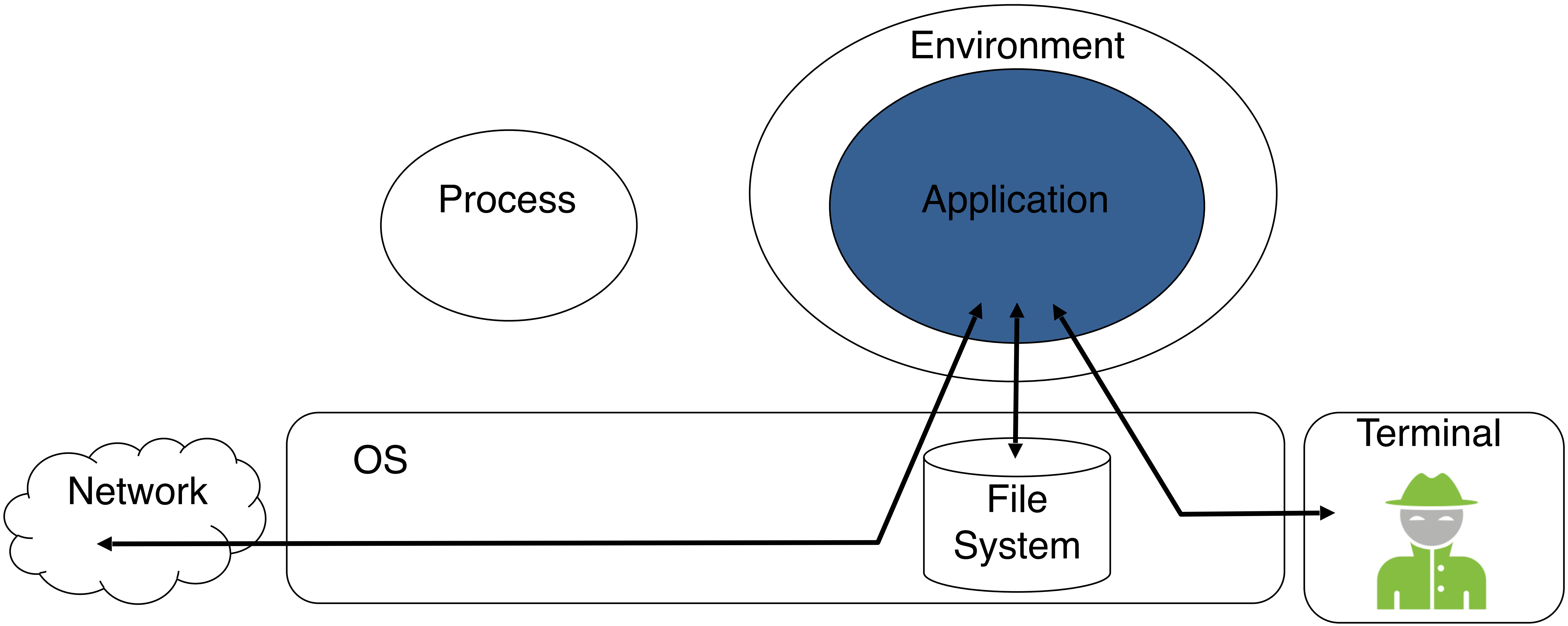

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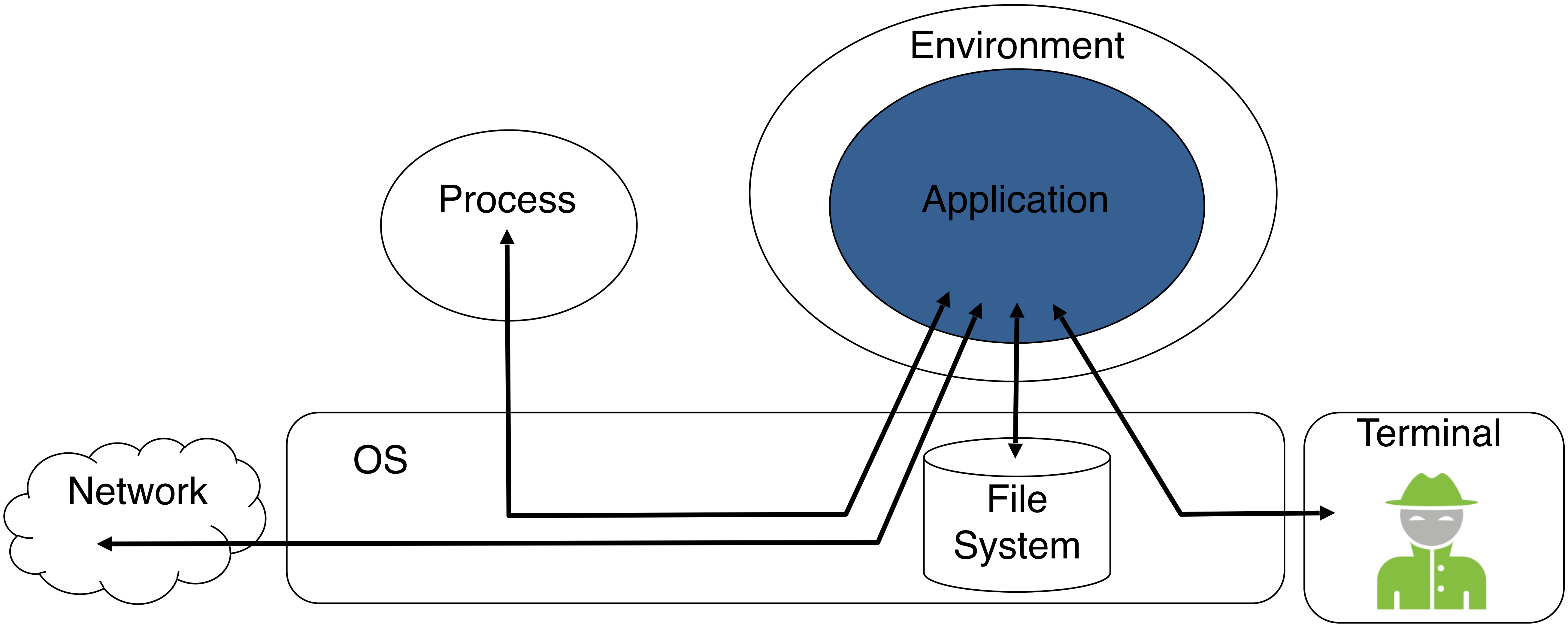

