von Neumann and the Current Computer Security Landscape

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This talk

- Overview of the von Neumann computer architecture
- Security implications
  - software vulnerabilities
  - limitations in detecting malware
  - defenses that play on the architecture

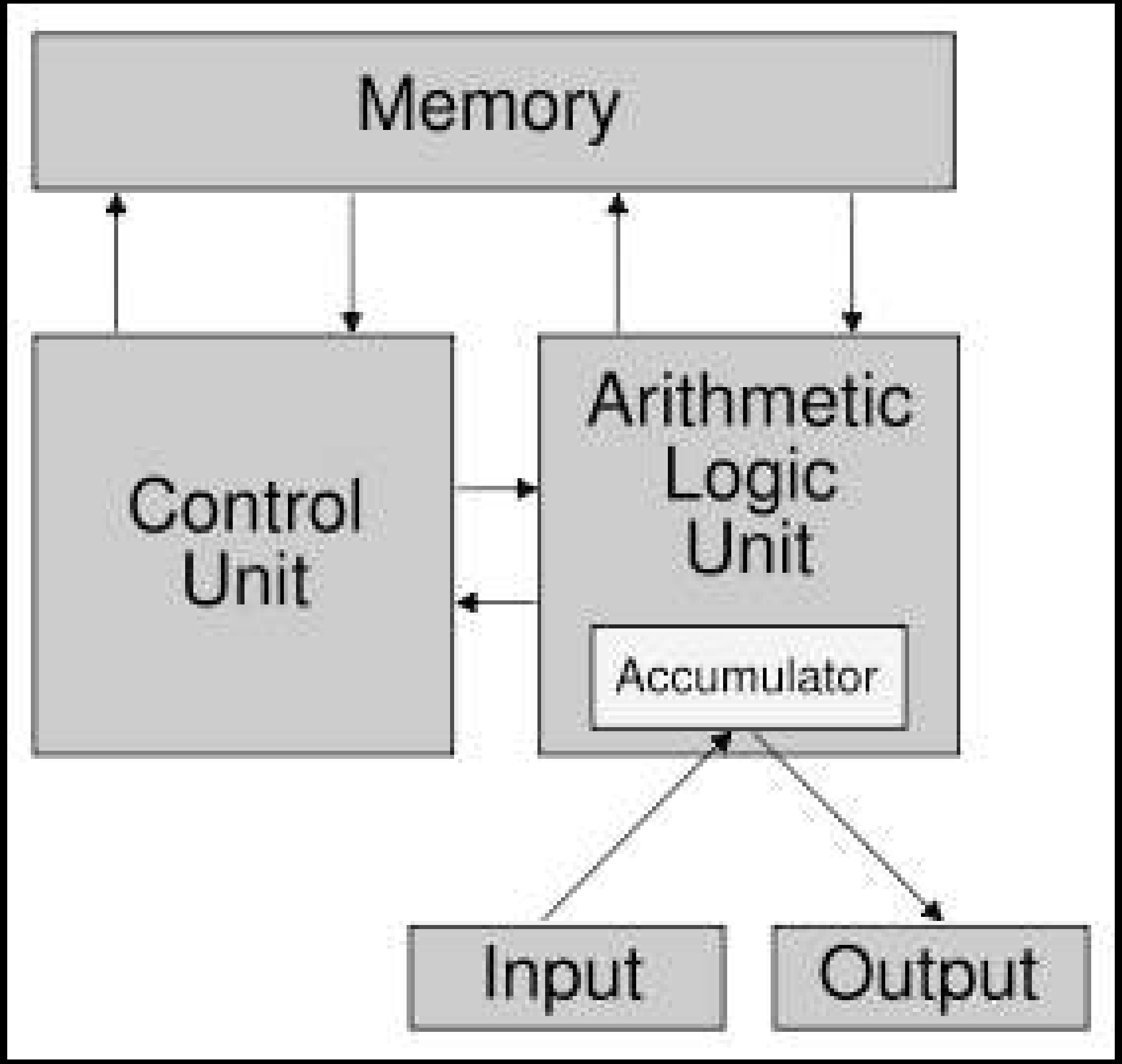
John von Neumann

John von Neumann 1903-1957

- Mathematician, instrumental in the developing
  - quantum mechanics
  - cellular automata
  - economics & game theory
  - nuclear physics
  - computer architecture

von Neumann architecture

- Unified memory for instructions and data
  - Contrast: Harvard architecture
  - Specified in tech report on EDVAC in 1945
    - Similar ideas floating previously
- Simplicity led to wide acceptance
  - Practically all modern computers based on this architecture



Corollary

- Code and data look "the same"
  - is 0x90 data or an x86 instruction?
- We must somehow differentiate between code and data
  - Program and/or OS must know
  - debugging is easy (or easier)

Corollary (2)

- Code can be treated as data
  - self-modifying code
  - dynamic code generation
  - debugging
- Code is treated as data
  - copy a program vs. run a program

Performance implications

- Performance bottleneck due to shared memory bus
  - “von Neumann bottleneck”
  - led to the development of caches, branch prediction, etc.
- For many years, this was the main issue

Implications for reliability

- Mistaking data and instructions leads to undefined behavior
  - CPU will try to execute data as instructions
    - for random data, this will cause exception (memory, opcode, etc.)
  - code-as-data can be modified
    - RO code pages to avoid mistakes

Implications for security

- What if random data is not random?
    - data is/contains code
    - code can be written by attacker
- Program will end up executing foreign code that will do the attacker's work
    - Privileges of program/user or of program source

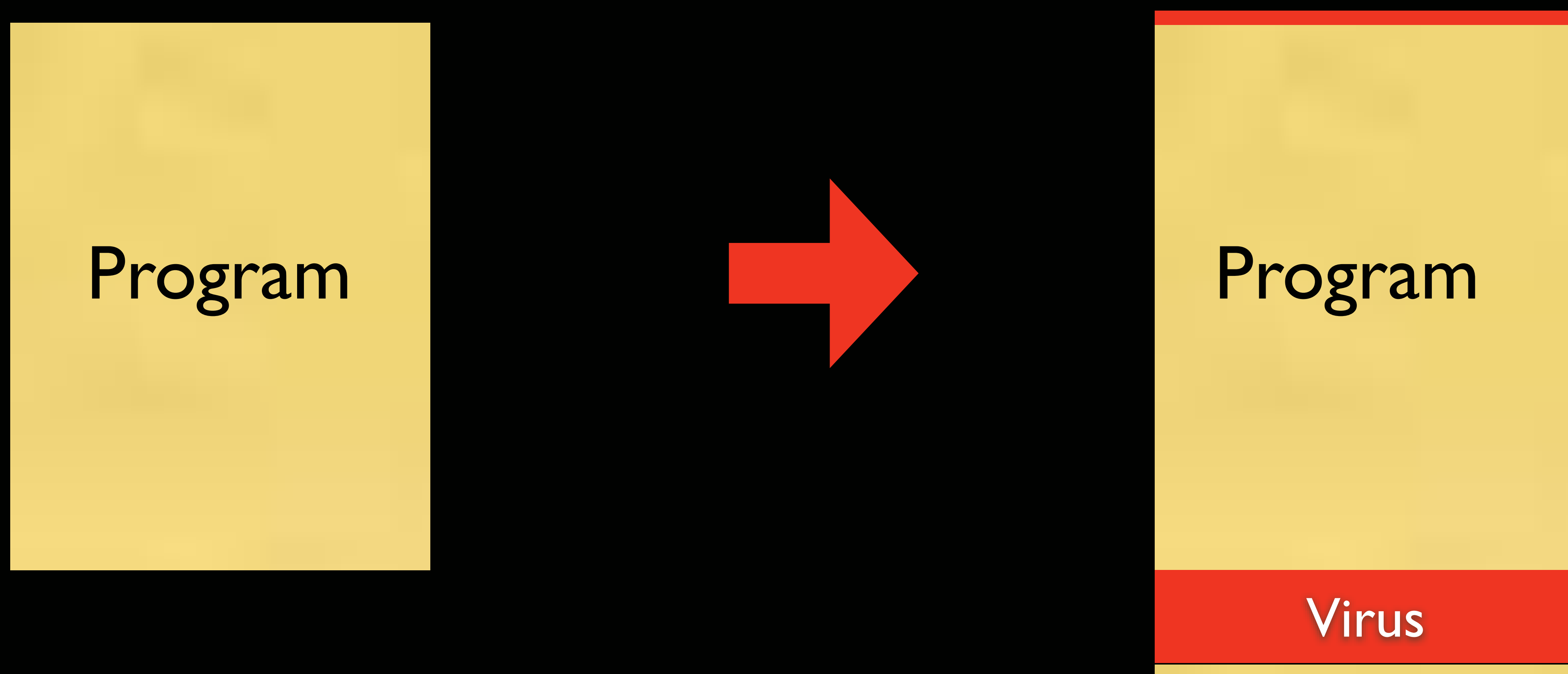
Security problems

- Viruses
- Detection of malware
- Code injection attacks
  - buffer overflows
  - SQL injection
  - Cross-site Scripting (XSS)

Viruses

- Self-propagating code
- First "large scale" outbreaks in 1981, for MS-DOS
  - infected executable files (.exe, .com)
  - treated code (programs) as data
    - modified binaries to insert themselves

Virus-infected file



Virus detection

- Anti-virus programs typically look for “signatures” (byte strings) of known viruses
  - prior to program execution, after download, incoming email attachments, etc.
- Attackers’ response: polymorphism

