CTSRD

CRASH-WORTHY
TRUSTWORTHY
SYSTEMS
RESEARCH AND
DEVELOPMENT

Clean Application Compartmentalization with SOAAP

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Vulnerabilities galore…

[Insert next big vulnerability here]

Heartbleed

STAGEFRIGHT

Shellshock

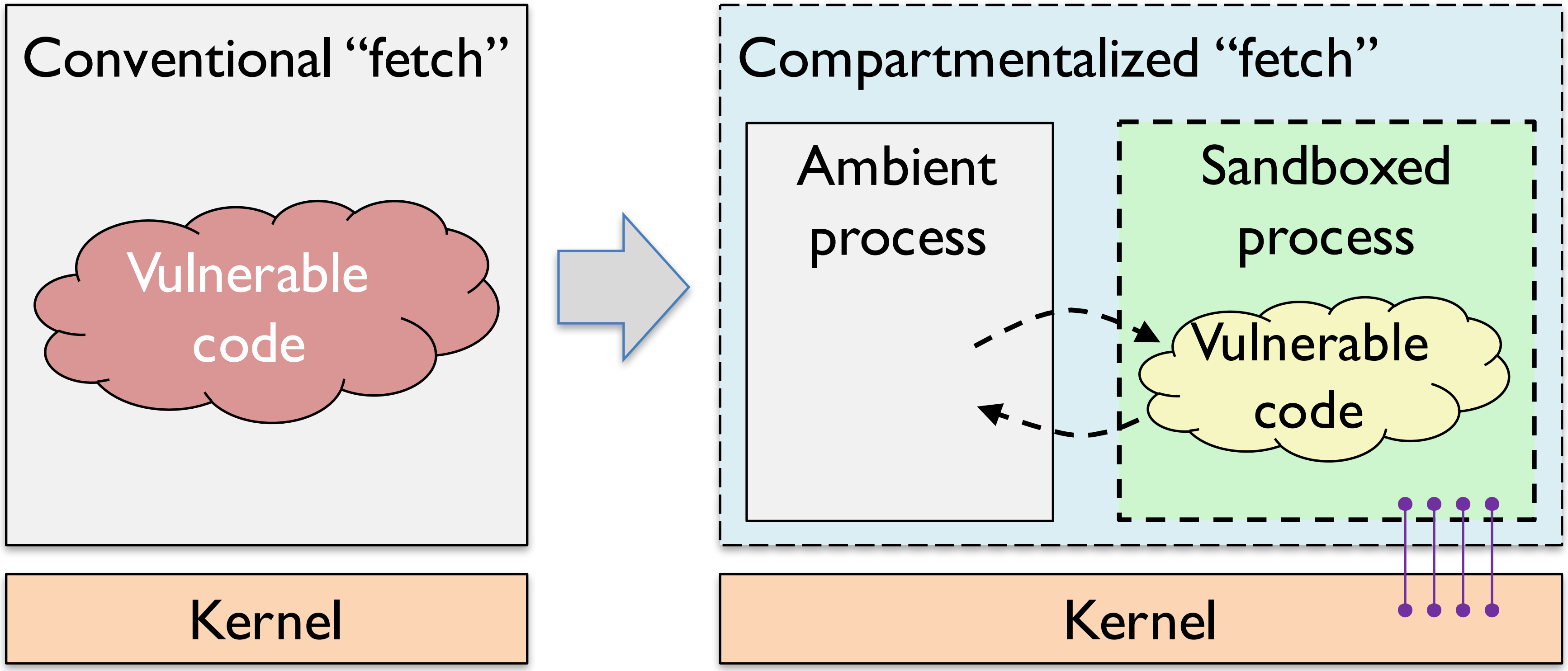
Mitigate both known and unknown vulnerabilities

Principle of least privilege

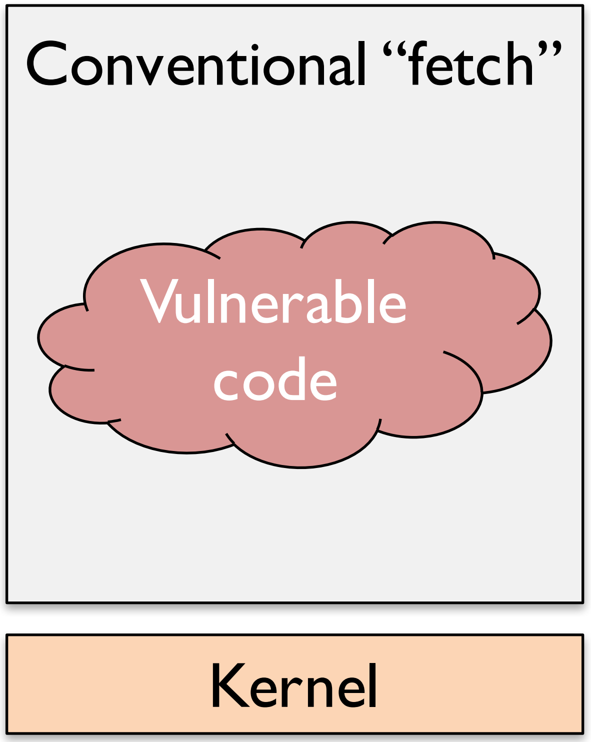
Every program and every privileged user of the system should operate using the least amount of privilege necessary to complete the job.

Saltzer 1974 - CACM 17(7)
Saltzer and Schroeder 1975 - Proc. IEEE 63(9)
Needham 1972 - AFIPS 41(1)

Application Compartmentalization



Application Compartmentalization

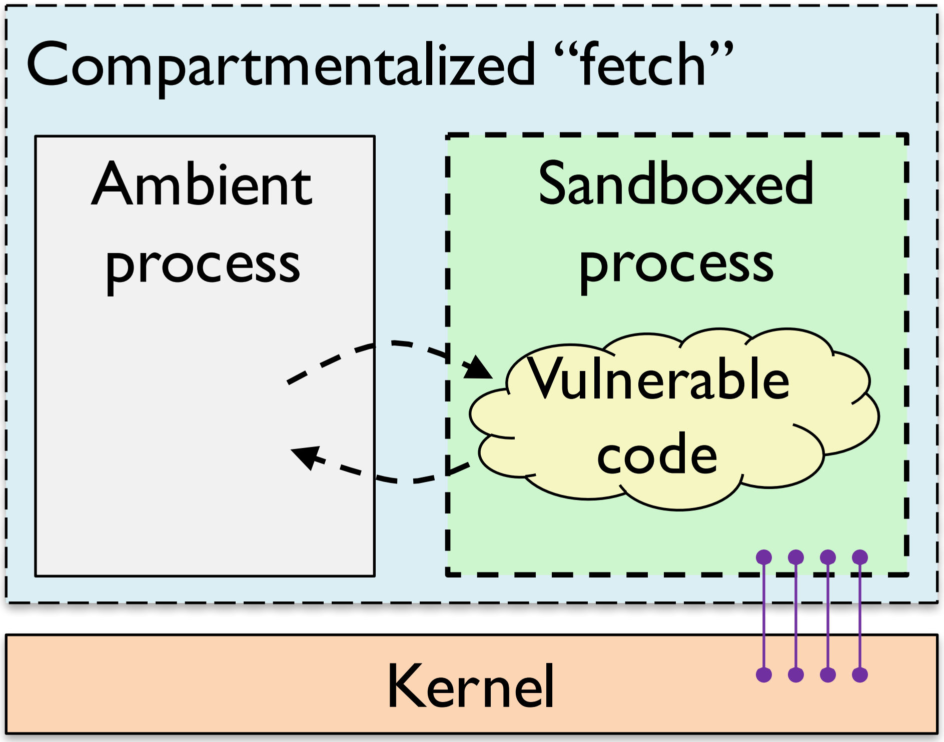


When a conventional application is compromised, its ambient rights are leaked to the attacker, e.g., full network and file system access.

Application Compartmentalization

When a compartmentalized application is compromised, only rights held by the exploited component leak to the attacker.

Most vulnerabilities will no longer yield significant rights, and attackers must exploit many vulnerabilities to meet their goals.



