Towards Practical Application-level Support for Privilege Separation

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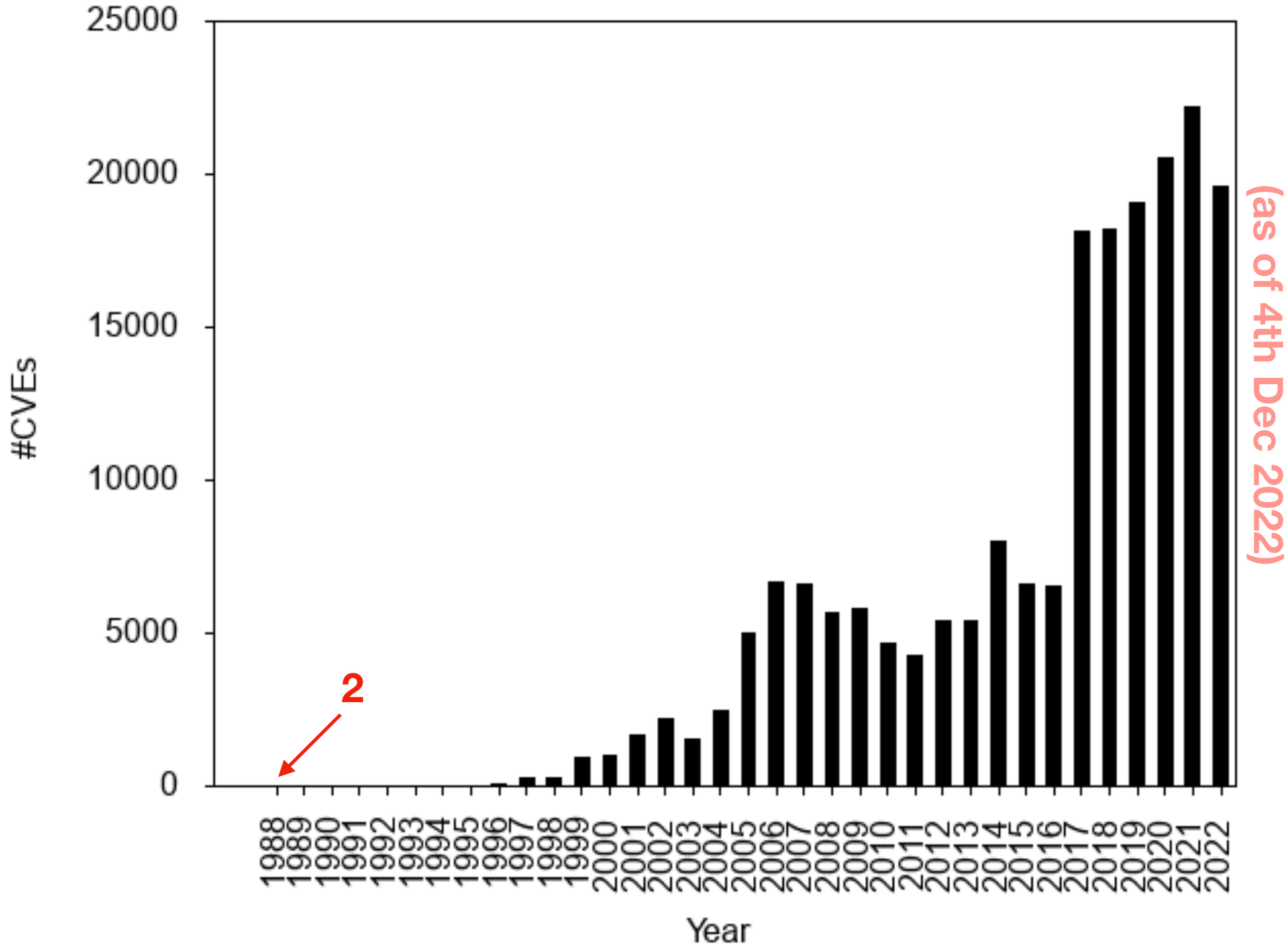
ACSAC'22

Motivation: Software Security



Increased trend in # of CVEs:

Good: we know about problems.

Bad: there are more problems.

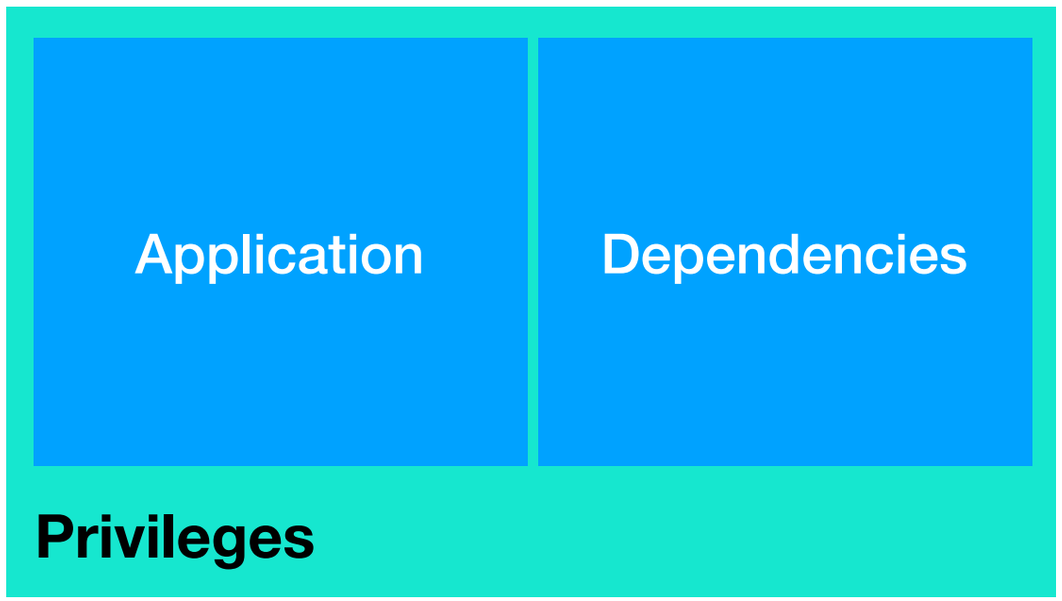
Ack: Graph generated using dataset from https://www.cve-search.org/dataset/