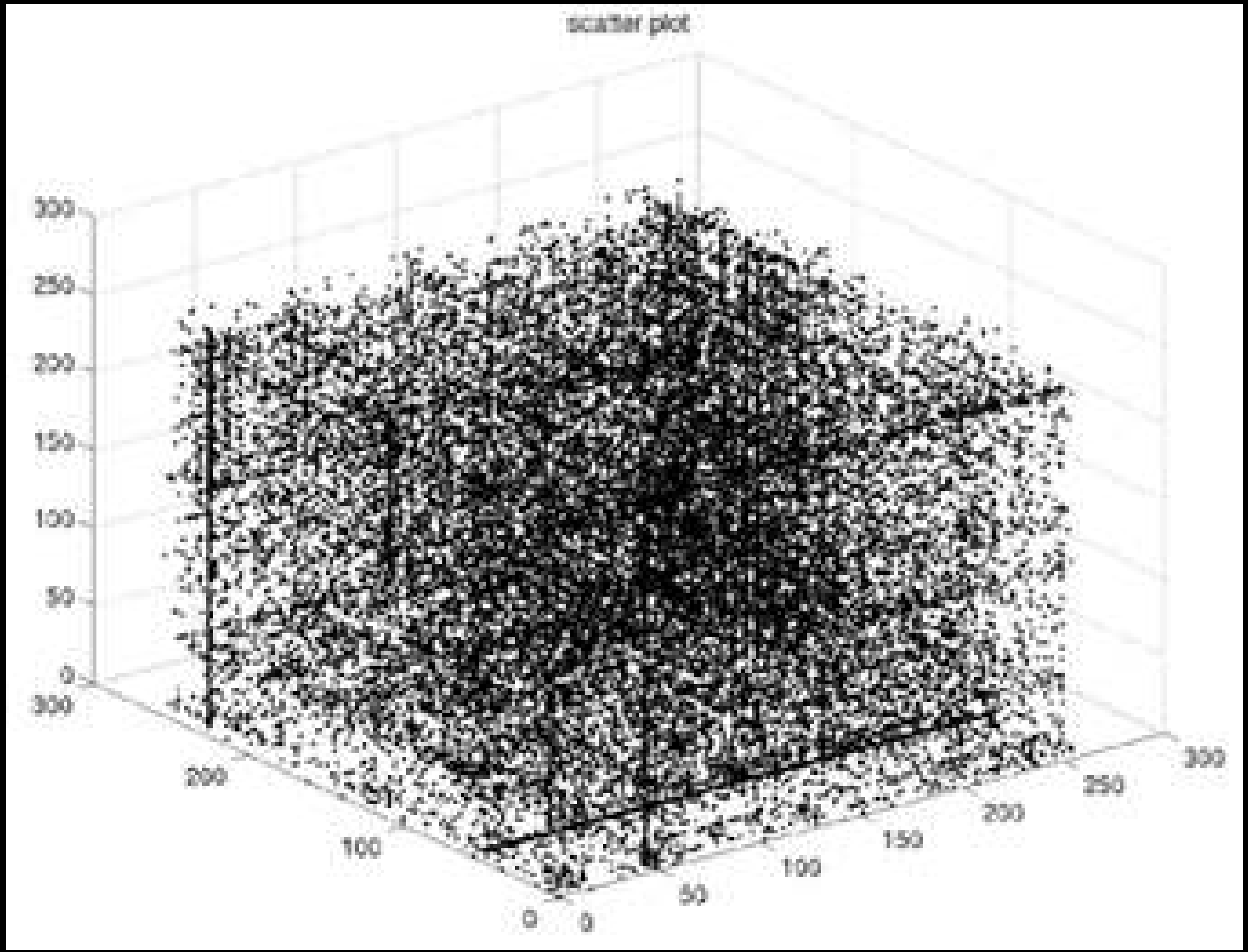
Polymorphism

- Two-part viruses
  - small first part (decoder) decrypts second part
  - second part contains main attack payload
- Signatures on second part are difficult/impossible
- Small decoder means signatures are likely to have false positives

```
address    byte values    x86 code
--------   ------------   -----------------
00000000   EB2D           jmp short 0x2f
00000002   59             pop ecx
00000003   31D2           xor edx,edx
00000005   B220           mov dl,0x20
00000007   8B01           mov eax,[ecx]
00000009   C1C017         rol eax,0x17
0000000C   35892FC9D1     xor eax,0xd1c92f89
00000011   C1C81F         ror eax,0x1f
00000014   2D9F253D76     sub eax,0x763d259f
00000019   0543354F48     add eax,0x484f3543
0000001E   8901           mov [ecx],eax
00000020   81E9FDFFFFFF   sub ecx,0xfffffffd
00000026   41             inc ecx
00000027   80EA03         sub dl,0x3
0000002A   4A             dec edx
0000002B   7407           jz 0x34
0000002D   EBD8           jmp short 0x7
0000002F   E8CEFFFFFF     call 0x2
00000034   FE             db 0xFE
...
payload follows
```

Polymorphism

- Increasing use in all kinds of malware
  - viruses, worms, trojans, etc.
  - self-extracting "packers"
- Attackers can create large numbers of decoders



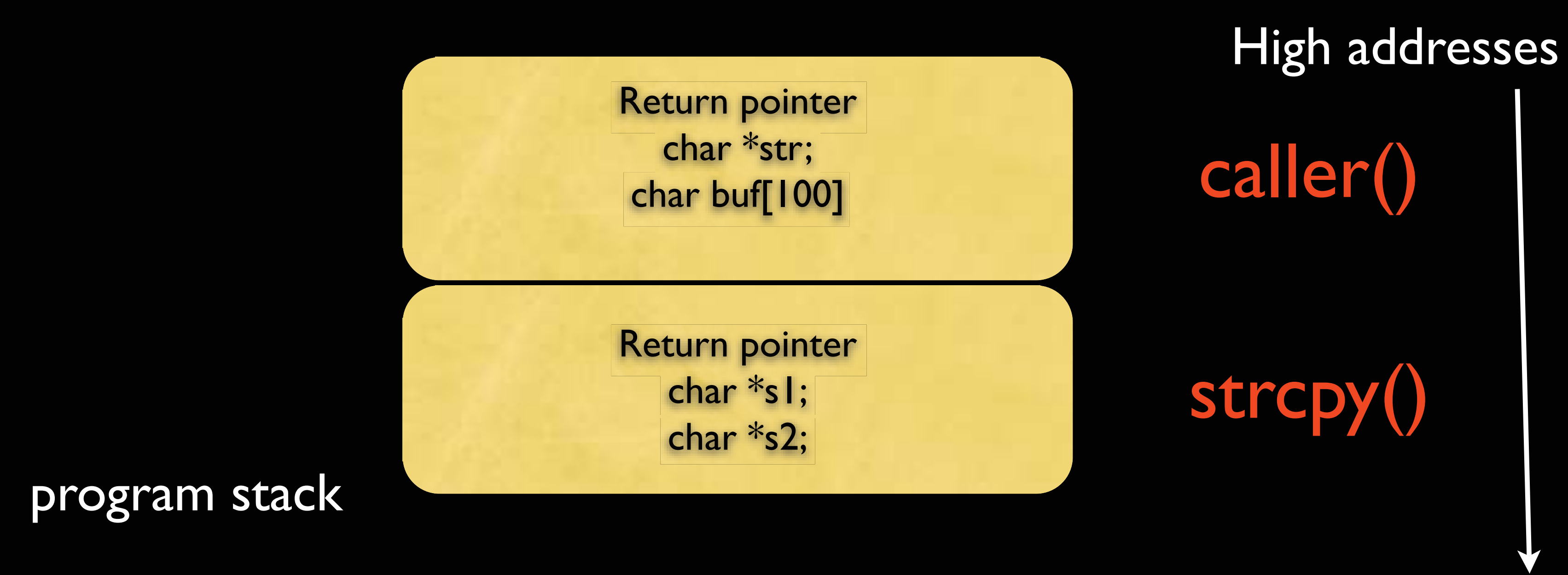
Code injection attacks

- Programs may be tricked into treating input data as code
  - data received over the network or otherwise supplied by an untrusted user
  - exploit weaknesses in input validation to overwrite control information

Buffer overflow attacks

- Specific instance of code injection in C/C++ (and similar languages)
    - function return address in function frame is overwritten with attacker-controlled data
    - same data contains attack code

```
caller(char *str) {
    char buf[100];
    strcpy(buf, str);
}
```



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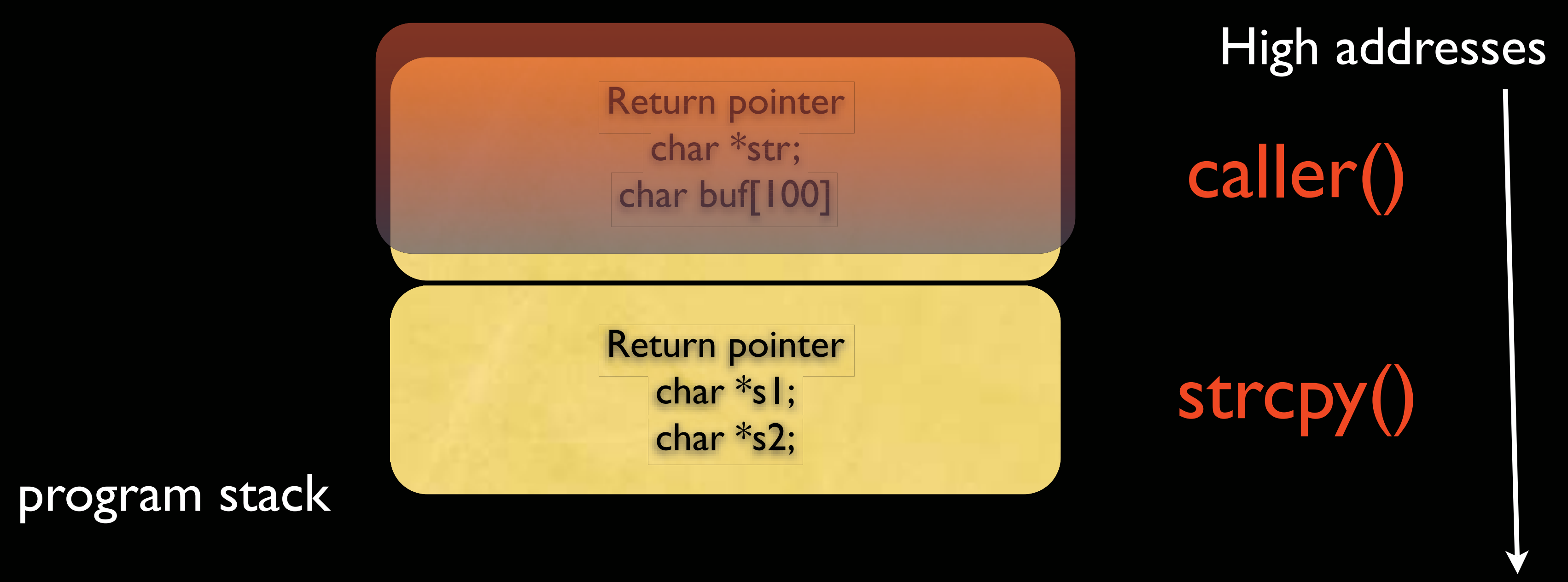


