NDC Security 2023

Using seccomp to limit the kernel attack surface

Michael Kerrisk, man7.org © 2023

mtk@man7.org

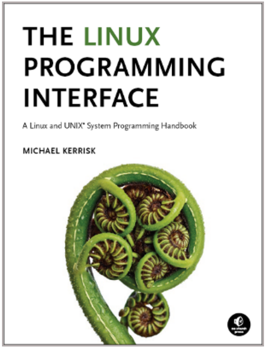
19 January 2023, Oslo

Outline

Outline

Who?

- Linux *man-pages* project
  - `https://www.kernel.org/doc/man-pages/`
    - Approx. 1060 pages documenting syscalls and C library
  - Contributor since 2000
  - Maintainer 2004-2020
  - Comaintainer 2020-2021
- I wrote a book
- Trainer/writer/engineer
  `http://man7.org/training/`
- `mtk@man7.org`, `@mkerrisk`



Outline

What is seccomp?

- Kernel provides large number of system calls
  - $\approx$400 system calls
- Each system call is a vector for attack against kernel
- Most programs use only small subset of available system calls
- Remaining systems calls should never occur
  - **If they do occur, perhaps it is because program has been compromised**
- Seccomp = mechanism to **restrict the system calls that a process may make**
  - Reduces attack surface of kernel
  - A key component for building application sandboxes

Development history

- First version in Linux 2.6.12 (2005)
  - But, much simpler functionality
- Linux 3.5 (2012) adds "filter" mode (AKA "seccomp2")
  - `prctl(PR_SET_SECCOMP, SECCOMP_MODE_FILTER, ...)`
  - Can control which system calls are permitted to caller
    - Control based on system call number and argument values
  - By now used in a range of tools
    - E.g., Chrome, Firefox, OpenSSH, *vsftpd*, *systemd*, Docker, LXC, Flatpak, Firejail, *strace*
- Linux 3.17 (2014):
  - *seccomp()* system call added
    - Provides additional seccomp functionality that is unavailable via *prct()*
- And work is ongoing...

Outline

Seccomp filtering overview

- Fundamental idea: filter system calls based on syscall number and argument (register) values
  - Pointers are **not** dereferenced
- To employ seccomp, the user-space program does following:
  1. **Construct filter program** that specifies permitted syscalls
  2. **Install filter program into kernel** using *seccomp()*/*prctl()*
  3. **Execute untrusted code**: *exec()* new program or invoke function inside dynamically loaded shared library (plug-in)
- Once installed, **every syscall triggers execution of filter**
- Installed filters **can't** be removed
  - Filter == declaration that we don't trust subsequently executed code

BPF byte code

- Seccomp filters are expressed as BPF (Berkeley Packet Filter) programs
- BPF is a **byte code which is interpreted by a virtual machine (VM) implemented inside kernel**

man7.org

BPF origins

- BPF originally devised (in 1992) for *tcpdump*
  - Monitoring tool to display packets passing over network
  - `http://www.tcpdump.org/papers/bpf-usenix93.pdf`
- Volume of network traffic is enormous ⇒ must filter for packets of interest
- BPF allows **in-kernel selection of packets**
  - Filtering based on fields in packet header
- Filtering in kernel more efficient than filtering in user space
  - Unwanted packets are **discarded early**
  - **Avoid expense of passing every** packet over kernel-user-space boundary
- ☺ Seccomp ⇒ generalize BPF model to filter on syscall info

BPF virtual machine

- BPF defines a **virtual machine** (VM) that can be implemented inside kernel
- VM characteristics:
    - **Simple instruction set**
        - Small set of instructions
        - All instructions are same size (64 bits)
        - Implementation is simple and fast
    - Only **branch-forward** instructions
        - Programs are directed acyclic graphs (DAGs)
    - Kernel can verify validity/safety of BPF programs
        - Program completion is guaranteed (DAGs)
        - Simple instruction set ⇒ can verify opcodes and arguments
        - Can detect dead code
        - Can verify that program completes via a "return" instruction
        - BPF filter programs are limited to 4096 instructions

Outline

Key features of BPF virtual machine

- Accumulator register (32-bit)
- Data area (data to be operated on)
  - In seccomp context: data area describes system call
- All instructions are 64 bits, with a fixed format
  - Expressed as a C structure, that format is:

```
struct sock_filter {
    __u16 code;     /* Filter code (opcode)*/
    __u8  jt;       /* Jump true */
    __u8  jf;       /* Jump false */
    __u32 k;        /* Generic multiuse field (operand) */
};
```

