Secure Software Development

Countermeasures: Privilege Minimization

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Attacker's perspective

- Vulnerability discovery ✓

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- Privilege minimization (today)

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Privilege minimization

- System call filtering, sandboxing, virtualization

Recap: What if Vulnerability Prevention Fails?

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- Attacker gained arbitrary code execution
  - Part 2: Can we prevent further damage? → Privilege Minimization
  - Our enemy: arbitrary code execution

Privilege Minimization

Arbitrary Code Execution I

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  - Native x86, Bytecode, JavaScript, WebAssembly ...

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☺ Cloud computing: run a kernel → arbitrary native x86 instructions

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- Goal: **privilege minimization**

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☞ Goal: **privilege minimization**

- Same privilege isolation (e.g., App vs. App)

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  - Same privilege isolation (e.g., App vs. App)
  - Cross-privilege isolation (e.g., App vs. kernel)

Think inside boxes ...

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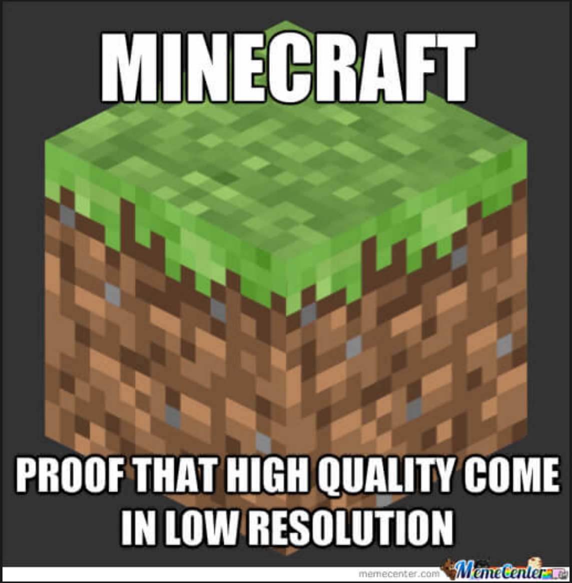
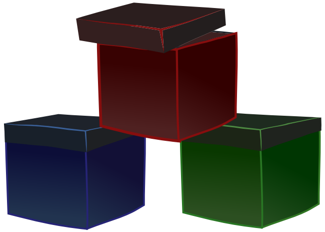


Privilege Minimization Overview



Everything is a box

- Make boxes as small as possible (Compartmentalization)
- A box shall have minimal permission (Isolation)
- "Principle of least privileges"

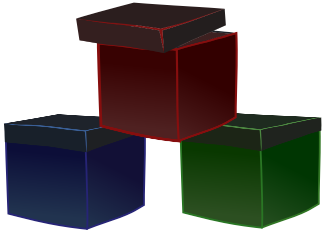
Compartmentalization

- Break large boxes into smaller boxes
- Virtual machines, processes, libraries, functions ...
- Mostly manual effort

Isolation

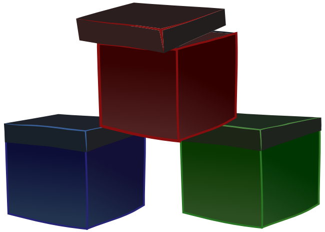
- Isolate boxes from each other
- Safeguard all interfaces
  - File permissions, network firewall ... system calls

Privilege Minimization Techniques



Isolation techniques

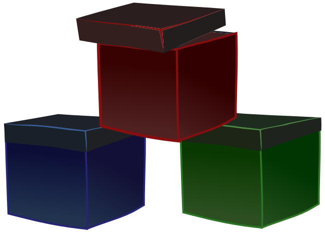
Privilege Minimization Techniques



Isolation techniques

- In-process Sandboxing

Privilege Minimization Techniques



Isolation techniques

- In-process Sandboxing
- Process Sandboxing

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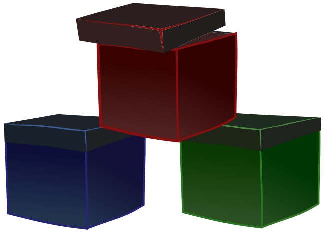