Software Security **Techniques**

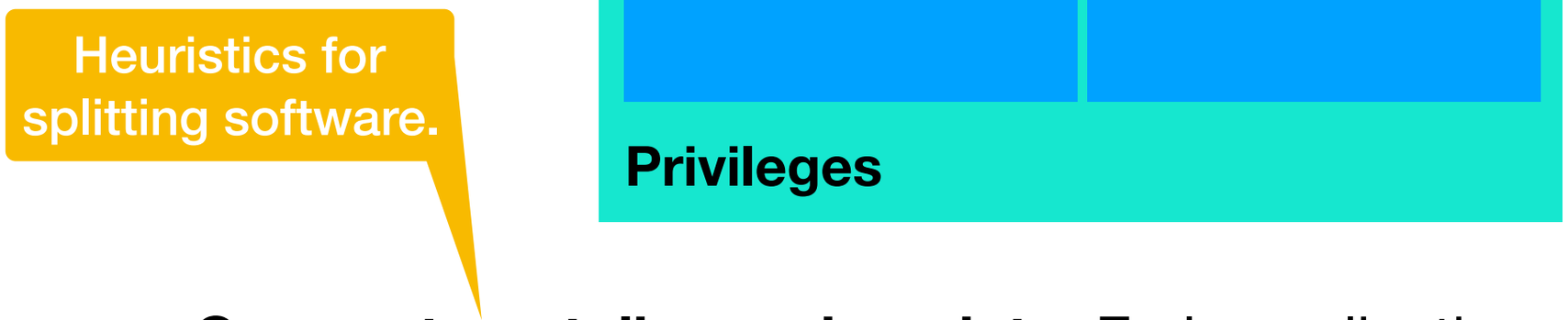
- Range of techniques available: ASLR, Stack canaries, Sandboxing, Soft/hard bounds checking, …
- Combining them is good practice.
  But some techniques are difficult to apply.

  We focus on one such technique: **privilege separation.**

What is Privilege Separation? (privsep)



What is Privilege Separation? (privsep)



- **Compartmentalize code + data**. Early application: servers: SMTP, SSH.
- Monolithic application ➡ Concurrent set of cooperating programs.
  - Monolithic application: often common privileges throughout.
  - **Distributed system**: granularity of privilege allocation.

Why

~~What is~~ Privilege Separation? (privsep)

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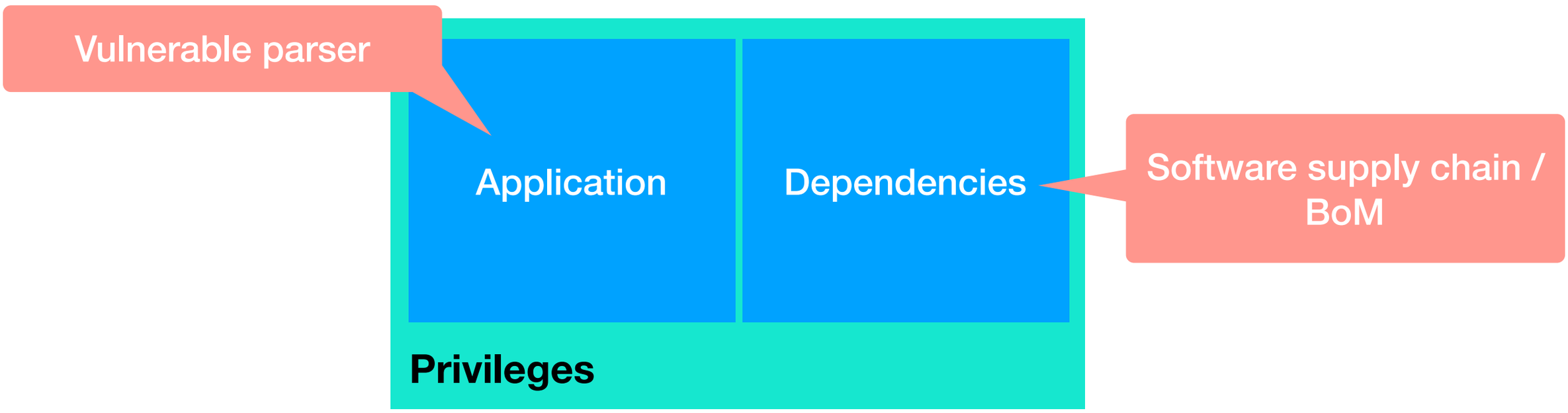