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- Implementation vulnerabilities
  - Application is not able to correctly handle unexpected events
    - Unexpected input, Unexpected errors/exceptions
    - Unexpected interleaving of events
- Deployment vulnerabilities
  - Incorrect/faulty deployment/configuration of the application
    - Installed with more privileges than the ones it should have
    - Installed on a system that has a faulty security policy and/or mechanism (e.g., a file that should be read-only is actually writeable)

The Life of an Application

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- The application terminates

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- Each instruction is parsed and executed
- In most interpreted languages it is possible to generate and execute code dynamically
  - Bash: eval <string>
  - Python: eval(<string>)
  - JavaScript: eval(<string>)
  - …

Compilation

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  - GNU/Linux: The C preprocessor is cpp
- The compiler turns the code into architecture-specific assembly
  - GNU/Linux: The C compiler is gcc
    - gcc -S prog.c will generate the assembly
    - Use gcc's -m32 option to generate 32-bit assembly

Compilation

Compilation

- The assembler turns the assembly into a binary object
  - GNU/Linux: The assembler is as
  - A binary object contains the binary code and additional metadata
    - Relocation information about things that need to be fixed once the code and the data are loaded into memory
    - Information about the symbols defined by the object file and the symbols that are imported from different objects
    - Debugging information

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Compilation

- The linker combines the binary object with libraries, resolving references that the code has to external objects (e.g., functions) and creates the final executable
    - GNU/Linux: The linker is ld
    - Static linking is performed at compile-time
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- Most common executable formats:
    - GNU/Linux: ELF
    - Windows: PE

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- Tools: readelf, file

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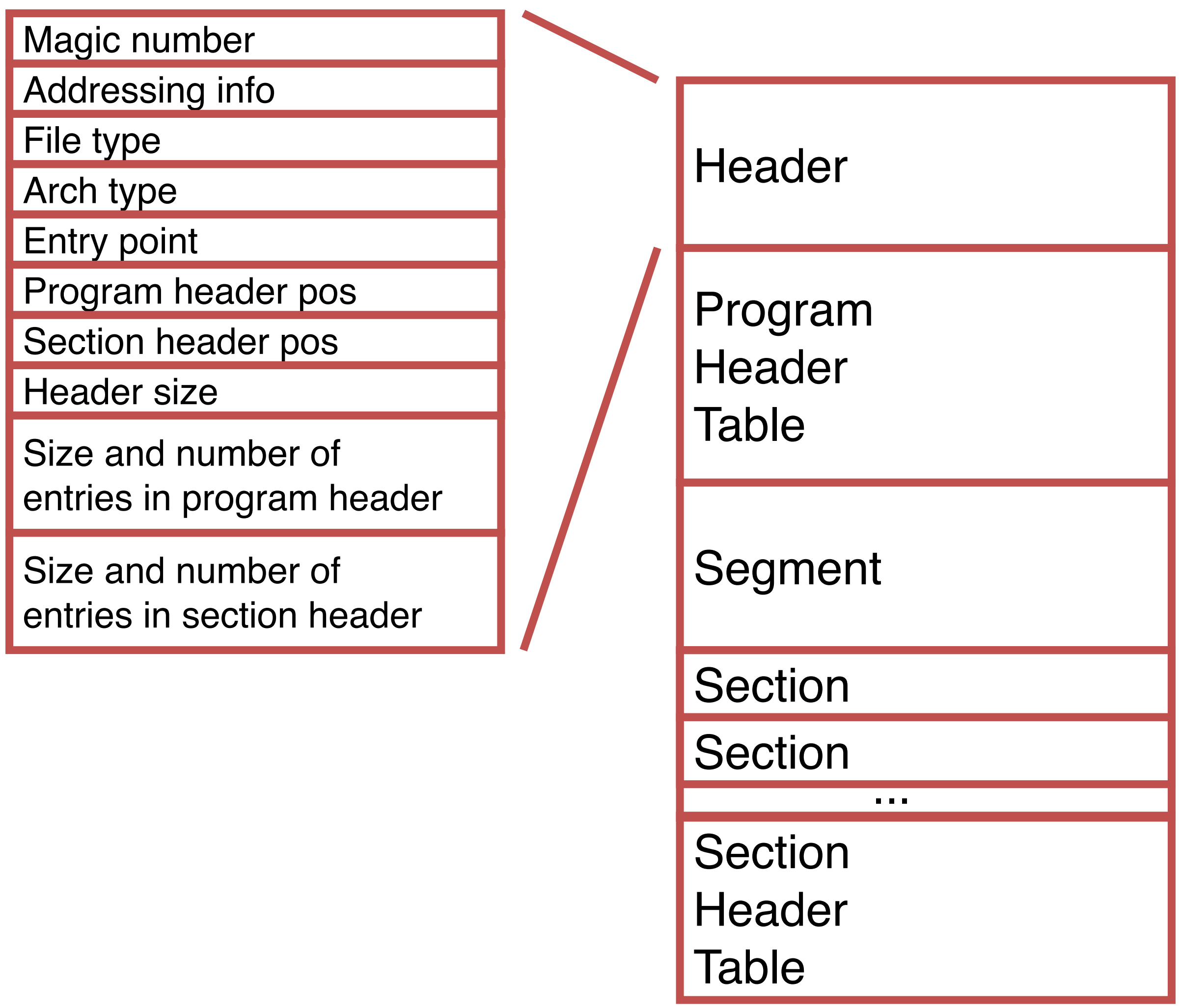

- A program is seen as a collection of segments by the loader and as a collection of sections by the compiler/linker
- A segment is usually made of several sections
- The segment structure is defined in the Program Header Table
- The section structure is defined in the Section Header Table