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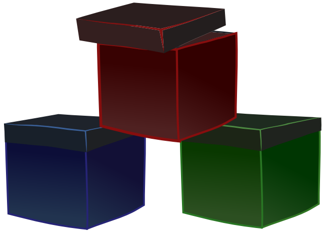

Isolation techniques

- In-process Sandboxing
- Process Sandboxing
- Virtualization
- Enclaves

In-process Sandboxing

ME AFTER ESCAPING THE SANDBOX
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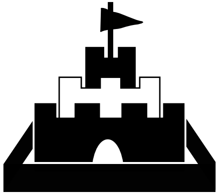
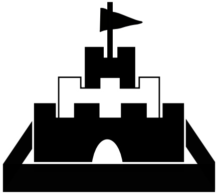
In-process Sandboxing



- Goal: confine parts of an application

In-process Sandboxing



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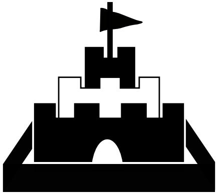

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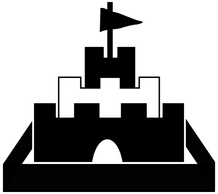

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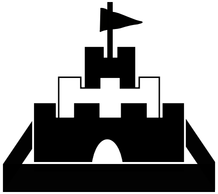

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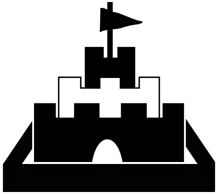

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  - (Binary rewriting)

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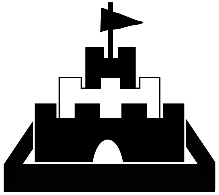

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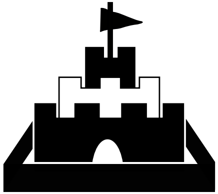

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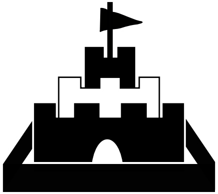

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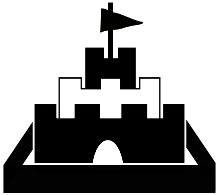

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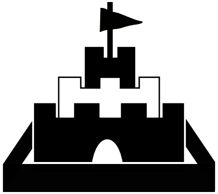

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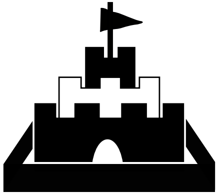

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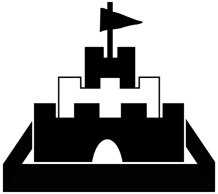

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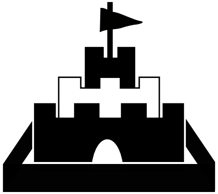

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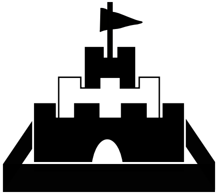

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  - is an implicit sandbox

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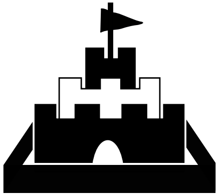

- Properties

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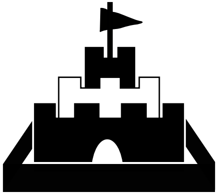

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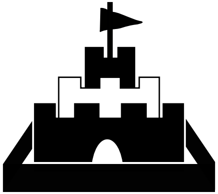

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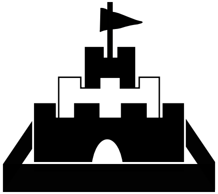

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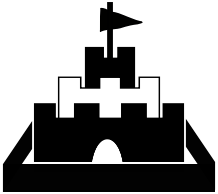

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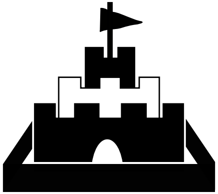

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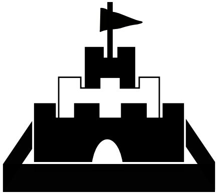

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- Example: Berkeley Packet Filters (BPF)

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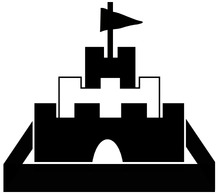

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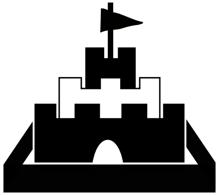

