Practical and Effective Sandboxing for Non-root users

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Why yet another sandbox for desktop applications?

- There are many existing sandbox mechanisms
  - Chroot / Lxc (Unix/Linux)
  - Jail (Freebsd)
  - Seatbelt (Mac OS X)
  - VM?

    …
- Difficult-to-use, requiring root privilege, or slow!

TL;DR

Our tool

Unknown binary downloaded from the Internet

```
$ mbox -- ./downloaded-bin
...
Network Summary:
 > [11279] -> 173.194.43.51:80
 > [11279] Create socket(PF_INET,...)
 > [11279] -> a00::2607:f8b0:4006:803:0
 ...
Sandbox Root:
 > /tmp/sandbox-11275
 >   N:/tmp/index.html
[c]ommit, [d]iff, [i]gnore, [l]ist, [s]hell, [q]uit ?>
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Where to connect?

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Protecting the host filesystem from modification

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Without root privilege!

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Design overview

- **Layered sandbox filesystem**
  - Overlaying the host filesystem
  - Confining modification made by sandboxed processes
  - Persistent storage: in fact, just a regular directory

- **System call interposition**
  - Commodity OSes provide one for non-root users
  - Enabling a variety of applications: installing pkgs, restricting network, build/dev. env ...

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Installing packages as normal user

```