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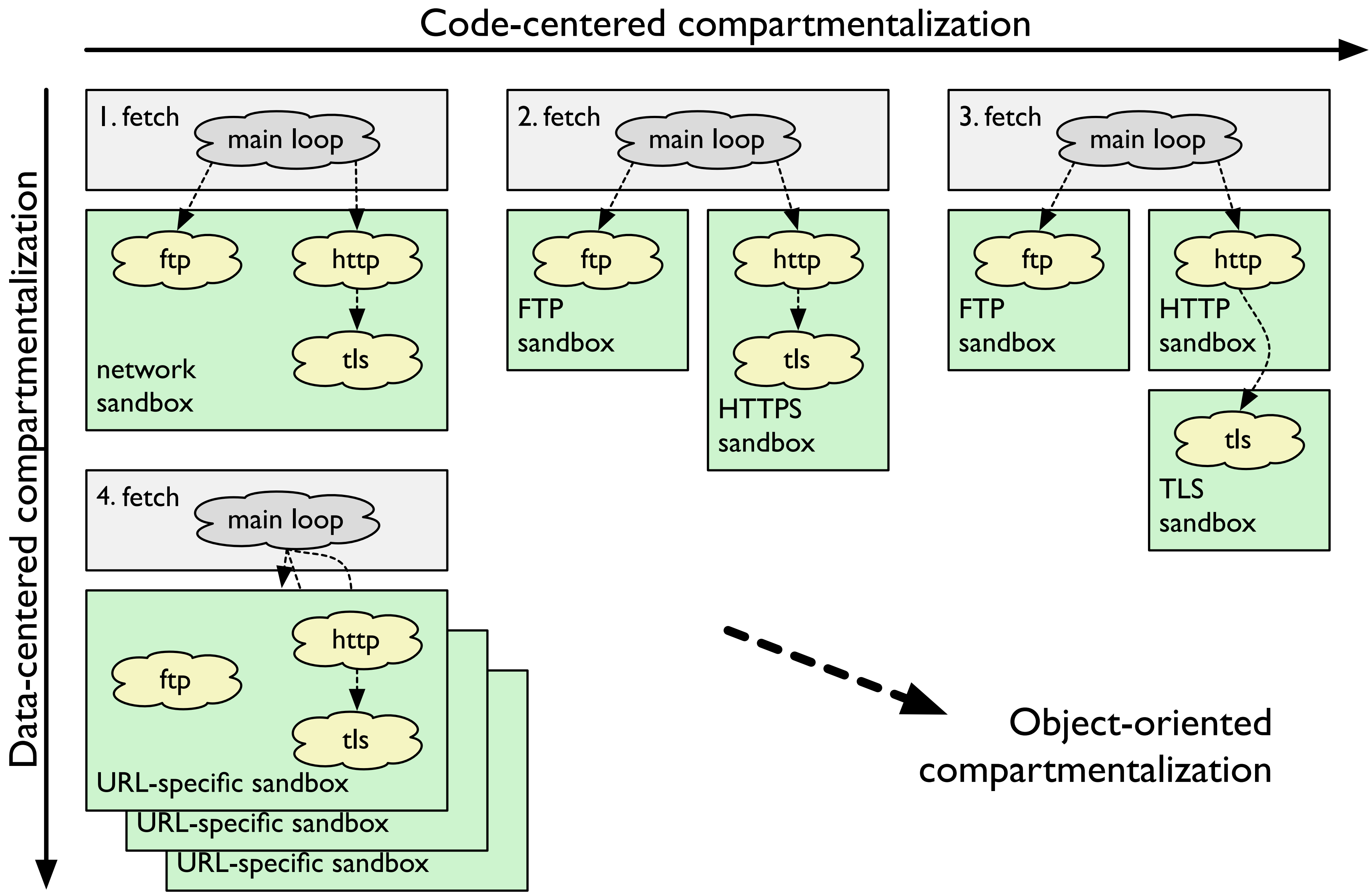