- **Compartmentalize code + data**. Early application: servers: SMTP, SSH.
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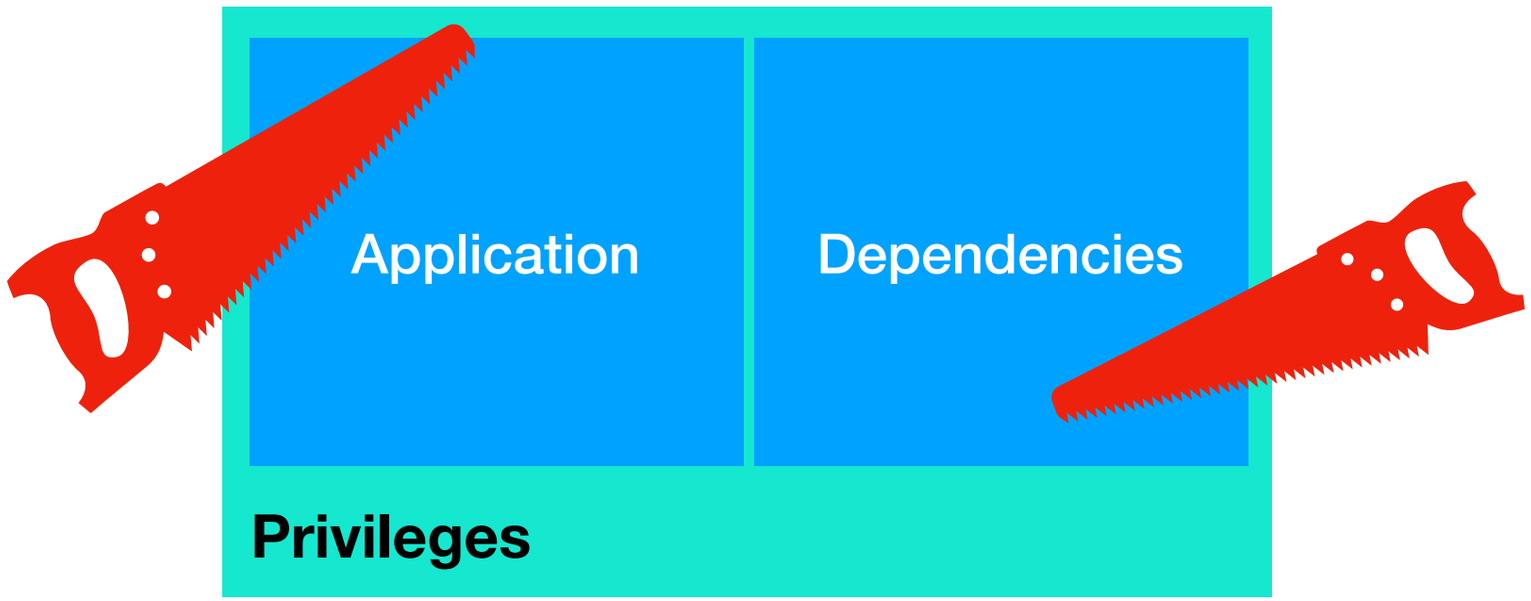
Main benefit: **vulnerability containment.**
Best case: if a vulnerability is exploitable, then fewer privileges can be abused.

Implementing Privsep

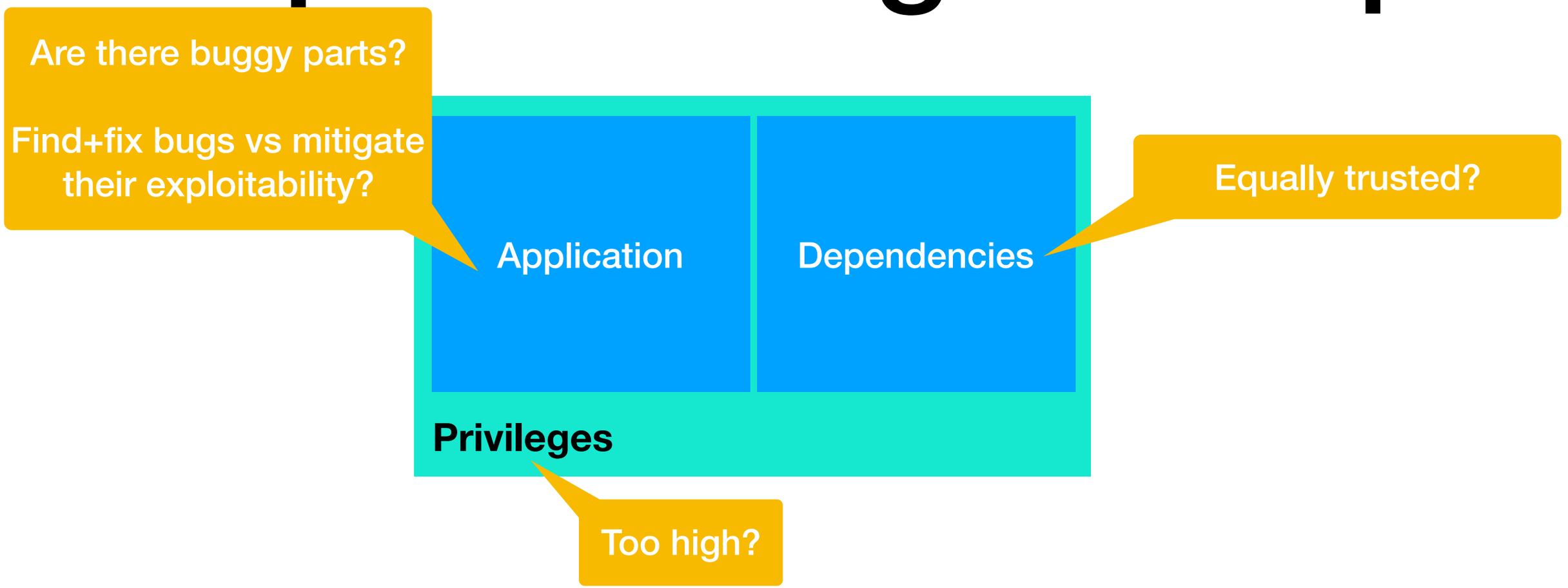


- **Implementing** privsep: usually a lot of work.
  Restructuring logic and code, positive and negative tests.

- Changing software without introducing bugs!

- There are many **decisions** to take (and retake later) wrt what+how to separate.