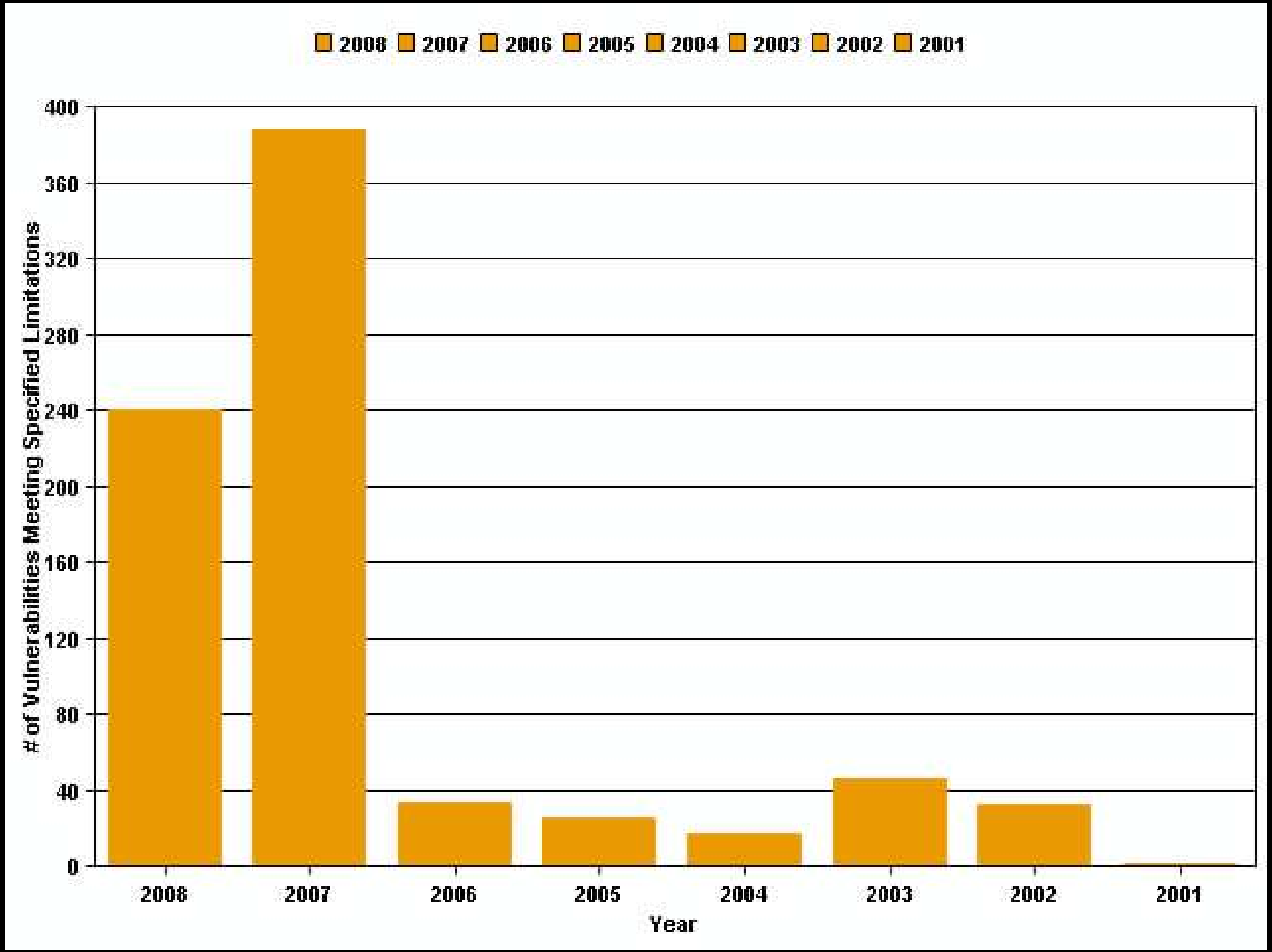
Note on buffer overflows

- There are many different variants
  - not all inject code
    - e.g., "return-into-libc" attacks
  - some compromise control data in other ways
- All end up subverting the control flow of the program to meet attacker's goals

Real problem

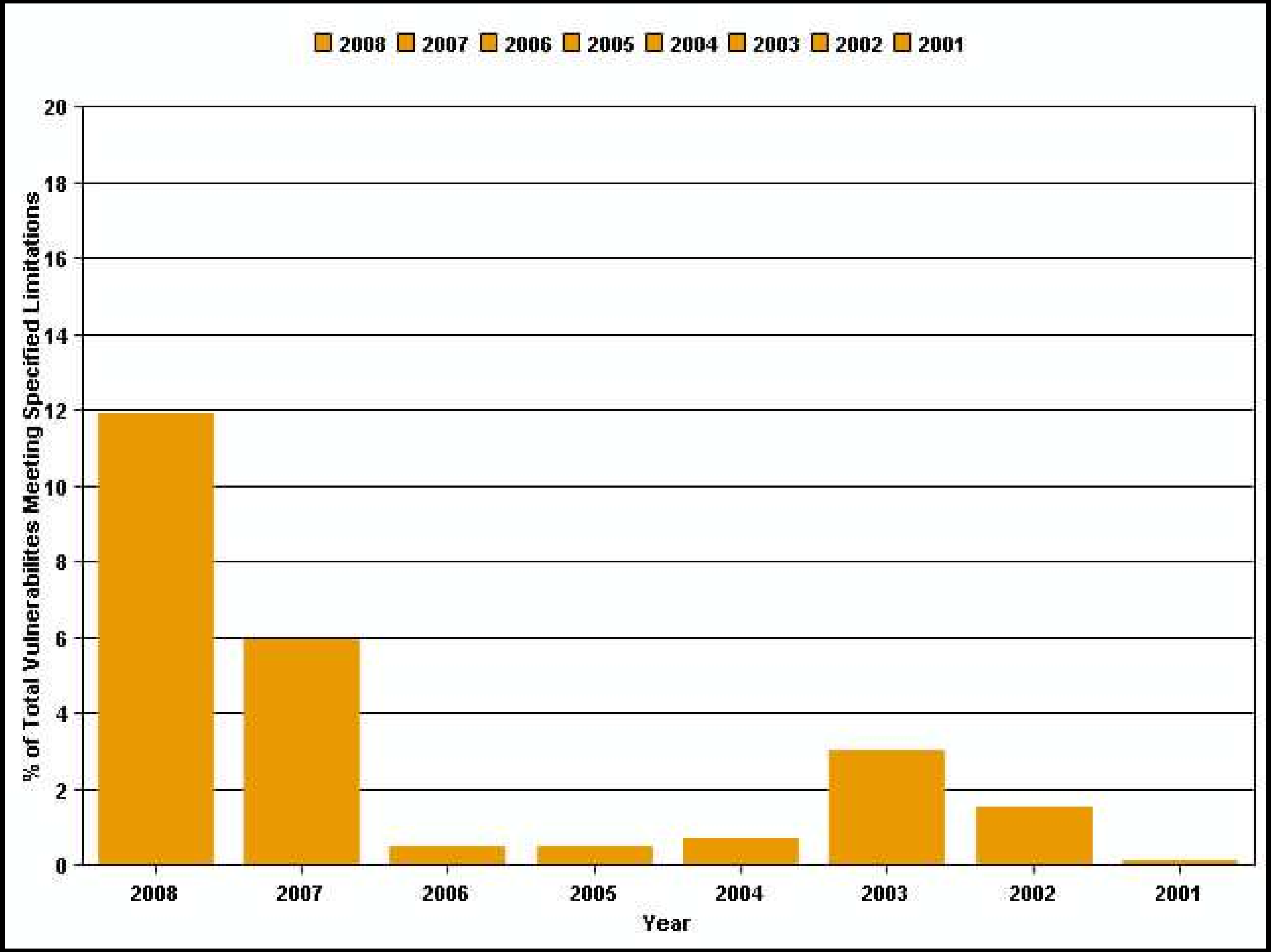
- Many vulnerabilities discovered daily on commercial and open-source software
  - enable remote compromise
  - typically also confer superuser privileges to attacker
  - enabling technology for fast-spreading worms