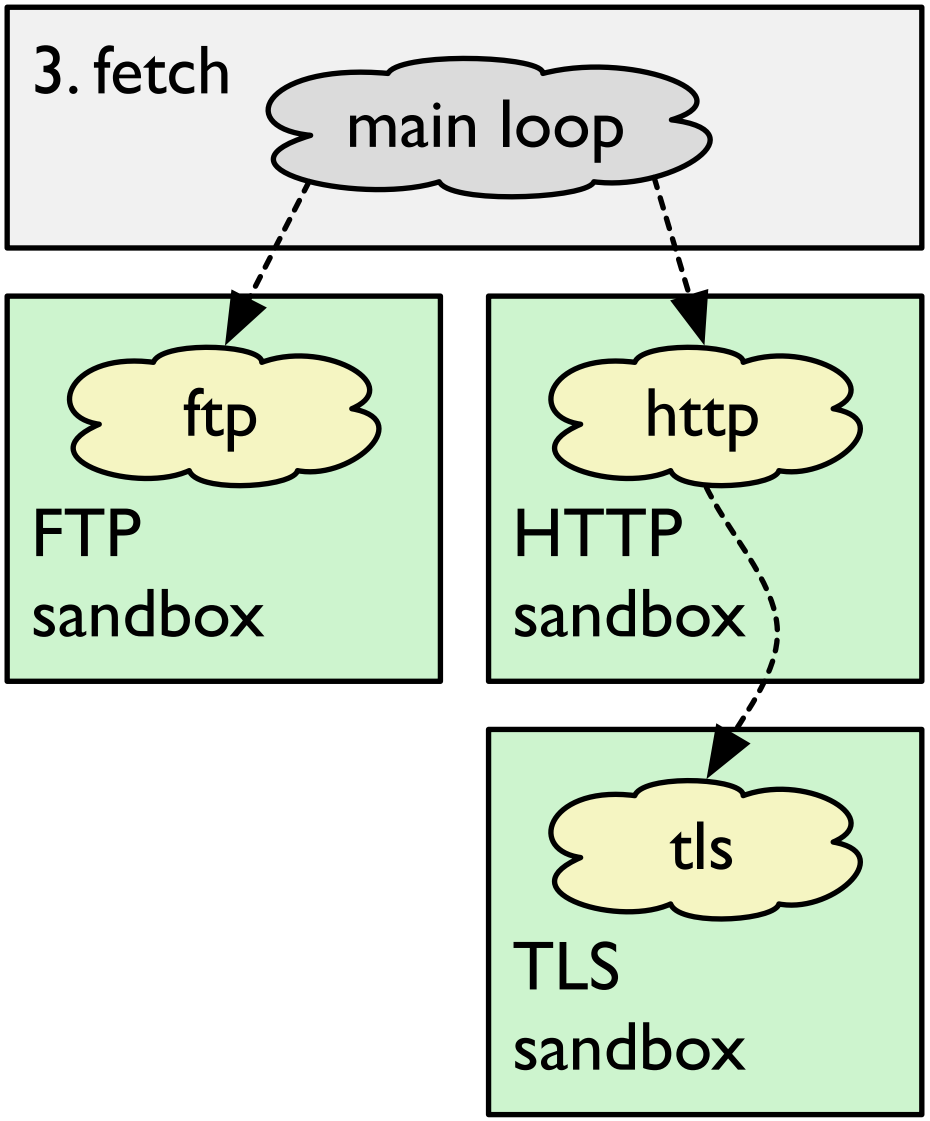
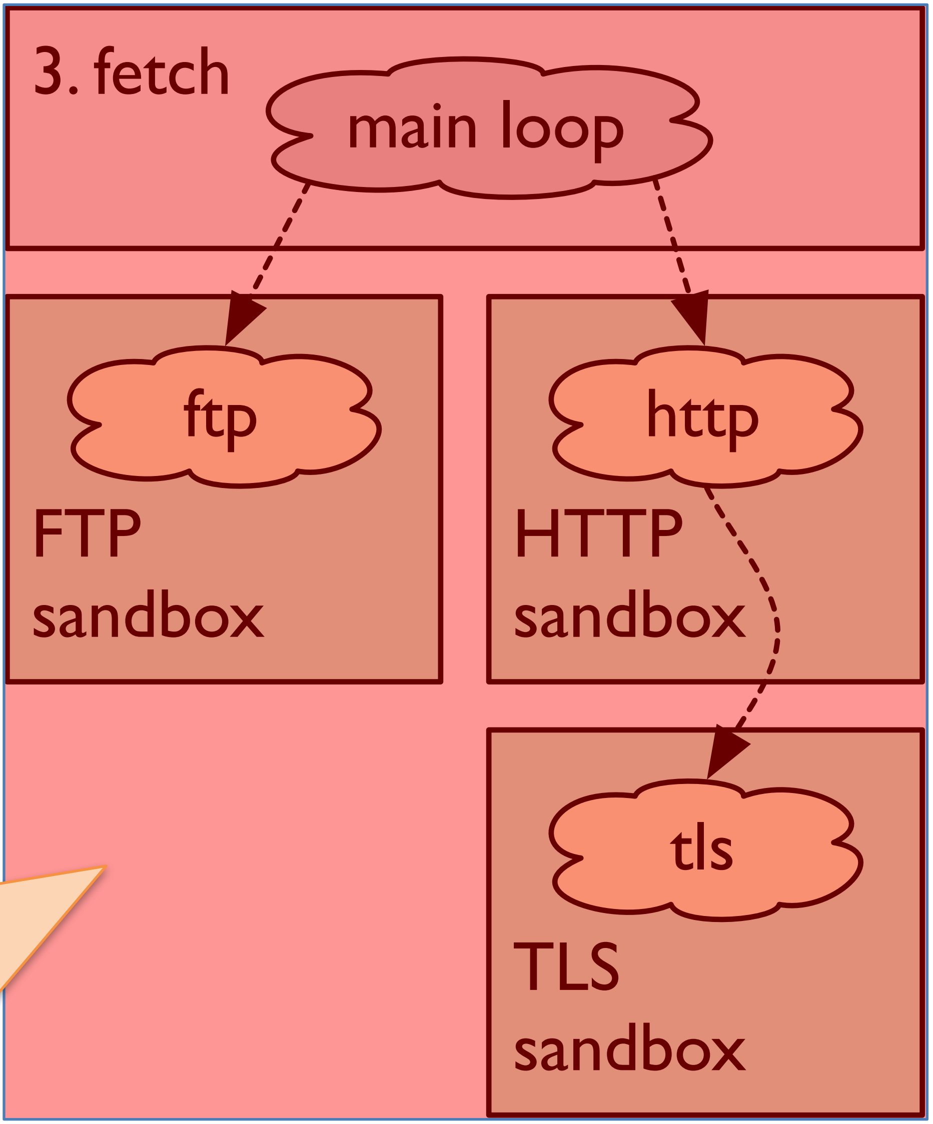
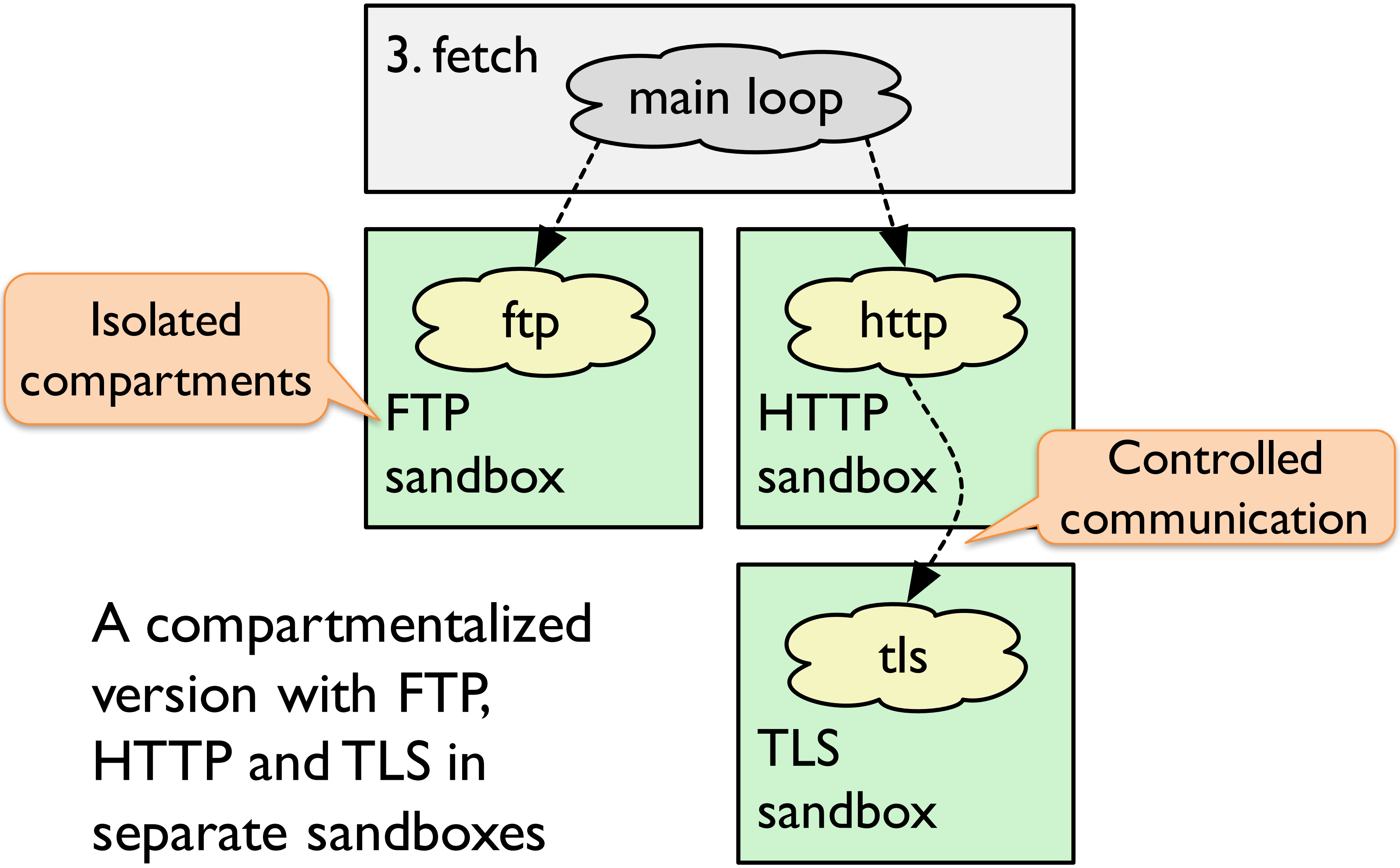