Implementing Privsep



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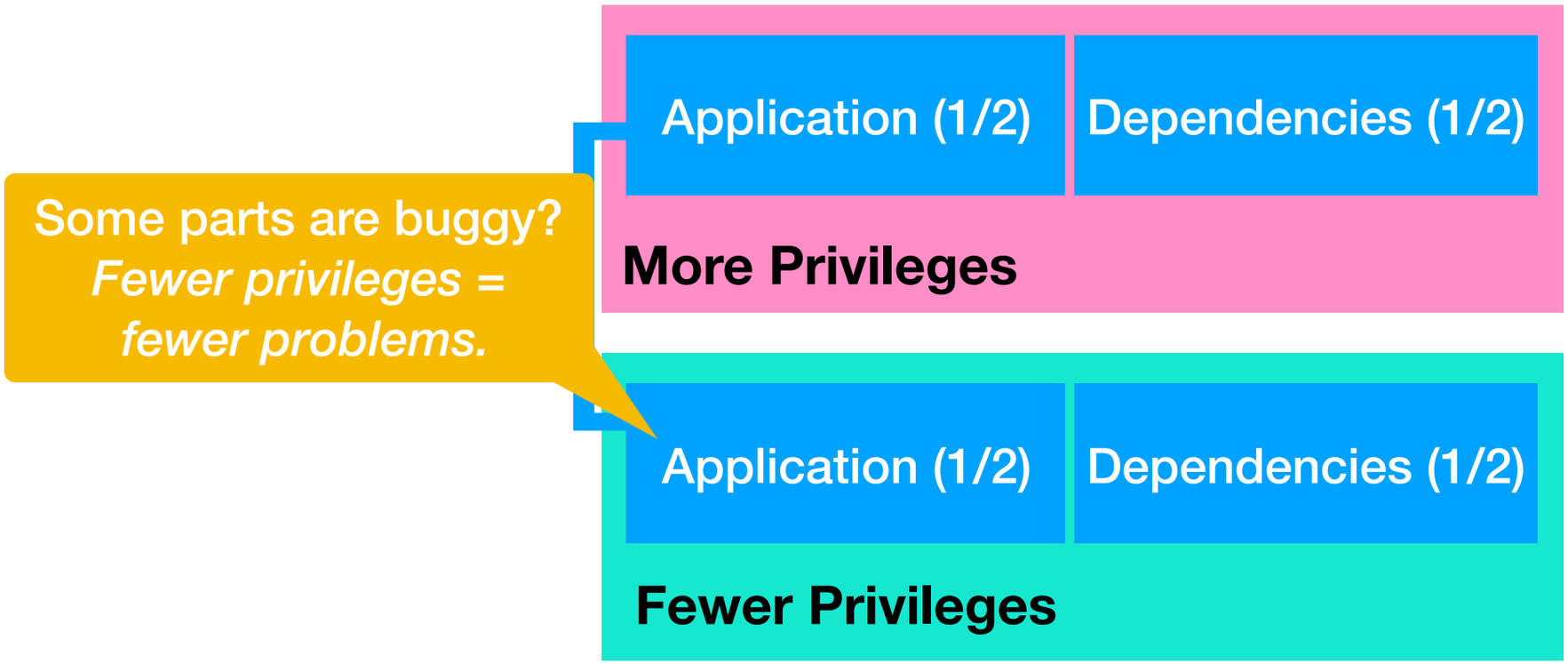
What Privsep looks like

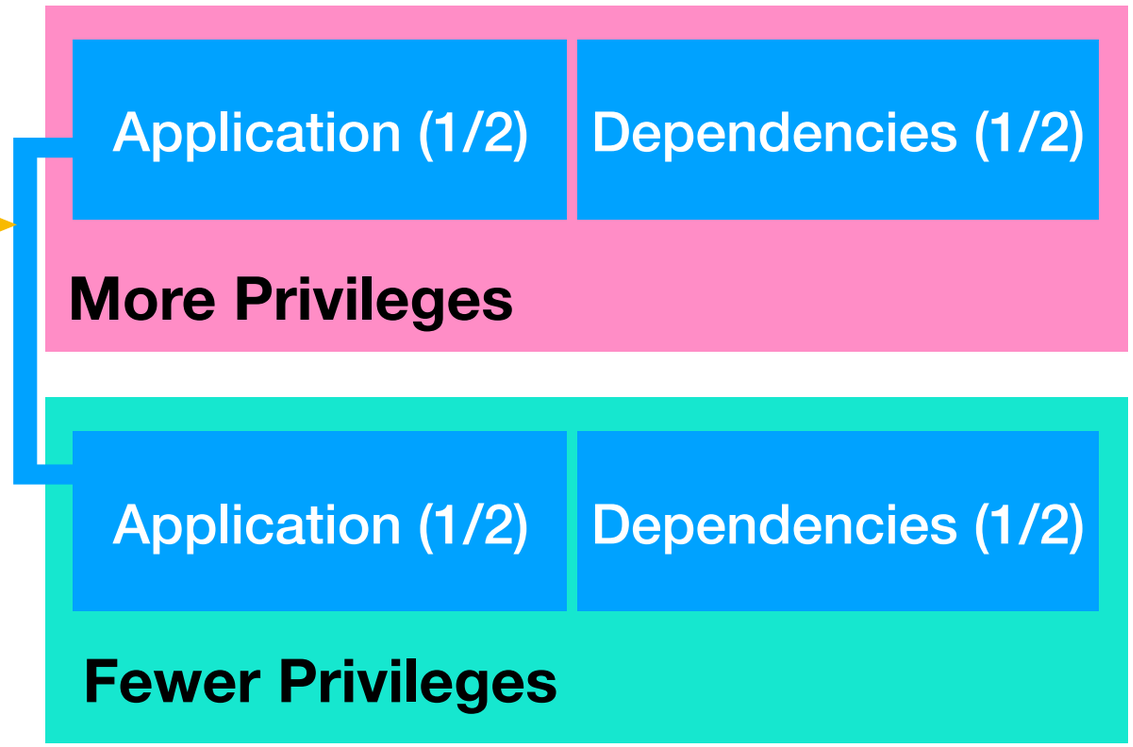


- Distributed system, heterogeneous privileges.