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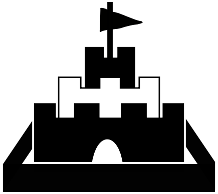

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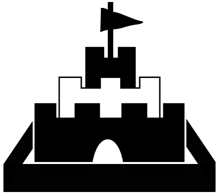

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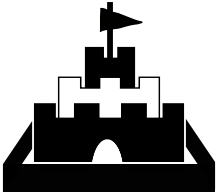

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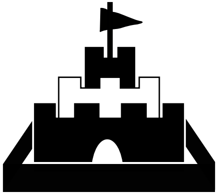

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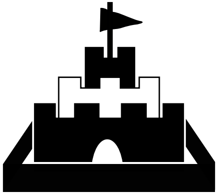

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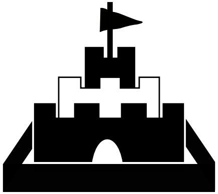

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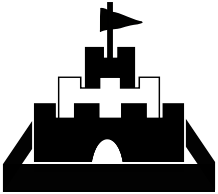

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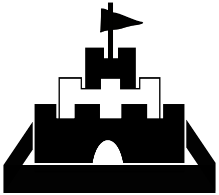

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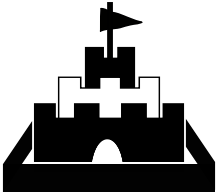

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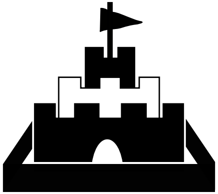

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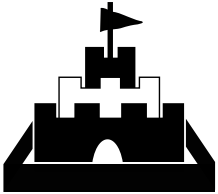

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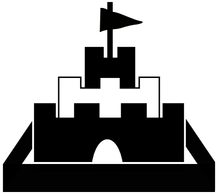

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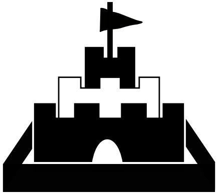

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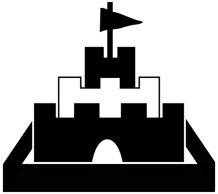

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Properties

- Much faster than interpretation
- Requires DEP (W⊕X) to prevent bypassing the checks

Process Sandboxing

SECCOMP

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- Program installs seccomp filters on startup
- Seccomp supports small *Berkeley Packet Filter (BPF) programs*

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- Program installs seccomp filters on startup
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- Kernel does the filtering (e.g., executes the BPF program) on every system call

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Implementation

- Program installs seccomp filters on startup
- Seccomp supports small *Berkeley Packet Filter (BPF) programs*
- Kernel does the filtering (e.g., executes the BPF program) on every system call
- On a filter violation: deny syscall, send signal, kill program ...

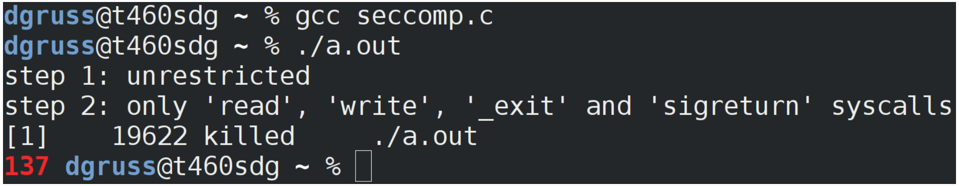
Seccomp Example I

```
#include <stdio.h>         /* printf */
#include <sys/prctl.h>     /* prctl */
#include <linux/seccomp.h> /* seccomp's constants */
#include <unistd.h>        /* dup2: just for test */

int main() {
  printf("step 1: unrestricted\n");
  prctl(PR_SET_SECCOMP, SECCOMP_MODE_STRICT); // Enable filtering
  printf("step 2: only 'read', 'write', '_exit' and 'sigreturn' syscalls\n");
  dup2(1, 2); // redirect stderr to stdout
  printf("step 3: !! YOU SHOULD NOT SEE ME !!\n");
  return 0;
}
```

https://blog.yadutaf.fr/2014/05/29/introduction-to-seccomp-bpf-linux-syscall-filter/

