# Secure Software Development

## Defensive Programming

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# Defense-in-Depth

# Defense-in-Depth

- Understand the attacker's perspective
  - *"Know your enemy"* – Sun Tzu, *The Art of War*
- Defend on all layers
  - The weakest link will break first

**Attacker's perspective**

- Vulnerability discovery ☑
- Exploitation ☑
- Privilege elevation (soon)

**Defender's perspective**

- Vulnerability prevention (today)
- Exploit prevention (next time)
- Privilege minimization (next time)

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- admin flag, spawn a shell, cat flag.txt, gain persistence

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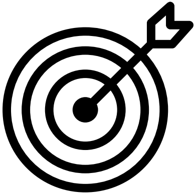

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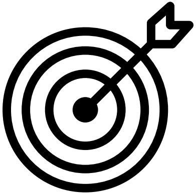

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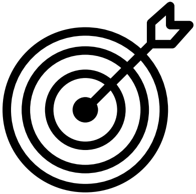

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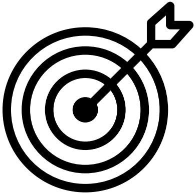

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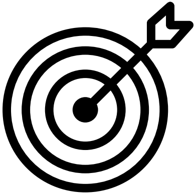

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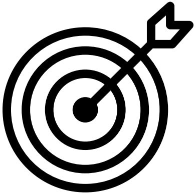

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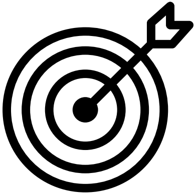

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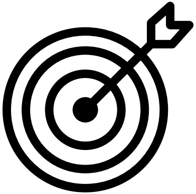

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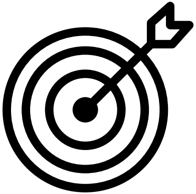

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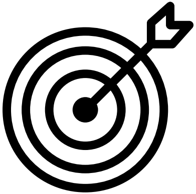

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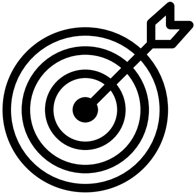

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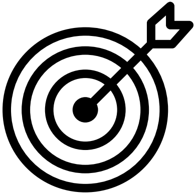

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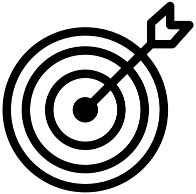

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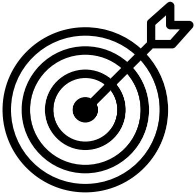

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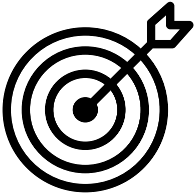

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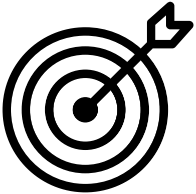

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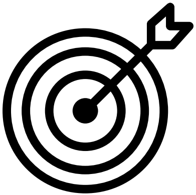

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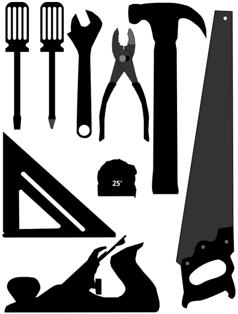


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- Memory safety
- Type safety
- Integer safety
- Secure data flow
    - Input sanitization
- Secure control flow
    - Error handling

- Choose appropriate language
- Improve code quality
    - Coding standard
    - Source code reuse
    - Portability / Assumptions
    - Documentation
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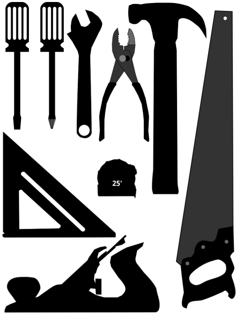


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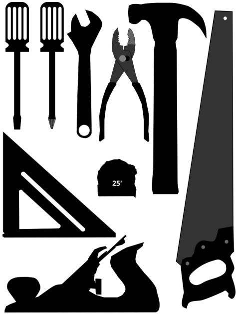