Code-centered compartmentalization
Data-centered compartmentalization
1. fetch
main loop
ftp
http
tls
network sandbox
2. fetch
main loop
ftp
FTP sandbox
http
tls
HTTPS sandbox
3. fetch
main loop
ftp
FTP sandbox
http
HTTP sandbox
tls
TLS sandbox
4. fetch
main loop
http
ftp
tls
URL-specific sandbox
URL-specific sandbox
URL-specific sandbox
Object-oriented compartmentalization

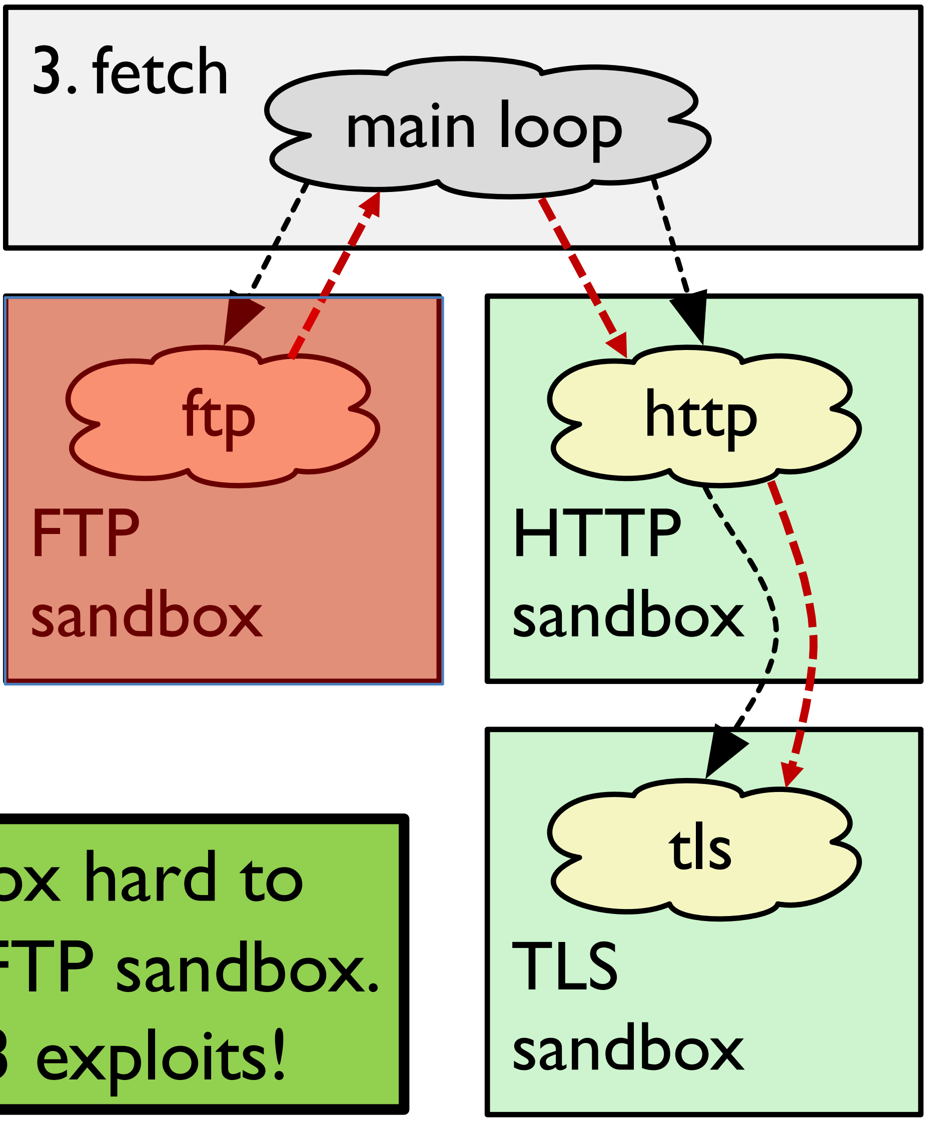

3. fetch
main loop
ftp
FTP sandbox
http
HTTP sandbox
tls
TLS sandbox



Before, a single exploit anywhere in the program would have leaked ambient rights

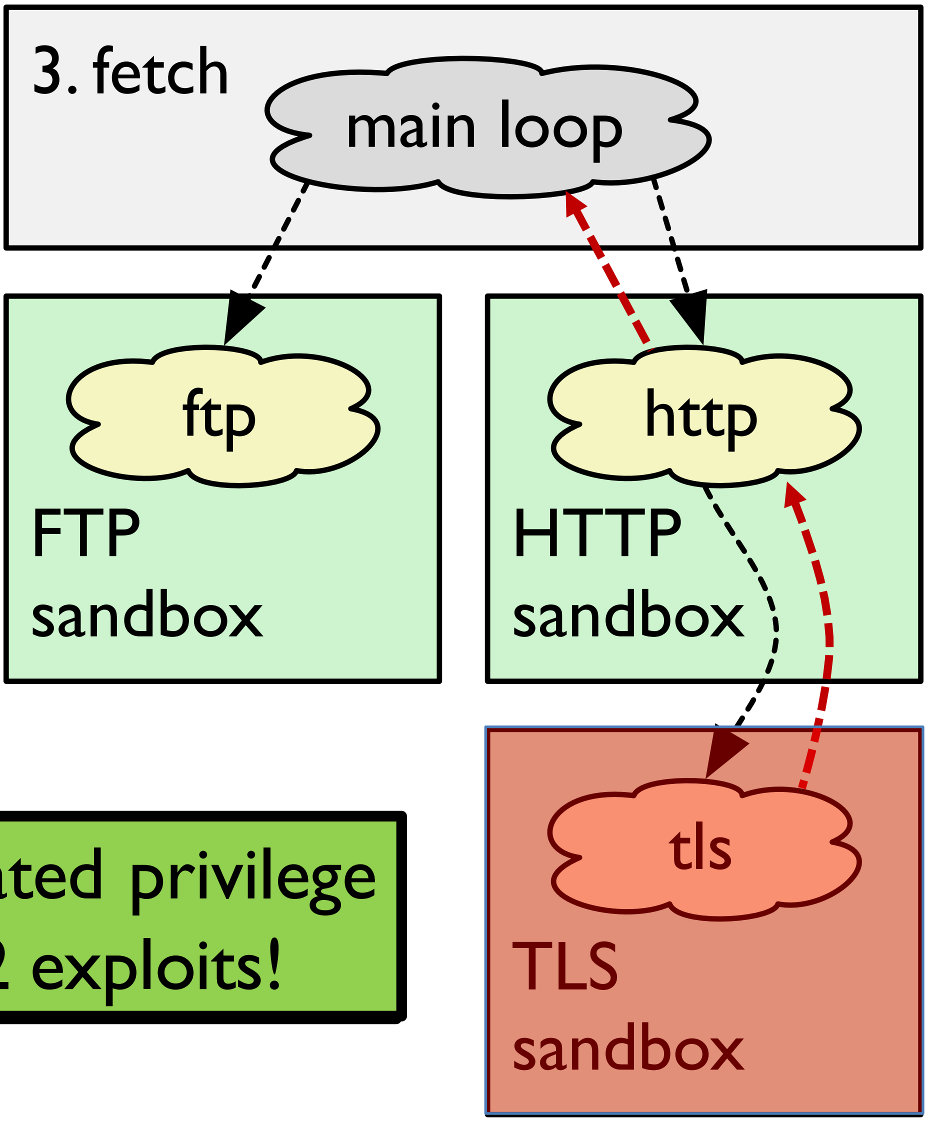


A compartmentalized version with FTP, HTTP and TLS in separate sandboxes "exploit FTP to access TLS state"



TLS sandbox hard to access from FTP sandbox. Requires 3 exploits!

"exploit TLS to gain elevated privilege"



Gaining elevated privilege requires 2 exploits!

Compartmentalization is hard!

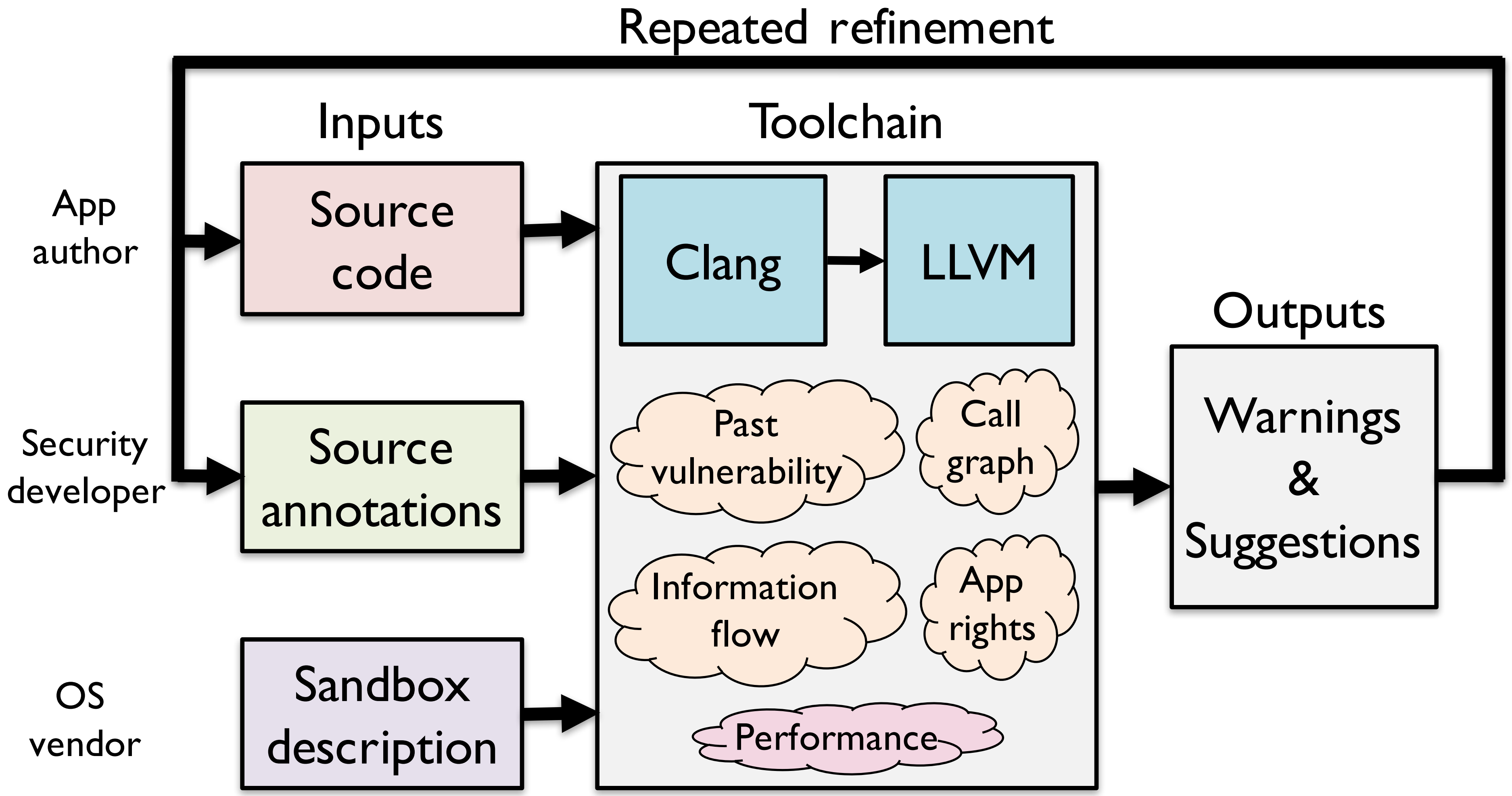
- “local” program turned into a distributed one
- Preserving functional correctness
- Mapping security model to sandboxing substrate
- Different compartmentalization tradeoffs
- Hard to change and maintain