$ mbox -R -- apt-get install git
(-R: emulate a fakeroot environment)
```

- Mbox provides a writable sandbox layer on top of the host filesystem
  - User owns the sandbox directory
  - Contain newly installed files, and package databases
- Mbox emulates a fakeroot environment
  - Use standard package managers without modification
  - Support: apt-get (Ubuntu), dpkg (Debian), pip (Python)

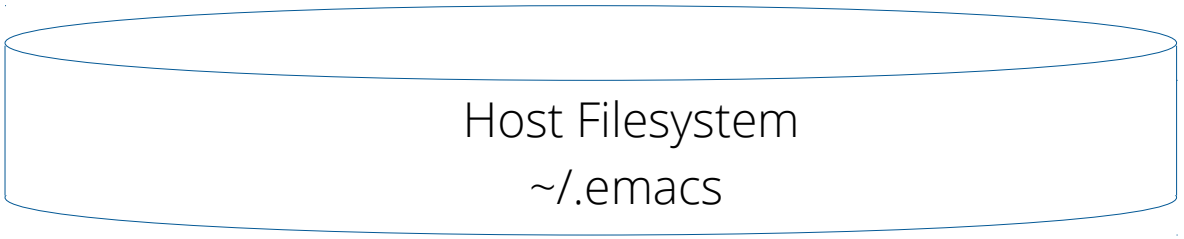
Running unknown binary safely

```
$ mbox -n -- ./downloaded-bin
(-n: disable remote network accesses)
```

- Mbox protects the host filesystem from modifications
- Mbox restricts or monitors network accesses
  - Interpret socket-like system calls
  - Summarize network activity when terminated

Checkpointing filesystem

```
$ mbox -i -- emacs ~/.emacs
(-i: enable interactive commit-mode)
```



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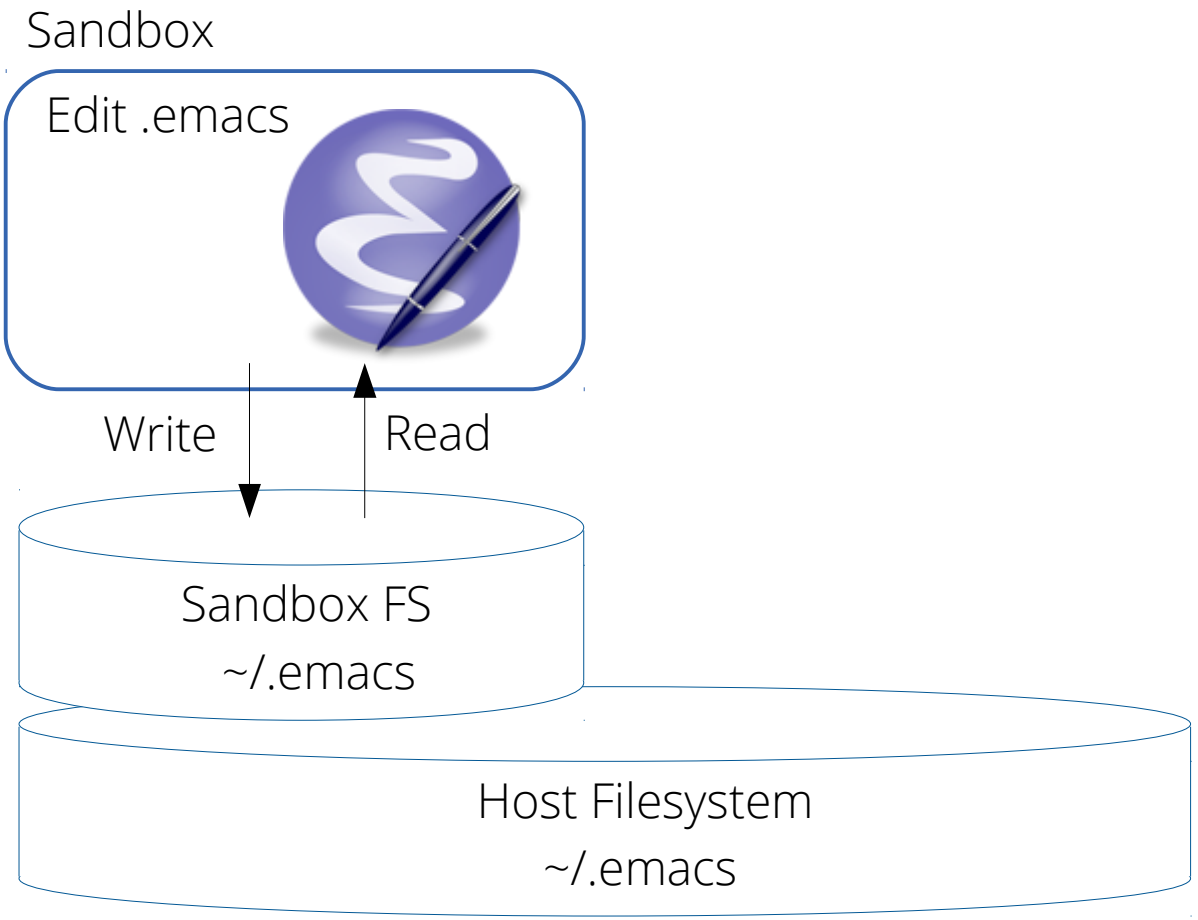

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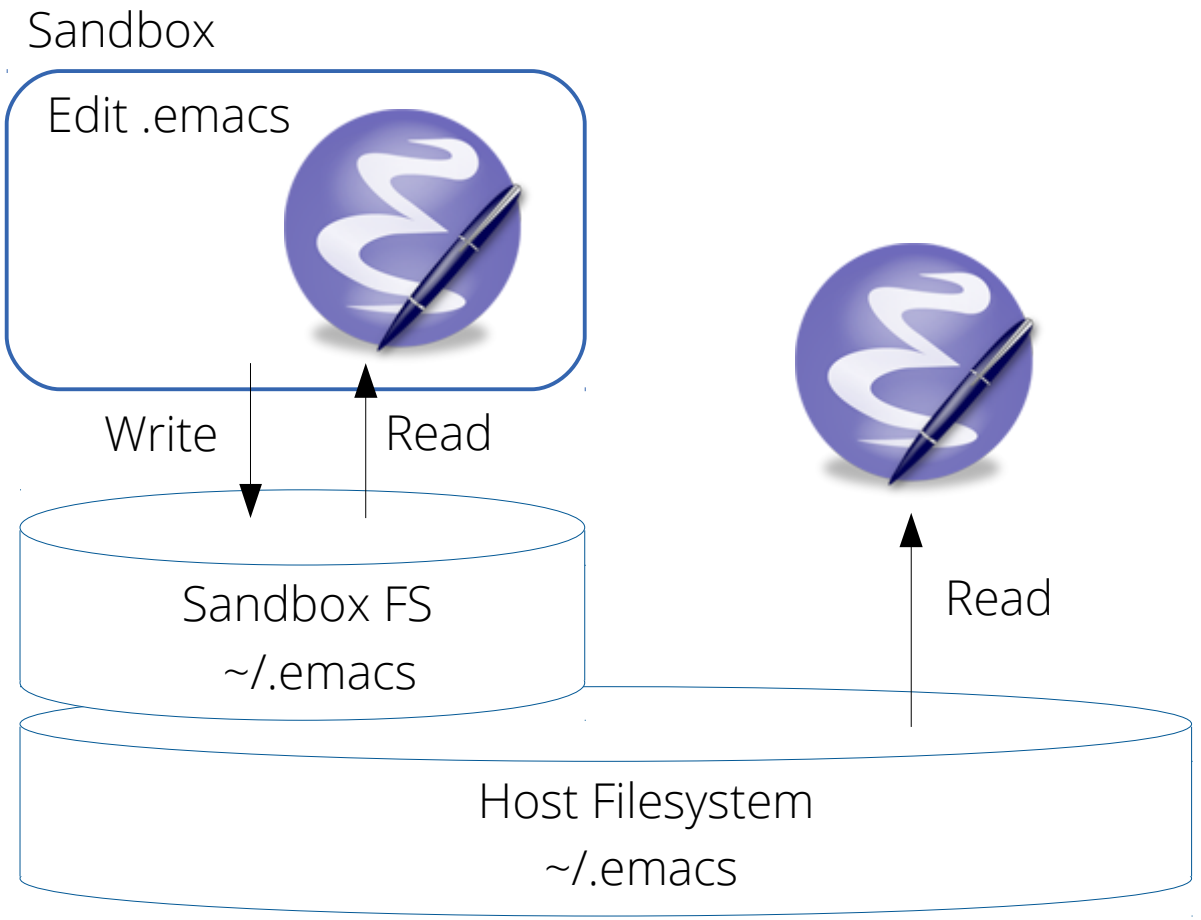

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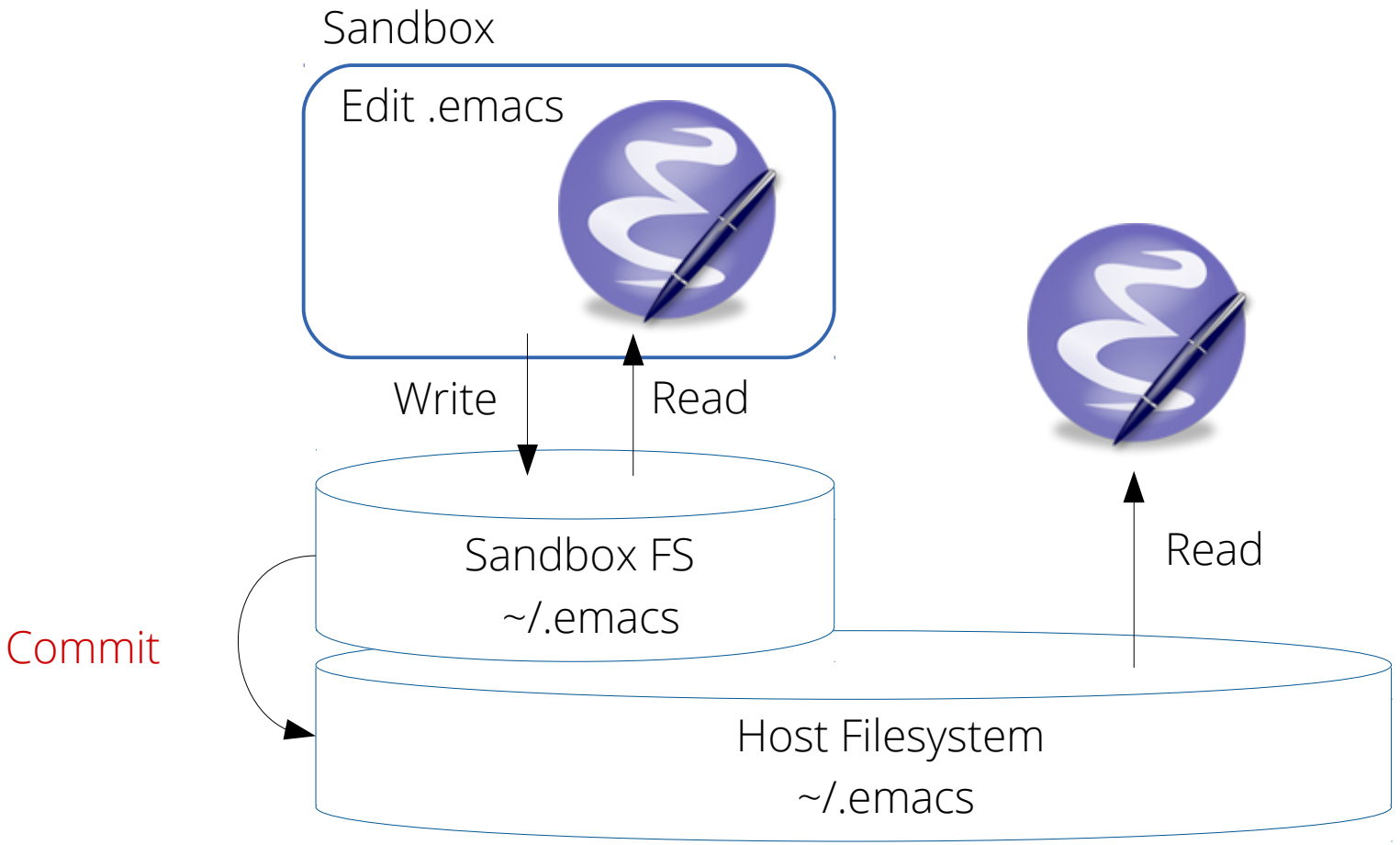
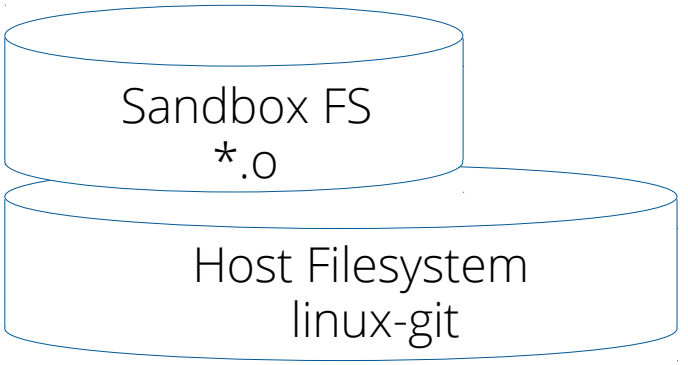


Build/development environment

```
$ tree linux-git
  ...
  +--mm--mmap.c
       +-mlock.c

$ mbox -r outdir -- make
(-r dir: specify a sandbox directory)
```

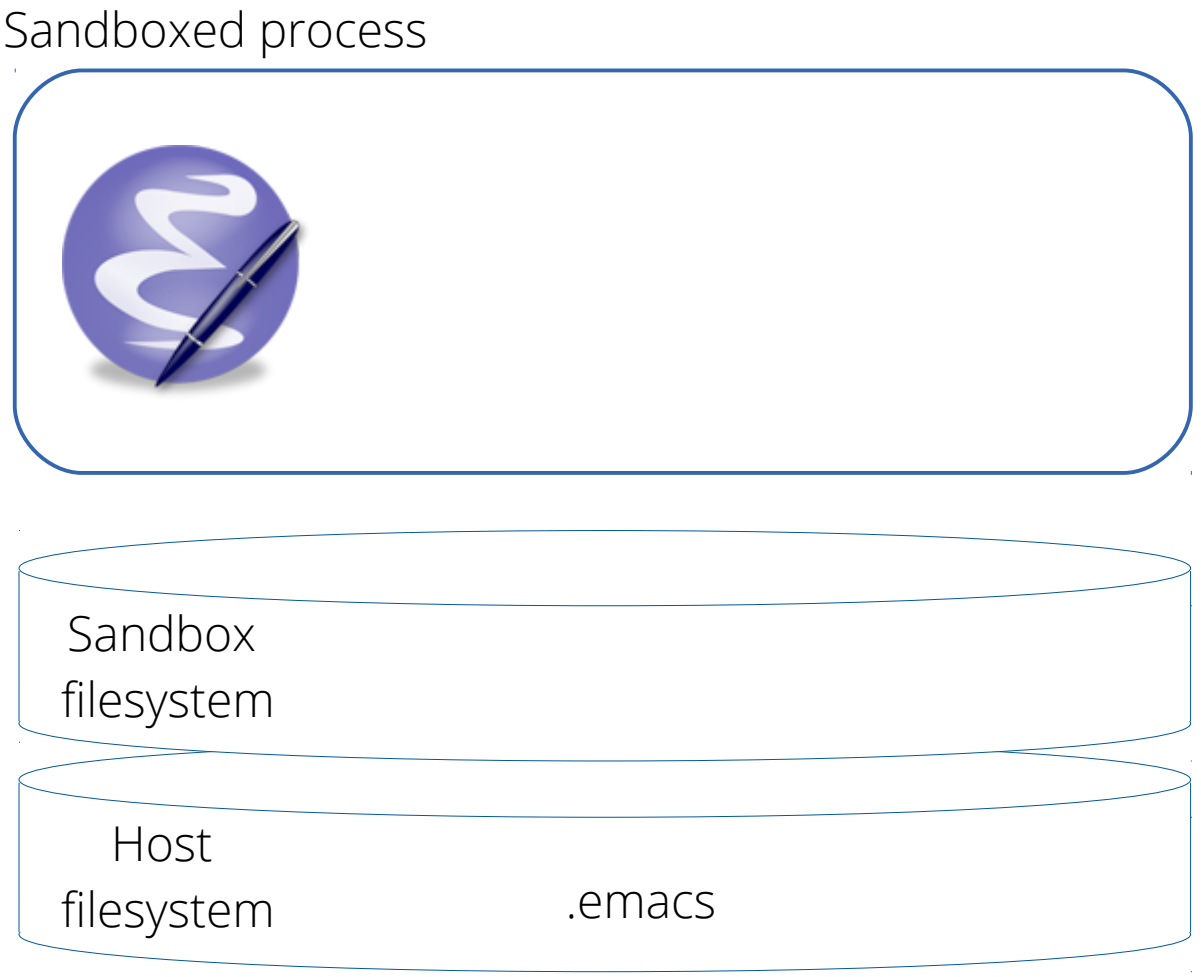


- Mbox can separate out the generated obj files
  - make clean == rm -rf outdir
- Mbox can also be used for virtual dev. env.