Buffer overflow prevalence

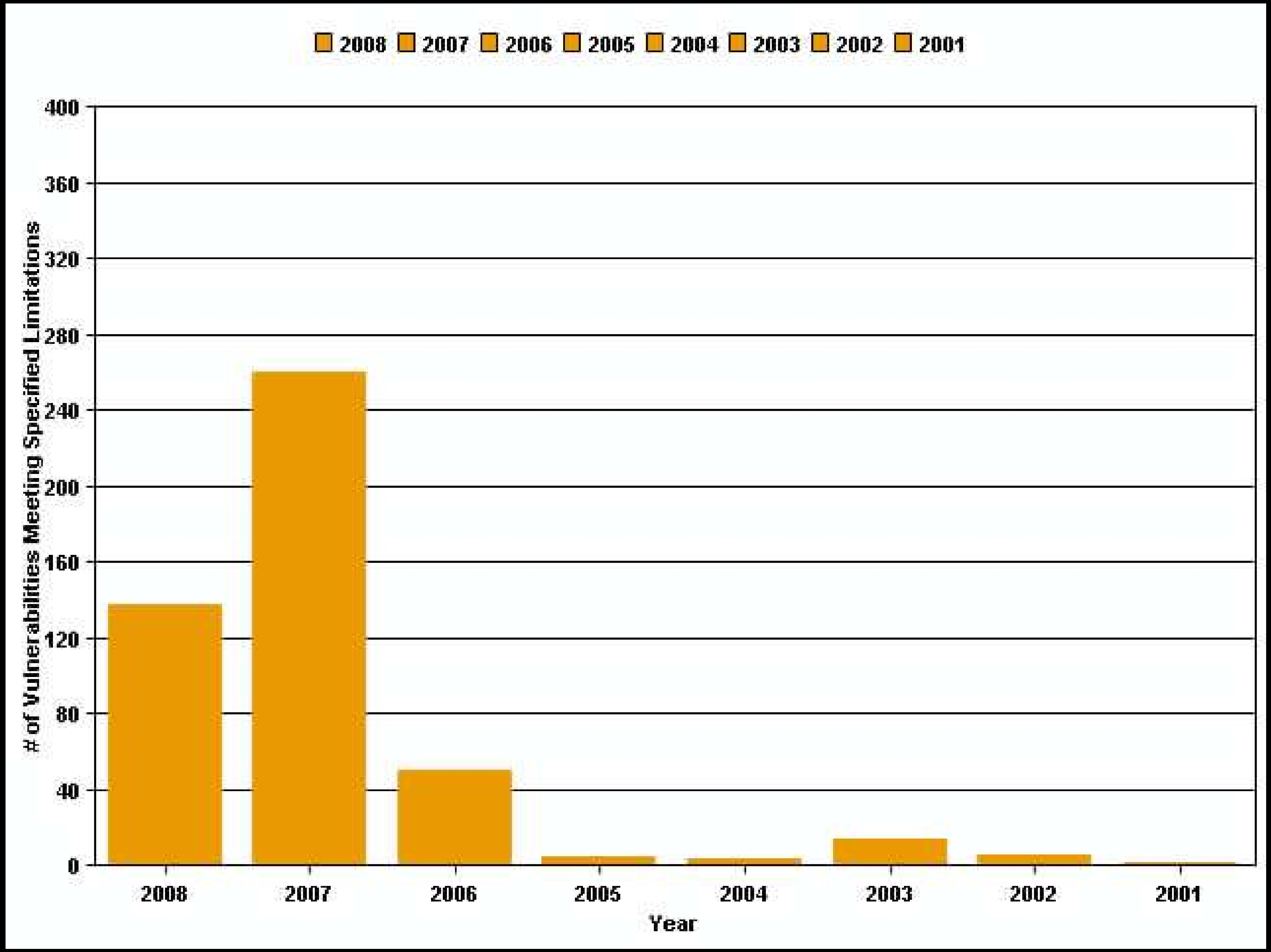


Source: NIST

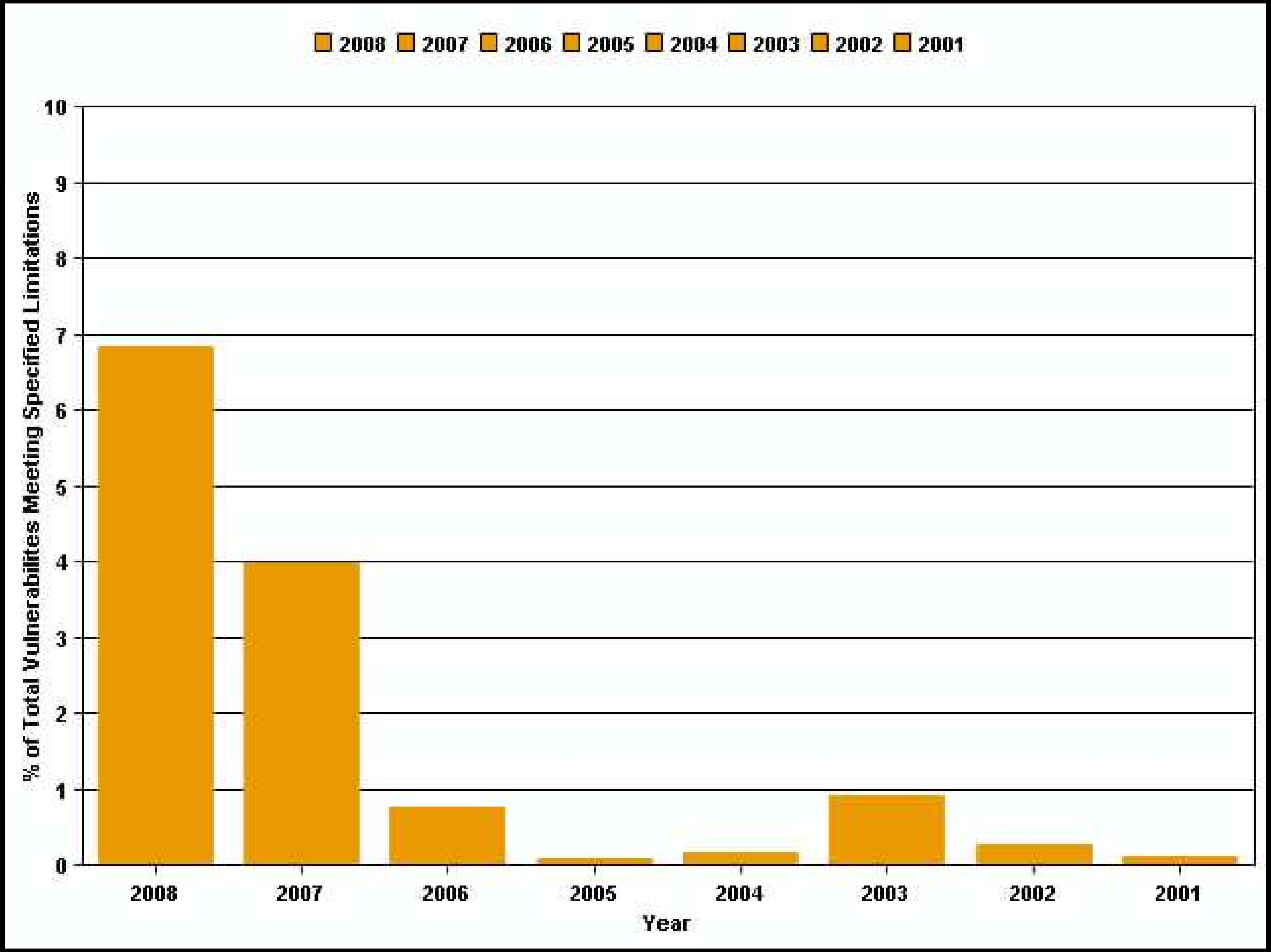
Buffer overflow prevalence



Code injection prevalence



Code injection prevalence



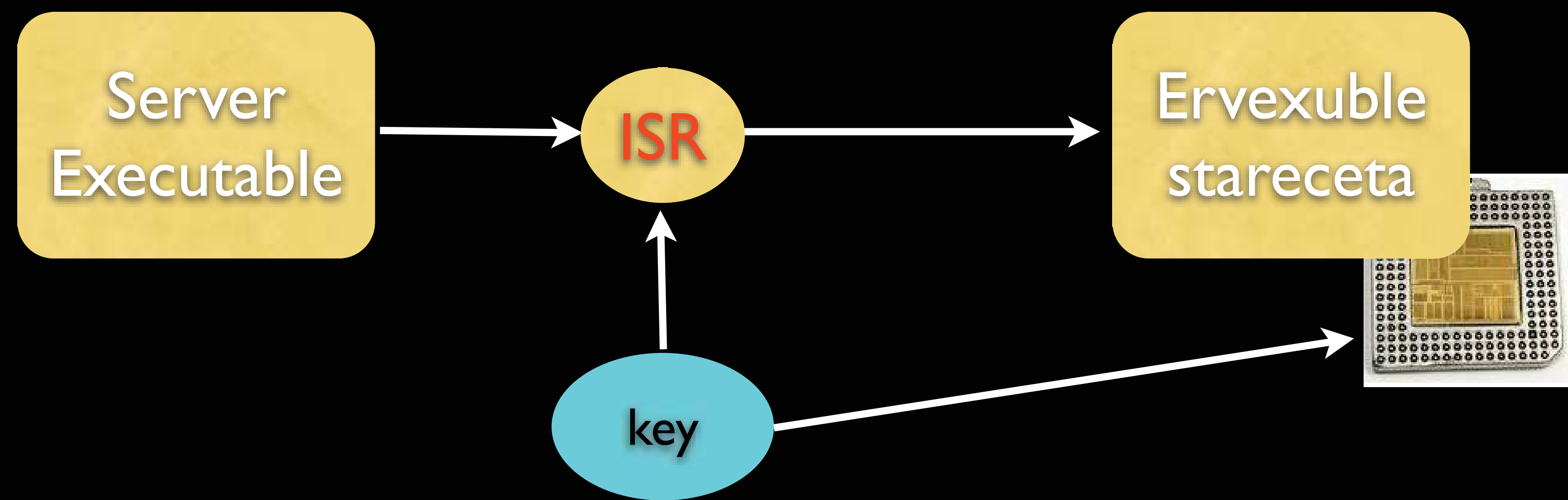
Defenses?

- Network and A/V-style defenses seem problematic (re: polymorphism)
- Drastic change (e.g., safe languages) is slow and difficult
- Move closer to the host/software
  - detect symptoms of attack
  - slow and difficult to scale defenses
- Model legitimate inputs rather than detect anomalous inputs
- Open area(s) of research and practice

Some interesting defenses

- Hardware support (NX bit)
- Secrecy-based separation
  - Instruction-Set Randomization
  - Address Space Obfuscation

ISR



Randomization

Randomization

```
0x08048262 <foobar+122>:   add    $0x10,%esp
0x08048265 <foobar+125>:   mov    0x8(%ebp),%eax
0x08048268 <foobar+128>:   mov    0x8(%ebp),%edx
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code_slice XOR 0xA7 produces:

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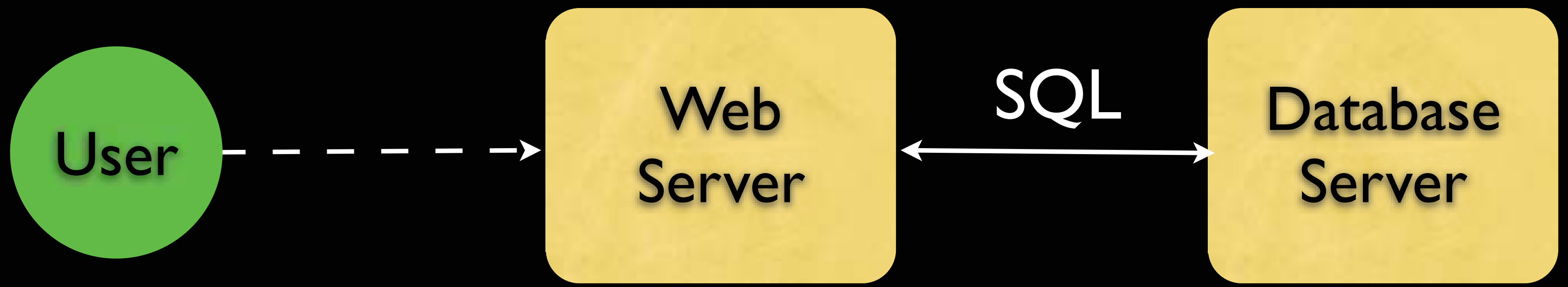
code_slice XOR 0xA7 produces:

```
0x08048262 <foobar+122>:   and    $0x63,%al
0x08048264 <foobar+124>:   mov    $0x2c,%bh
0x08048266 <foobar+126>:   loop   0x8048217 <foobar+47>
0x08048268 <foobar+128>:   sub    $0xf2,%al
0x0804826a <foobar+130>:   scas   %es:(%edi),%eax
0x0804826b <foobar+131>:   sub    $0xb5,%al
0x0804826d <foobar+133>:   and    $0x65,%al
0x0804826f <foobar+135>:   lods   %ds:(%esi),%eax
0x08048270 <foobar+136>:   cs
```

SQL injection

- Code injection attacks are not limited to binaries