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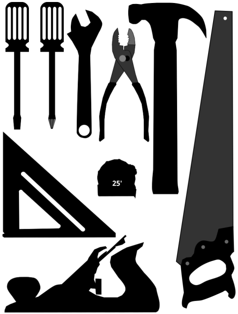

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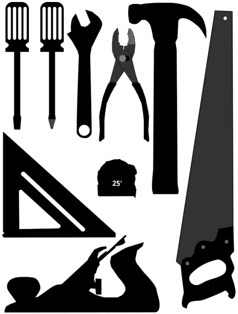


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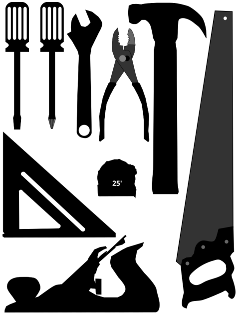


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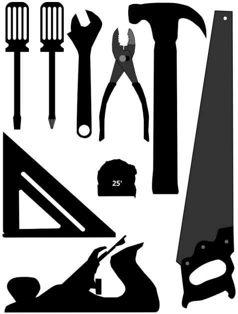


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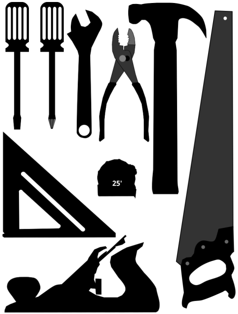


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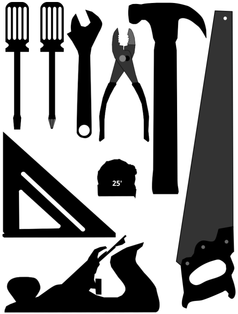


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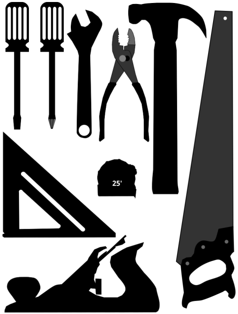


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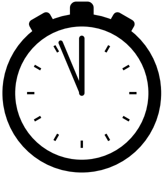

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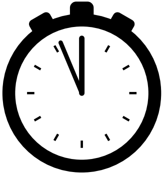

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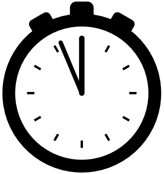

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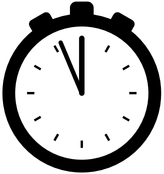

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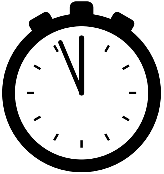

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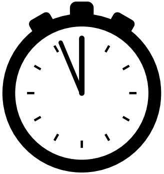

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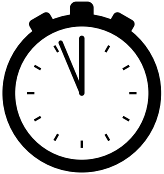

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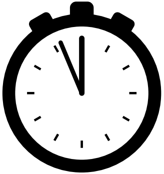

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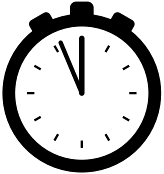

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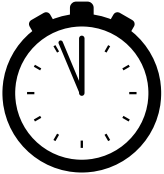

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```
memset(ptr, 0, size); free(ptr); ptr = NULL;
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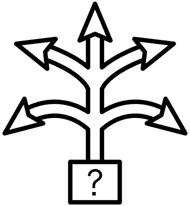


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- Avoid use of `unions` in C++, use `std::variant`
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  - Avoid cast to `(void*)`. This should mainly be used for memory allocators
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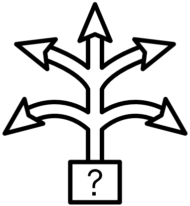


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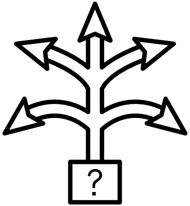