  - Install packages with standard package managers

Outline

- Motivation / use cases
- Layered sandbox filesystem
- System call interposition (using seccomp/BPF)
- Implementation / evaluation
- Related work
- Summary

Sandbox filesystem supports copy-on-write



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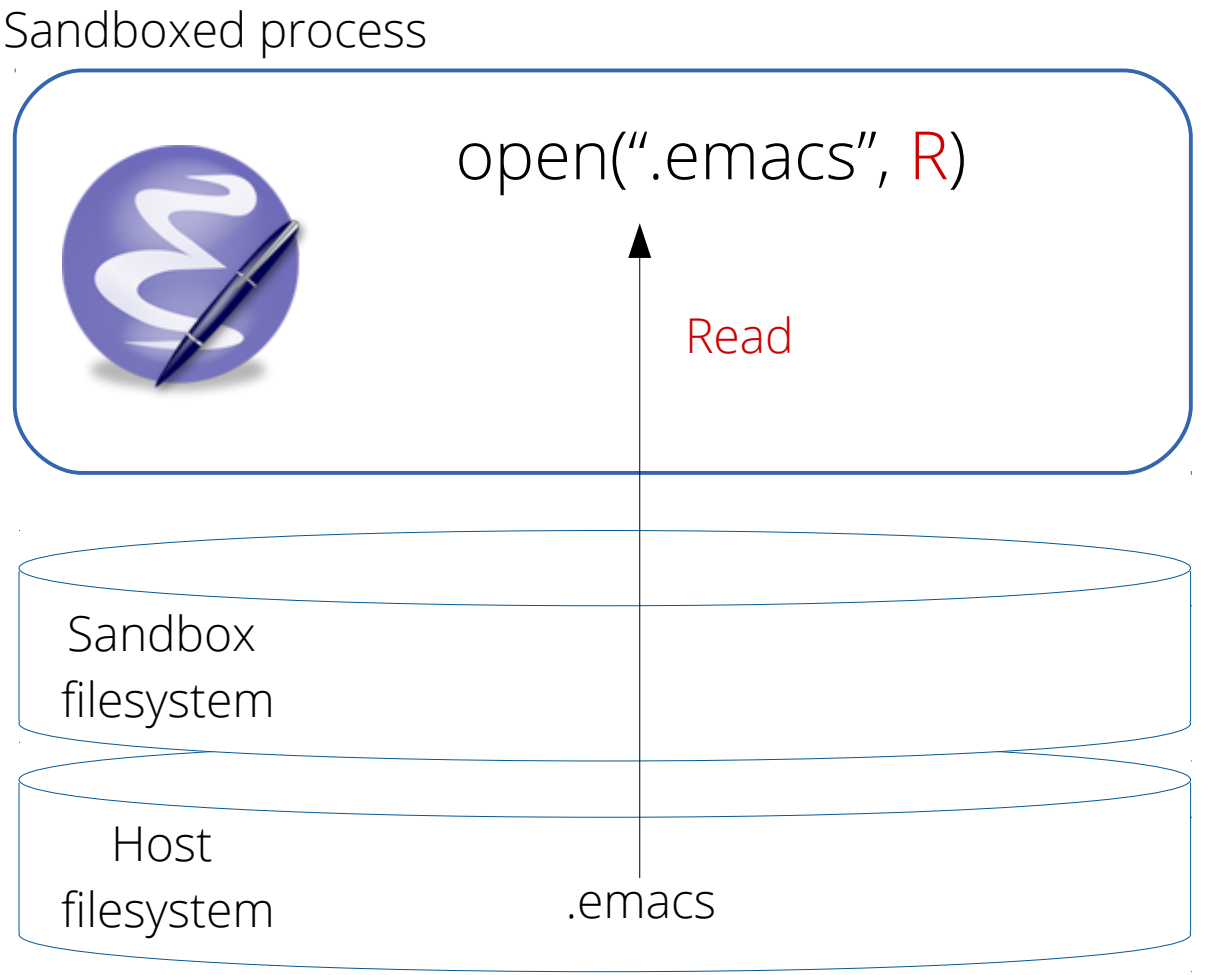

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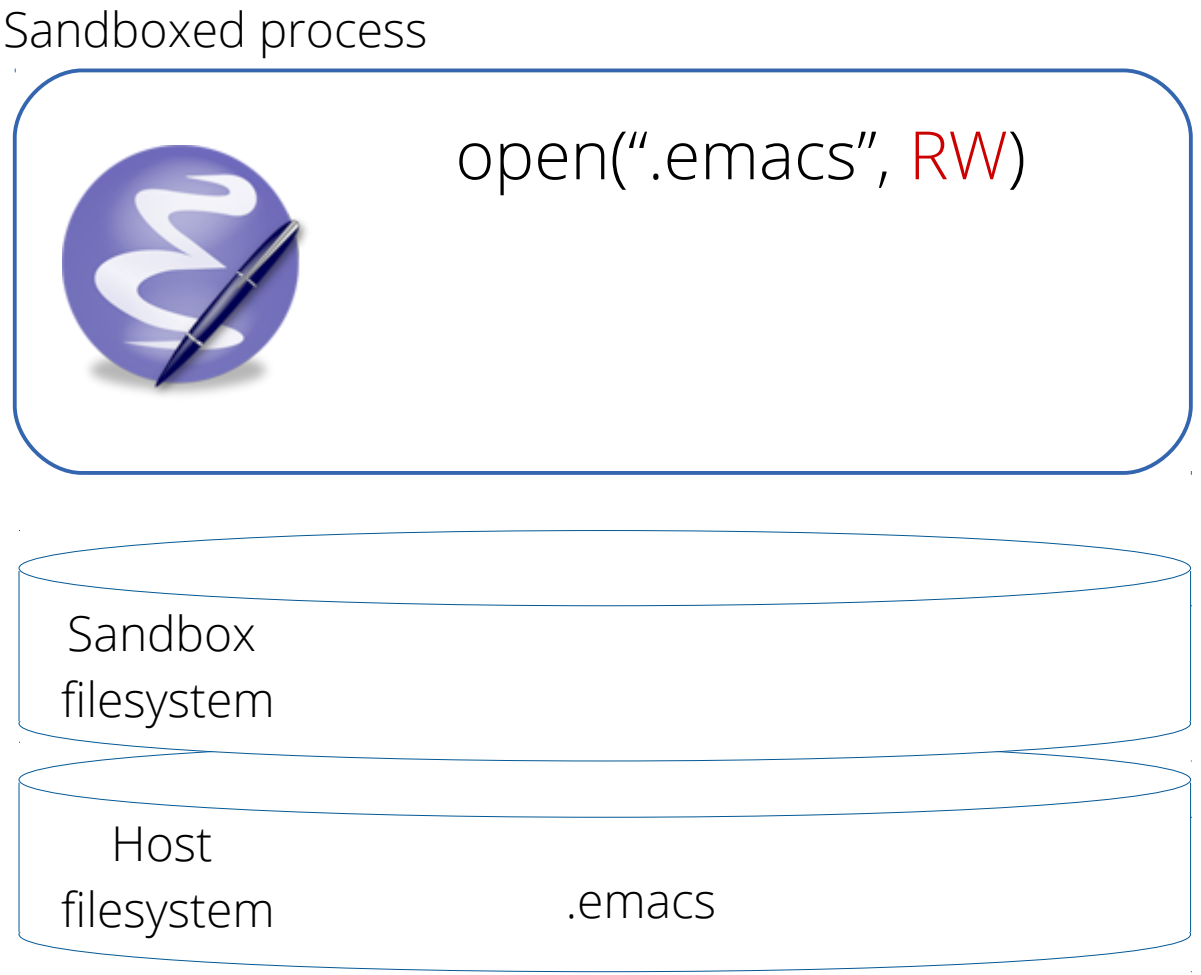

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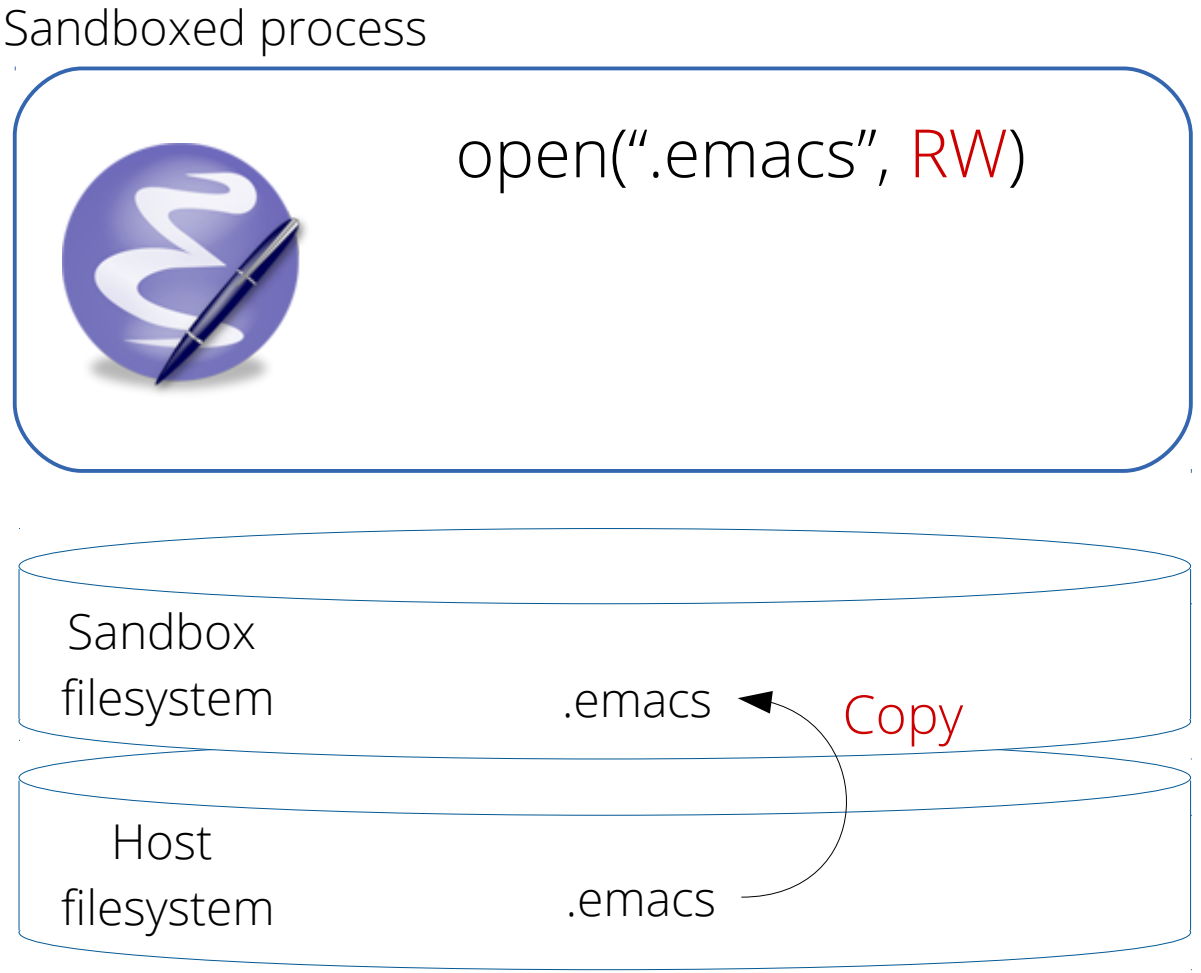

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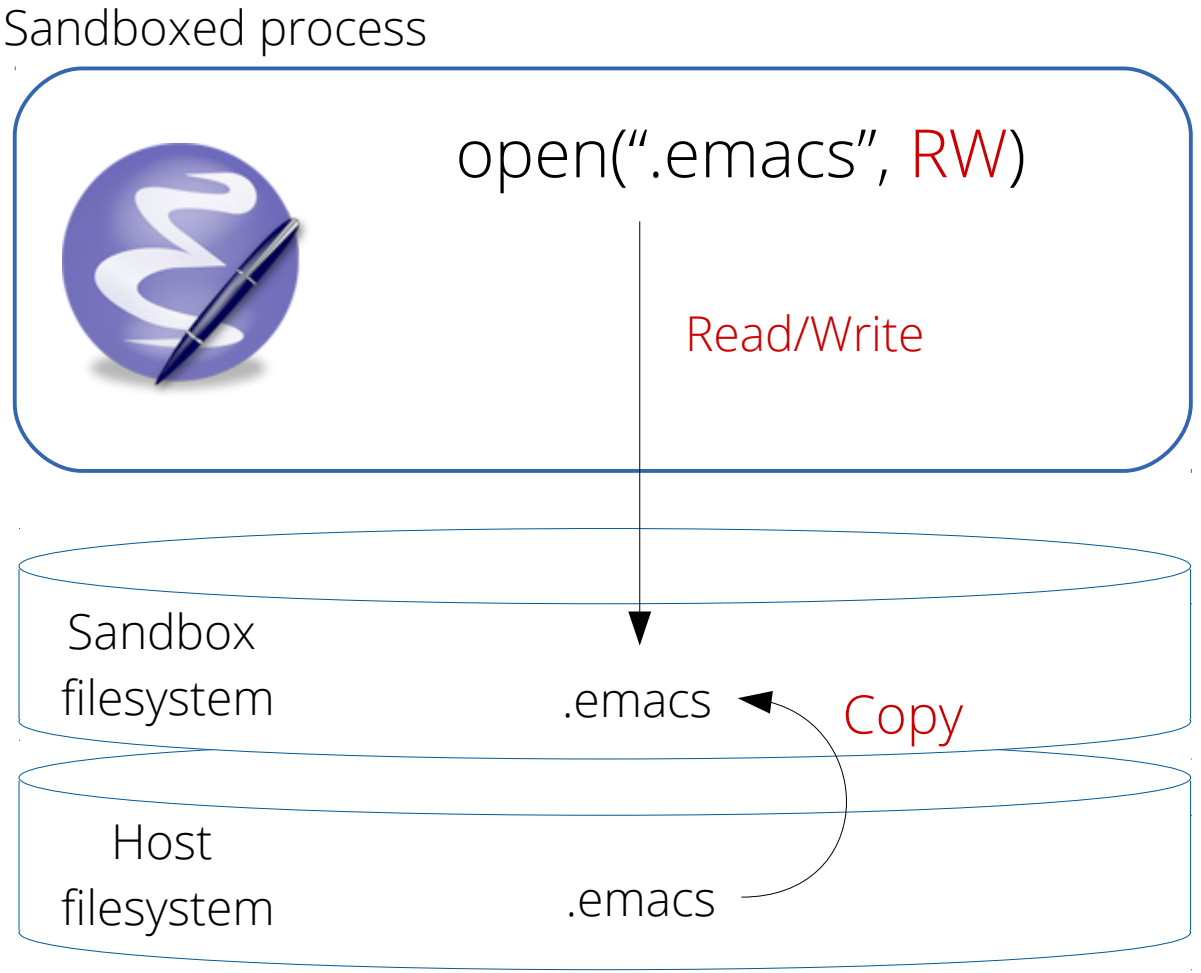
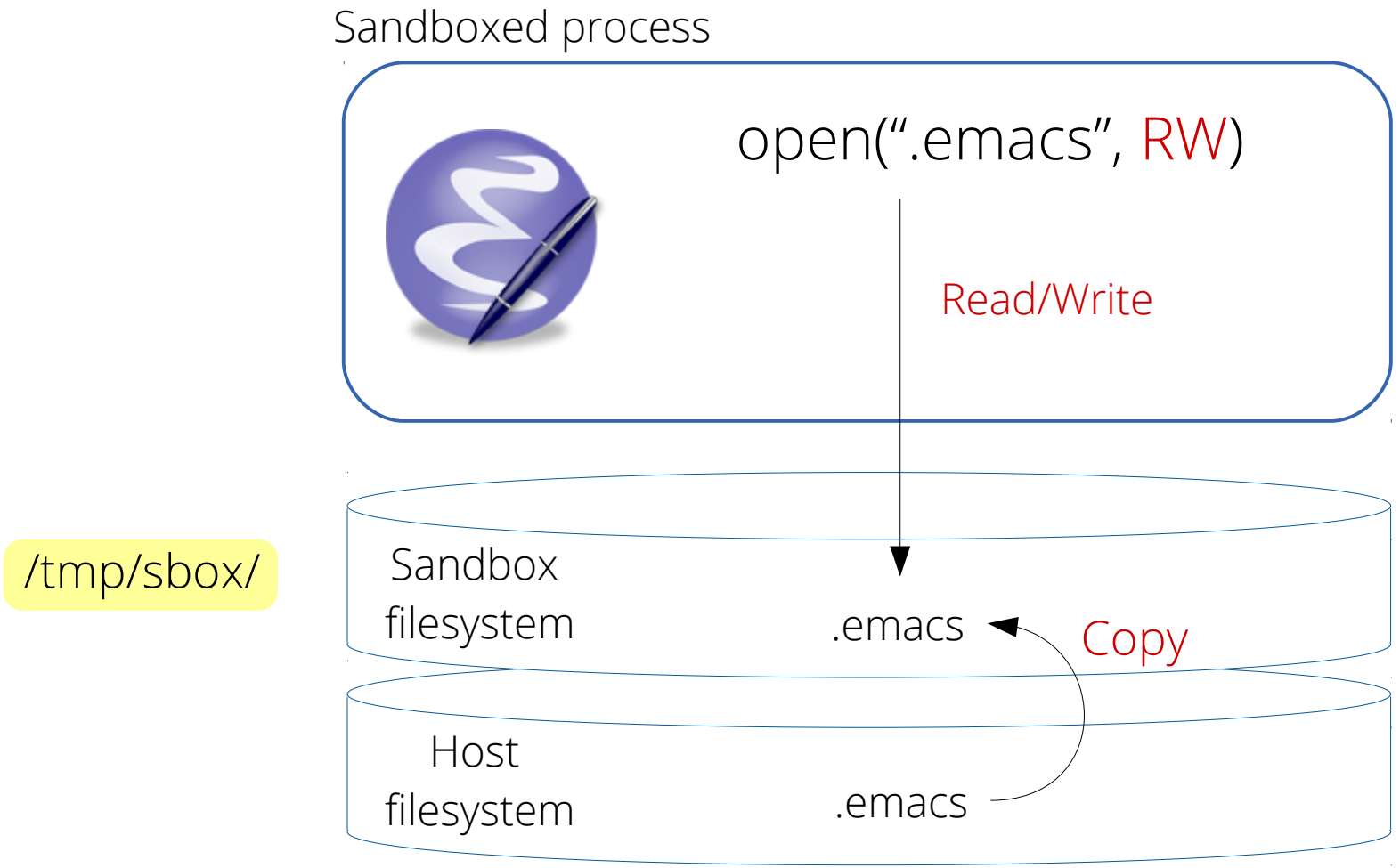


Copy-on-write by rewriting path arguments



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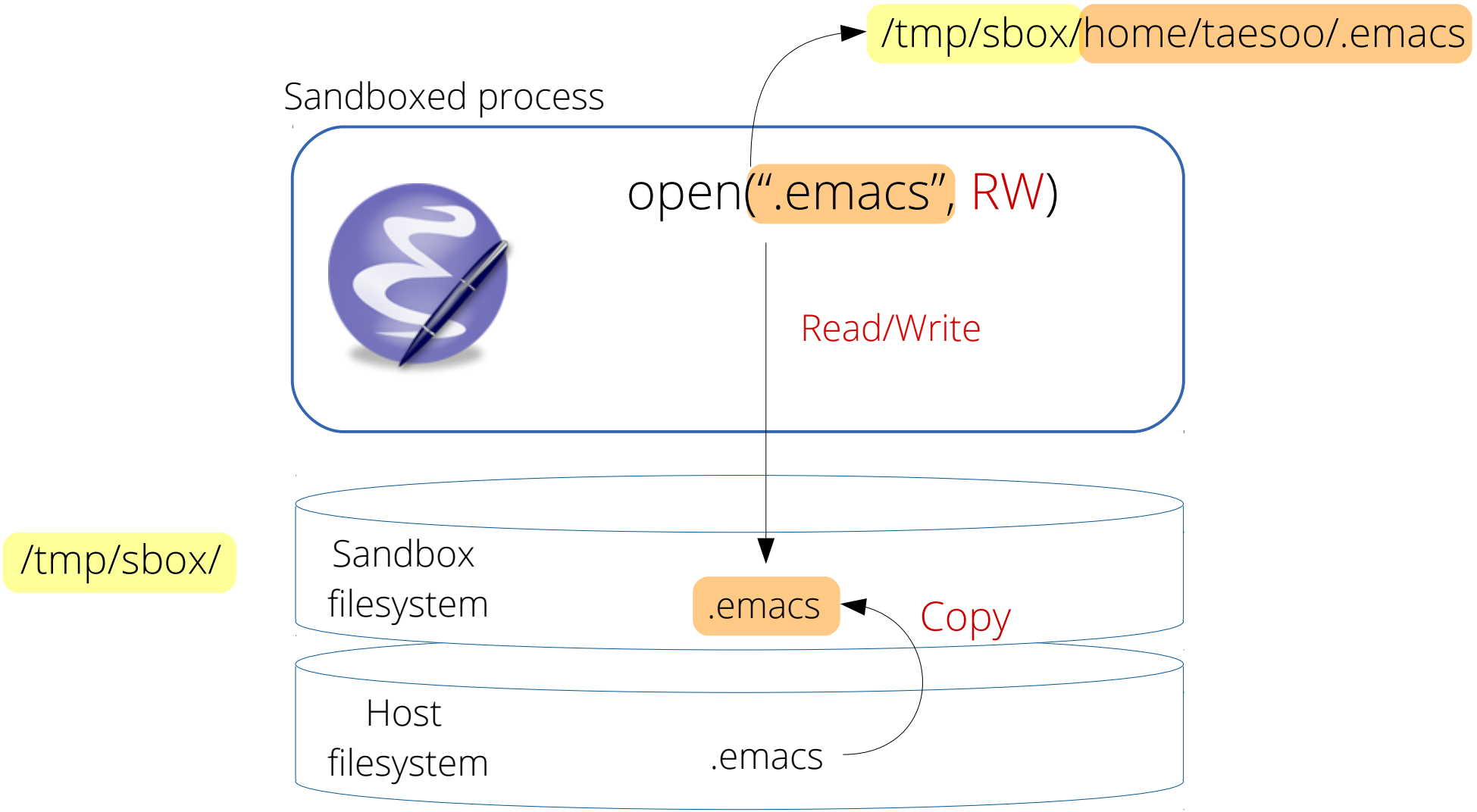
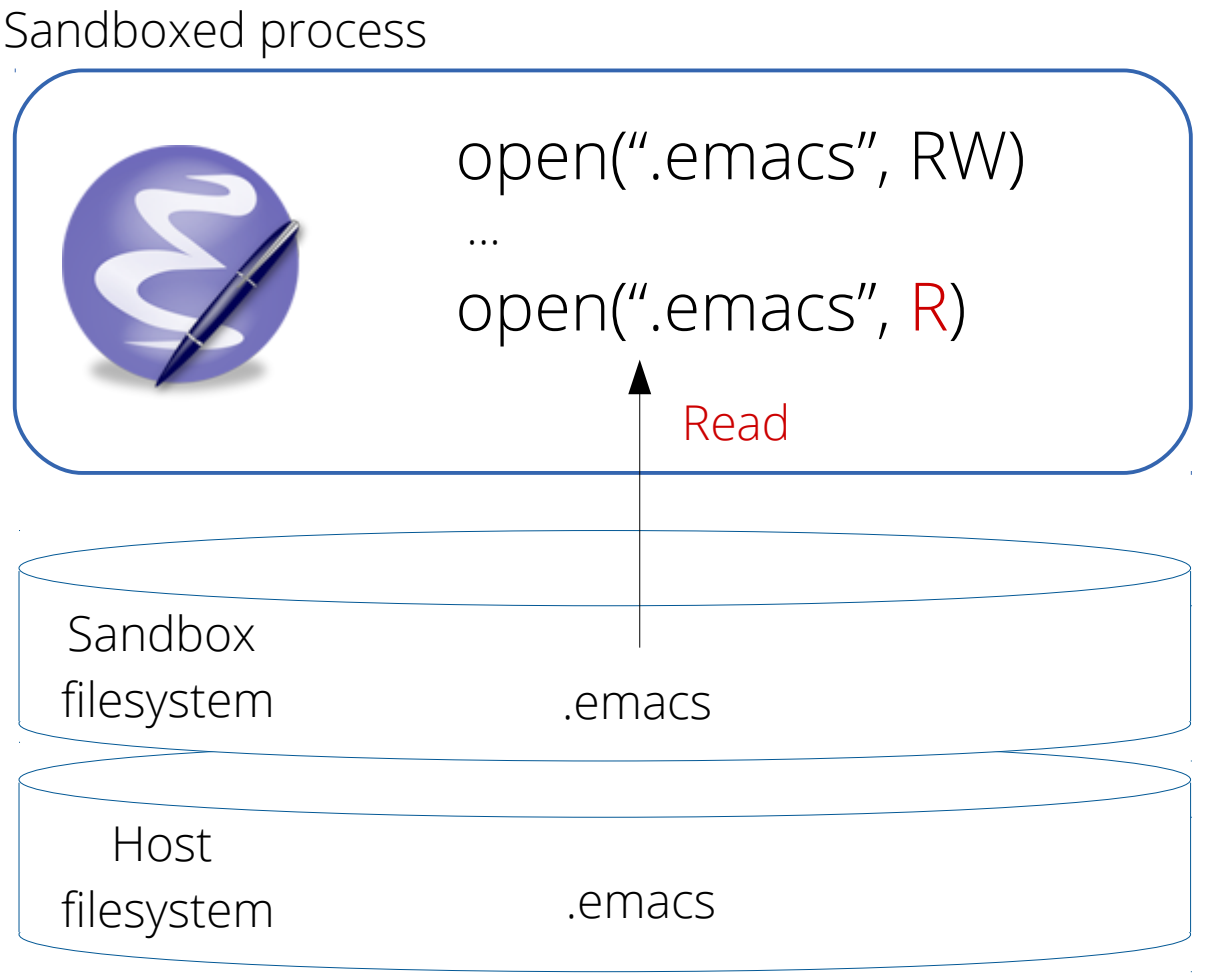


All subsequent read/write should happen on the sandbox filesystem