```
SELECT * from items
where customer_name='$USERNAME';
```



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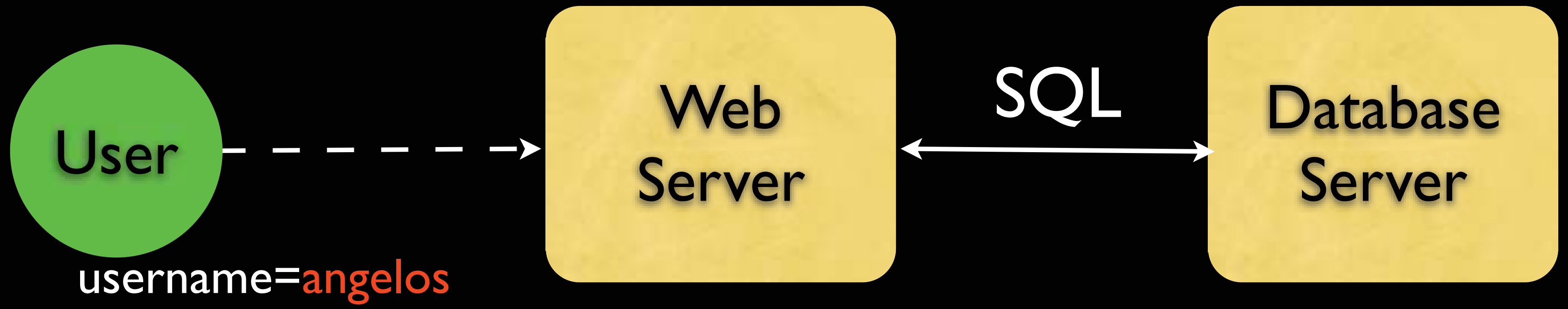

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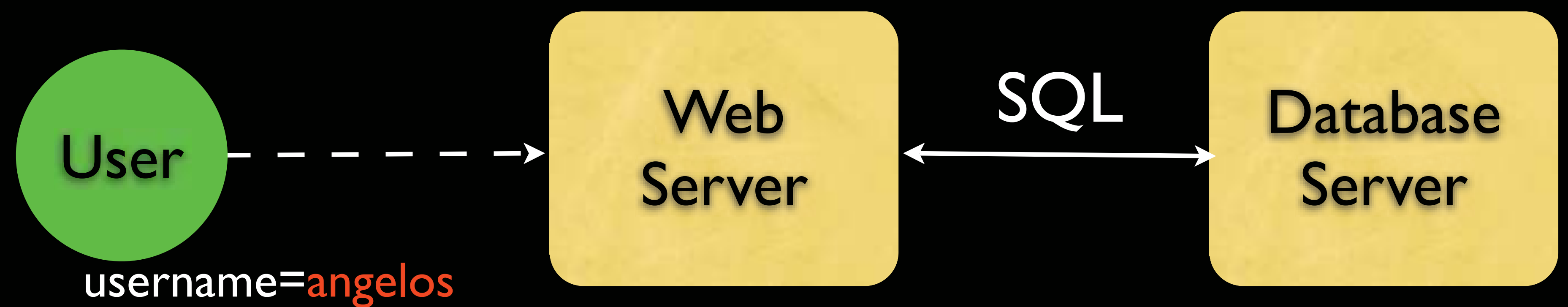

SELECT * from items
where customer_name='angelos';

SQL injection

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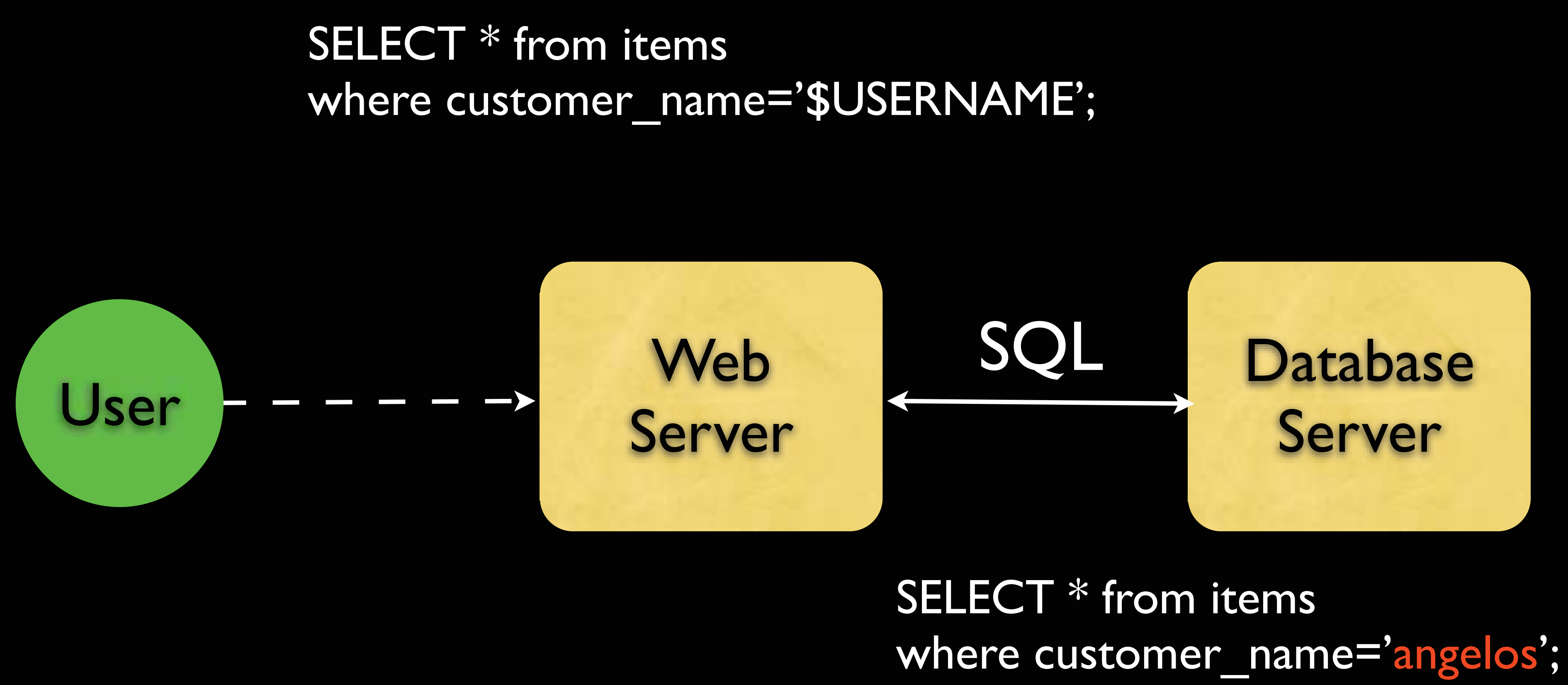

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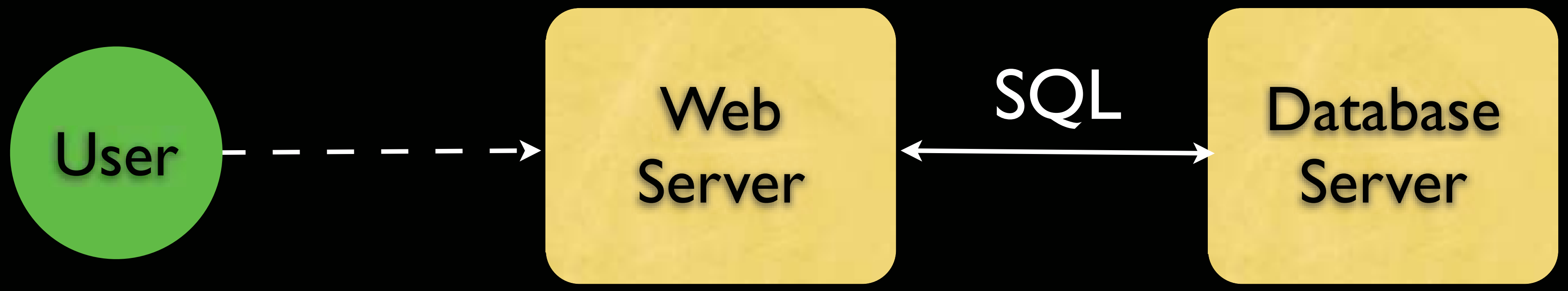

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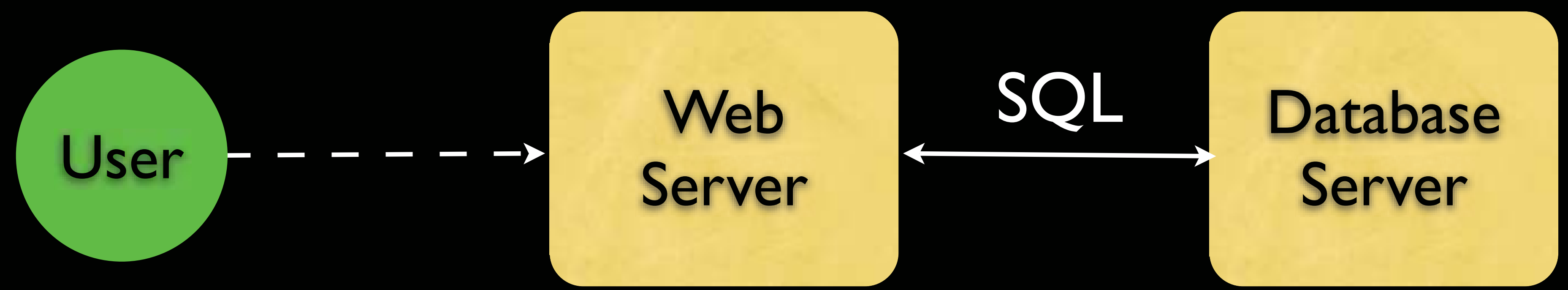

username=' or username is not null
or username = '

SQL injection

- *Code injection attacks are not limited to binaries*

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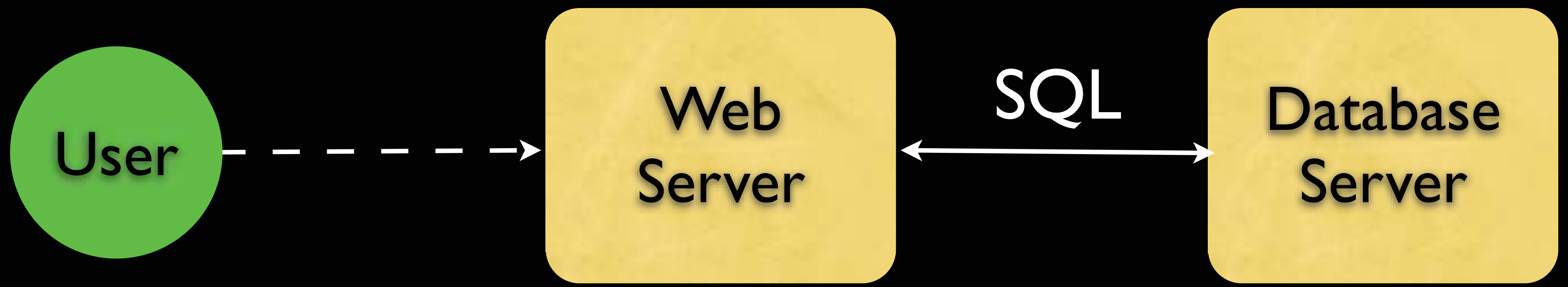


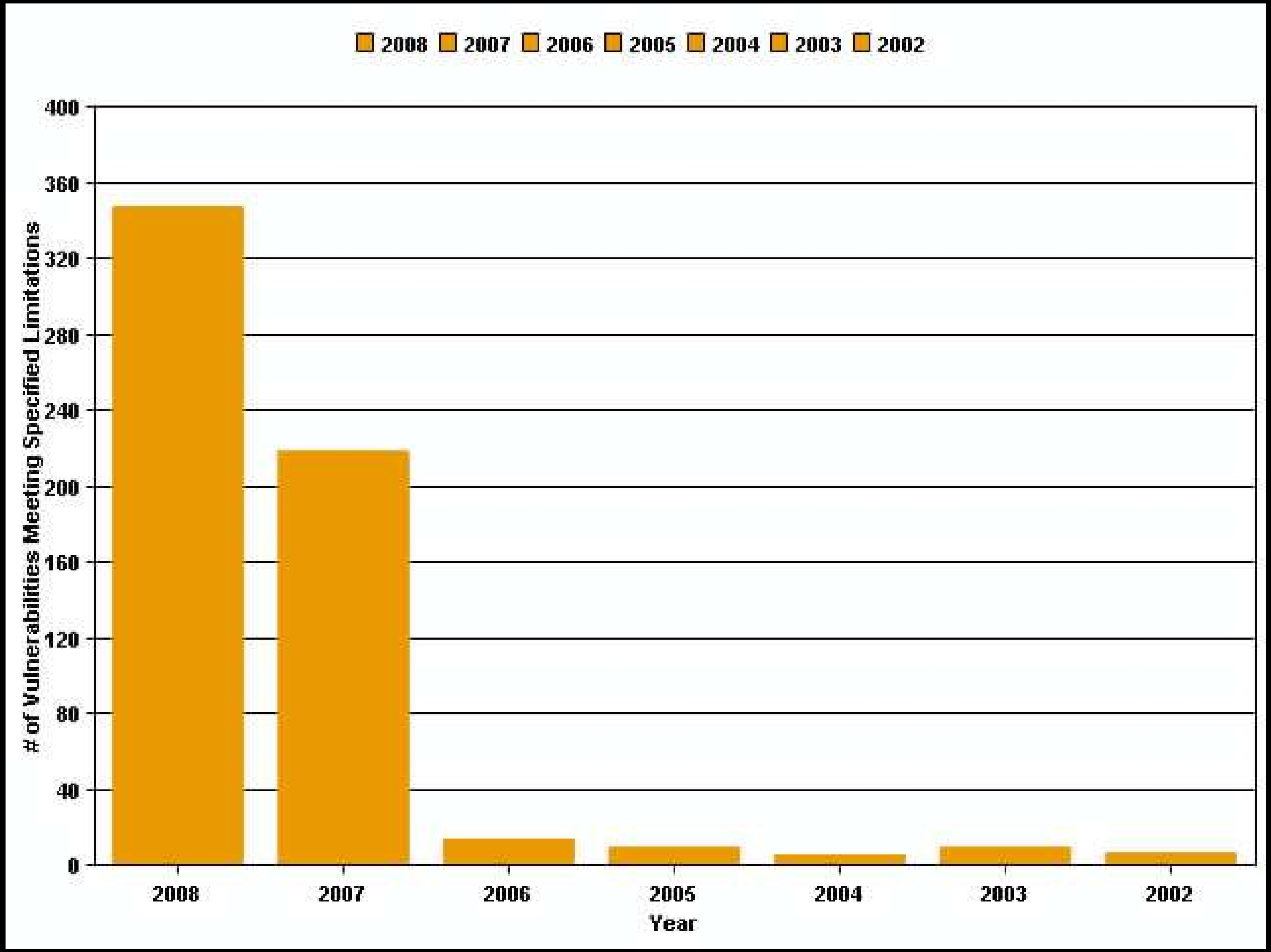
username=' or username is not null
or username = '

SELECT * from items
