Trusted computing base and Code safety
Trusted computing bases
Every system has a TCB

- Your reference monitor
- Compiler
- OS
- CPU
- Memory
- Keyboard
What is trustworthy here?
What is not trustworthy here?
Security requires the TCB be

- Correct
- Complete
- Secure
Security requires the TCB be

- Correct
- Complete
- Secure

Two key principles behind a good TCB:

KISS       Privilege Separation
KISS: Small TCB

• Keep the TCB small (and simple) to reduce overall susceptibility to compromise
  • The trusted computing base (TCB) comprises the system components that must work correctly to ensure security

• Example: Operating system kernels
  • Kernels enforce security policies, but are often millions of lines of code
    - Compromise in a device driver compromises security overall
  • Better: Minimize size of kernel to reduce trusted components
    - Device drivers moved outside of kernel in micro-kernel designs
Failure: Large TCB

- **Security software** is part of the TCB

- But as it grows in size and complexity, it becomes vulnerable itself, and can be bypassed

October 2010 vulnerability watchlist

<table>
<thead>
<tr>
<th>Vulnerability Title</th>
<th>Fix Avail?</th>
<th>Date Added</th>
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Color Code Key:
- **Vendor Replied – Fix in development**
- **Awaiting Vendor Reply/Confirmation**
- **Awaiting CC/S/A use validation**

Additional security layers often create vulnerabilities...

6 of the vulnerabilities are in security software

TCB: Privilege Separation

Isolate privileged operations to as small a module as possible

- Don’t give a part of the system more privileges than it needs to do its job ("need to know")
  - Principle of least privilege
TCB: Privilege Separation

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- Example: Web server daemon
  - Binding to port 80 requires root
  - Don’t want your whole web server running as root!
TCB: Privilege Separation

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• Don’t give a part of the system more privileges than it needs to do its job (“need to know”)
  • **Principle of least privilege**

• **Example**: Web server daemon
  • Binding to port 80 requires root
  • Don’t want your whole web server running as root!

• **Example**: Email apps often drop you into an editor
  • vi, emacs
  • But these editors often permit dropping you into a shell
Lesson: Trust is Transitive

- If you trust something, you trust what it trusts
  - This trust can be misplaced

- Previous e-mail client example
  - Mailer delegates to an arbitrary editor
  - The editor permits running arbitrary code
  - Hence the mailer permits running arbitrary code
SecComp
SecComp

• Linux system call enabled since 2.6.12 (2005)
  • Affected process can subsequently **only perform** read, write, exit, and sigreturn system calls
    - No support for open call: Can only use already-open file descriptors
  • **Isolates a process by limiting possible interactions**
SecComp

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• Follow-on work produced seccomp-bpf
  • Limit process to policy-specific set of system calls, subject to a policy handled by the kernel
    - Policy akin to Berkeley Packet Filters (BPF)
  • Used by Chrome, OpenSSH, vsftpd, and others
Idea: Isolate Flash Player
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- Receive .swf code, save it
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- Call exec to run Flash player
Idea: Isolate Flash Player

- Receive .swf code, save it
- Call fork to create a new process
- In the new process, open the file
- Call exec to run Flash player
- Call seccomp-bpf to compartmentalize
Case study: VSFTPD
Very Secure FTPD

• FTP: File Transfer Protocol
  - More popular before the rise of HTTP, but still in use
  - 90's and 00's: FTP daemon compromises were frequent and costly, e.g., in Wu-FTPD, ProFTPD, …

• Very thoughtful design aimed to prevent and mitigate security defects

• But also to achieve good performance
  - Written in C

• Written and maintained by Chris Evans since 2002
  - No security breaches that I know of

https://security.appspot.com/vsftpd.html
VSFTPD Threat model
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- Once authenticated, **limited** trust:
  - According to user’s **file access control policy**
  - For the files being served FTP (and not others)
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- Steal or corrupt resources (e.g., files, malware)
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VSFTPDP Threat model

- Clients untrusted, until authenticated

- Once authenticated, **limited** trust:
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- Possible attack goals
  - **Steal** or **corrupt resources** (e.g., files, malware)
  - **Remote code injection**

- Circumstances:
VSFTPD Threat model

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  - Client attacks server
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- Possible attack goals
  - **Steal** or **corrupt resources** (e.g., files, malware)
  - **Remote code injection**

- Circumstances:
  - **Client attacks server**
  - **Client attacks** another **client**
struct mystr
{
    char* PRIVATE_HANDS_OFF_p.buf;
    unsigned int PRIVATE_HANDS_OFF_len;
    unsigned int PRIVATE_HANDS_OFF_alloc_bytes;
};
Defense: Secure Strings