    - See `<linux/filter.h>` and `<linux/bpf_common.h>`
- **No state is preserved** between BPF program invocations
  - E.g., can't intercept *n*'th syscall of a particular type

BPF instruction set

Instruction set includes:

- Load instructions (BPF_LD)
- Jump instructions (BPF_JMP)
- Arithmetic/logic instructions (BPF_ALU)
  - BPF_ADD, BPF_SUB, BPF_MUL, BPF_DIV, BPF_MOD, BPF_NEG
  - BPF_OR, BPF_AND, BPF_XOR, BPF_LSH, BPF_RSH
- Return instructions (BPF_RET)
  - Terminate filter processing
  - Report a status telling kernel what to do with syscall

BPF jump instructions

- Conditional and unconditional jump instructions provided
- Conditional jump instructions consist of
  - **Opcode** specifying condition to be tested
  - **Value** to test against
  - **Two** jump targets
    - *jt*: target if condition is true
    - *jf*: target if condition is false
- Conditional jump instructions:
  - `BPF_JEQ`: jump if equal
  - `BPF_JGT`: jump if greater
  - `BPF_JGE`: jump if greater or equal
  - `BPF_JSET`: bit-wise AND + jump if nonzero result
  - *jf* target ⇒ no need for `BPF_{JNE,JLT,JLE,JCLEAR}`

BPF jump instructions

- Targets are expressed as relative offsets in instruction list
  - 0 == no jump (execute next instruction)
  - *jt* and *jf* are 8 bits ⇒ 255 maximum offset for conditional jumps
- Unconditional `BPF_JA` ("jump always") uses *k* (operand) as offset, allowing much larger jumps

Seccomp BPF data area

- Seccomp provides data describing syscall to filter program
  - Buffer is **read-only**
    - I.e., seccomp filter can't change syscall or syscall arguments
- Can be expressed as a C structure...

Seccomp BPF data area

```
struct seccomp_data {
    int   nr;                     /* System call number */
    __u32 arch;                   /* AUDIT_ARCH_* value */
    __u64 instruction_pointer;    /* CPU IP */
    __u64 args[6];                /* System call arguments */
};
```

- *nr*: system call number (architecture-dependent); 4-byte *int*
- *arch*: identifies architecture
  - Constants defined in `<linux/audit.h>`
    - `AUDIT_ARCH_X86_64`, `AUDIT_ARCH_ARM`, etc.
- *instruction_pointer*: CPU instruction pointer
- *args*: system call arguments
  - System calls have maximum of six arguments
  - Number of elements used depends on system call

Building BPF instructions

- One could code BPF instructions numerically by hand...
- But, header files define symbolic constants and convenience macros (BPF_STMT(), BPF_JUMP()) to ease the task

```
#define BPF_STMT(code, k) \
                { (unsigned short)(code), 0, 0, k }
#define BPF_JUMP(code, k, jt, jf) \
                { (unsigned short)(code), jt, jf, k }
```

  - These macros just plug values together to form *sock_filter* structure initializer

```
struct sock_filter {
    __u16 code;     /* Filter code (opcode)*/
    __u8  jt;       /* Jump true */
    __u8  jf;       /* Jump false */
    __u32 k;        /* Multiuse field (operand) */
};
```

Building BPF instructions: examples

- Load architecture number into accumulator

```
BPF_STMT(BPF_LD | BPF_W | BPF_ABS,
          (offsetof(struct seccomp_data, arch)))
```

- Opcode here is constructed by ORing three values together:
  - `BPF_LD`: load
  - `BPF_W`: operand size is a word (4 bytes)
  - `BPF_ABS`: address mode specifying that source of load is data area (containing system call data)
  - See `<linux/bpf_common.h>` for definitions of opcode constants
- Operand is *architecture* field of data area
  - `offsetof()` yields byte offset of a field in a structure

Building BPF instructions: examples

- Test value in accumulator

```
BPF_JUMP(BPF_JMP | BPF_JEQ | BPF_K, AUDIT_ARCH_X86_64, 1, 0)
```

  - `BPF_JMP | BPF_JEQ`: jump with test on equality
  - `BPF_K`: value to test against is in generic multiuse field (*k*)
  - *k* contains value `AUDIT_ARCH_X86_64`
  - *jt* value is 1, meaning skip one instruction if test is true
  - *jf* value is 0, meaning skip zero instructions if test is false
    - I.e., continue execution at following instruction