where customer_name='' or
username is not null or
username = '';

Significance

- Another instance of mixing data and code
  - not direct result of von Neumann architecture
  - result of decades of mentally ignoring the difference between code and data

SQL injection prevalence



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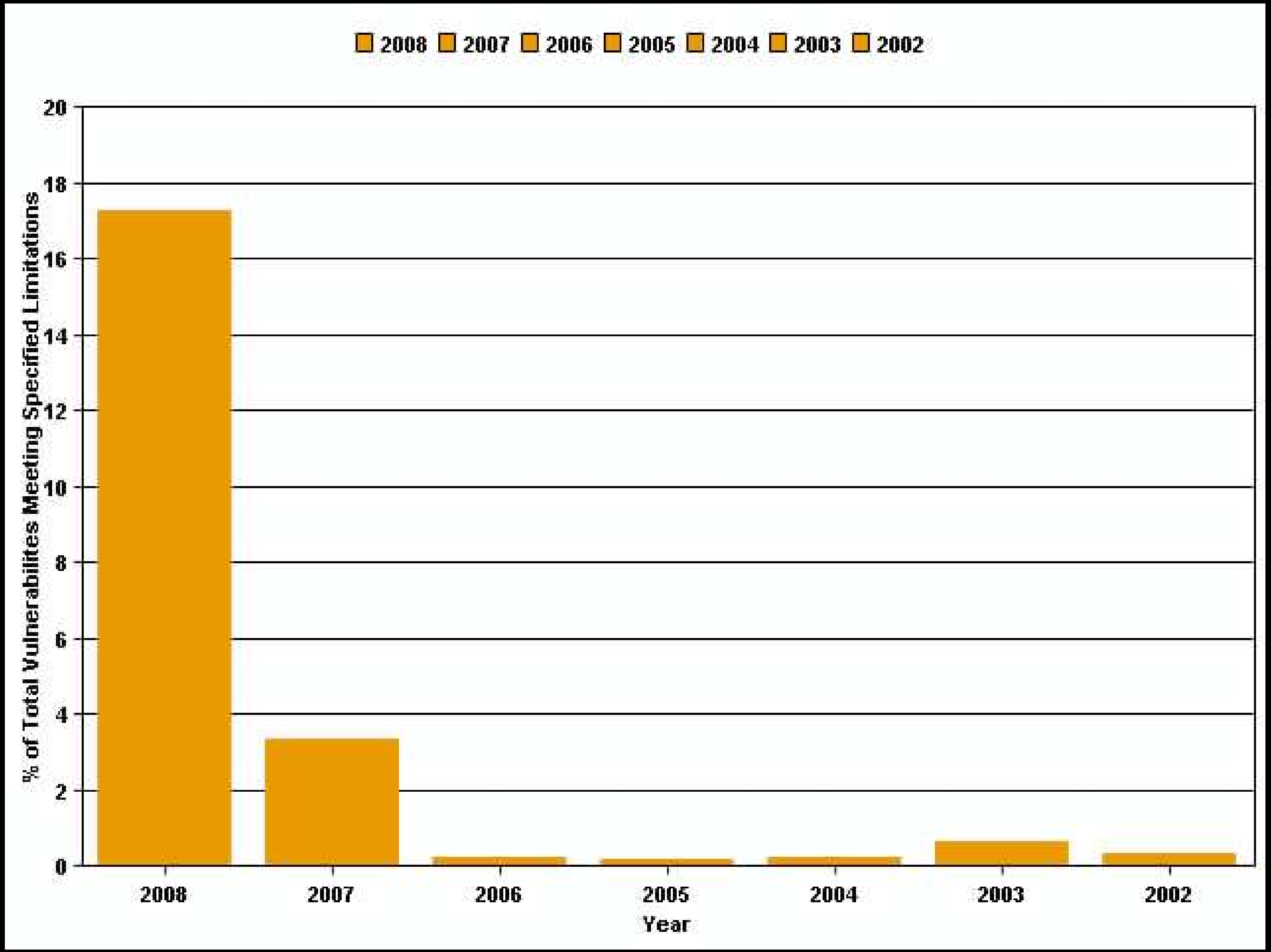


Command injection

- The problem does not end with SQL injection
  - any interpreted language that receives untrusted input is susceptible
    - PHP, Perl, shell script, ...

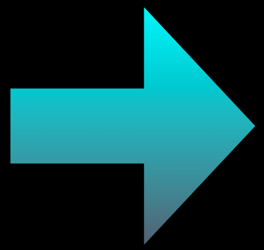
Taint tracking

- Modify runtime environment (e.g., Perl interpreter) to track use of data from untrusted sources
  - alert/stop if such data is used in sensitive operations
- Variant for use with binaries
  - use emulation or hardware support
    - very slow

SQL randomization

- Apply randomization to SQL templates
  - Parameterize all keywords and operators