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- Also known as the "EXE" format
- The header contains a number of relocation entries that are used at loading time to "fix" the addresses (this procedure is called rebasing)
  - Programs are written as if they were always loaded at address 0
  - The program is actually loaded in different points in memory

x86 Registers

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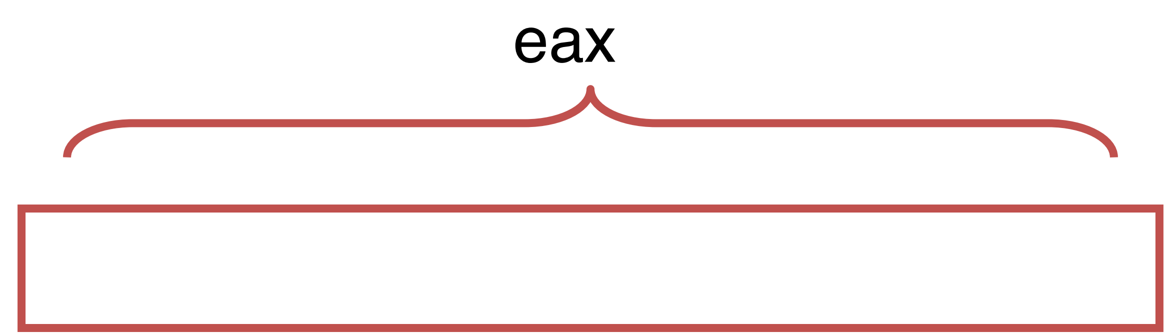

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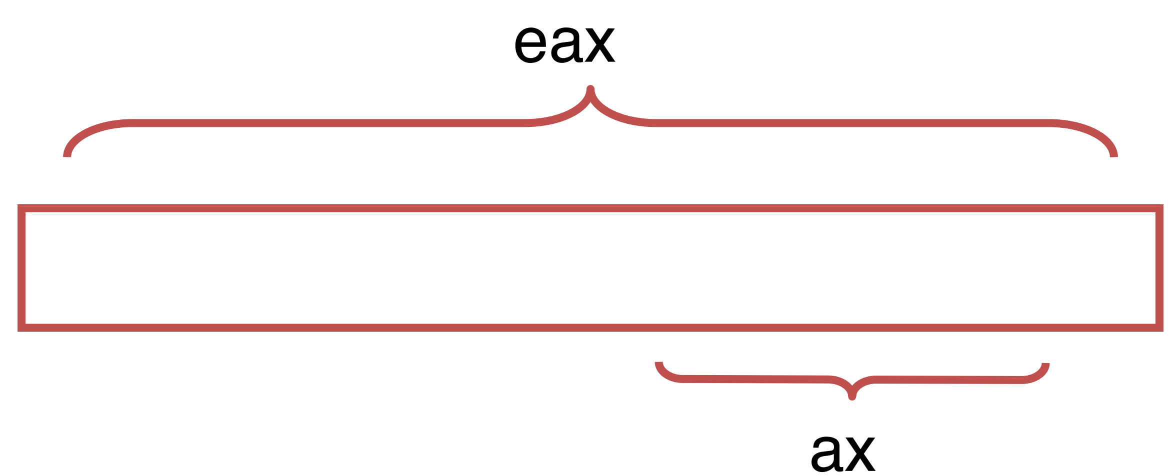

x86 Registers

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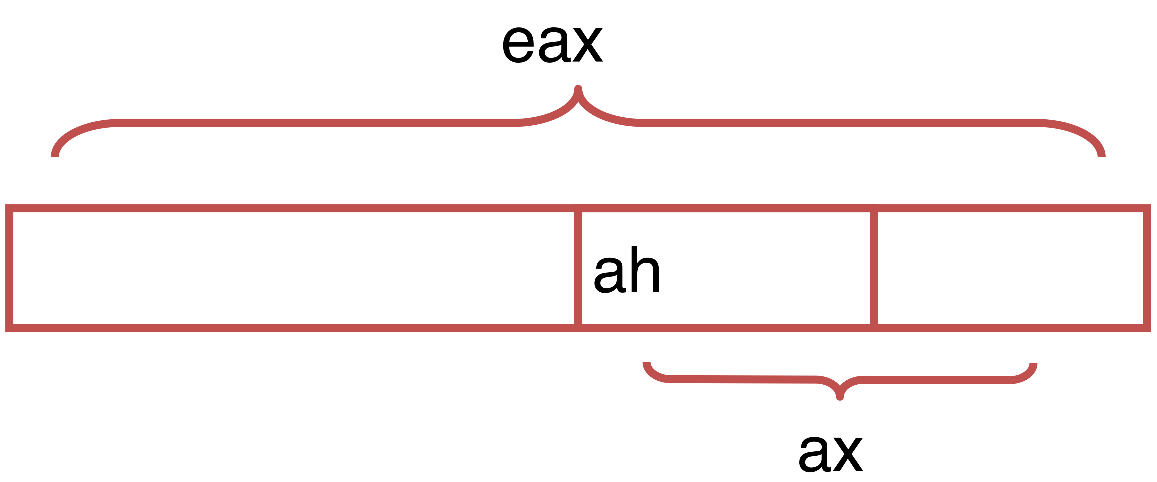

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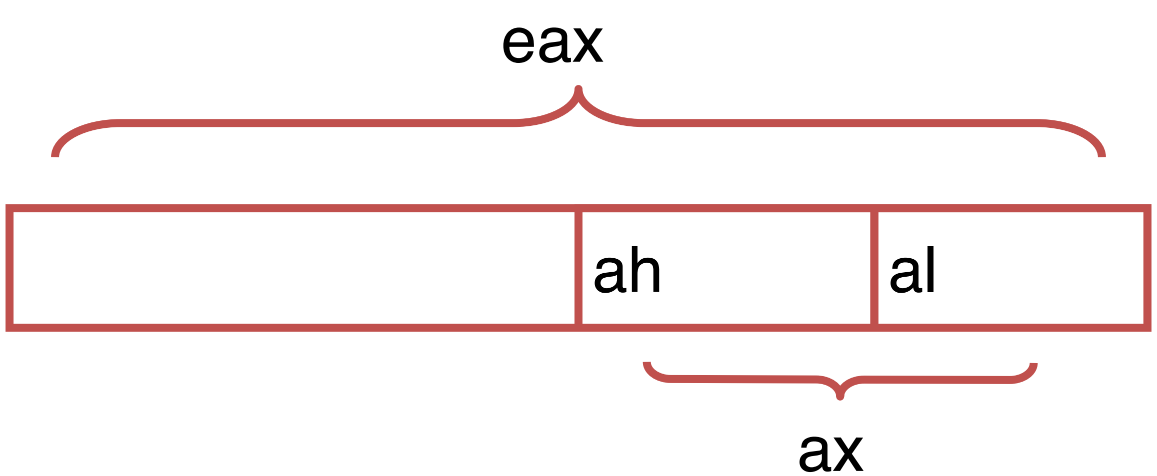