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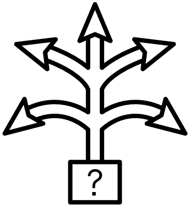


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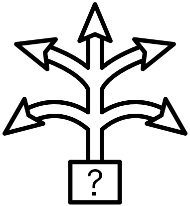


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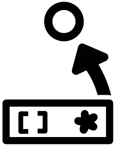
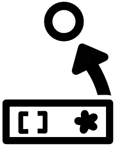
# Fat Pointers






- General concept
- Store additional runtime metadata alongside pointer, e.g.:
  - pointer type
  - length
  - validity
  - access permissions
- Examples: C++ smart pointer
- `dynamic_cast<>` is similar but not a fat pointer

☹ Typically consume 2–5 times more memory per pointer



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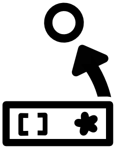

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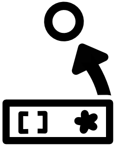

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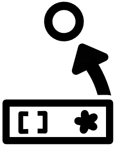

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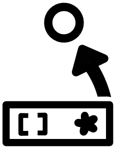

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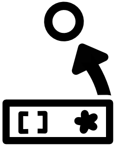

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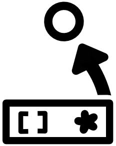

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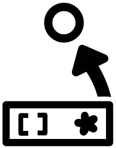

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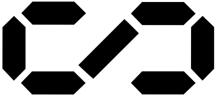

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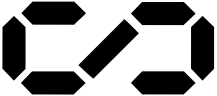

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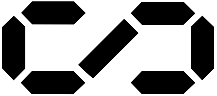

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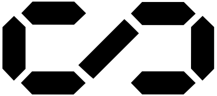

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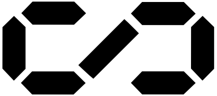

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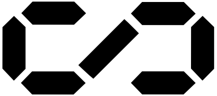

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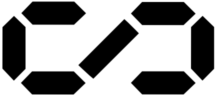

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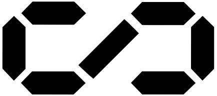

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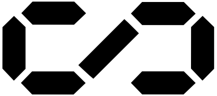

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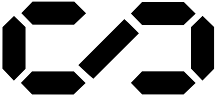

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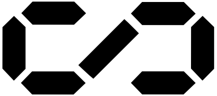
  - Attention: `char` can be `signed` or `unsigned`
- Make large types explicit
- Perform range checks on each downcast

# Integer Safety II



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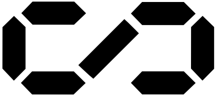

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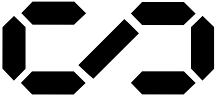

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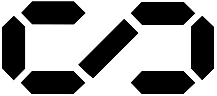

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int y = ...;
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long long x = (long long)y + 2LL;
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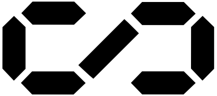
- Perform range checks on each downcast

# Integer Safety II



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Daniel Gruss, Vedad Hadzic, Andreas Kogler, Martin Schwarzl, Marcel Nageler — Winter 2021/22, www.iaik.tugraz.at

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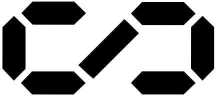

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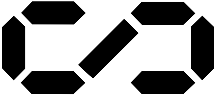
- Perform range checks on each downcast

```c
int x = ...;
if (x > SHORT_MAX) error();
short y = (short)x;
```

- Goal 3: prevent undefined behavior
- Know undefined behavior! E.g.,
  - Left-shift a signed type
    - number could become negative if MSB is reached
  - Left-shift by a negative number
  - Increment of void pointers:



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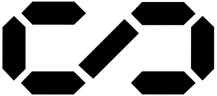

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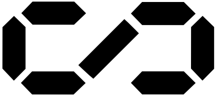

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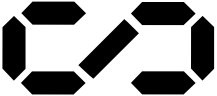