```
select gender, avg(age)
from cs101.students
where dept = %d
group by gender
```



```
select123 gender, avg123 (age)
from123 cs101.students
where123 dept =123 %d
group123 by123 gender
```

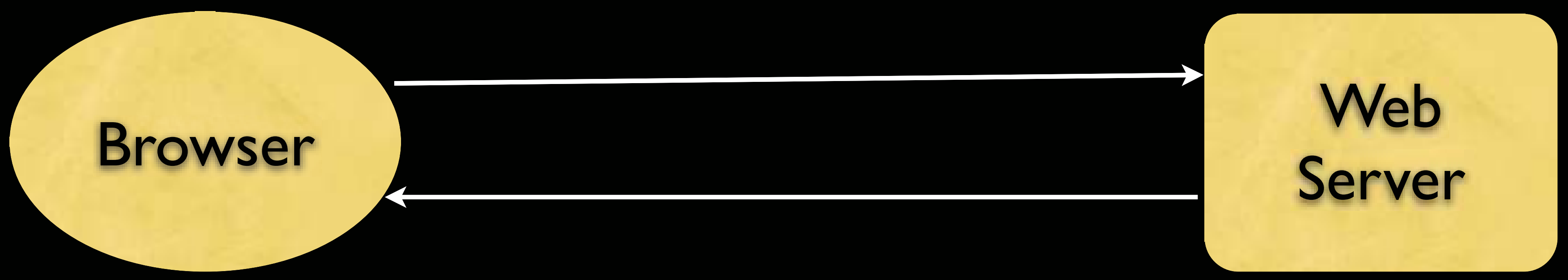
- Use de-randomizing proxy between client application and DBMS

Cross-Site Scripting (XSS)

- Web-oriented class of vulnerabilities
- Bypasses browser security sandbox
  - convinces browser (and user) that source of program is different (trusted?) site
- Programs are typically Javascript
  - can be other active content

How does it work?

- Some servers will mirror input from the URL in the returned page
  - error pages, naive applications, etc.
- Browsers don't know the provenance of data in a returned page



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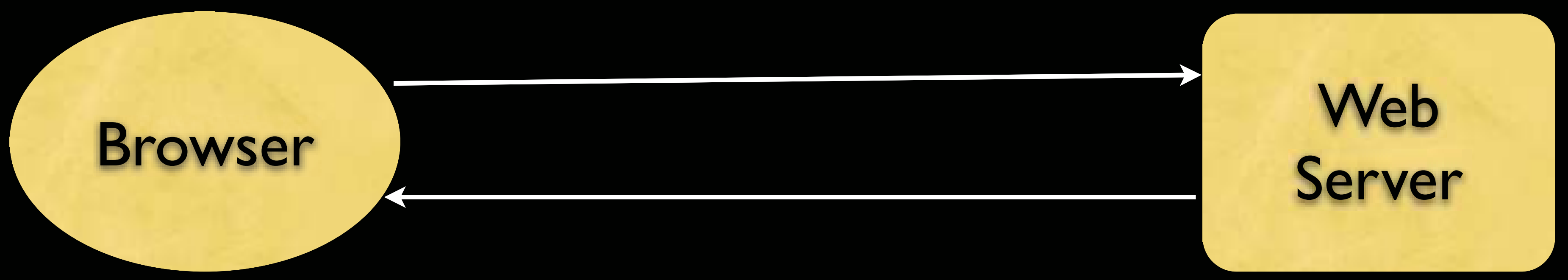

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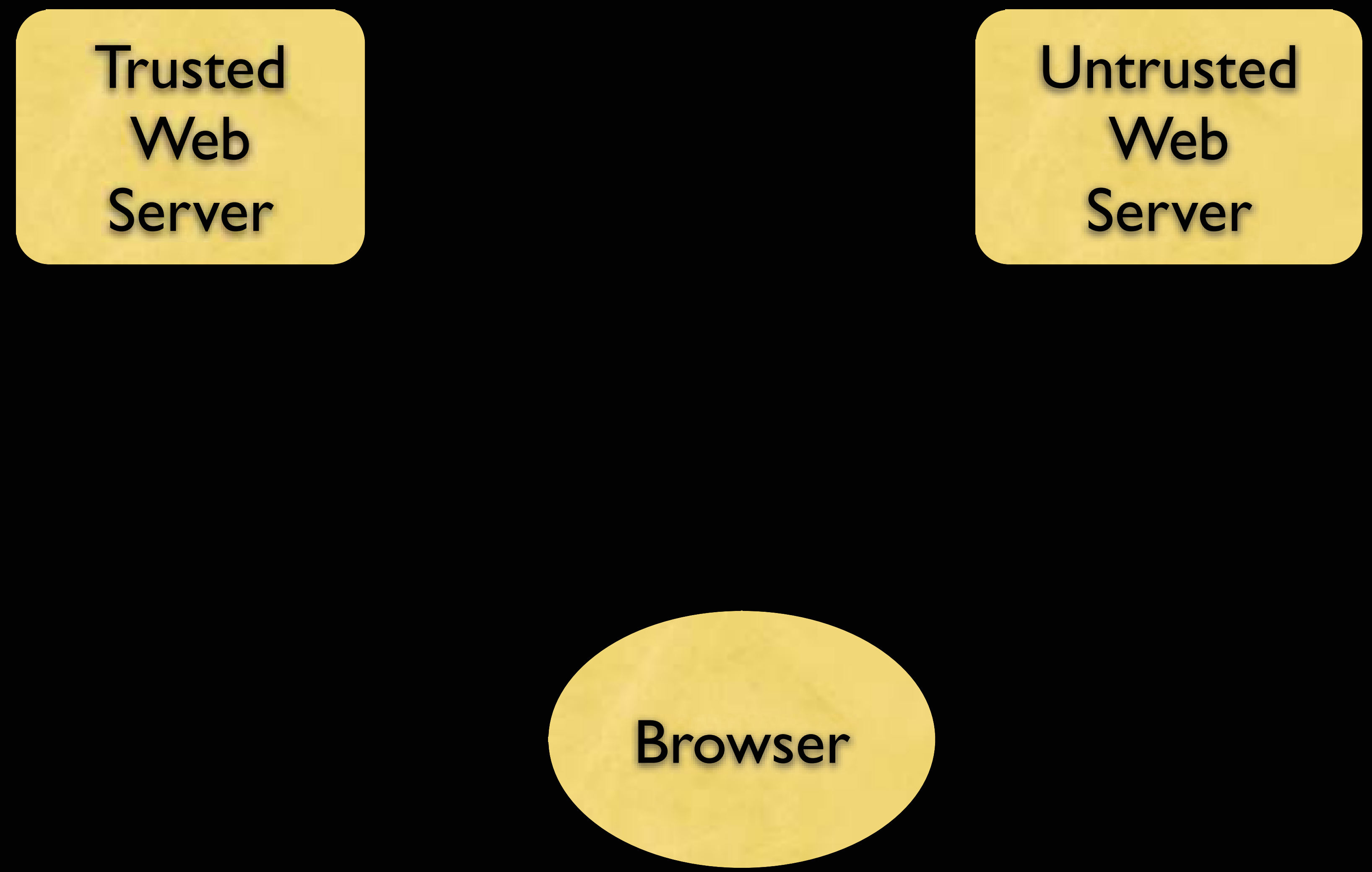
XSS in operation



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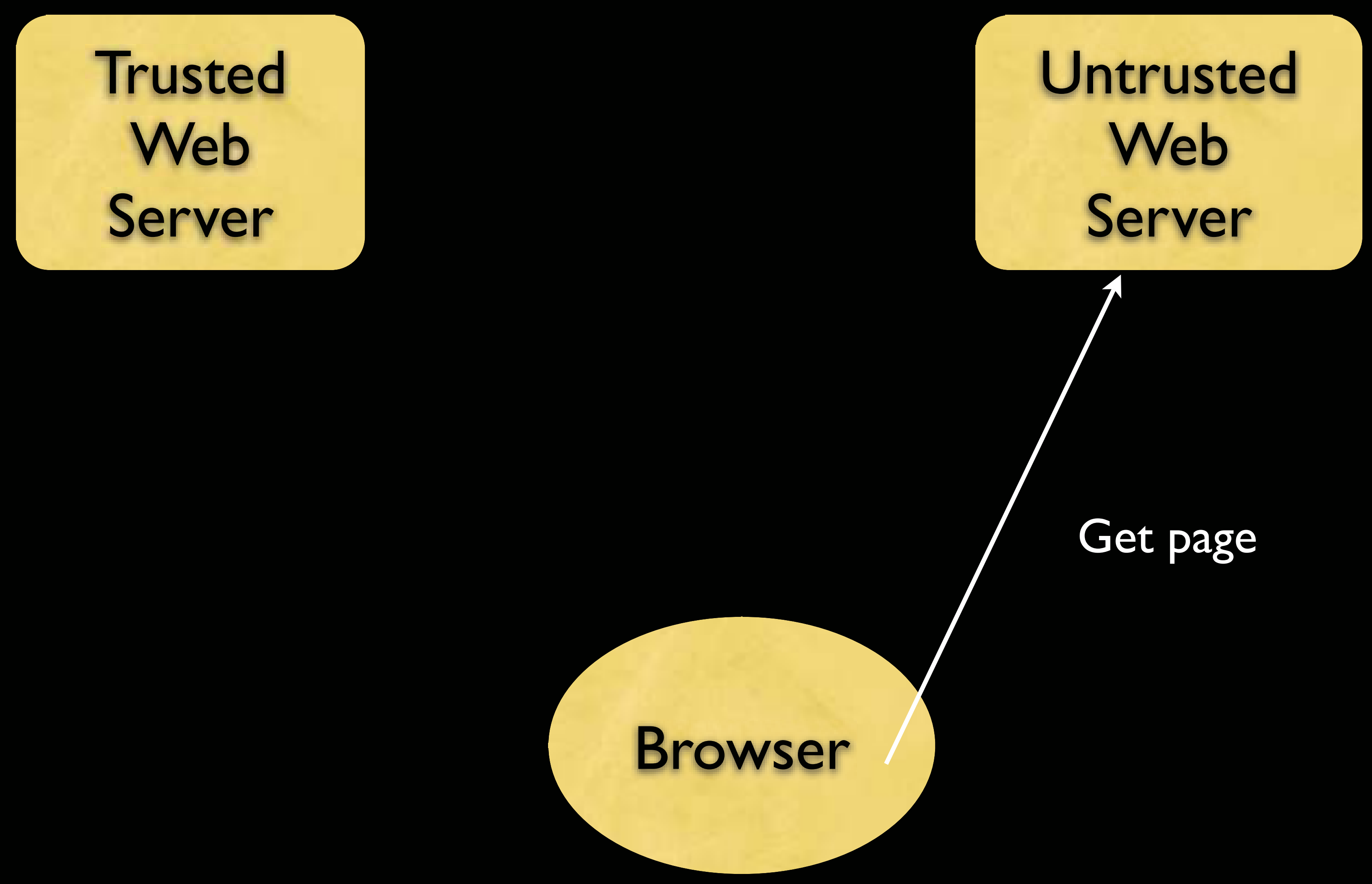

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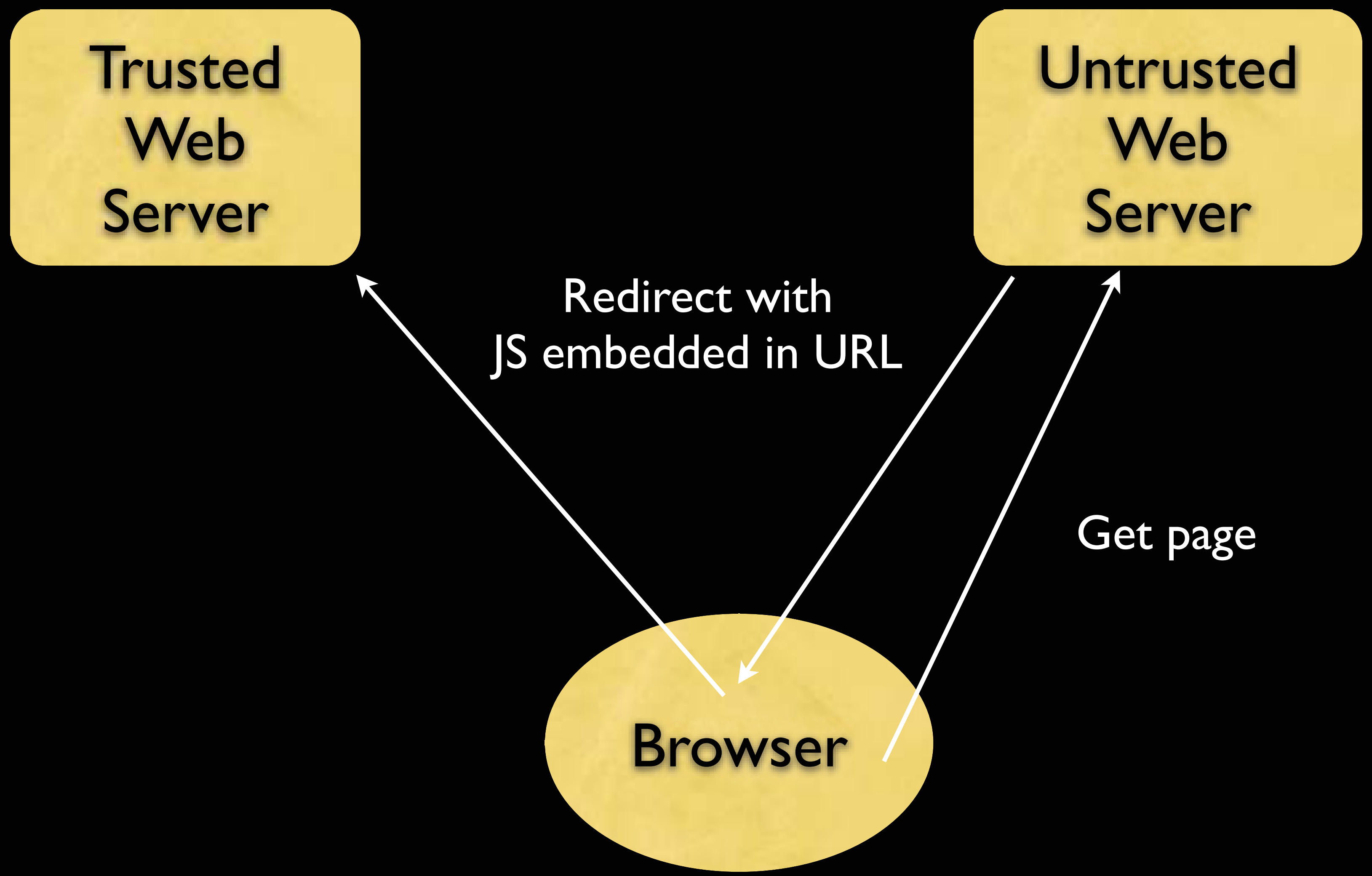