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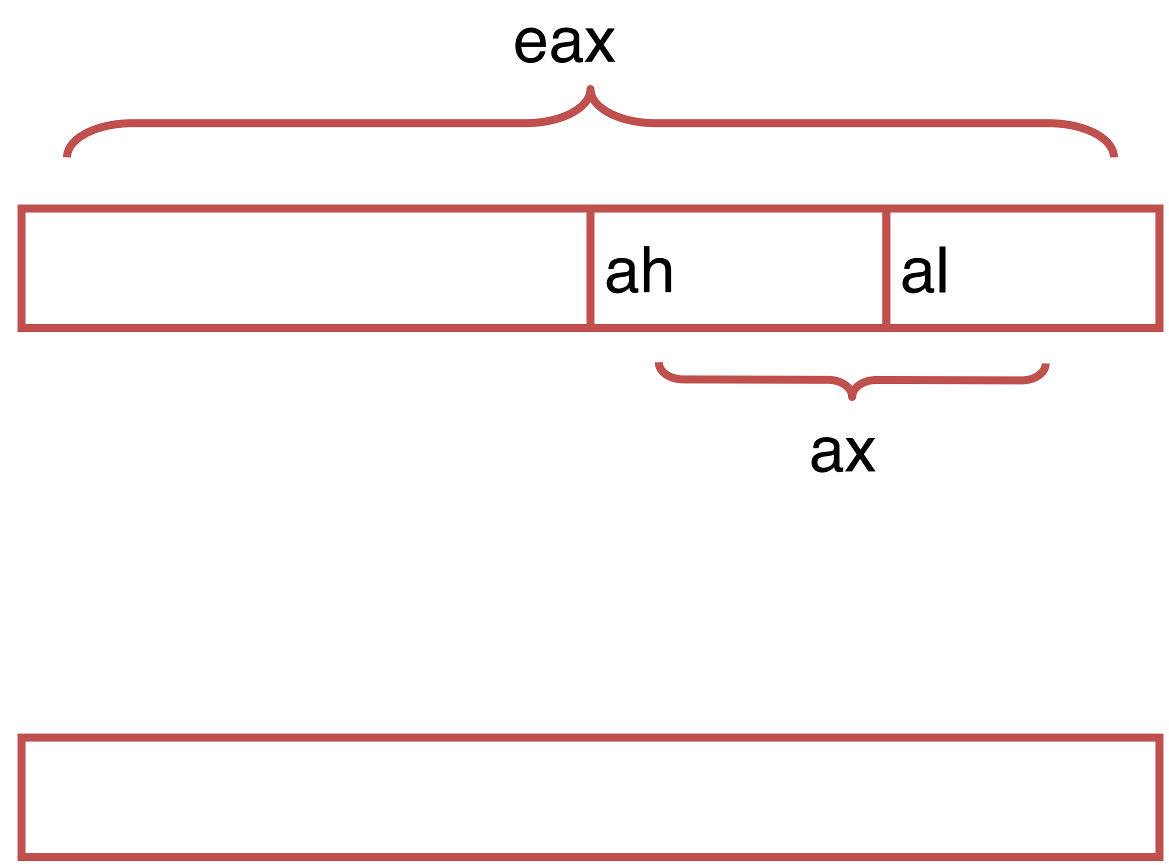

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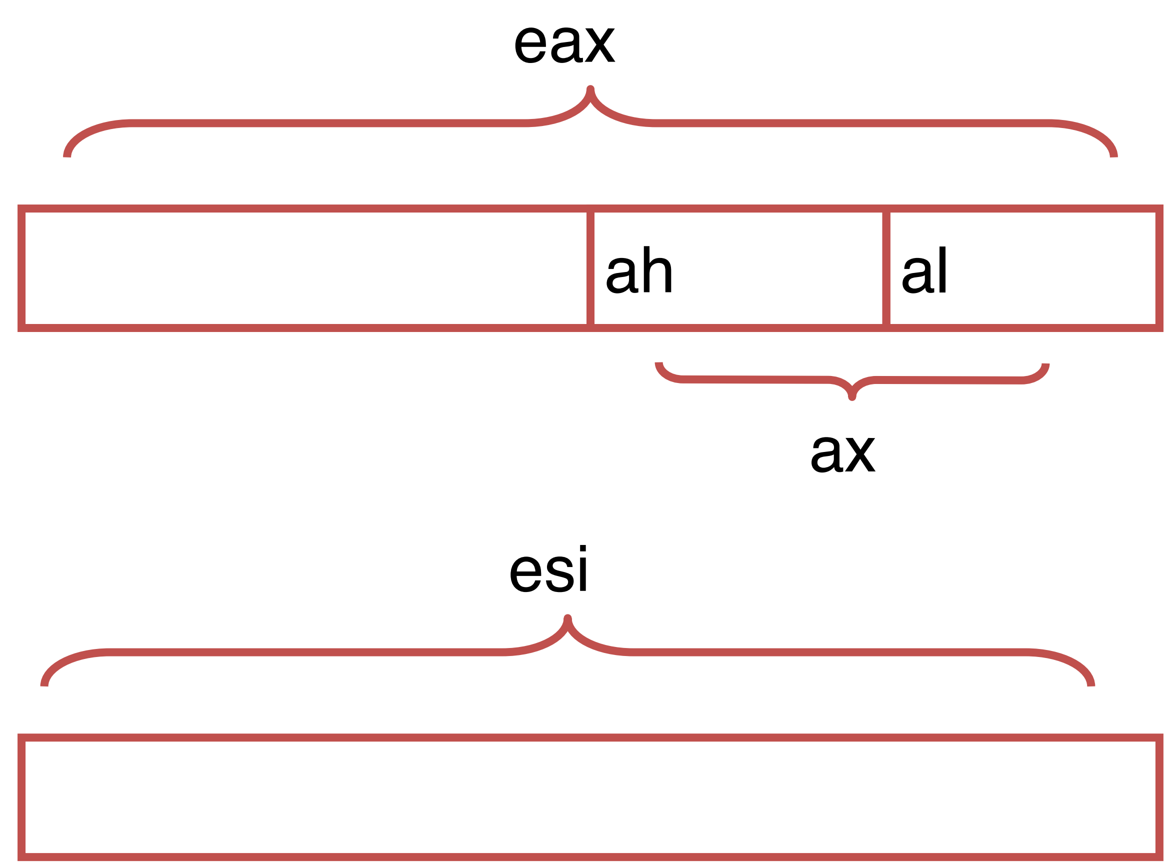