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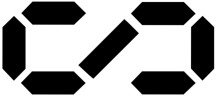

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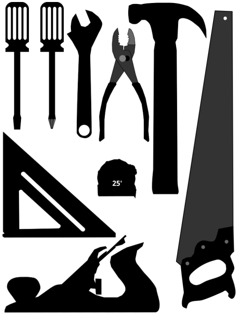
```
size_t strlen(void* string) {
  while(*(char*)string != '\0')
      string++;   // undefined increment
}
```




**Sub-goals**

- Memory safety
- Type safety
- Integer safety
- Secure data flow
  - Input sanitization
- Secure control flow
  - Error handling

**General principles**

- Choose appropriate language
- Improve code quality
  - Coding standard
  - Source code reuse
  - Portability / Assumptions
  - Documentation
  - Testing & Assertions
  - Compiler assistance

- Observation: Attacker injects payload as data, which might get misinterpreted as code
- Idea: Focus on data flow rather than memory objects, types, etc.
- Goal: Secure data flow → attacker cannot inject payload
  - Check *every* input an attacker can control directly or indirectly
  - Better: Check *every* input.
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by **Michael Mimoso** Follow @mike_mimoso January 28, 2016 , 9:04 am

Stepankin said he was able to execute arbitrary shell commands on PayPal servers by taking advantage of insecure Java object deserialization. He wrote in a blog post that he was able to access PayPal's production servers.

"I realized that I could execute arbitrary OS commands on manager.paypal.com web servers and moreover, I could establish a back connection to my own internet server and, for example, upload and execute a backdoor," he wrote. "[As a] result, I could get access to production databases used by manager.paypal.com application."

"I just read "/etc/passwd" file by sending it to my server as a proof of the vulnerability," he wrote.

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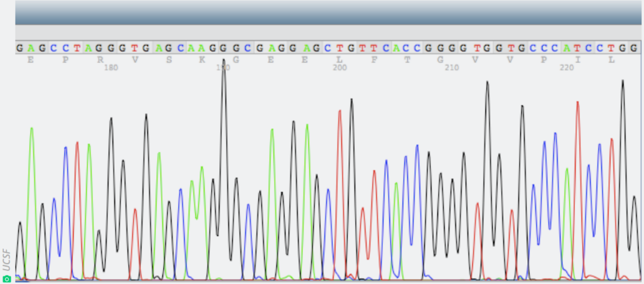
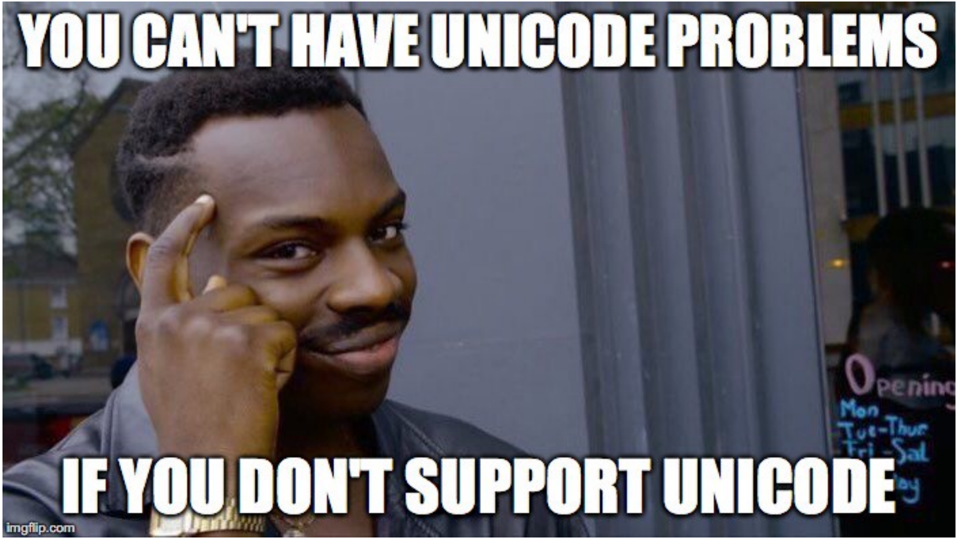
*LIFEHACKER* —

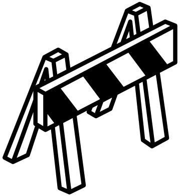
# Researchers encode malware in DNA, compromise DNA sequencing software

It's a proof-of-principle, done after making DNA analysis software vulnerable.