Onus is on the developer

"It's up to <u>you</u> to understand these elements [of App Sandbox] and then to use <u>your understanding</u> to create a plan for adopting App Sandbox."

- Apple App Sandbox Design Guide

Security-Oriented Analysis of Application Programs



Example: Confidentiality/IFC

```
char* server_key __soaap_classify("secret");
extern void compute_session_key(char*,char*);

void main() {
  ...
  while (...) {
    accept_connection();
  }
}

__soaap_sandbox_persistent("session")
void accept_connection() {
  char session_key[256] __soaap_private;
  compute_session_key(session_key,server_key);
  ...
}
```

Example: Confidentiality/IFC

Classify tag

```
char* server_key __soaap_classify("secret");
extern void compute_session_key(char*,char*);

void main() {
  ...
  while (...) {
    accept_connection();
  }
}

__soaap_sandbox_persistent("session")
void accept_connection() {
  char session_key[256] __soaap_private;
  compute_session_key(session_key,server_key);
  ...
}
```

Sandbox entrypoint

Private state

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Example: Past vulnerabilities/ supply-chain trojans

```
__soaap_provenance("some vendor")

__soaap_sandbox_ephemeral("parser")
void parse(__soaap_fd_permit(read) int ifd, DOMTree* out) {
    if (...) {
        __soaap_vuln_pt("CVE-2005-ABC");
        ...
    }
}

__soaap_vuln_fn("CVE-2005-DEF")
void not_sandboxed() {
  ...
}
```

Example: Past vulnerabilities/ supply-chain trojans

```
__soaap_provenance("some vendor")

__soaap_sandbox_ephemeral("parser")
void parse(__soaap_fd_permit(read) int ifd, DOMTree* out) {
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        ...
    }
}

__soaap_vuln_fn("CVE-2005-DEF")
void not_sandboxed() {
  ...
}
```