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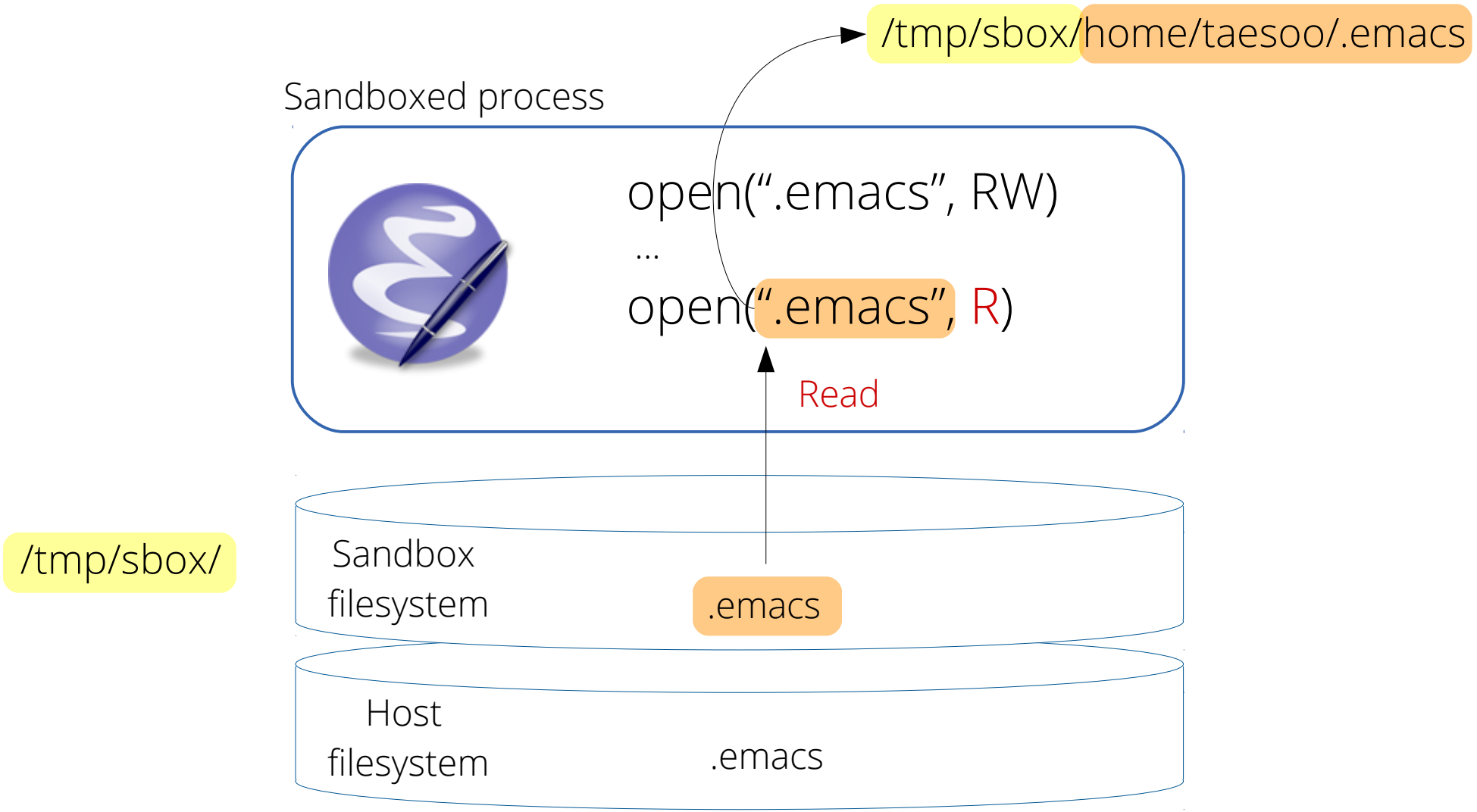
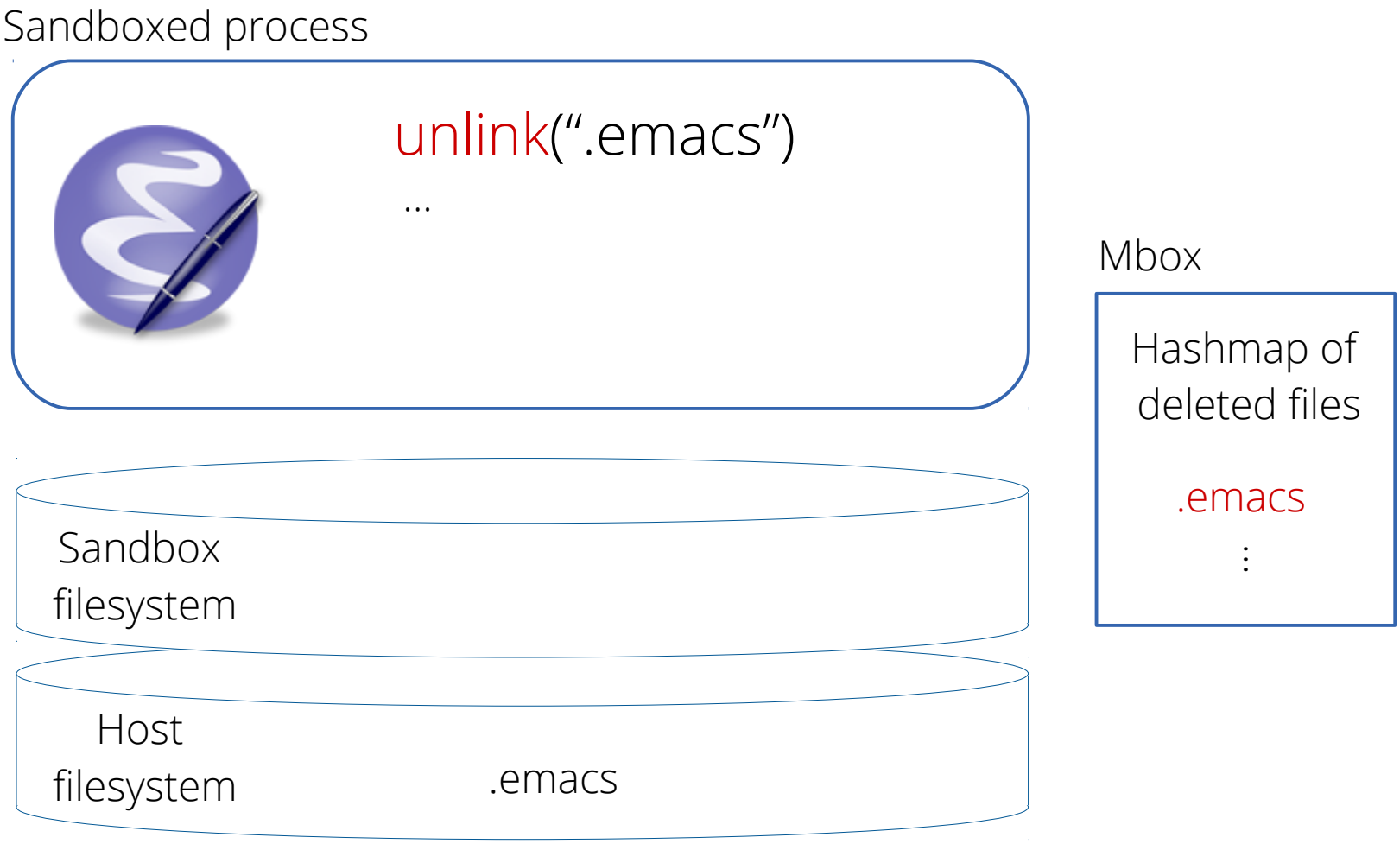


Sandbox filesystem keeps track of deleted files



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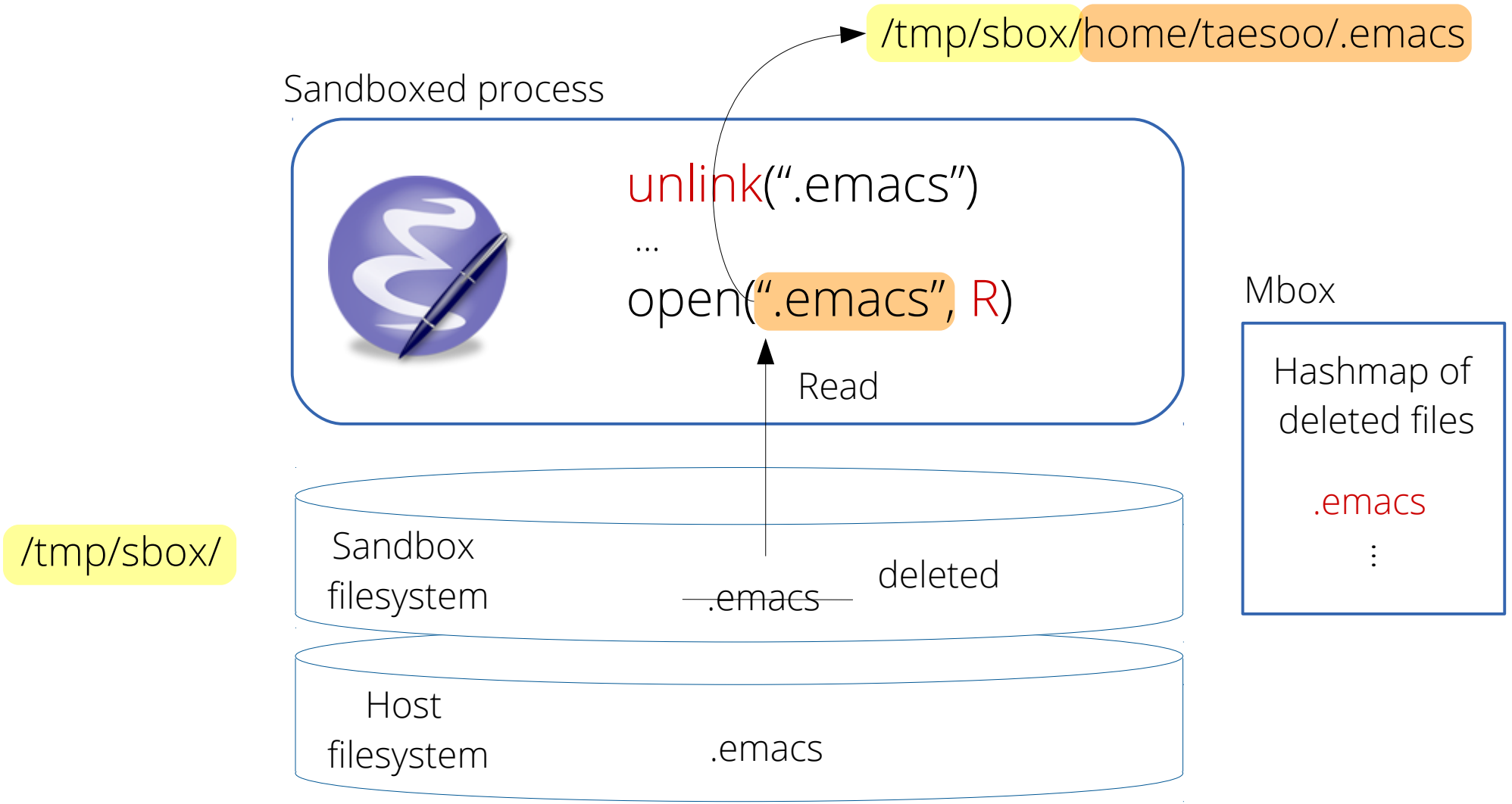


Mbox doesn't have to interpose on every system call

```
fd = open(".emacs", R)
read(fd, buf, size)
```

```
fd = open(".emacs", RW)
write(fd, buf, size)
```

- After redirecting the path in open(), we don't have to interpose on read/write() system calls
- Mbox needs to interpose on 48 system calls getting a path argument to provide a layered sandbox filesystem

Mechanism: system call interposition

- Ptrace is a common technique, but slow
  - Interpose entry/exit of every system call
  - Serialize system calls of child processes

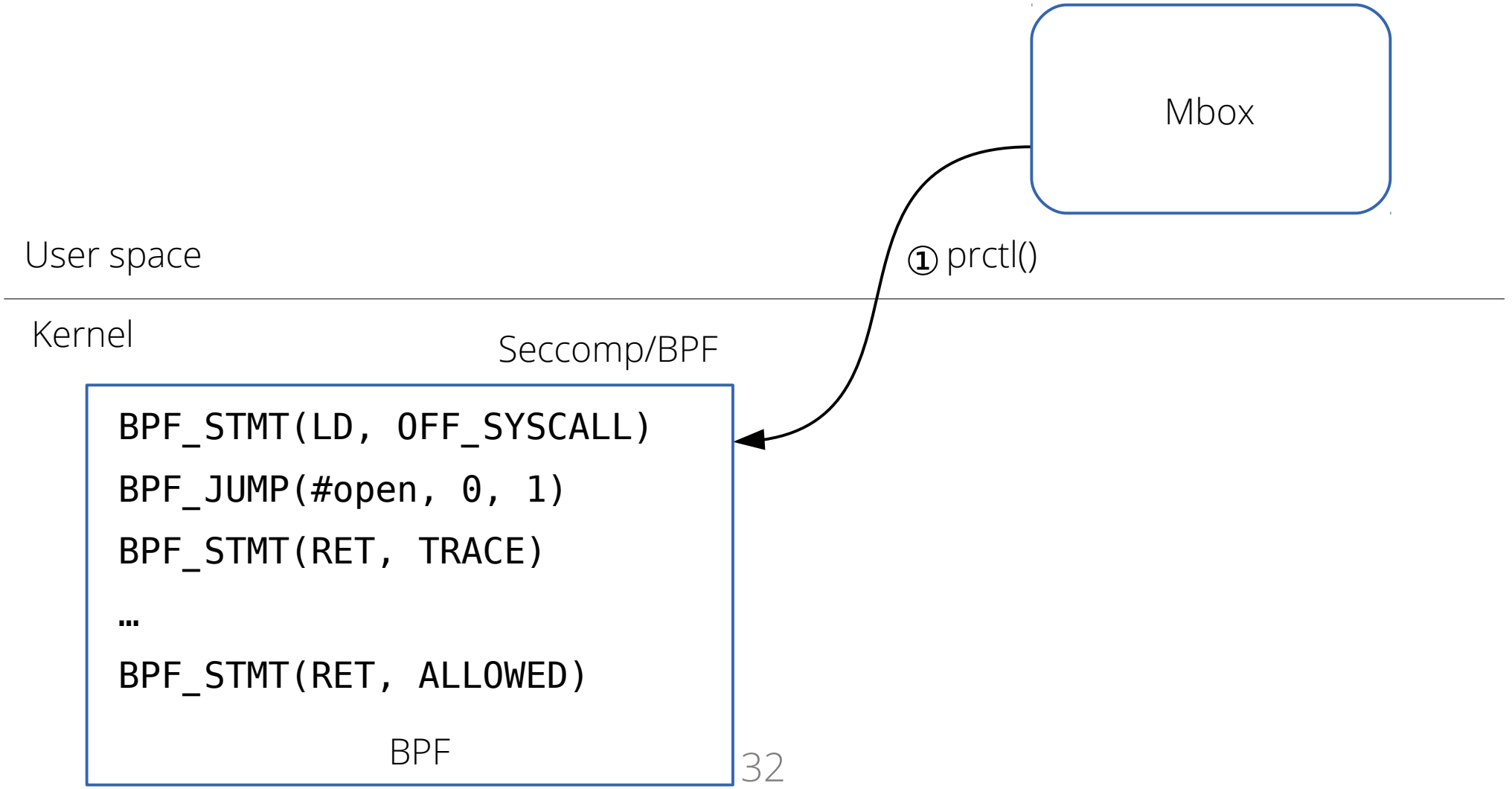
- Using seccomp/BPF (>= Linux 3.5)
  - Seccomp is a security mechanism for isolating a process by allowing a certain set of system calls