Seccomp Example II

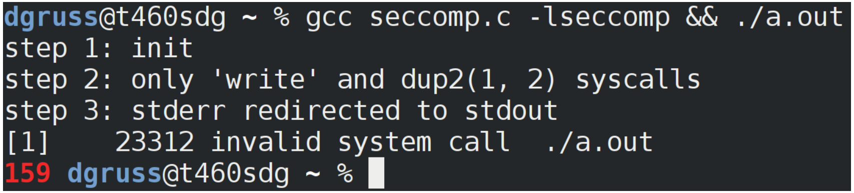


```
dgruss@t460sdg ~ % gcc seccomp.c
dgruss@t460sdg ~ % ./a.out
step 1: unrestricted
step 2: only 'read', 'write', '_exit' and 'sigreturn' syscalls
[1]    19622 killed     ./a.out
137 dgruss@t460sdg ~ % 
```

Seccomp Example III

```c
int main() {
  printf("step 1: init\n");
  prctl(PR_SET_NO_NEW_PRIVS, 1);
  prctl(PR_SET_DUMPABLE, 0);      // ptrace on this process / childs is not allowed
  scmp_filter_ctx ctx;
  ctx = seccomp_init(SCMP_ACT_KILL);                          // blacklist everything
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(rt_sigreturn), 0);    // whitelist
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(exit), 0);            // whitelist
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(exit_group), 0);      // whitelist
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(read), 0);            // whitelist
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(write), 0);           // whitelist
  seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(dup2), 2,             // whitelist
                    SCMP_A0(SCMP_CMP_EQ, 1), SCMP_A1(SCMP_CMP_EQ, 2)); // whitelist
  seccomp_load(ctx);
  printf("step 2: only 'write' and dup2(1, 2) syscalls\n");
  dup2(1, 2);     // redirect stderr to stdout
  printf("step 3: stderr redirected to stdout\n");
  dup2(2, 42);    // redirect stderr to stdout
}
```