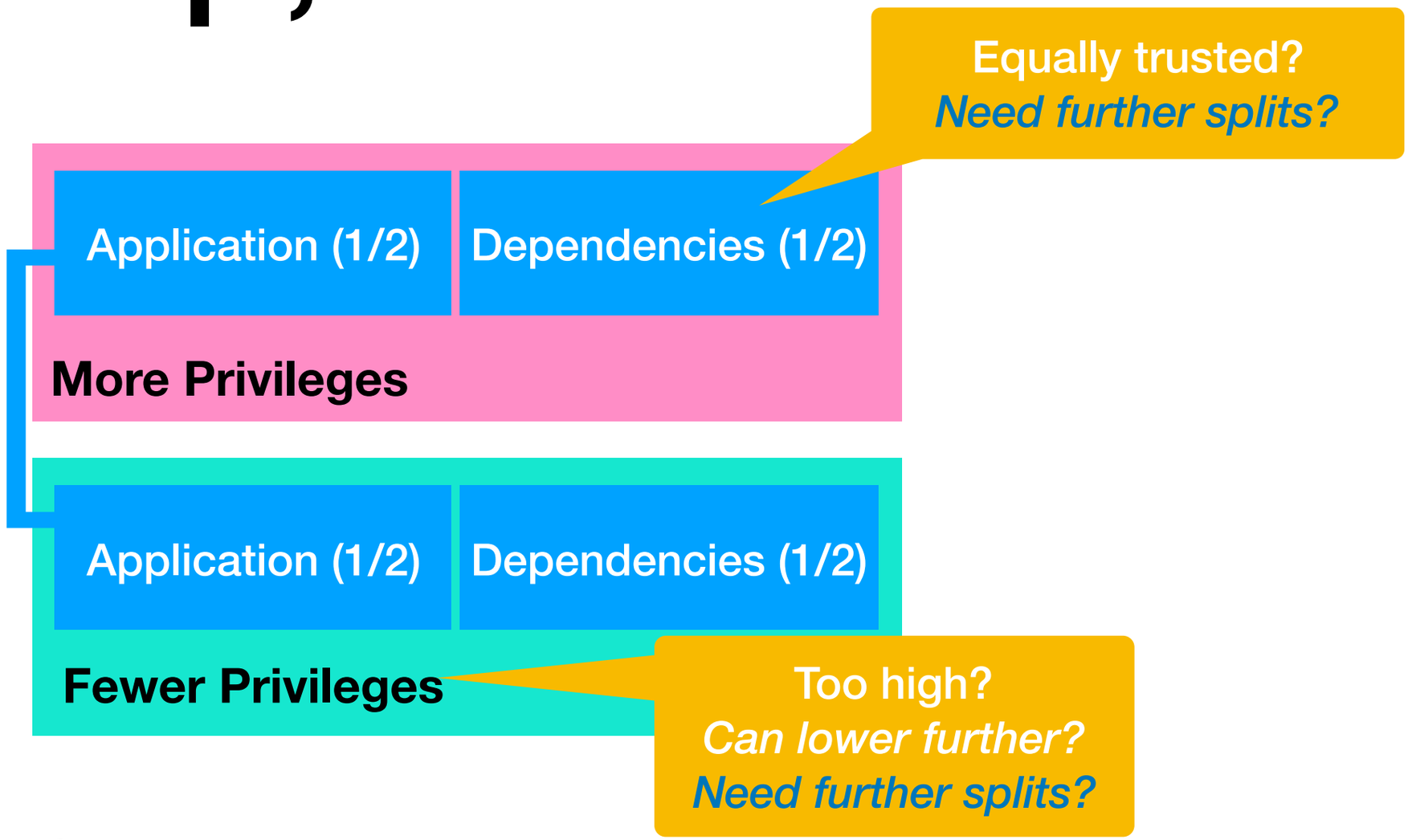
  Sometimes: separating between trusted vs untrusted.

What Privsep looks like

Heuristics:
- Components needing specific access.
- Dependencies incl. libraries.
- Cross-domain interfaces (e.g., parts of network, filesystem)



Privsep, *and then?*



- **Drawbacks** include:
  Inertia wrt **splitting software**, introduction of **new failure modes** (hello distributed systems), performance **overhead**, inertia wrt **maintainability and portability** (e.g., if use hardware enforcement).

(Longstanding) # Research Goal

Widely-applicable tool support for privsep

(This paper)

Foundations:
- compartment model
- tool infrastructure
- software-level

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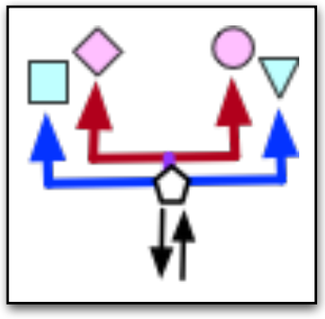