Provenance

Sandbox entrypoint

Delegated rights

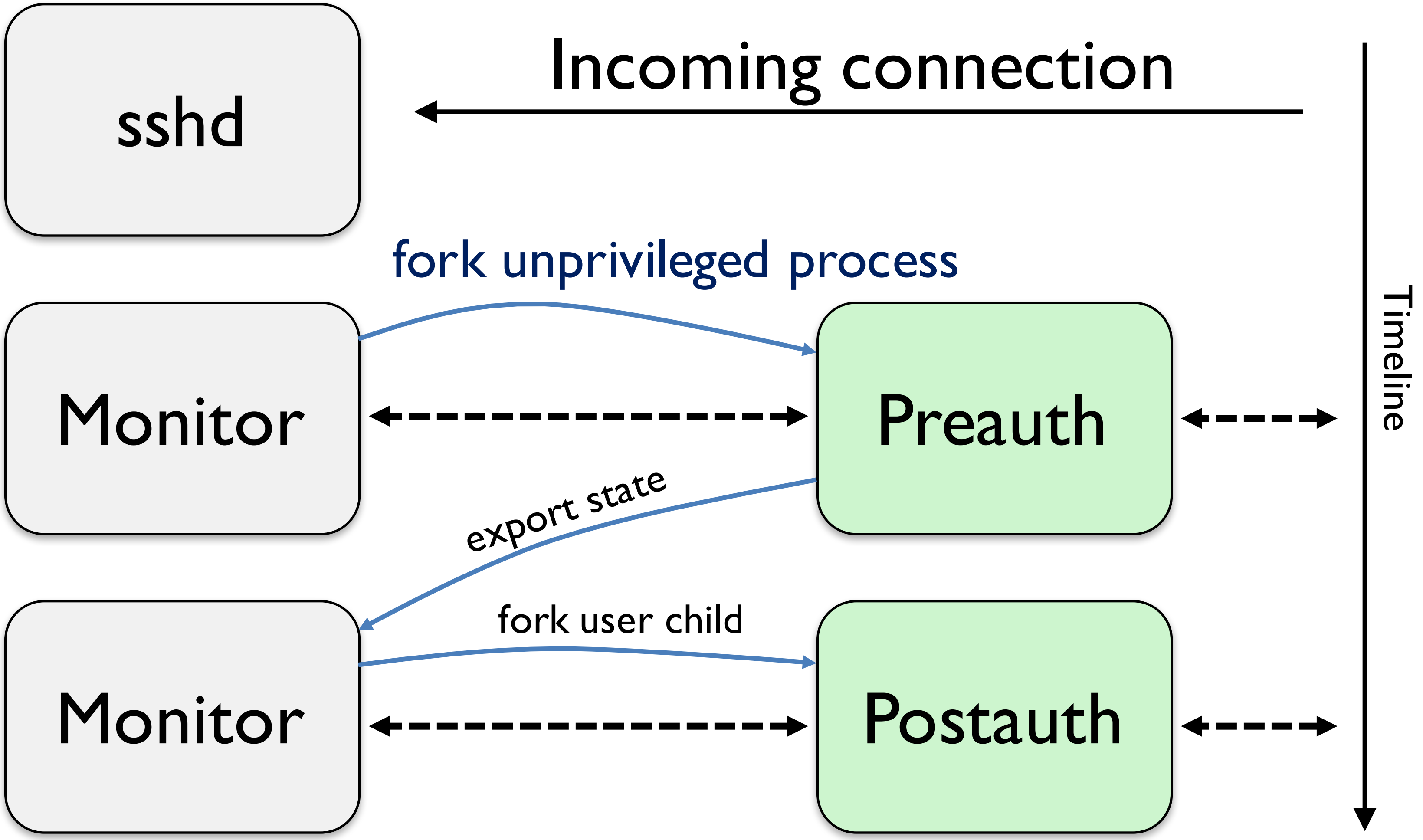
Past vulnerable point

Past vulnerable function

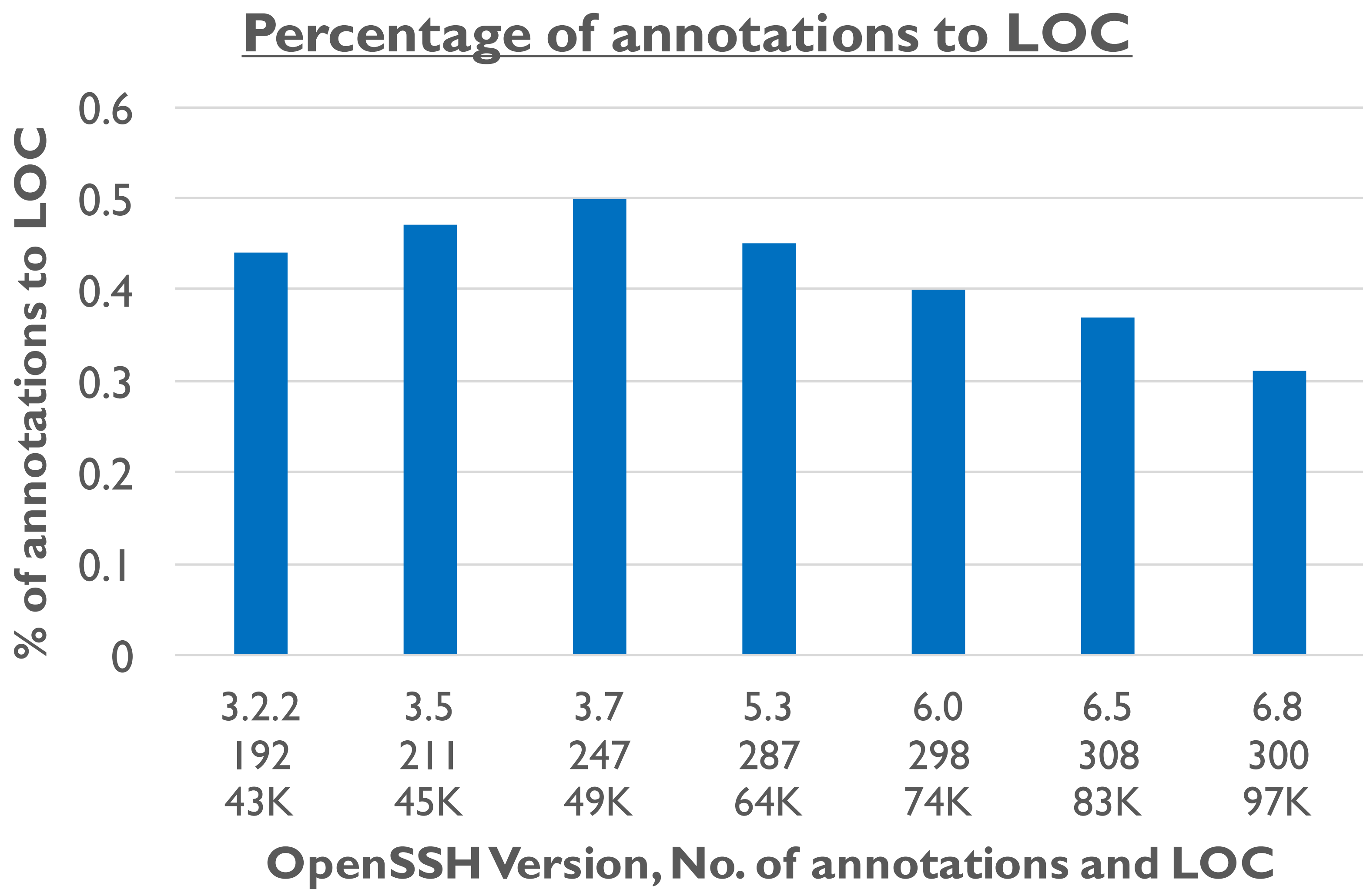
Case studies

- Fetch – design-space exploration
- Okular – large-scale new compartmentalization
- **OpenSSH – long-term maintenance**
- **Chromium – sandboxing effectiveness**

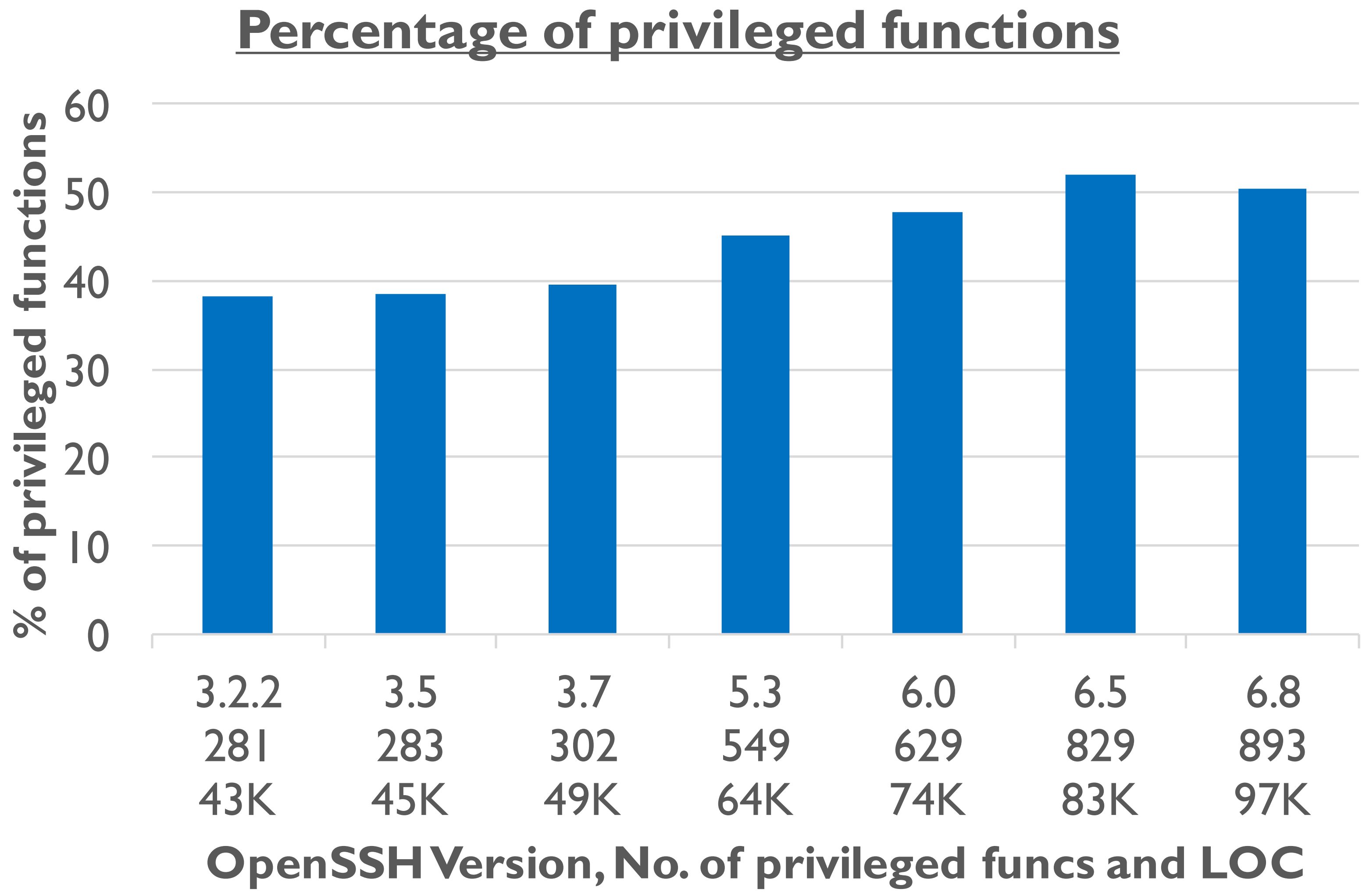
OpenSSH


sshd
Incoming connection
fork unprivileged process
Monitor
Preauth
export state
Timeline
fork user child
Monitor
Postauth