  - Seccomp/BPF uses BPF (Berkeley Packet Filter) to specify rules for filtering system calls

BPF program for interposition

User space

Kernel

BPF program for interposition



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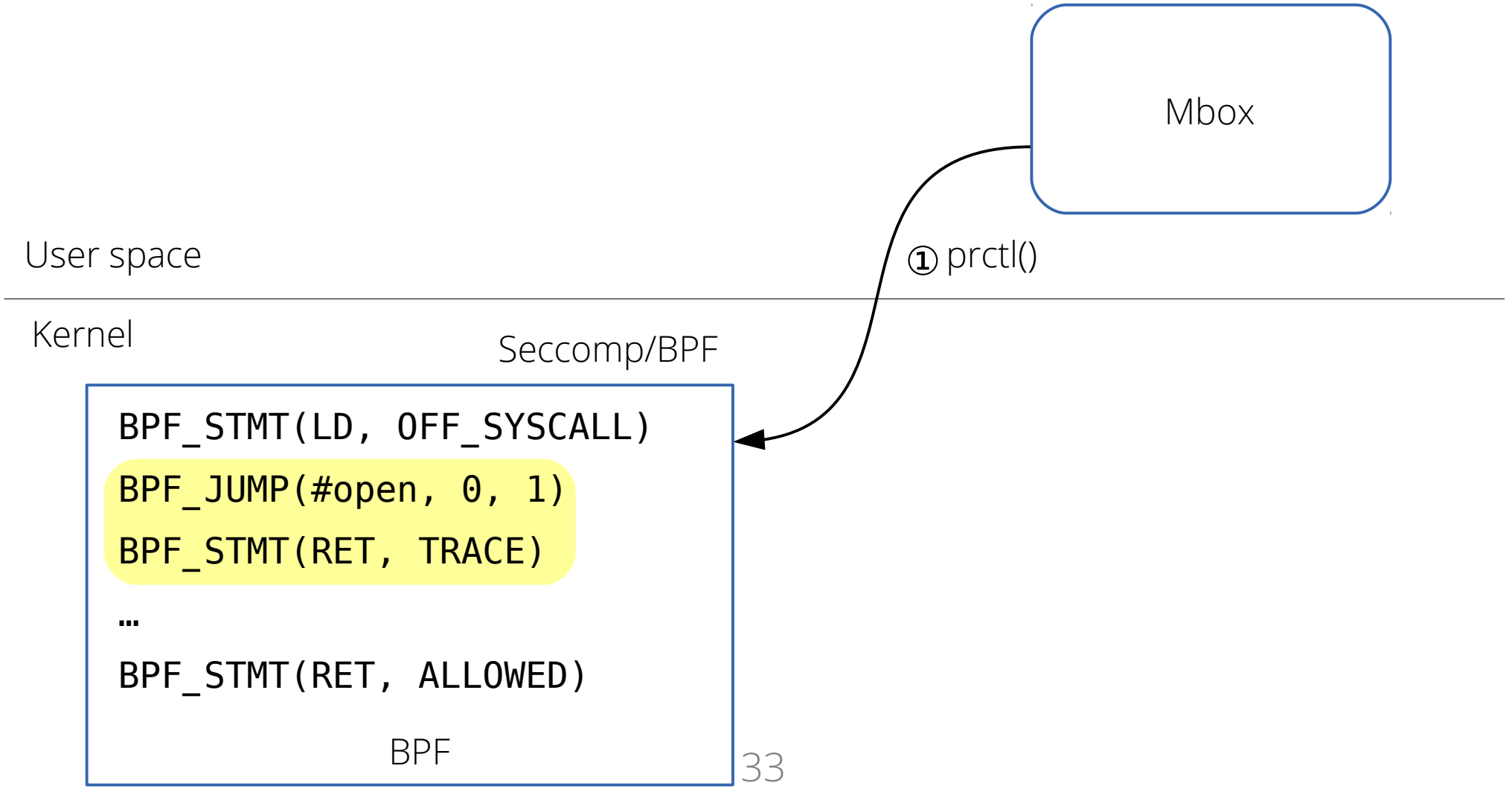

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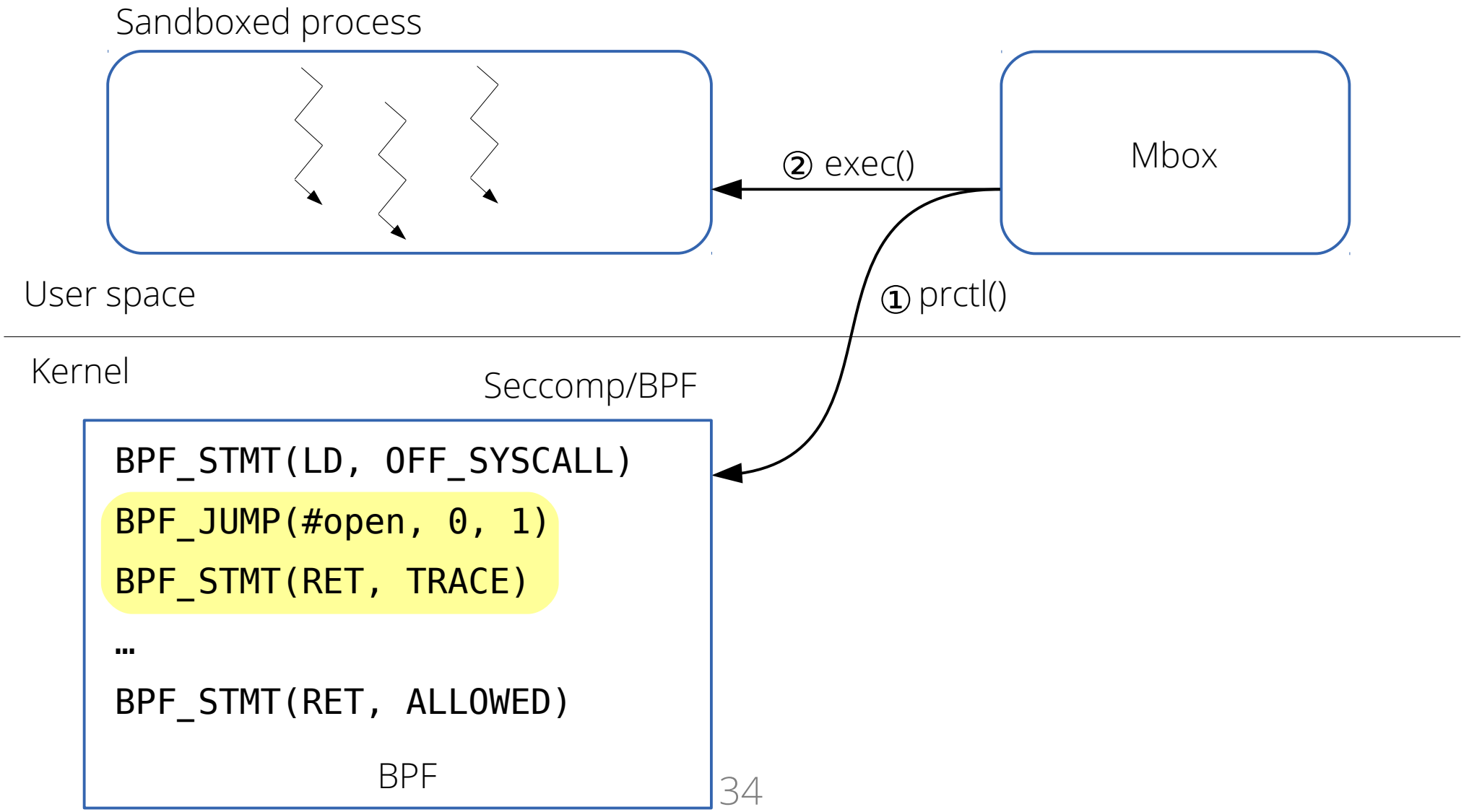

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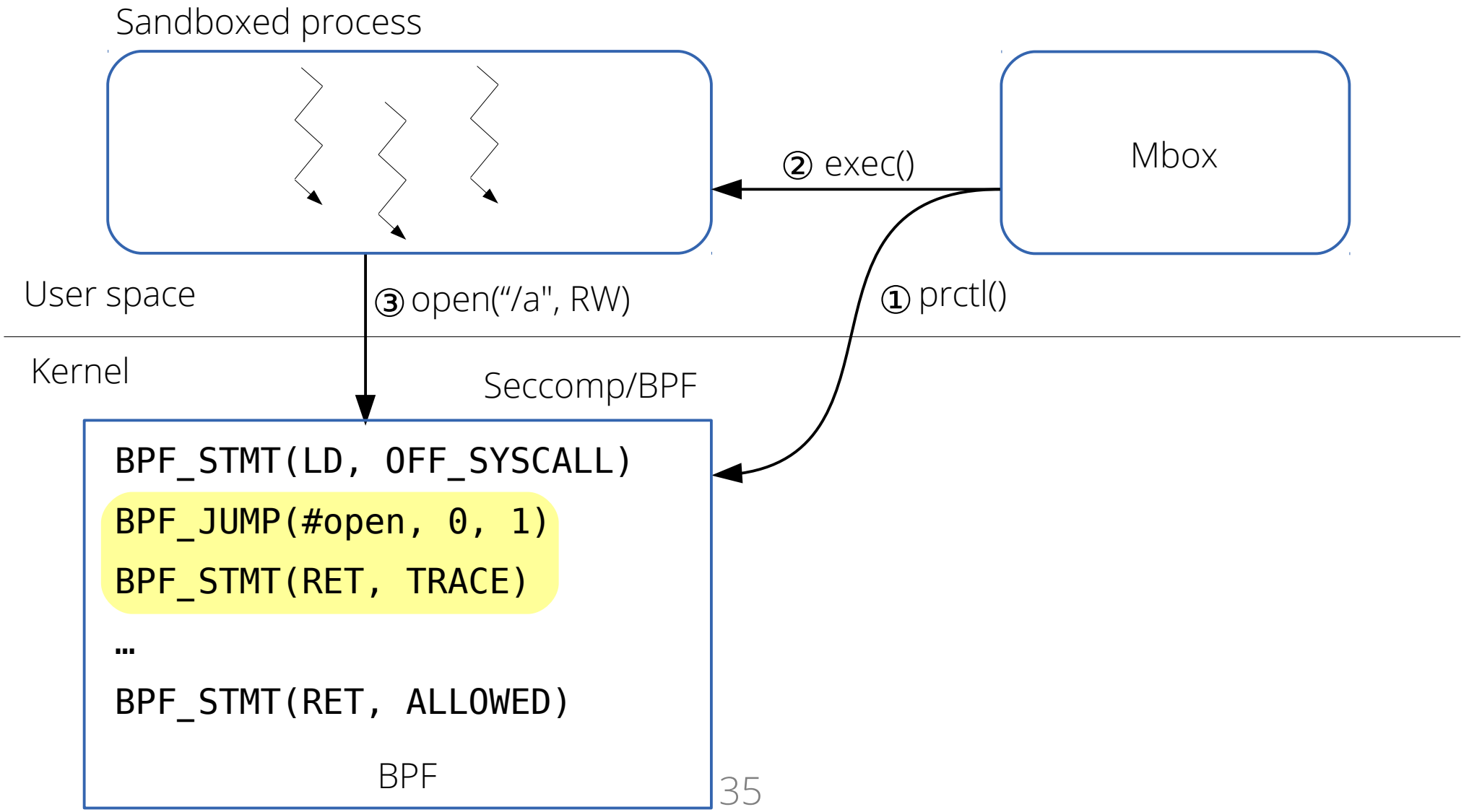

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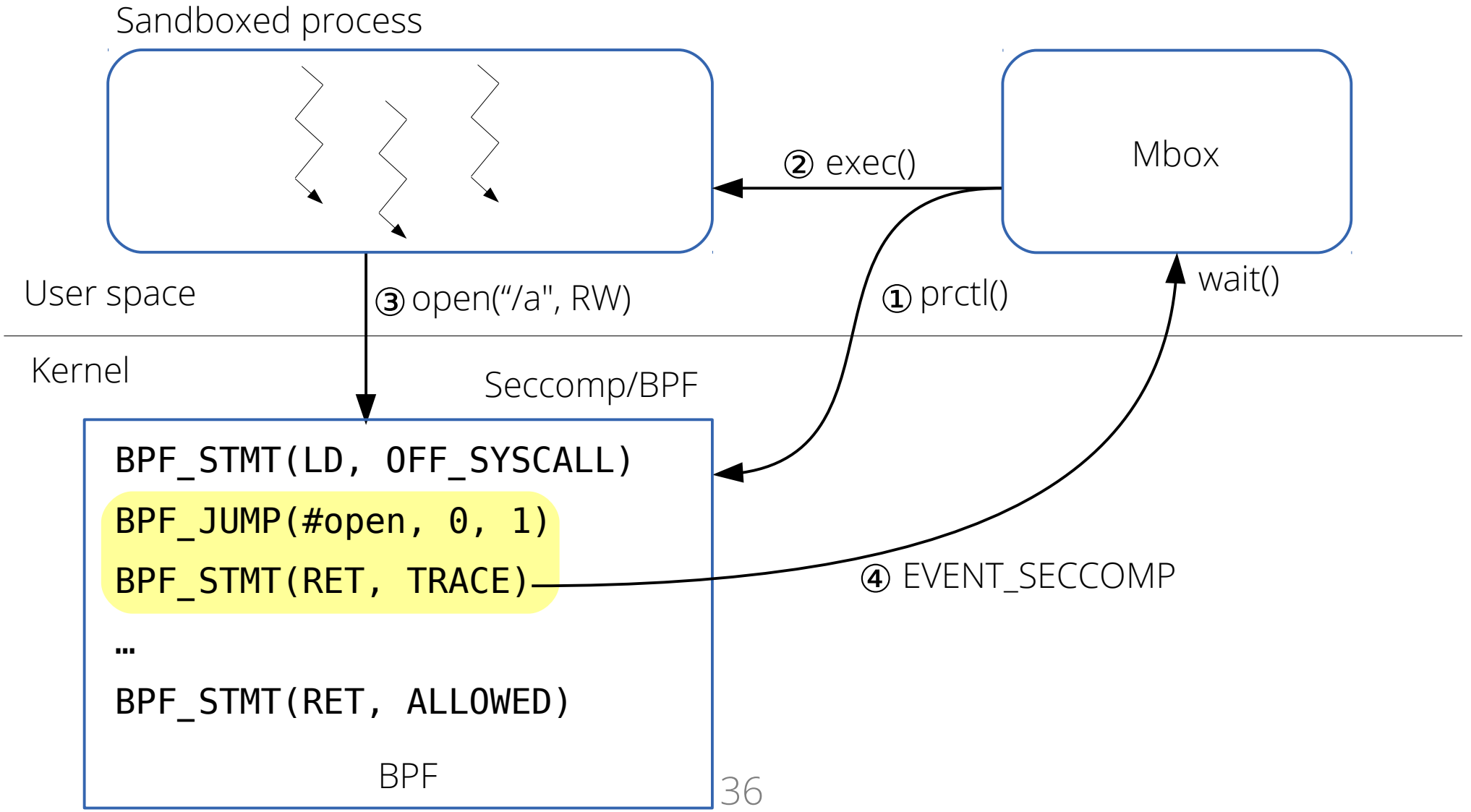

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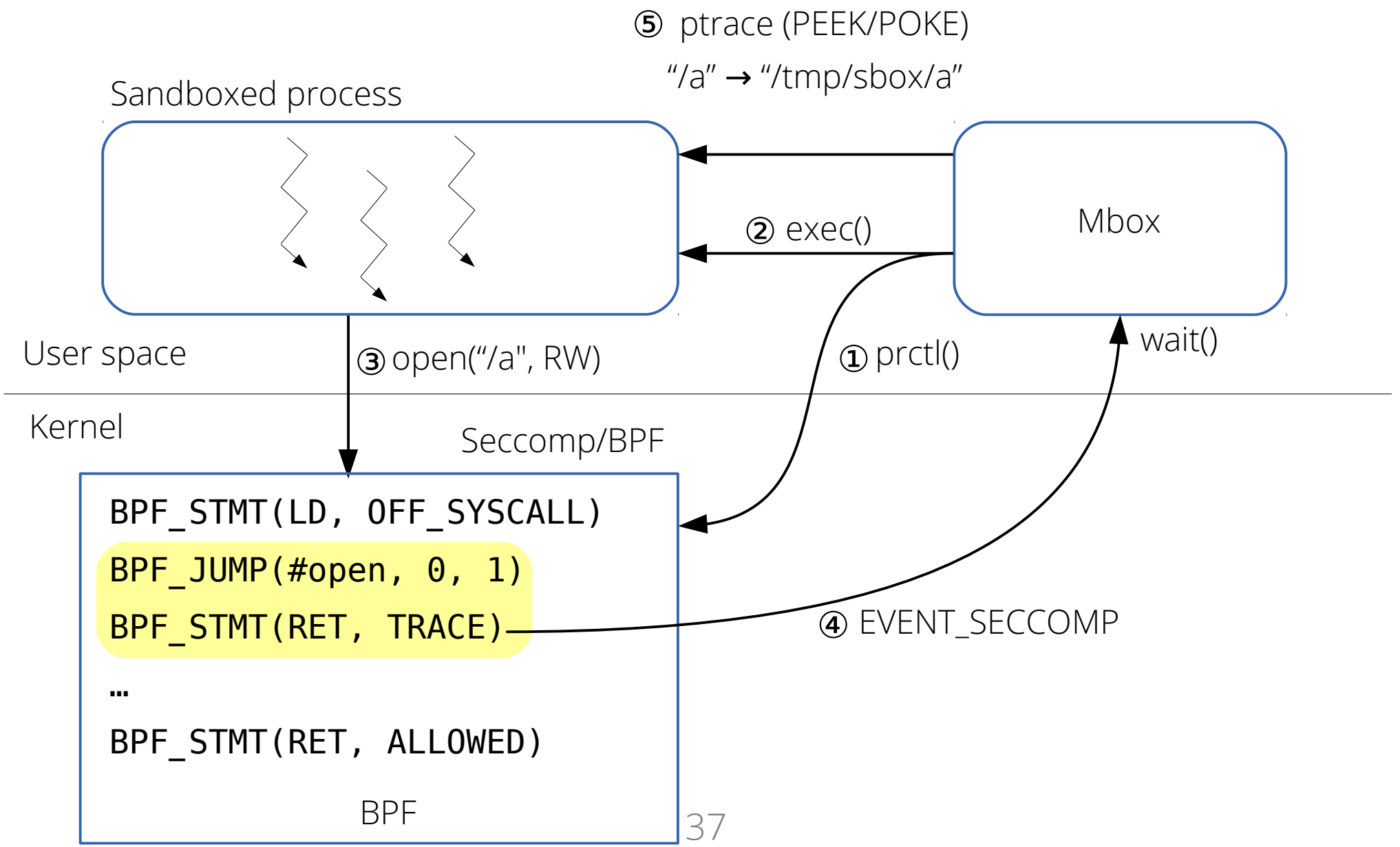

More story to come …

- How to avoid time-of-check-to-time-of-use?
- How to avoid replicating OS state?
- …

Please, check the paper!

Implementation

- Mbox: a prototype for Linux (>= 3.5, x86-64)
  - Using seccomp/BPF and ptrace
  - Extending strace 4.7
  - 1,500 Lines of code