Building BPF instructions: examples

- Return value that causes kernel to kill process

```
BPF_STMT(BPF_RET | BPF_K, SECCOMP_RET_KILL_PROCESS)
```

- Arithmetic/logic instruction: add one to accumulator

```
BPF_STMT(BPF_ALU | BPF_ADD | BPF_K, 1)
```

- Arithmetic/logic instruction: right shift accumulator 12 bits

```
BPF_STMT(BPF_ALU | BPF_RSH | BPF_K, 12)
```

Outline

Filter return value

- Once a filter is installed, each system call is tested against filter
- Seccomp filter returns a value to kernel indicating whether system call is permitted
- Return value is 32 bits, in two parts:
  - Most significant 16 bits (SECCOMP_RET_ACTION_FULL mask) specify an action to kernel
  - Least significant 16 bits (SECCOMP_RET_DATA mask) specify "data" for return value

```
#define SECCOMP_RET_ACTION_FULL 0xffff0000U
#define SECCOMP_RET_DATA        0x0000ffffU
```

man7.org

Filter return action

Various possible filter return actions, including:

- SECCOMP_RET_ALLOW: system call is allowed to execute
- SECCOMP_RET_KILL_PROCESS: process (all threads) is killed
  - Terminated *as though* process had been killed with SIGSYS
    - There is no actual SIGSYS signal delivered, but...
    - To parent (via *wait()*) it appears child was killed by SIGSYS
- SECCOMP_RET_KILL_THREAD: calling thread is killed
  - Terminated *as though* thread had been killed with SIGSYS
- SECCOMP_RET_ERRNO: return an error from system call
  - System call is not executed
  - Value in SECCOMP_RET_DATA is returned in *errno*
- Also: SECCOMP_RET_TRACE, SECCOMP_RET_TRAP, SECCOMP_RET_LOG, SECCOMP_RET_USER_NOTIF

Outline

Installing a BPF program

- A process installs a filter for itself using one of:
  - `seccomp(SECCOMP_SET_MODE_FILTER, flags, &fprog)`
    - Only since Linux 3.17
  - `prctl(PR_SET_SECCOMP, SECCOMP_MODE_FILTER, &fprog)`
- *&fprog* is a pointer to a BPF program:

```
struct sock_fprog {
  unsigned short len;          /* Number of instructions */
  struct sock_filter *filter;  /* Pointer to program
                                  (array of instructions) */
};
```

man7.org

Installing a BPF program

To install a filter, one of the following must be true:

- Caller is privileged (has CAP_SYS_ADMIN in its user namespace)
- Caller has to set the no_new_privs attribute:

```
prctl(PR_SET_NO_NEW_PRIVS, 1, 0, 0, 0);
```

  - Causes set-UID/set-GID bit / file capabilities to be ignored on subsequent *execve()* calls
    - Once set, no_new_privs can't be unset
  - Prevents possibility of attacker starting privileged program and manipulating it to misbehave using a seccomp filter
  - ! no_new_privs && ! CAP_SYS_ADMIN ⇒ *seccomp()*/*prctl(PR_SET_SECCOMP)* fails with EACCES

man7.org

Outline

Example: `seccomp/seccomp_deny_open.c`

```c
int main(int argc, char *argv[]) {
    prctl(PR_SET_NO_NEW_PRIVS, 1, 0, 0, 0);

    install_filter();

    open("/tmp/a", O_RDONLY);

    printf("We shouldn't see this message\n");
    exit(EXIT_SUCCESS);
}
```

Program installs a filter that prevents *open()* and *openat()* being called, and then calls *open()*

- Set `no_new_privs` bit
- Install seccomp filter
- Call *open()*

Example: seccomp/seccomp_deny_open.c

```
static void install_filter(void) {
    struct sock_filter filter[] = {

        /* Architecture-check code not shown */

        BPF_STMT(BPF_LD | BPF_W | BPF_ABS,
                 (offsetof(struct seccomp_data, nr))),
        ...
```