Artefacts:
+ tooling
+ several examples
+ supporting scripts & documentation

Foundations:
- compartment model
- tool infrastructure
- software-level

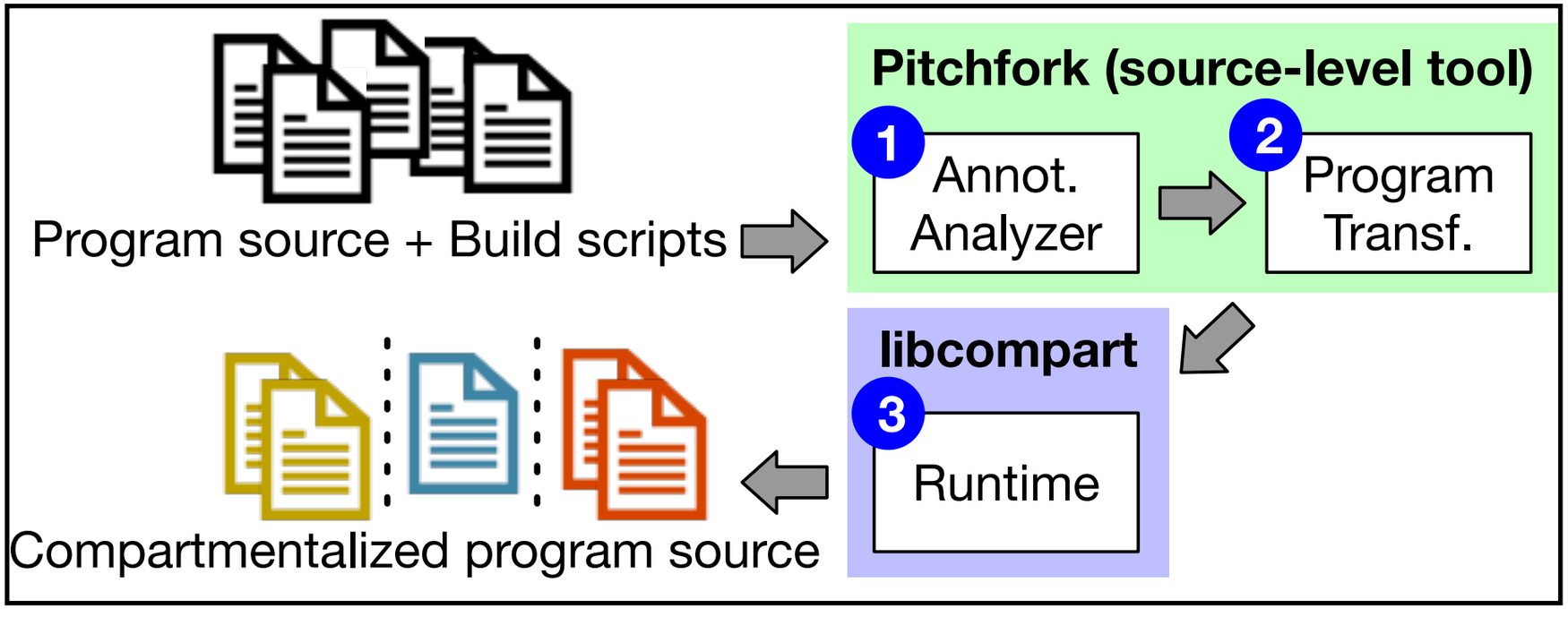
What’s different from prior art?

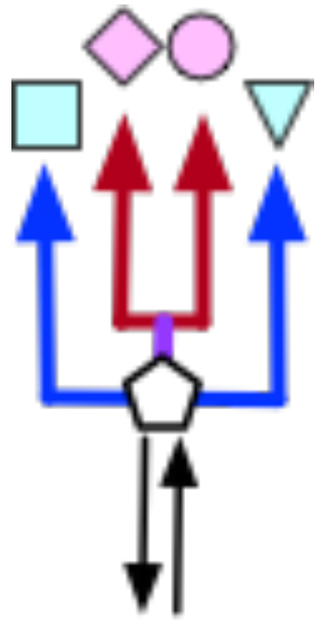
- **Separation “distance” + flexibility.**
  Separate binaries vs separate processes.
  Number of compartments.
  Commodity kernels and hardware.

- **Both tool and library.**
  Either can be used directly.
  Tool adapts code to use library.

- **Model-based approach.**
  Implemented abstractions provided/explained by the model.