  - Distributions: Ubuntu 12.04 and Arch 64bit

Performance evaluation

- How much overhead does Mbox exhibit?
- How much faster is seccomp/BPF than ptrace?

Benchmark

Task	Description
Octave	Octave Benchmark calculating matrix
Zip	Compress source files of Linux 3.8
Untar	Decompress source files of Linux 3.8
Build Linux (-j1)	Compile Linux 3.8 kernel

- Following the benchmark from Apiary
- Run each benchmark in three configurations
  - Normal
  - Mbox with ptrace
  - Mbox with seccomp/BPF

Mbox imposes modest end-to-end performance overhead

Task	Normal	Mbox	
		Seccomp/BPF	
Octave	2.1s	2.1s	0.1%
Zip	15.6s	17.4s	12.0%
Untar	13.6s	16.4s	20.9%
Build Linux (-j1)	43.6s	49.7s	13.9%

- 0.1% ~ 20.9% overhead
- Octave: a computation-heavy workload
  - Exhibits negligible performance overhead (0.1%)
  - Spends 98% of its execution in userspace

Seccomp/BPF reduces the interposition overhead

Task	Normal	Mbox			
		Ptrace		Seccomp/BPF	
Octave	2.1s	2.1s	0.1%	2.1s	0.1%
Zip	15.6s	21.2s	36.5%	17.4s	12.0%
Untar	13.6s	19.0s	40.3%	16.4s	20.9%
Build Linux (-j1)	43.6s	53.2s	21.9%	49.7s	13.9%

- Compare overheads of using ptrace and seccomp/BPF
- Seccomp/BPF reduces overhead up to 24.5%

Seccomp/BPF has better concurrency than ptrace

Task	Normal	Mbox			
		Ptrace		Seccomp/BPF	
Build Linux (-j1)	43.6s	53.2s	21.9%	49.7s	13.9%
Build Linux (-j4)	21.7s	45.6s	110.1%	31.5s	45.2%

- When compiling the Linux kernel with 4 parallel jobs, performance improves 64.9% compared to ptrace
- By avoiding unnecessary serialization of system calls, multiple processes execute system calls concurrently

Seccomp/BPF has better concurrency than ptrace

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Related work

- **Layered filesystems**: UnionFS [Quigley '06] / Aufs
  - Following unification rules / copy-on-write
    - → Require no modifications in commodity OSes
- **System call interposition**: Ostia [Garfinkel '04]
  - Enforcing security policies / studied common pitfalls
    - → Summarize our experience of using seccomp/BPF
- **Namespace**: Plan9 [Pike '90] / Lxc container (Docker)
  - Private namespace for each process
    - → Enabling various applications via system call interposition

Summary

Mbox: a lightweight sandboxing mechanism

- **Layered** sandbox filesystem
- Revision-control-system like sandbox usage model
- Interposing on system calls with **seccomp/BPF**
- Enabling a variety of applications for **non-root** users

http://pdos.csail.mit.edu/mbox

Questions (if you don't have any)

- What if files are modified by other processes running outside of Mbox?
- Why 20% on tar? just rewriting path arguments doesn't seem to be demanding work.
- How complicated the BPF program? Why not implement everything in BPF then?
- Why does Mbox support only 64bit? and is Mbox ready for users (not developers)?
- Can Mbox be used for A, B and C ... ?