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Normal (zero-terminated) C string
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The actual length (i.e., `strlen(PRIVATE_HANDS_OFF_p_buf)`)
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Size of buffer returned by `malloc`
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Normal (zero-terminated) C string

The actual length (i.e., `strlen(PRIVATE_HANDS_OFF_p_buf)`)  

Size of buffer returned by `malloc`
void private_str_alloc_memchunk(struct mystr* p_str, const char* p_src, unsigned int len)
{
    ...
}

void str_copy(struct mystr* p_dest, const struct mystr* p_src)
{
    private_str_alloc_memchunk(p_dest, p_src->p_buf, p_src->len);
}

replace uses of char* with struct mystr* and uses of strcpy with str_copy
void private_str_alloc_memchunk(struct mystr* p_str, const char* p_src, unsigned int len)
{
    /* Make sure this will fit in the buffer */
    unsigned int buf_needed;
    if (len + 1 < len)
    {
        bug("integer overflow");
    }
    buf_needed = len + 1;
    if (buf_needed > p_str->alloc_bytes)
    {
        str_free(p_str);
        s_setbuf(p_str, vsf_sysutil_malloc(buf_needed));
        p_str->alloc_bytes = buf_needed;
    }
    vsf_sysutil_memcpy(p_str->p_buf, p_src, len);
    p_str->p_buf[len] = '\0';
    p_str->len = len;
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    }
    vsf_sysutil_memcmpy(p_str->p_buf, p_src, len);
    p_str->p_buf[len] = '\0';
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struct mystr
{
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Copy in at most len bytes from p_src into p_str

consider NUL terminator when computing space
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  • Libraries assume that arguments are well-formed
Defense: Secure Stdcalls

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• Example: malloc()
Defense: Secure Stdcalls

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  • What if **argument is non-positive**?
    - We saw earlier that integer overflows can induce this behavior
    - Leads to buffer overruns
Defense: Secure StdCalls

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• Example: `malloc()`
  - What if **argument is non-positive?**
    - We saw earlier that integer overflows can induce this behavior
    - Leads to buffer overruns
  - What if **returned value is NULL?**
    - Oftentimes, a de-reference means a crash
    - On platforms without memory protection, a dereference can cause corruption
void*
vsf_sysutil_malloc(unsigned int size)
{
    void* p_ret;
    /* Paranoia - what if we got an integer overflow/underflow? */
    if (size == 0 || size > INT_MAX)
    {
        bug("zero or big size in vsf_sysutil_malloc");
    }
    p_ret = malloc(size);
    if (p_ret == NULL)
    {
        die("malloc");
    }
    return p_ret;
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Defense: Minimal Privilege
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- **Untrusted input** always handled by non-root process
  - Uses IPC to delegate high-privilege actions
    - Very little code runs as root
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    - File system access control enforced by OS
  - Use capabilities and/or SecComp on Linux
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  - Keeps visible only those files served by FTP
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*principle of least privilege*
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Connection Establishment

connection
server

client
Connection Establishment

connection
server

TCP conn request

client
Connection Establishment

connection
server

command
processor

client
Connection Establishment

Connection server

command processor

login reader

client
Connection Establishment

Connection server

command processor

login reader

client

U+P

OK

OK

USER, PASS
Connection Establishment

connection server
command processor
command reader/executor
client
Performing Commands

- connection server
- command processor
- command reader/executor
- client
Performing Commands

connection server

command processor

command reader/executor

client

OK

CHDIR
Performing Commands

connection server

command processor

command reader/executor

client

CHOWN

OK

OK

CHOWN
Logging out

- connection server
- command processor
- command reader/executor
- client
Logging out

collection
server

client
Attack: Login

- connection server
- command processor
- login reader
- client
Attack: Login

connection server

command processor

login reader

client

ATTACK
Attack: Login

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  - And allowed input very limited
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- **Comm. proc. only talks to reader**
  - And, again, white-lists its limited input
Attack: Commands

connection server
command processor
command reader/executor
client
Attack: Commands

connection server

command processor

command reader/executor

client

ATTACK
Attack: Commands

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  - Not root
  - Handles most commands
  - Except few requiring privilege
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Attack: Cross-session

connection
server

client 1

client 2
Attack: Cross-session
Attack: Cross-session

collection processor
command reader/executor

collection processor
command reader/executor

collection processor
command reader/executor

collection processor
command reader/executor

client 1

client 2
Attack: Cross-session

connection server

command reader/executor

client 1

client 2

command reader/executor
Attack: Cross-session
Attack: Cross-session

- Each session isolated
- Only can talk to one client
Presenting vsftpd's secure design

vsftpd employs a secure design. The UNIX facilities outlined above are used to good effect. The design decisions taken are as follows:

1) All parsing and acting on potentially malicious remote network data is done in a process running as an unprivileged user. Furthermore, this process runs in a chroot() jail, ensuring only the ftp files area is accessible.