Pitchfork

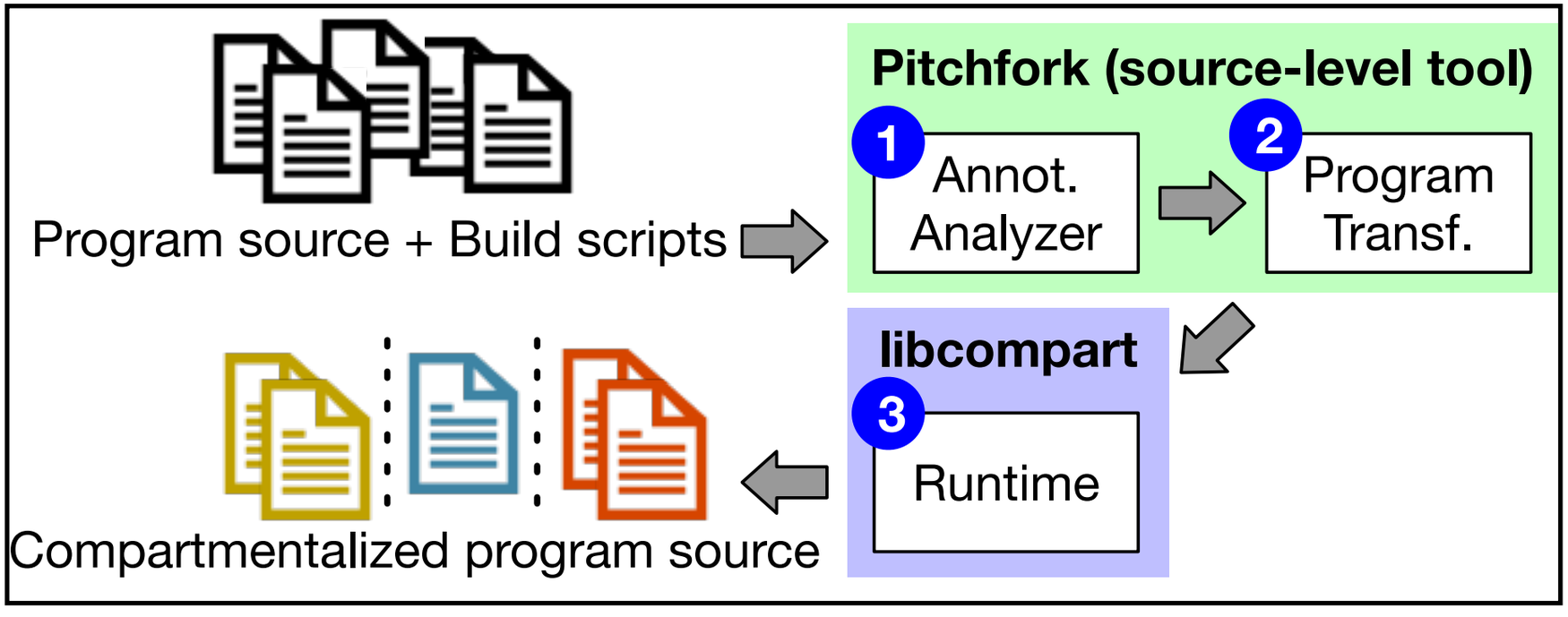


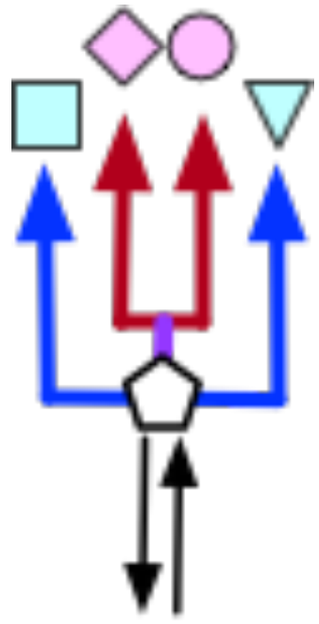


The **system** has two components based on a **model**:

- Pitchfork 1 2
- libcompart 3

Pitchfork





The **system** has two components based on a **model**:

- Pitchfork 1 2
- libcompart 3

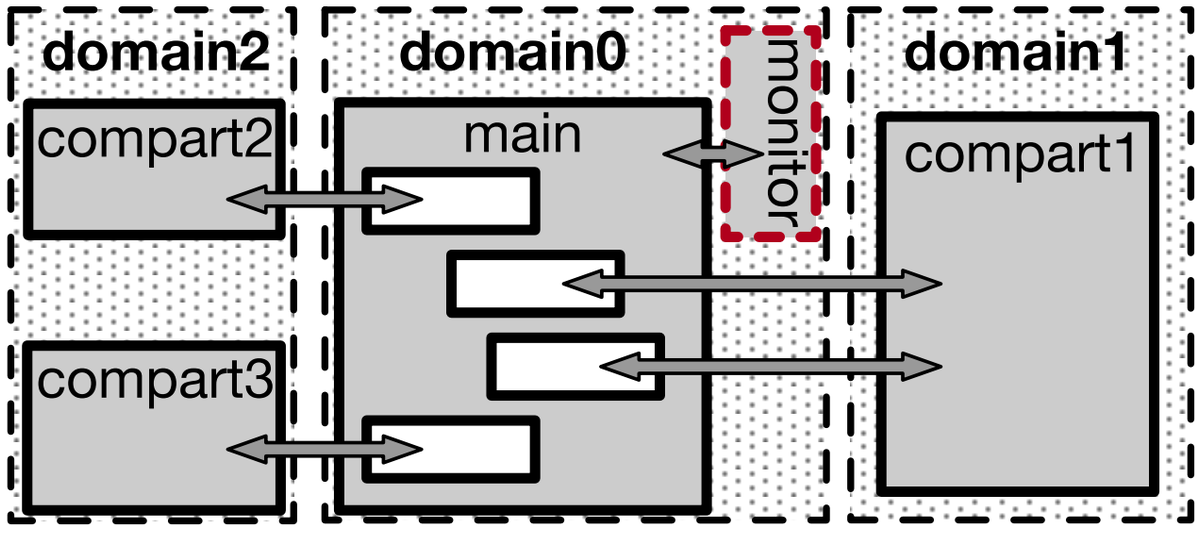
The **model** supports**:**

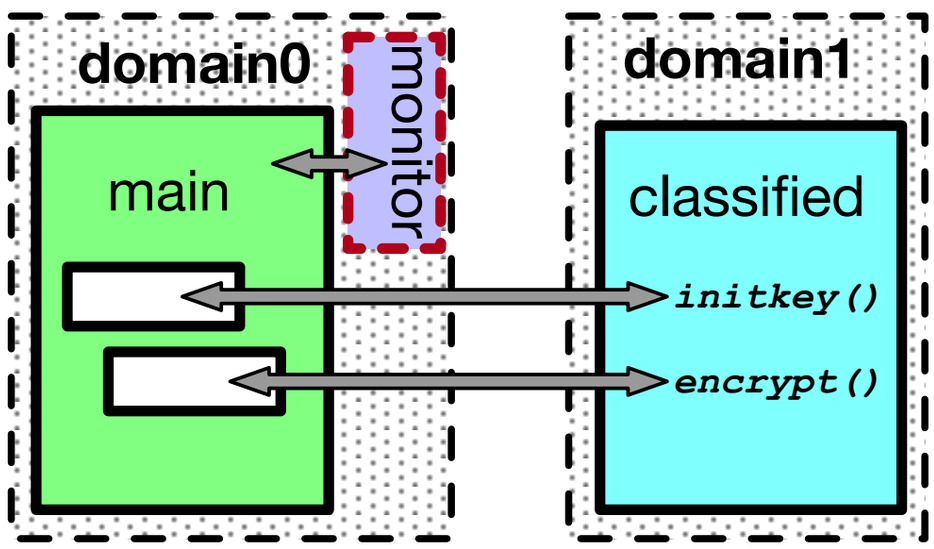
- Multiple compartments (different levels of trust)
- Synchronous communication
- Monitoring and failure-handling