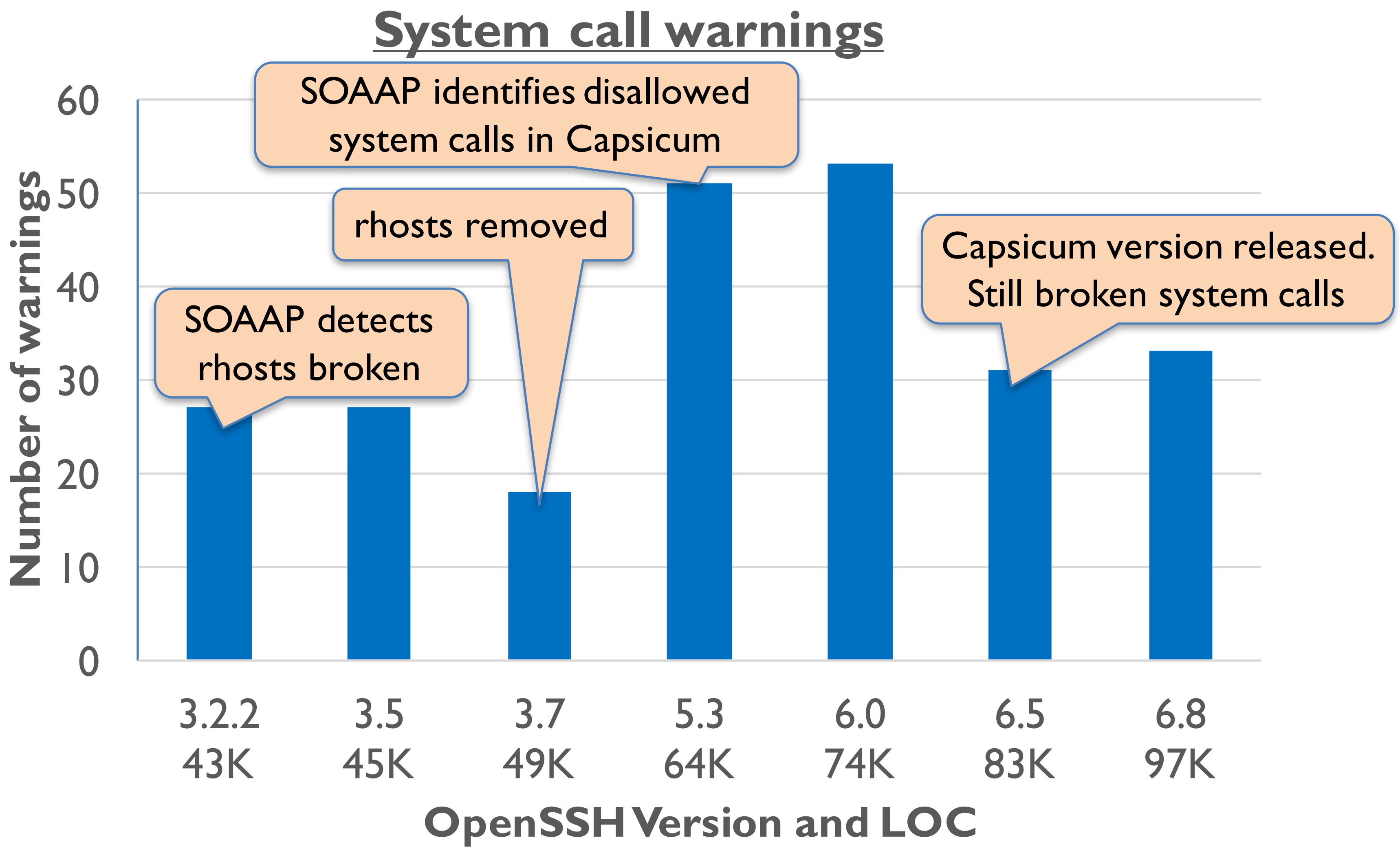
OpenSSH


Percentage of annotations to LOC
% of annotations to LOC
0.6
0.5
0.4
0.3
0.2
0.1
0
3.2.2 192 43K
3.5 211 45K
3.7 247 49K
5.3 287 64K
6.0 298 74K
6.5 308 83K
6.8 300 97K
OpenSSH Version, No. of annotations and LOC

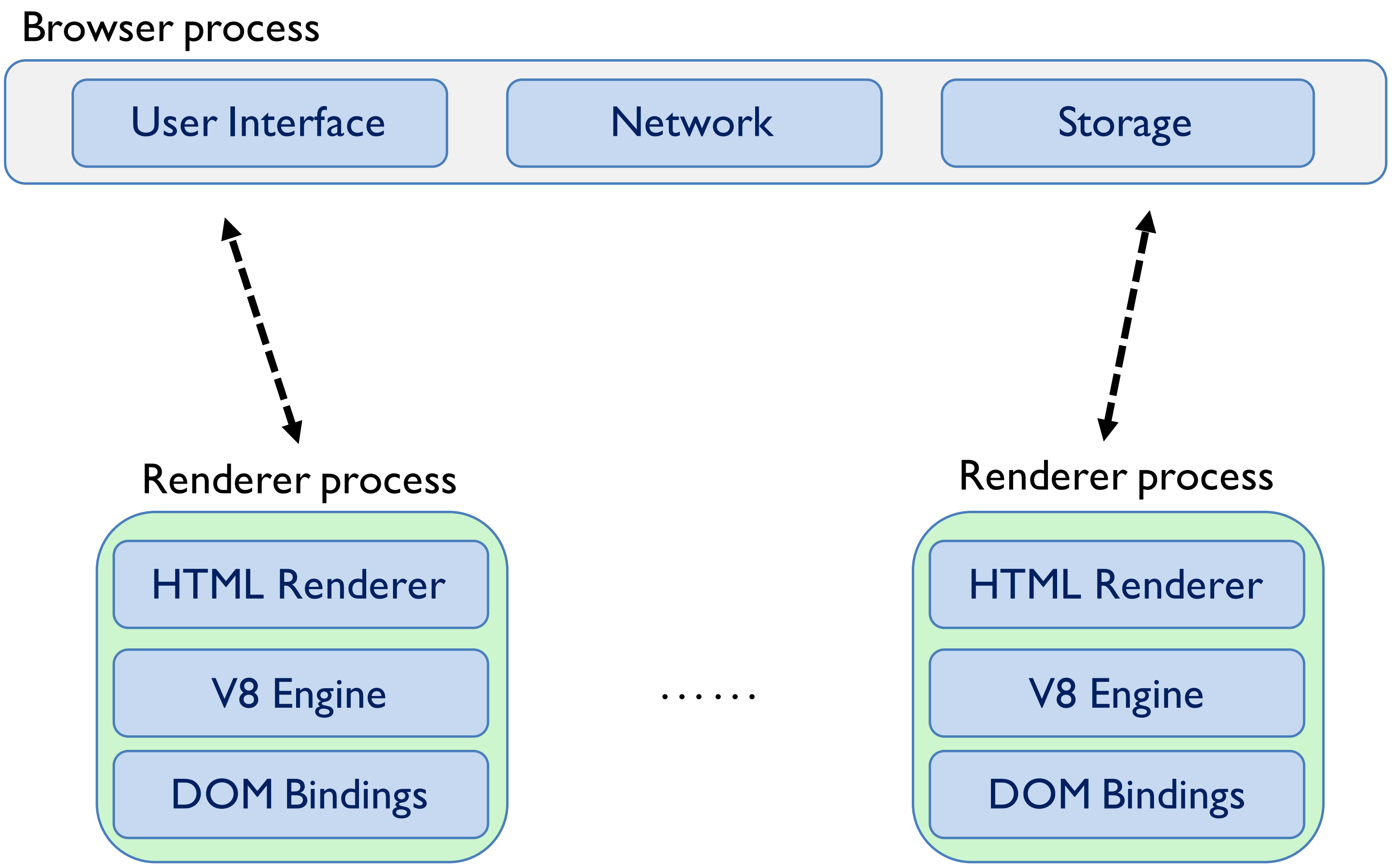
OpenSSH


Percentage of privileged functions
% of privileged functions
60
50
40
30
20
10
0
3.2.2 281 43K
3.5 283 45K
3.7 302 49K
5.3 549 64K
6.0 629 74K
6.5 829 83K
6.8 893 97K
OpenSSH Version, No. of privileged funcs and LOC