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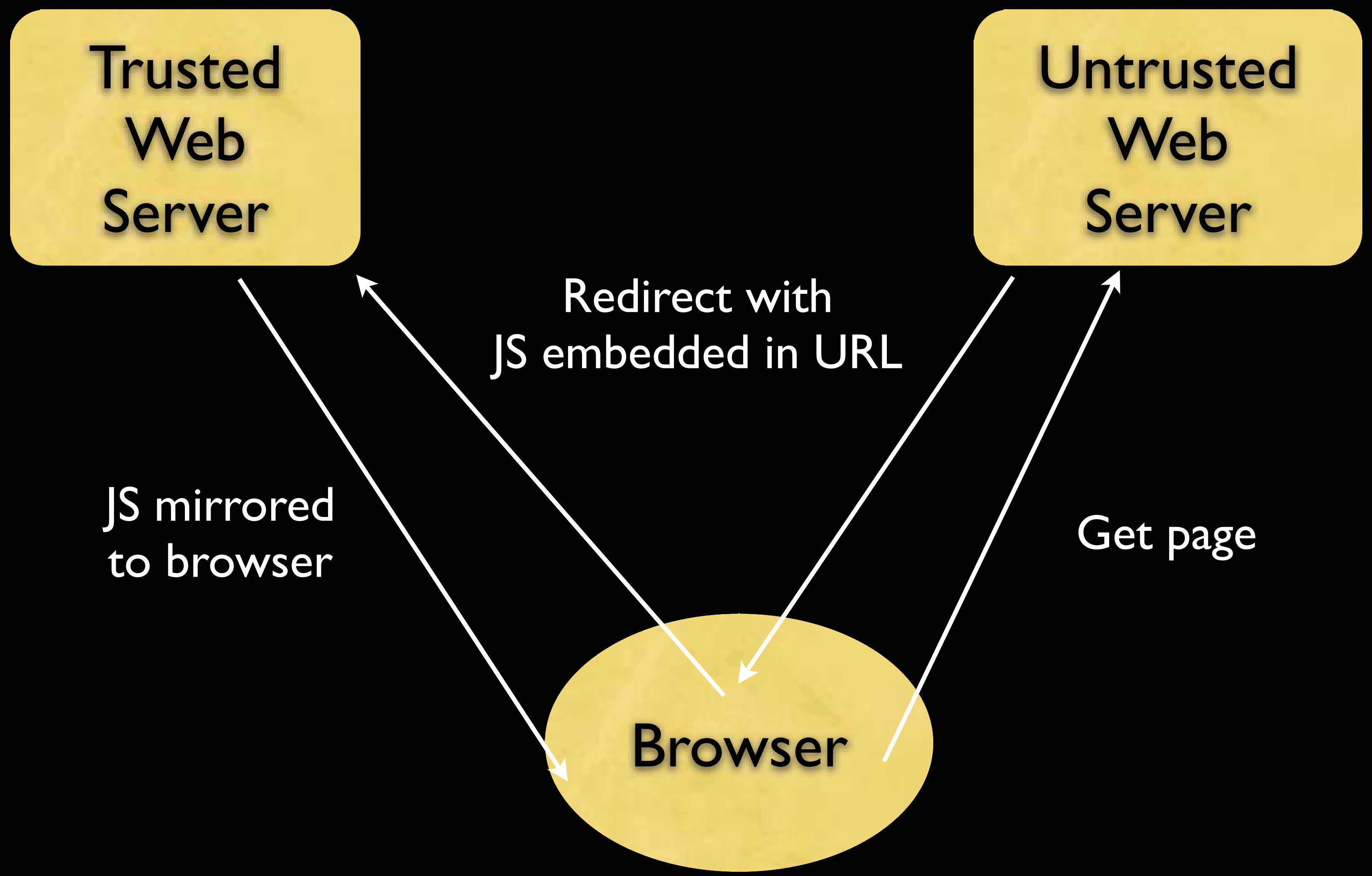
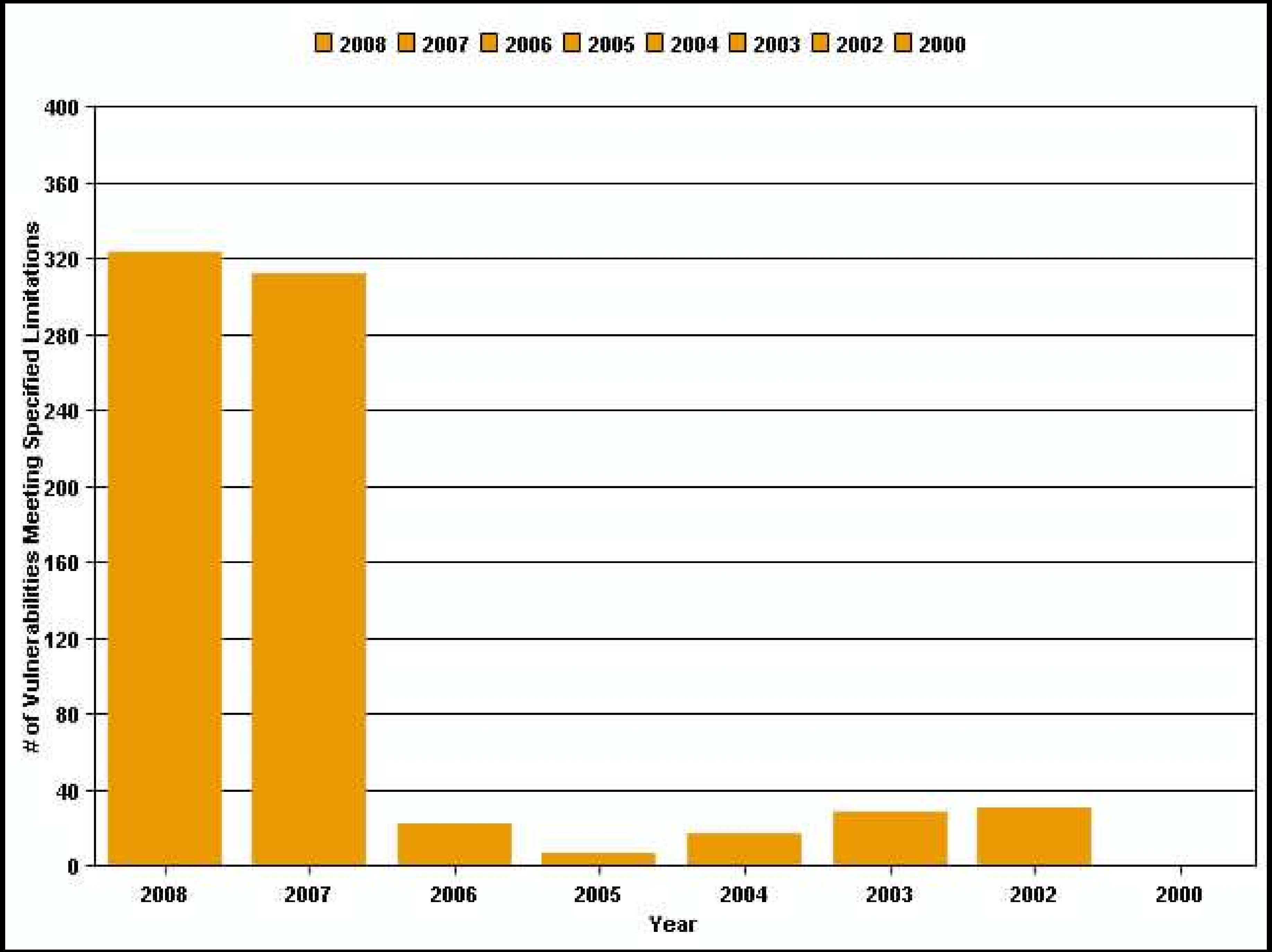


Notes on XSS

- Injected JS appears to come from trusted website
  - may fool the user through direct interaction
    - e.g., fake login prompt
  - can access cookies, issue direct requests against the trusted website
    - particularly powerful if user does not log out

XSS prevalence



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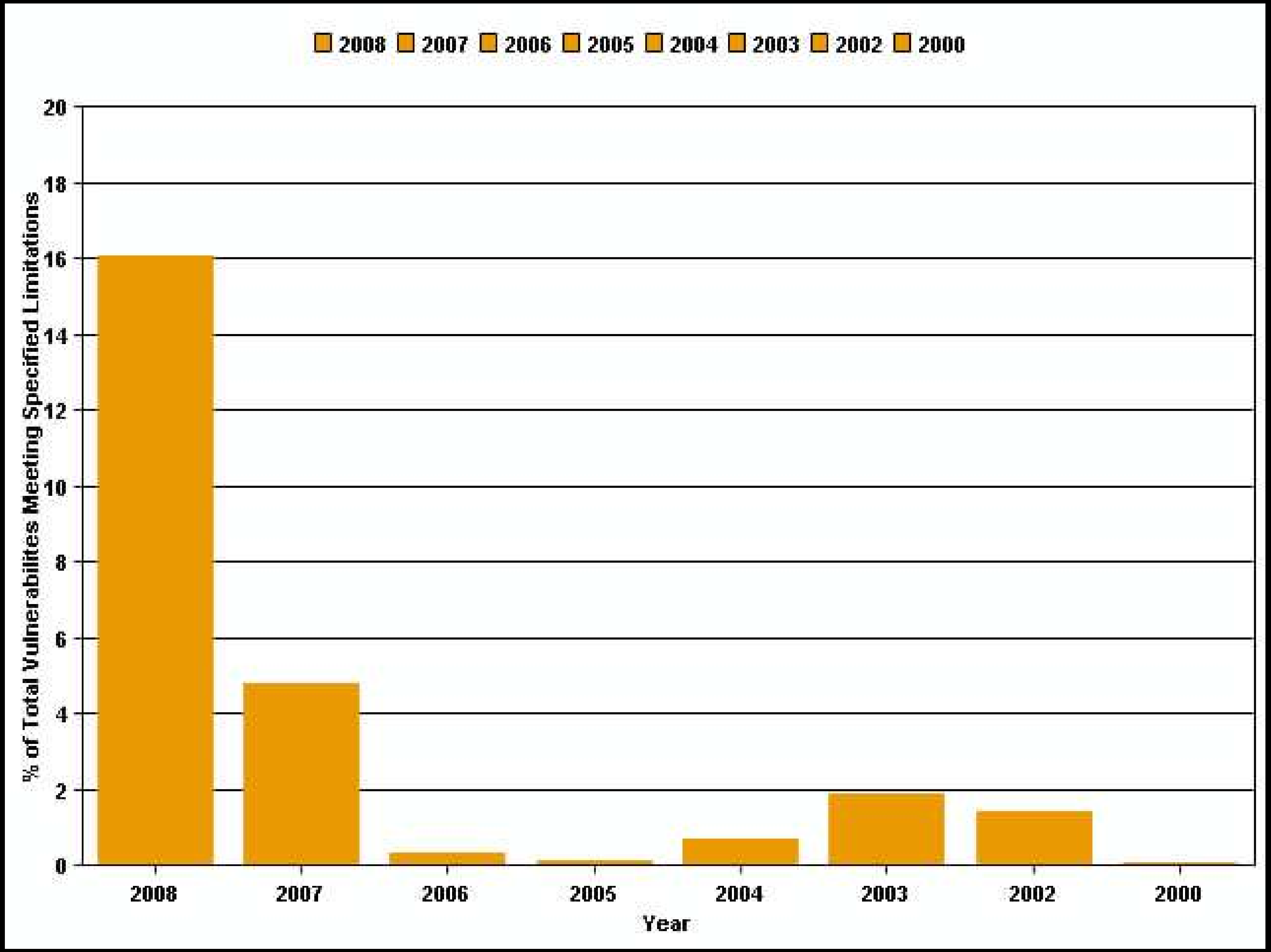

XSS defenses

- No good known defenses
- Current state of practice
  - fix server configurations
  - fix applications
  - do not allow JS or other active content(?) from unknown websites

The future?

- Continuing mixing of code and data
  - data serialization formats such as JSON
  - “rich” document formats
    - Office, PDF, etc.
  - increasing focus on browser

Conclusion

- Overview of a large and important class of software vulnerabilities
  - widely exploited on a daily basis
  - difficult to get it right
  - programmer education is lacking
- Historical perspective on architectural choices and their impact on security 40+ years later
- How do we change things, given current course?