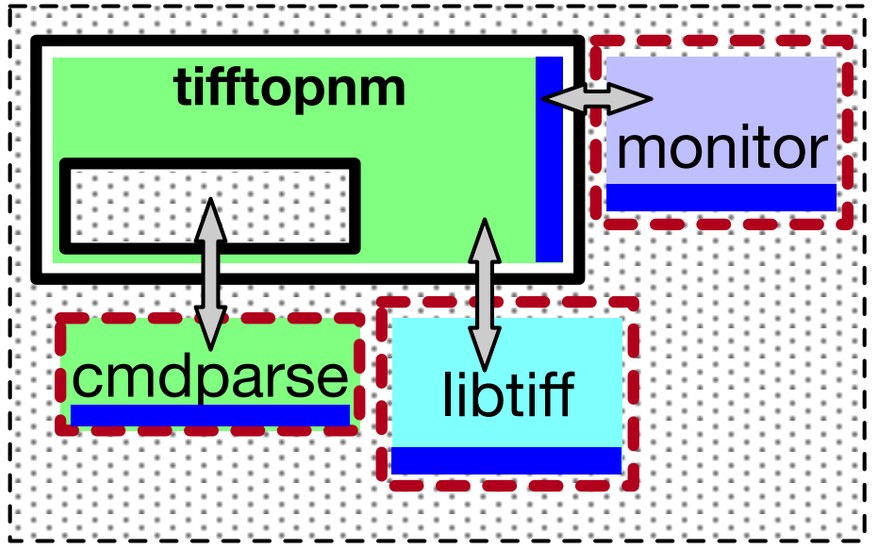
Pitchfork

```
105 if(console_type == BEEP_TYPE_CONSOLE) {
106   pitchfork_start("Privileged");
107   if(ioctl(console_fd, KIOCSOUND, period) < 0) {
108     putchar('\a'); /* Output the only beep we can, in an
                effort to fall back on usefulness */
109     perror("ioctl");
110   }
111   pitchfork_end("Privileged");
112 } else {
113    /* BEEP_TYPE_EVDEV */
114   struct input_event e;
115   e.type = EV_SND;
116   e.code = SND_TONE;
117   e.value = freq;
118   pitchfork_start("Privileged");
119   if(write(console_fd, &e, sizeof(struct input_event)) <
              0) {
120     putchar('\a'); /* See above */
121     perror("write");
122   }
123   pitchfork_end("Privileged");
124 }
```

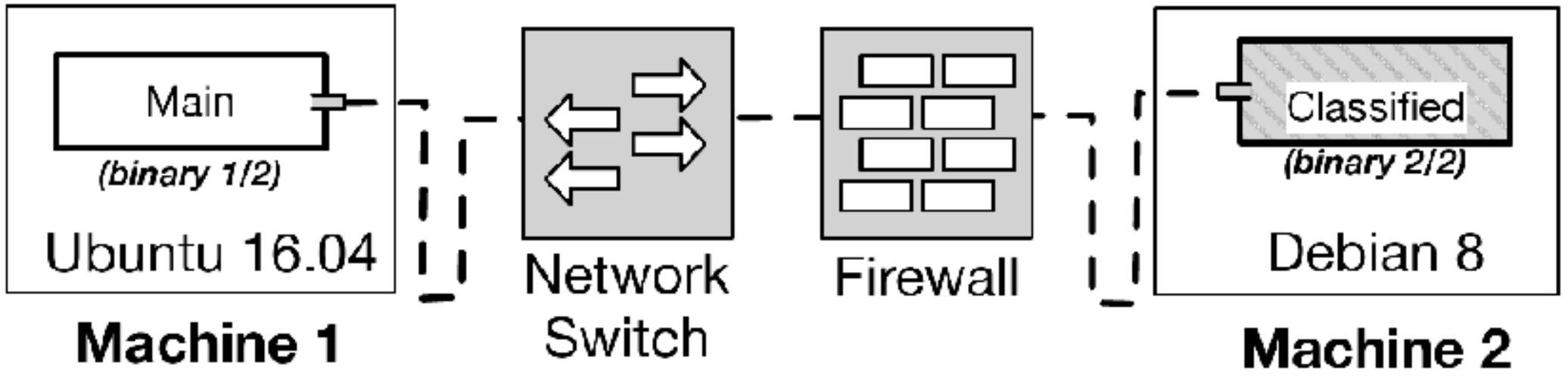
Compartment Model







Example of what's enabled



- Machine and network-level policy+enforcement.

- Communication channel over TCP.

- Organization:
  Domain: one on each machine
  Compartments: one in each domain.
  Segments: 2 in Classified, 1 in Main.

Evaluation

(Many more details in the paper)

- Applicability
  - Examples
  - Maintainability
  - Convenience
- Security
  - Known CVEs
  - Heuristics
- Overhead: running time, memory, binary size.

Evaluation

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Software	Plat.	Separation Goal
cURL	L	Command invocation, parsing, file transfer.
Evince	L	libspectre dependency—see §2.
gil	L	Historical vulnerability [13].
ioquake3	m	Applying server updates.
tifftopnm	L	Separating parsers—see §C.
nginx	L	HTTP request parsing
redis	L	Isolating low-use commands.
tcpdump, uniq	F	Leveraging Capsicum [68].
Viletris	L	Network-facing code—see §2.

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$$\text{SAR} = \frac{\#\text{LOC Synthesized}}{\#\text{Lines of Annotation}}$$

Soft.	#LOC	#Annot.	#LOC Synthesized		SAR
			Compart.	De/marsh.	
beep	372	9	133	245	42
PuTTY	123K	6	52	29	13.5
wget[6]	62.6K	3	65	168	77.7
wget[7]	62.8K	8	57	38	11.9

Evaluation

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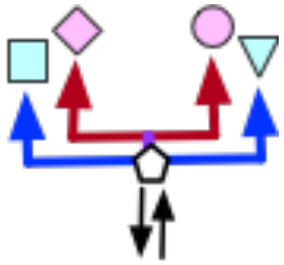
Software	CVE-*-*	Vulnerability
beep	2018-0492	Race condition
PuTTY	2016-2563	Stack buffer overflow
wget	2016-4971	Arbitrary file writing
wget	2017-13089	Stack buffer overflow



System release

- http://pitchfork.cs.iit.edu
- Everything is released except for exploit code:
  - libcompart
  - Pitchfork
  - examples of applying libcompart & Pitchfork
  - FreeBSD ports analysis
- Apache 2.0 license

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