- BPF filter program consists of a series of *sock_filter* structs
- For now we ignore some BPF code that checks the architecture that BPF program is executing on
  - ⚠ **This is an essential part of every BPF filter program**
- Load system call number into accumulator
- (BPF program continues on next slide)

man7.org

Example: seccomp/seccomp_deny_open.c

```
#ifdef __NR_open        /* Not all architectures have open() */
        BPF_JUMP(BPF_JMP | BPF_JEQ | BPF_K, __NR_open, 2, 0),
#endif
        BPF_JUMP(BPF_JMP | BPF_JEQ | BPF_K, __NR_openat, 1, 0),
        BPF_STMT(BPF_RET | BPF_K, SECCOMP_RET_ALLOW),
        BPF_STMT(BPF_RET | BPF_K, SECCOMP_RET_KILL_PROCESS)
    };
```

- Test if system call number matches `__NR_open`
  - True: advance 2 instructions ⇒ kill process
  - False: advance 0 instructions ⇒ next test
  - (*open()* is absent on some architectures, because it can be implemented using *openat()*)
- Test if system call number matches `__NR_openat`
  - True: advance 1 instruction ⇒ kill process
  - False: advance 0 instructions ⇒ allow syscall

Example: seccomp/seccomp_deny_open.c

```
    struct sock_fprog prog = {
        .len = sizeof(filter) / sizeof(filter[0]),
        .filter = filter,
    };

    seccomp(SECCOMP_SET_MODE_FILTER, 0, &prog);
}
```

- Construct argument for *seccomp()*
- Install filter

man7.org

Example: seccomp/seccomp_deny_open.c

Upon running the program, we see:

```
$ ./seccomp_deny_open
Bad system call    # Message printed by shell
```

- "Bad system call" was printed by shell, because it looks like its child was killed by SIGSYS

Outline

Example: seccomp/seccomp_control_open.c

- A more sophisticated example
- Filter based on *flags* argument of *open()* / *openat()*
  - O_CREAT specified ⇒ kill process
  - O_WRONLY or O_RDWR specified ⇒ cause call to fail with ENOTSUP error
- *flags* is arg. 2 of *open()*, and arg. 3 of *openat()*:

```
int open(const char *pathname, int flags, ...);
int openat(int dirfd, const char *pathname, int flags, ...);
```

  - *flags* serves exactly the same purpose for both calls

Example: seccomp/seccomp_control_open.c

```
struct sock_filter filter[] = {
    /* Architecture-check code not shown */

    BPF_STMT(BPF_LD | BPF_W | BPF_ABS,
             (offsetof(struct seccomp_data, nr))),
    ...
#ifdef __NR_open        /* Not all architectures have open() */
    /* Is this an open() syscall? */
    BPF_JUMP(BPF_JMP | BPF_JEQ | BPF_K, __NR_open, 0, 2),
    BPF_STMT(BPF_LD | BPF_W | BPF_ABS,
             (offsetof(struct seccomp_data, args[1]))),
    BPF_JUMP(BPF_JMP | BPF_JA, 3, 0, 0),
#endif
```

- Load system call number
- For *open()*, load *flags* argument (*args[1]*) into accumulator, and then skip to *flags* processing
  - (Some architectures don't have *open()*)

Example: seccomp/seccomp_control_open.c

```
    /* Is this an openat() syscall? */
    BPF_JUMP(BPF_JMP | BPF_JEQ | BPF_K, __NR_openat, 1, 0),

    BPF_STMT(BPF_RET | BPF_K, SECCOMP_RET_ALLOW),

    BPF_STMT(BPF_LD | BPF_W | BPF_ABS,
             (offsetof(struct seccomp_data, args[2]))),
```

- For *openat()*, load *flags* argument (*args[2]*) into accumulator and continue to *flags* processing
- Allow all other system calls

Example: seccomp/seccomp_control_open.c

```
    BPF_JUMP(BPF_JMP | BPF_JSET | BPF_K, O_CREAT, 0, 1),
    BPF_STMT(BPF_RET | BPF_K, SECCOMP_RET_KILL_PROCESS),

    BPF_JUMP(BPF_JMP | BPF_JSET | BPF_K, O_WRONLY | O_RDWR, 0, 1),
    BPF_STMT(BPF_RET | BPF_K, SECCOMP_RET_ERRNO | ENOTSUP),

    BPF_STMT(BPF_RET | BPF_K, SECCOMP_RET_ALLOW)
};
```

Process *flags* value:

- Test if `O_CREAT` bit is set in *flags*
  - True: skip 0 instructions ⇒ kill process
  - False: skip 1 instruction
- Test if `O_WRONLY` **or** `O_RDWR` is set in *flags*
  - True: cause call to fail with `ENOTSUP` error in *errno*
  - False: allow call to proceed