2) Any privileged operations are handled in a privileged parent process. The code for this privileged parent process is as small as possible for safety.

3) This same privileged parent process receives requests from the unprivileged child over a socket. All requests are distrusted. Here are example requests:
   - Login request. The child sends username and password. Only if the details are correct does the privileged parent launch a new child with the appropriate user credentials.
   - chown() request. The child may request a recently uploaded file gets chown'ed() to root for security purposes. The parent is careful to only allow chown() to root, and only from files owned by the ftp user.
   - Get privileged socket request. The ftp protocol says we are supposed to emit data connections from port 20. This requires privilege. The privileged parent process creates the privileged socket and passes it to child over the socket.

4) This same privileged parent process makes use of capabilities and chroot(), to run with the least privilege required. After login, depending on what options have been selected, the privileged parent dynamically calculates what privileges it requires. In some cases, this amounts to no privilege, and the privileged parent just exits, leaving no part of vsftpd running with privilege.

5) vsftpd-2.0.0 introduces SSL / TLS support using OpenSSL. ALL OpenSSL protocol parsing is performed in a chroot() jail, running under an unprivileged user. This means both pre-authenticated and post-authenticated OpenSSL protocol parsing; it's actually quite hard to do, but vsftpd manages it in the name of being secure. I'm unaware of any other FTP server which supports both SSL / TLS and privilege separation, and gets this right.

Comments on this document are welcomed.
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Separation of responsibilities

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- Think of it as a **contract** for using the module
  - “Statement 1’s postcondition should meet statement 2’s precondition”
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  - **Invariant** = Conditions that always hold within some part of a function
What are the preconditions to ensure safety?

/* requires: p != NULL (and p is a valid pointer) */
/* ensures: retval is the first four bytes p pointed to */

int deref(int *p) {
    return *p;
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int sum(int a[], size_t n) {
    int total = 0;
    for (size_t i=0; i<n; i++)
        total += a[i];
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}
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What are the preconditions to ensure safety?

Approach:
1. Identify each memory access
2. Annotate with preconditions it requires
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No line of code above this guarantees it will hold: so move it up

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Line above it: `size_t i` ensures that $0 \leq i$ always

Memory access

```
/* requires: 0 <= i */
/* requires: i < size(a) */
```
What are the preconditions to ensure safety?

Approach:
1. Identify each memory access
2. Annotate with preconditions it requires
3. Propagate the requirements up

```c
int sum(int a[], size_t n) {
    int total = 0;
    for (size_t i=0; i<n; i++)
        total += a[i];
    return total;
}
```

*/ requires: a != NULL   */

Line above it: `size_t i` ensures that `0 <= i` always

Memory access

/* requires: i < size(a) */
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/* requires: a != NULL */

Not guaranteed by above code

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/* requires: i < size(a) */
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What are the preconditions to ensure safety?

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/* requires: a != NULL */

/* requires: n <= size(a) */

Not guaranteed by above code
/* requires: i < size(a) */
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/* requires: a != NULL */
/* requires: n <= size(a) */
char *tbl[N]; /* N is of type int */

/* requires: s != NULL and valid, and NULL-terminated */
/* ensures: 0 <= retval < N */
int hash(char *s) {
    int h = 17;
    while (*s)
        h = 257*h + (*s++) + 3;
    return h % N;
}

/* requires: s != NULL (and a valid) and 0 <= hash < size(tbl) */
bool search(char *s) {
    int i = hash(s);
    return tbl[i] && (strcmp(tbl[i], s)==0);
}
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Does this code meet its postconditions?
char *tbl[N]; /* N is of type int */

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Does this code meet its postconditions? Need to change int to unsigned int
Why use pre & postconditions?

• Serves as documentation

• It allows **modular reasoning**: you can verify f() by only looking at
  • The code of f()
  • The annotations on every function that f() calls

• Thus, reasoning about a function’s safety becomes an (almost) *purely local activity*

• This is **related to defensive programming**:
  • **Ideally**: preconditions are the assumptions we make
  • **Practically**: they’re constraints that **honest** clients are expected to follow