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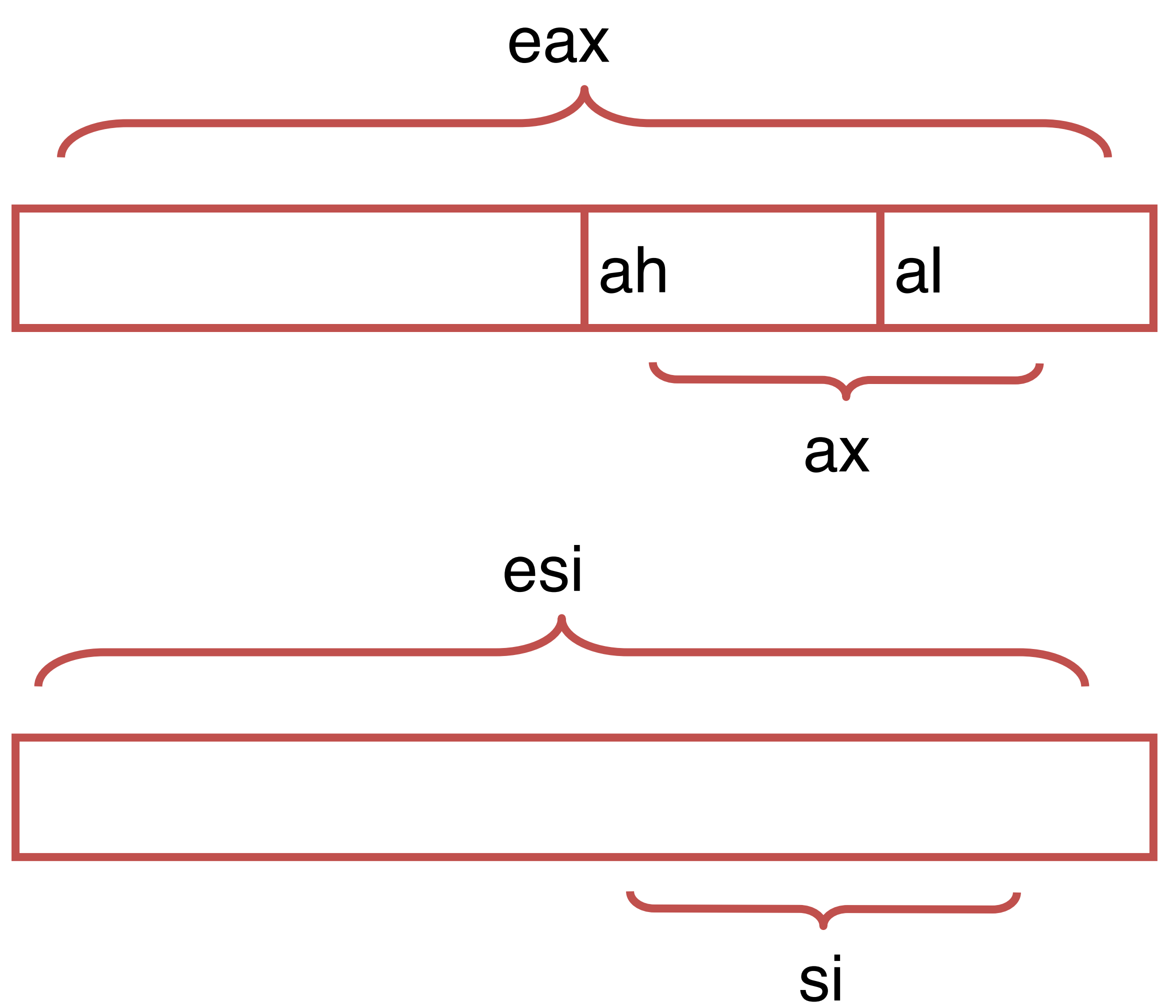

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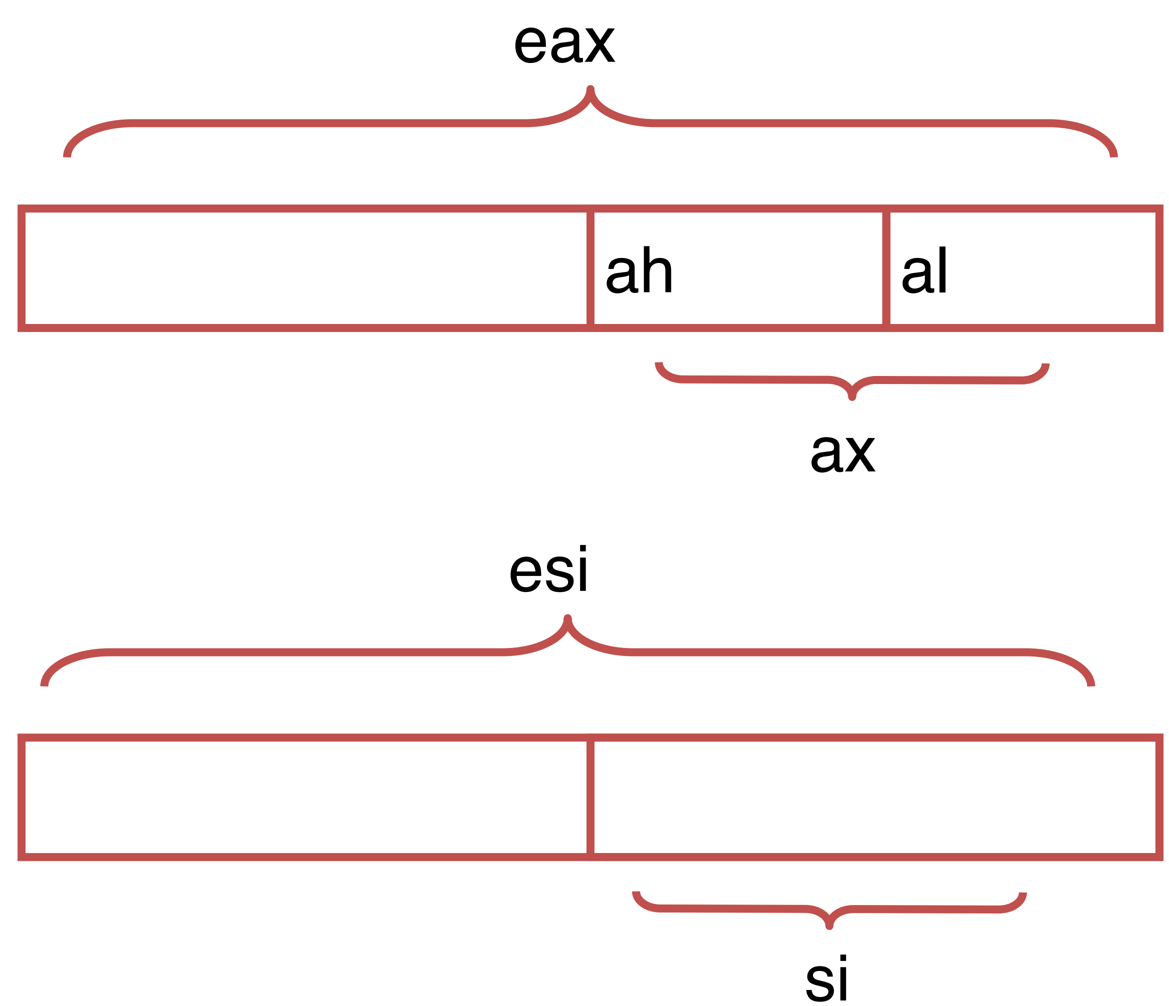