Example: seccomp/seccomp_control_open.c

```
int main(int argc, char *argv[]) {
    prctl(PR_SET_NO_NEW_PRIVS, 1, 0, 0, 0);
    install_filter();

    if (open("/tmp/a", O_RDONLY) == -1)
        perror("open1");
    if (open("/tmp/a", O_WRONLY) == -1)
        perror("open2");
    if (open("/tmp/a", O_RDWR) == -1)
        perror("open3");
    if (open("/tmp/a", O_CREAT | O_RDWR, 0600) == -1)
        perror("open4");

    exit(EXIT_SUCCESS);
}
```

- Test *open()* calls with various flags

Example: seccomp/seccomp_control_open.c

```
$ touch /tmp/a
$ ./seccomp_control_open
open2: Operation not supported
open3: Operation not supported
Bad system call
```

- First *open()* succeeded
- Second and third *open()* calls failed
  - Kernel produced ENOTSUP error for call
- Fourth *open()* call caused process to be killed

Outline

Checking the architecture

- Checking architecture value should be first step in any BPF program
- Syscall numbers differ across architectures!
  - May have built seccomp BPF BLOB for one architecture, but accidentally load it on different architecture
- Hardware may support multiple system call conventions
  - Modern x86 hardware supports three(!) architecture+ABI conventions
  - System call numbers may differ under each convention
  - Similar issues occur on other platforms
    - E.g., AArch64 can execute AArch32 code, but set of syscalls differs somewhat on each architecture

man7.org

Checking the architecture: Intel architectures

- E.g. modern Intel systems support x86-64, i386, and x32, each of which has unique syscall numbers
  - x86-64 (`AUDIT_ARCH_X86_64`): modern x86 arch. with 64-bit instructions, larger address space, richer register set
  - i386 (`AUDIT_ARCH_I386`): historical 32-bit Intel arch. with 32-bit instruction set and address space
  - x32 ABI (Linux 3.4, 2012): use modern x86 arch. with 32-bit pointers/*long*
    - Can result in more compact/faster code in some cases
    - ⚠ Same *arch* value (`AUDIT_ARCH_X86_64`) as x86-64, but bit 30 (`X32_SYSCALL_BIT`) set in syscall number (*nr*)
- Checking *arch* in each filter invocation is **essential** because **architecture may change over life of process** (*execve()*)

man7.org

Checking the architecture: Intel x86-64

```
#define X32_SYSCALL_BIT         0x40000000
...
struct sock_filter filter[] = {
    BPF_STMT(BPF_LD | BPF_W | BPF_ABS,
            (offsetof(struct seccomp_data, arch))),
    BPF_JUMP(BPF_JMP | BPF_JEQ | BPF_K, AUDIT_ARCH_X86_64, 0, 2),

    BPF_STMT(BPF_LD | BPF_W | BPF_ABS,
             (offsetof(struct seccomp_data, nr))),
    BPF_JUMP(BPF_JMP | BPF_JGE | BPF_K, X32_SYSCALL_BIT, 0, 1),

    BPF_STMT(BPF_RET | BPF_K, SECCOMP_RET_KILL_PROCESS),
```

- Load architecture; kill process if not as expected
- Load system call number; kill process if this is an x32 system call (bit 30 is set)

Outline

Tools: *libseccomp*

- High-level API for kernel creating seccomp filters
  - `https://github.com/seccomp/libseccomp`
  - Initial release: 2012
- Simplifies various aspects of building filters
  - Eliminates tedious/error-prone tasks such as changing branch instruction counts when instructions are inserted
  - Abstract architecture-dependent details out of filter creation
  - Don't have full control of generated code, but can give hints about which system calls to prioritize in generated code
    - *seccomp_syscall_priority()*
- `http://lwn.net/Articles/494252/`
- Fully documented with manual pages containing examples(!)

man7.org

libseccomp example (seccomp/libseccomp_demo.c)

```
scmp_filter_ctx ctx = seccomp_init(SCMP_ACT_ALLOW);
seccomp_rule_add(ctx, SCMP_ACT_ERRNO(EPERM), SCMP_SYS(clone), 0);
seccomp_rule_add(ctx, SCMP_ACT_ERRNO(ENOTSUP), SCMP_SYS(fork), 0);
...
seccomp_load(ctx);          /* Load filter */
seccomp_release(ctx);       /* Free filter state */

if (fork() != -1)
    fprintf(stderr, "fork() succeeded?!\n");
else
    perror("fork");
```

- Create seccomp filter state whose default action is to allow every syscall
- Disallow *clone()* and *fork()*, with different errors
- Load filter into kernel, and free user-space filter state (no longer needed)
- Try calling *fork()*

Example run (seccomp/libseccomp_demo.c)

```
$ ./libseccomp_demo
fork: Operation not permitted
```

- *fork()* fails, as expected
- EPERM error ⇒ *fork()* wrapper in glibc calls *clone()* (!)