Seccomp Example IV



```
dgruss@t460sdg ~ % gcc seccomp.c -lseccomp && ./a.out
step 1: init
step 2: only 'write' and dup2(1, 2) syscalls
step 3: stderr redirected to stdout
[1]    23312 invalid system call  ./a.out
159 dgruss@t460sdg ~ %
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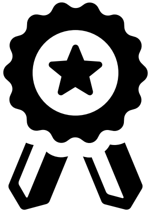

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- Test system is Ubuntu 20.04.1 LTS, kernel 4.19.0-11

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- Example: Google *sandbox2*

  `https://developers.google.com/sandboxed-api/`

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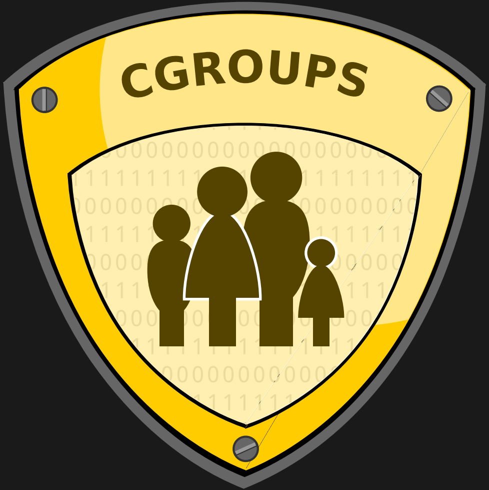
How can we virtualize resources?

Virtualization


CGROUPS

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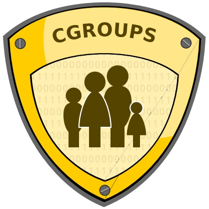

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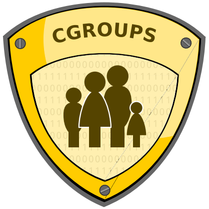

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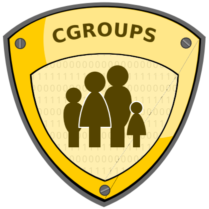

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- Cannot prevent privilege escalation

NAMESPACES

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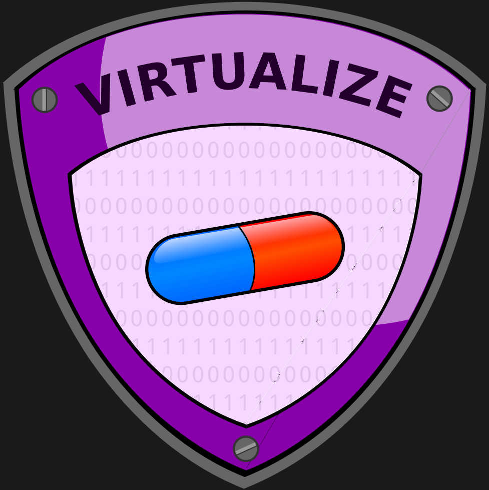
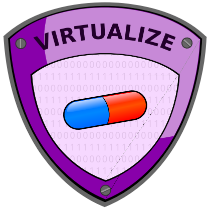
  - Kernel is shared between containers and host
  - What if one container compromises the host kernel?


VIRTUALIZE

Full System Virtualization

- Idea: fake the entire system



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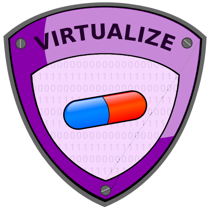

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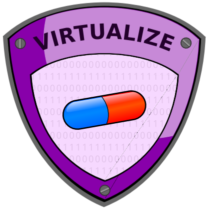

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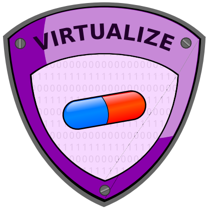

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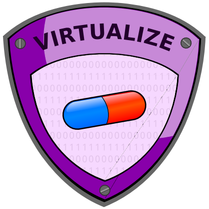

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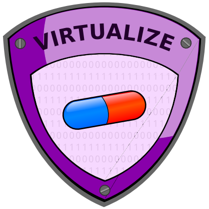

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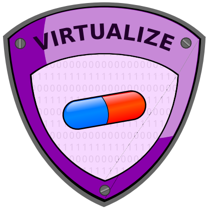

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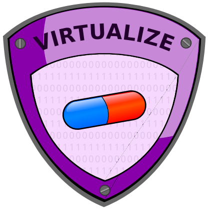

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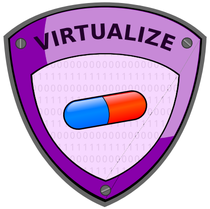

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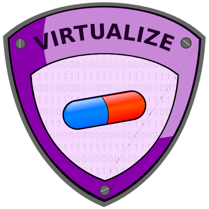

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Is there an end to this recursive problem?

ENCLAVES

Enclaves