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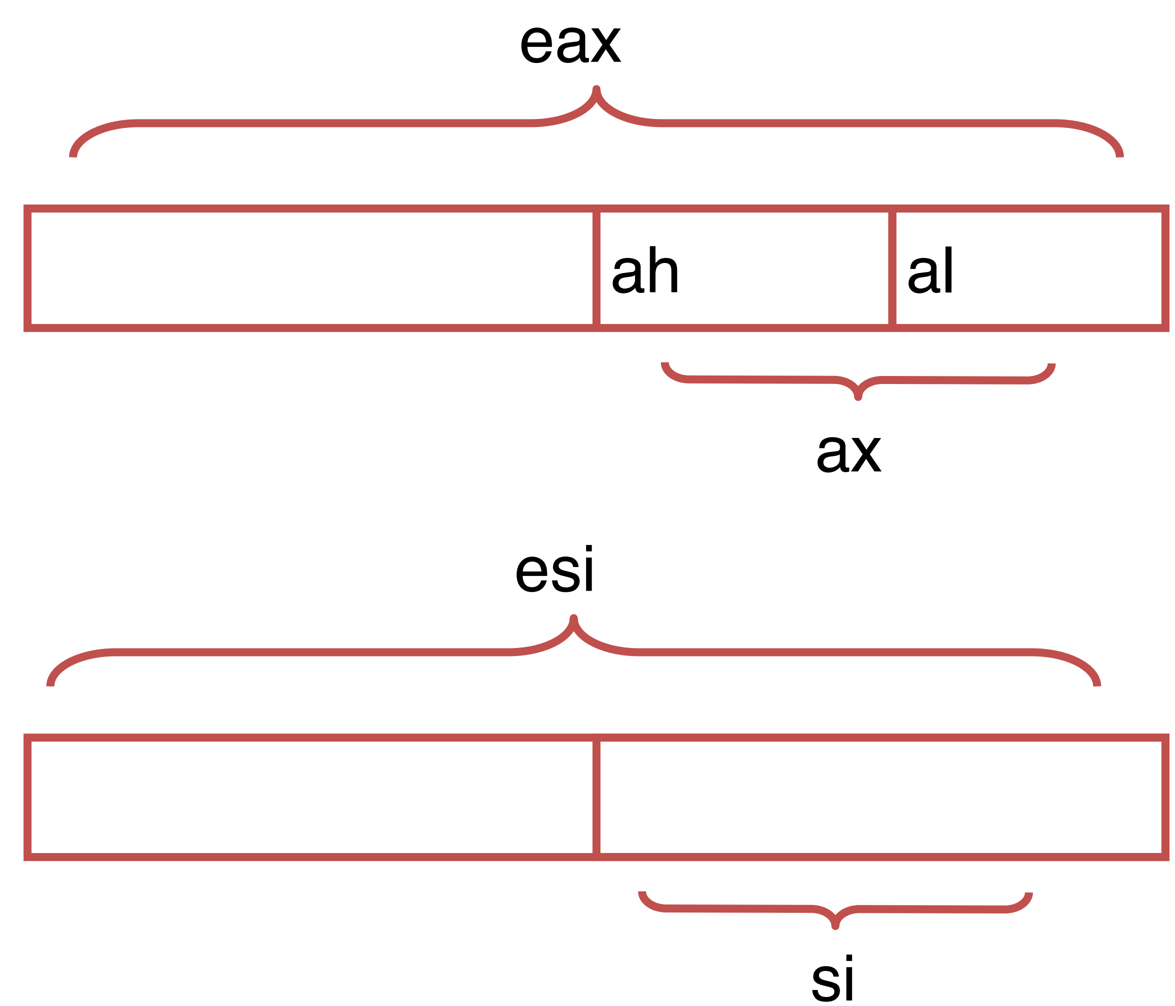