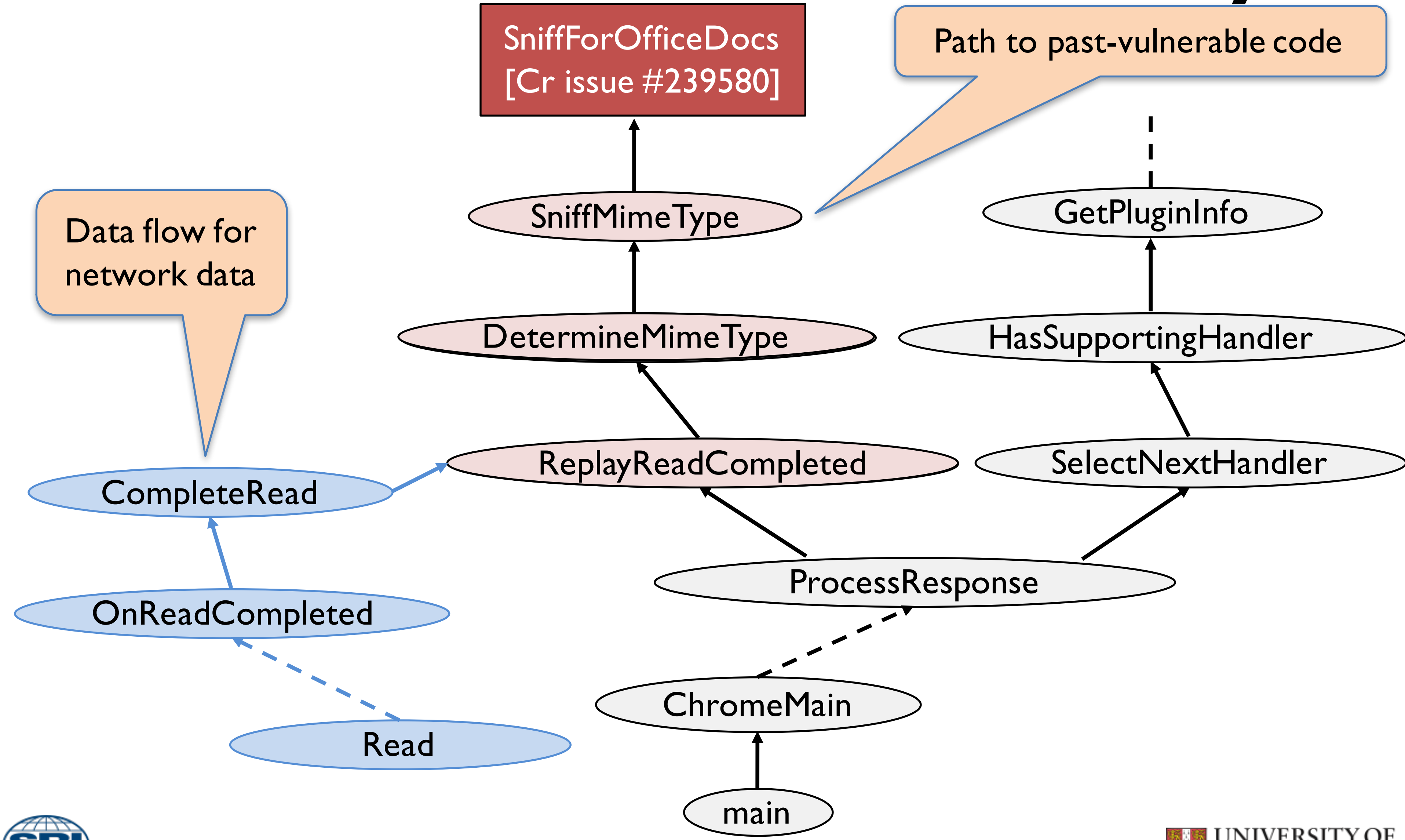
OpenSSH


System call warnings
Number of warnings
60
50
40
30
20
10
0
3.2.2 43K
3.5 45K
3.7 49K
5.3 64K
6.0 74K
6.5 83K
6.8 97K
OpenSSH Version and LOC
SOAAP identifies disallowed system calls in Capsicum
rhosts removed
SOAAP detects rhosts broken
Capsicum version released. Still broken system calls

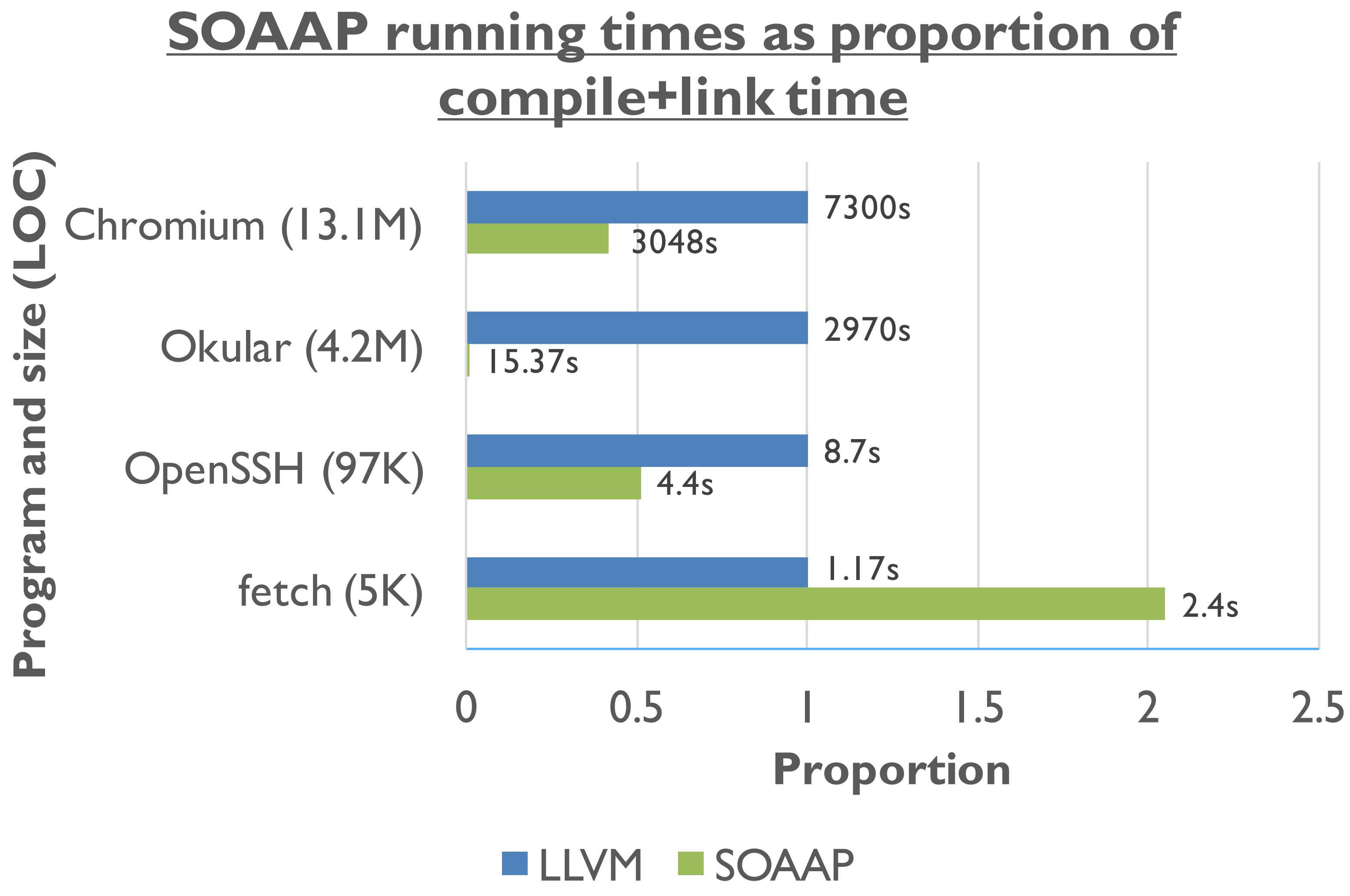
Chromium


Browser process
User Interface
Network
Storage
Renderer process
HTML Renderer
V8 Engine
DOM Bindings
Renderer process
HTML Renderer
V8 Engine
DOM Bindings
....

New Chromium vulnerability?



SOAAP tool performance



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Conclusion

- Application compartmentalization is important but hard to get right
- Conceptual framework gives structure
- SOAAP enables reasoning about tradeoffs
- SOAAP can scale to multi-million LoC programs

http://bit.ly/soaap

Example SOAAP output (1)

```
$ make soaap

*** Sandboxed method "accept_connection" read data
*** value of class: [secret] but only has clearances for: []
+++ Line 28 of file session.c

*** Sandboxed method "accept_connection" executing in
*** sandboxes: [session] may leak private data through
*** the extern function "compute_session_key"
+++ Line 28 of file session.c

*** Persistent sandbox "session" contains private data that
*** may leak when the sandbox is reused. Consider using an
*** ephemeral sandbox instead or scrub the memory region
*** before control returns
```

Example SOAAP output (2)

```
$ make soaap

*** Method "not_sandboxed" had past vulnerability
*** "CVE-2005-DEF" but is not sandboxed.  Another
*** vulnerability here could leak ambient authority
*** to an attacker including full network and file
*** system access

*** Sandboxed method "parse" has a past-vulnerability
*** annotation for "CVE-2005-ABC".  Another vulnerability
*** here would only leak the following:
+++ Read access to file descriptor "ifd"
```

Chromium security disparity

	OS	Sandbox	LoC	FS	IPC	NET	S≠S′	Priv
DAC	Windows	DAC ACLs	22,350	⚠	⚠	✘	✘	✔
	Linux	chroot()	600	✔	✘	✘	✔	✘
MAC	Mac OS X	Sandbox	560	✔	⚠	✔	✔	✔
	Linux	SELinux	200	✔	⚠	✔	✘	✘
Cap	Linux	seccomp	11,300	⚠	✔	✔	✔	✔
	FreeBSD	Capsicum	100	✔	✔	✔	✔	✔

Watson et al., "Capsicum: practical capabilities for UNIX"