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    - Host application, kernel, hypervisor
  - Example: Intel Software Guard Extensions (SGX)

Enclaves

★ Properties

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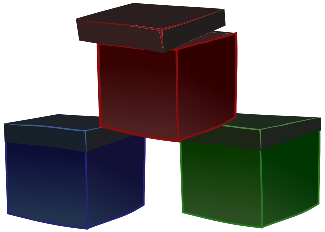
- Are we (too) secure now?

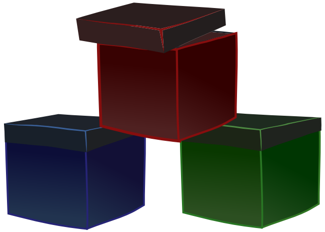
Summary & Outlook

Privilege Minimization Overview



💡 Everything is a box

Privilege Minimization Overview



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- **Compartmentalization**: Make boxes as small as possible

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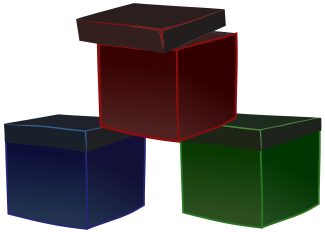

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- **Isolation**: A box shall have minimal permission

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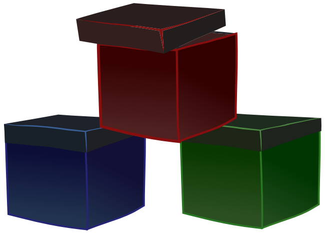
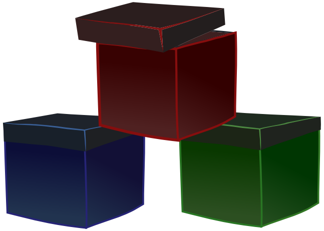


Everything is a box

- **Compartmentalization**: Make boxes as small as possible
- **Isolation**: A box shall have minimal permission
- "Principle of least privileges"

Privilege Minimization Techniques

Isolation techniques



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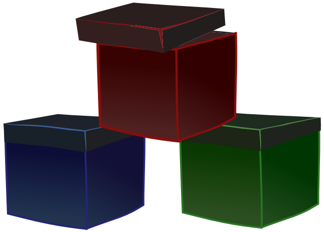
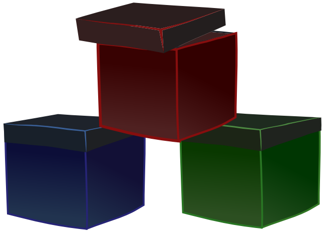


Isolation techniques

- In-process Sandboxing

Privilege Minimization Techniques



Isolation techniques

- In-process Sandboxing
  - Interpretation

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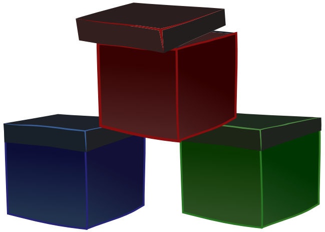

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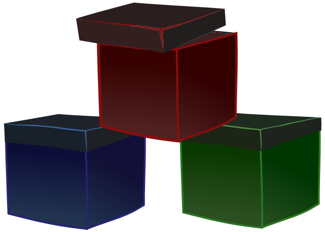

Isolation techniques

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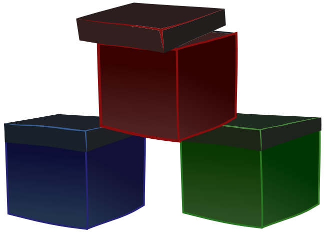

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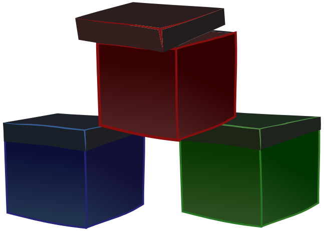

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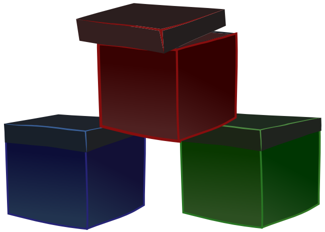

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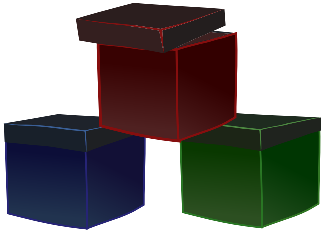

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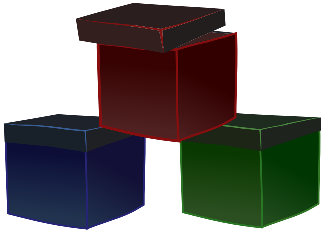

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- Friday, 18 December, afternoon

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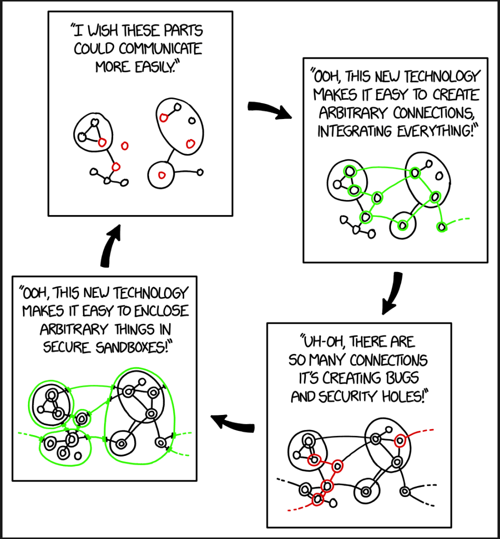
Questions?


"I WISH THESE PARTS COULD COMMUNICATE MORE EASILY."
"OOH, THIS NEW TECHNOLOGY MAKES IT EASY TO CREATE ARBITRARY CONNECTIONS, INTEGRATING EVERYTHING!"
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