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- Two registers are used for high-speed memory transfer operations
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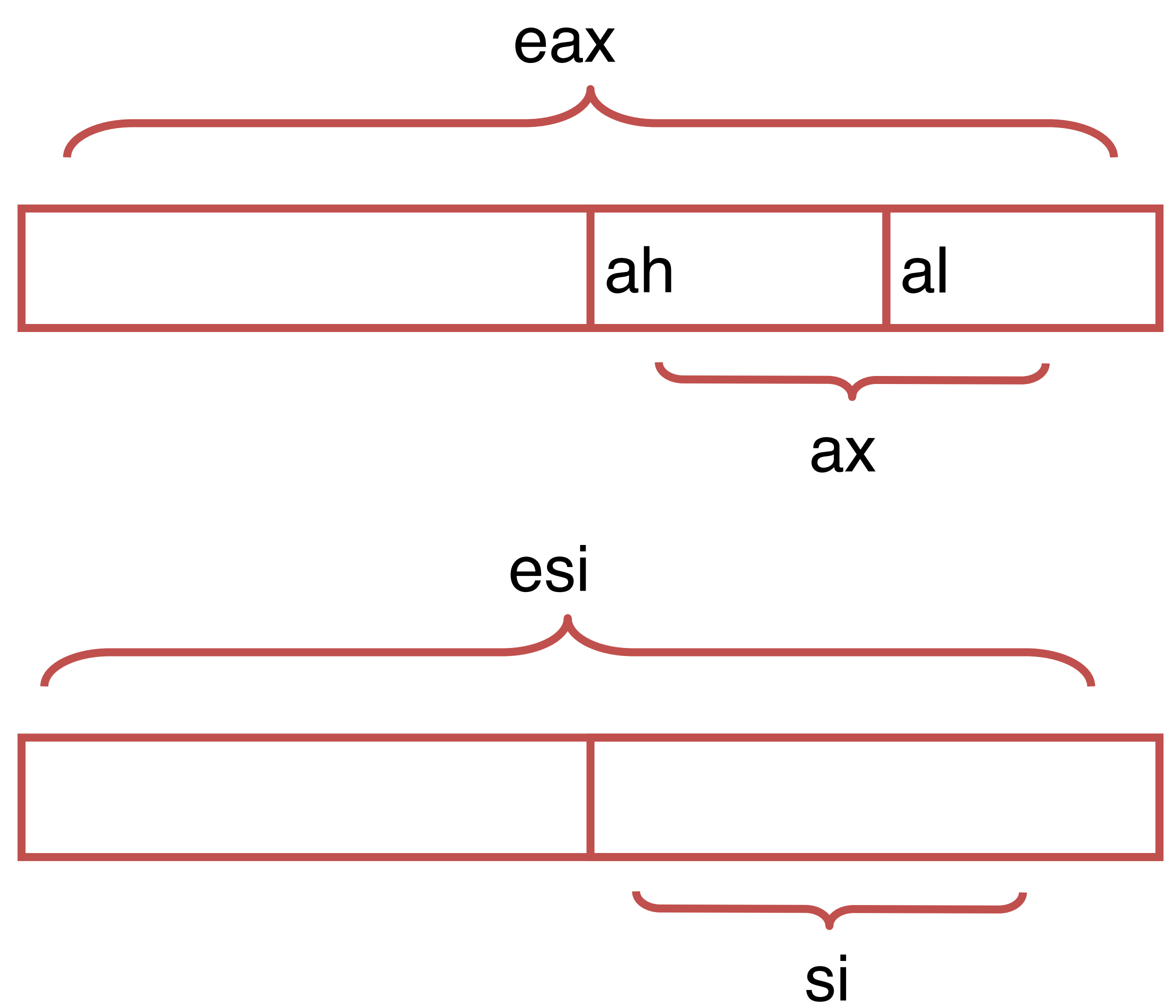
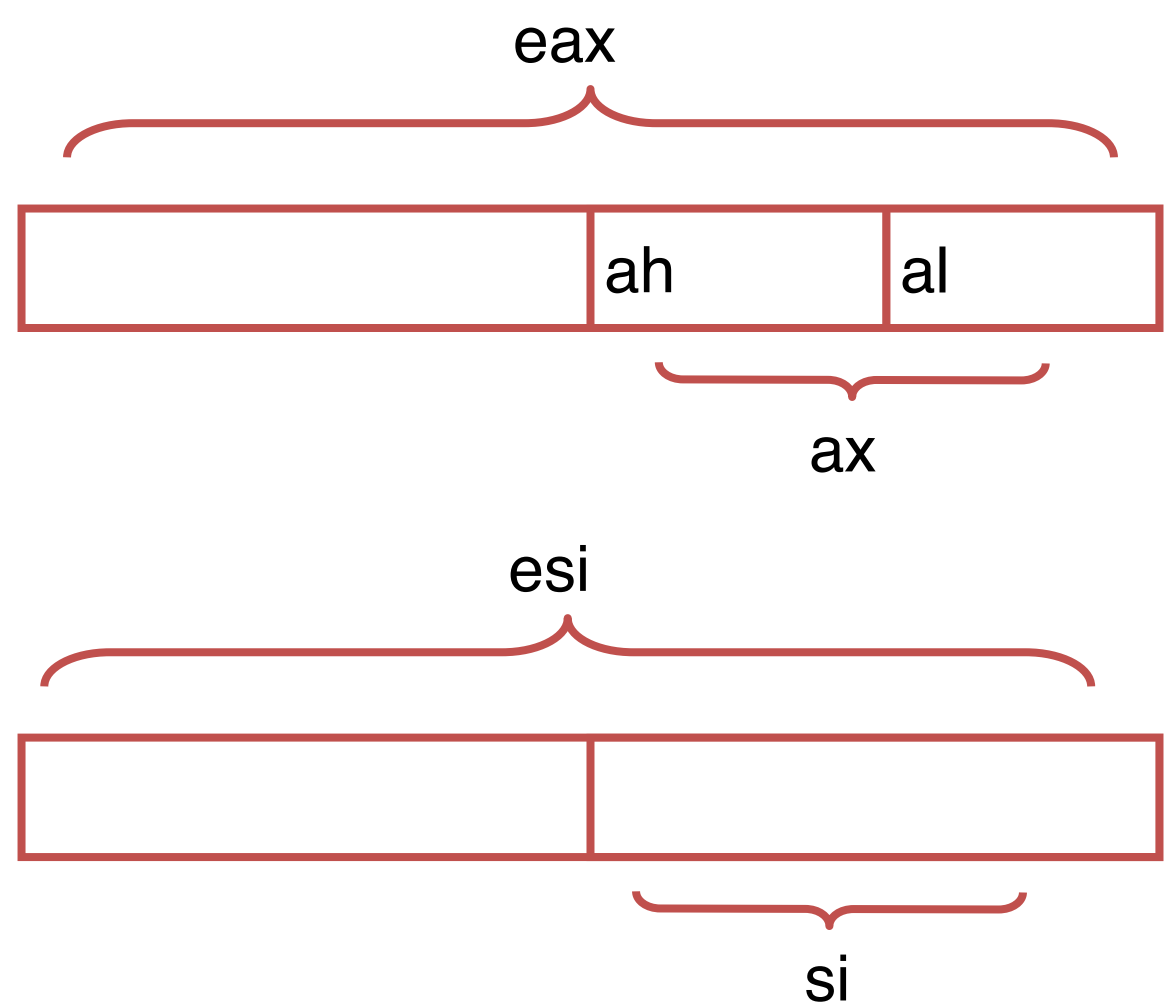


x86 Registers

- Two registers are used for high-speed memory transfer operations
  - esi/si (source), edi/di (destination)
- There are several 32-bit special purpose registers
  - esp/sp: the stack pointer
  - ebp/bp: the frame pointer