Other productivity aids

- *easyseccomp* - a DSL for writing seccomp filters
  - `https://github.com/giuseppe/easyseccomp`
  - New in 2021; worth watching, to see future progress
- *bpfc* (BPF compiler)
  - Compiles assembler-like BPF programs to byte code
  - Part of *netsniff-ng* project (`http://netsniff-ng.org/`)

Outline

fork() and *execve()* semantics

- If seccomp filters permit *fork()* or *clone()*, then child inherits parent's filters
- If seccomp filters permit *execve()*, then filters are preserved across *execve()*
    - `seccomp/seccomp_launch.c`: launch a program after first loading a specified BPF blob from a file

man7.org

Cost of filtering, construction of filters

- Installed BPF filter(s) are executed for every system call
  - ⇒ there's a performance cost
- **Indicative** timings on x86-64, Linux 5.2:
  - `seccomp/seccomp_perf.c`
    - Performs 6 BPF instructions / permitted syscall
    - Call *getppid()* repeatedly (one of cheapest syscalls)
  - +20% (JIT compiler enabled); +75% execution time (JIT compiler disabled)
    - Looks relatively high because *getppid()* is a cheap syscall

man7.org

Cost of filtering, construction of filters

- Obviously, order of filtering rules can affect performance
  - ⇒ construct filters so that most common cases yield shortest execution paths
- But: a significant part of cost seems to be filter start-up / termination
  - Even a filter consisting of just one (return) instruction adds 10% to *getppid()* loop
  - And different BPF instructions (unsurprisingly) have different costs
  - See `seccomp/seccomp_bench.c`

Outline

Caveats

There are subtleties when it comes to deploying seccomp filters:

- Adding a seccomp filter can **cause** bugs in application:
  - What if filter disallows a system call that should have been allowed?
    - ⇒ A buggy filter might **cause a legitimate application action to fail**
  - Such bugs may be hard to find in testing, especially in rarely exercised code paths
- Filtering is based on **syscall numbers**, but **applications normally call C library wrappers** (not direct syscalls)
  - Following slides...

Caveats

- Filtering is based on syscall numbers, but applications normally call C library wrappers; some implications:
  - Some wrapper functions use syscalls of a different name
    - Must filter for the correct underlying syscall
    - E.g., glibc *fork()* wrapper actually calls *clone()*
  - Wrapper function behavior may change across glibc versions
    - E.g., in glibc 2.26, the *open()* wrapper switched from using *open(2)* to using *openat(2)*
    - Such changes in the C library are ongoing (and necessary)
    - A robust filter will filter all related system calls
  - Wrapper function behavior may vary across C libraries
    - E.g., musl libc vs glibc

man7.org

Caveats

- Moral of the story: BPF filters are like any other production code
    - They need unit tests
    - They need CI testing
    - They need to be tested on all platforms and architectures where they might be deployed
    - This is far from easy...
        - A war story: `https://github.com/kristapsdz/acme-client-portable/blob/master/Linux-seccomp.md`

Outline

Resources

- Kernel source files:
  - `Documentation/userspace-api/seccomp_filter.rst`
  - `Documentation/networking/filter.txt` BPF VM in detail
- `http://outflux.net/teach-seccomp/`
- *seccomp(2)* man page
- "Seccomp sandboxes and memcached example"
  - `https://blog.viraptor.info/post/seccomp-sandboxes-and-memcached-example-part-1`
  - `https://blog.viraptor.info/post/seccomp-sandboxes-and-memcached-example-part-2`
- `https://lwn.net/Articles/656307/`
  - Write-up of a version of this presentation...

Thanks!

Michael Kerrisk, Trainer and Consultant
http://man7.org/training/

mtk@man7.org   @mkerrisk

Slides at http://man7.org/conf/
Source code at http://man7.org/tlpi/code/