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- Floating point units and mmx/xmm registers

Data Sizes

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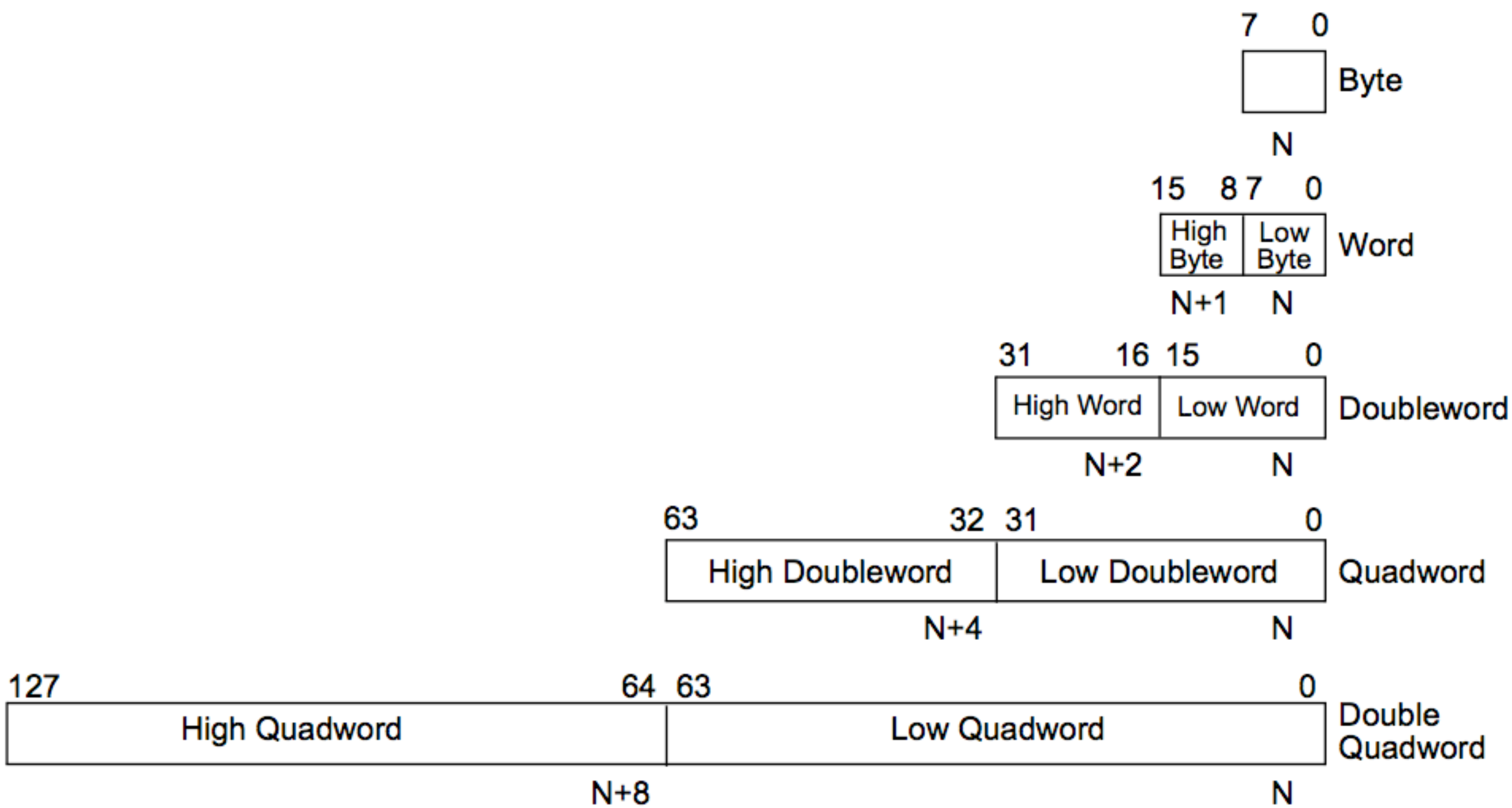

7
0
Byte
N
15
8 7
0
High Byte
Low Byte
Word
N+1
N
31
16 15
0
High Word
Low Word
Doubleword
N+2
N
63
32 31
0
High Doubleword
Low Doubleword
Quadword
N+4
N
127
64 63
0
High Quadword
Low Quadword
Double Quadword
N+8
N

x86 Assembly Language

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- Program is made of:
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    - jmp 0x08048f3f
- Two possible syntaxes, with different ordering of the operands!
  - AT&T syntax (objdump, GNU Assembler)
    - mnemonic source, destination
  - DOS/Intel syntax (Microsoft Assembler, Nasm, IDA Pro)
    - mnemonic destination, source
  - In gdb can be set using: set disassembly-flavor intel/att

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  mystr      DB "foo", 0                  # Null-terminated string
```

Addressing Memory

Addressing Memory

- Memory access is composed of width, base, index, scale, and displacement
  - Base: starting address of reference
  - Index: offset from base address
  - Scale: Constant multiplier of index
  - Displacement: Constant base
  - Width: (address suffix)
    - size of reference (b: byte, s: short, w: word, l: long, q: quad)
  - Address = base + index*scale + displacement
    - AT&T Syntax —> displacement(base, index, scale)
  - Example:
    - movl -0x20(%eax, %ecx, 4), %edx

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  - copies the value 0x804a0e4 into ebx
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  - copies the content of memory at address 0x804a0e4 into eax

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- Control transfer
  - jmp, call, ret, int, iret
  - Values can be compared using the cmp instruction
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- Misc
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- Linux/x86
  - int 0x80
    - eax contains the system call number

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Acknowledgments/References (1/2)

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