JOHN TIMMER - 8/12/2017, 4:15 PM



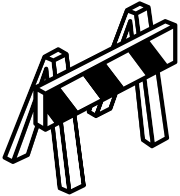

YOU CAN'T HAVE UNICODE PROBLEMS
IF YOU DON'T SUPPORT UNICODE
imgflip.com



- Goal: sanitize dangerous input
- Detect and reject
  - Pattern matching
  - Canonicalization
- Neutralize
  - Filtering
  - Character escaping

# Secure Data Flow: Input Sanitization





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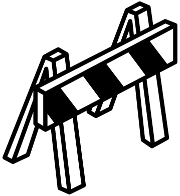

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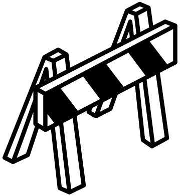

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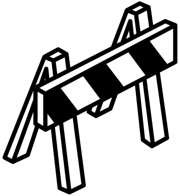

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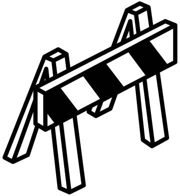

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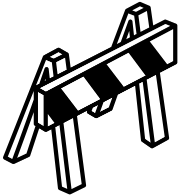

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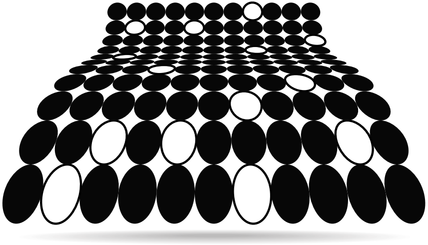

☞ Use existing sanitizers wherever possible!

- HTML, SQL, CSS, XML, E-mail ...

- Blacklist (deny list)
  - ☹ It is easy to overlook stuff
- Whitelist (allow list)
  - ☺ Very restrictive, thus secure
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- Regex
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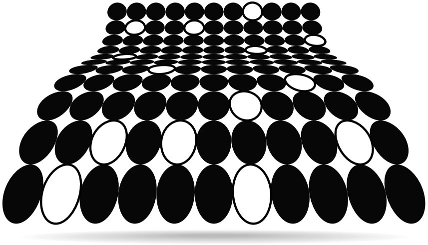

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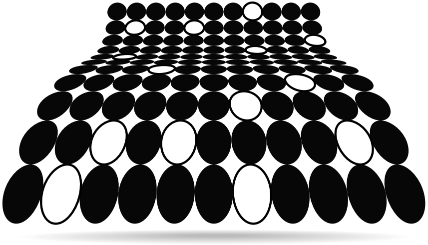

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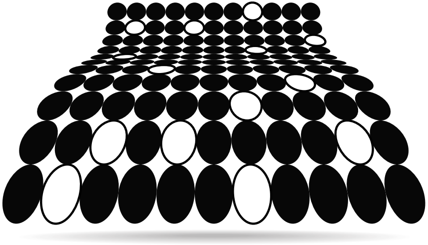

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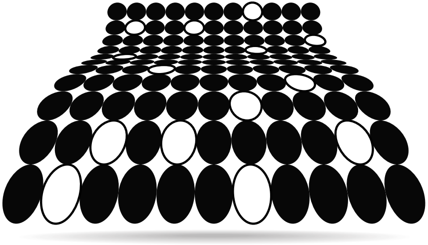

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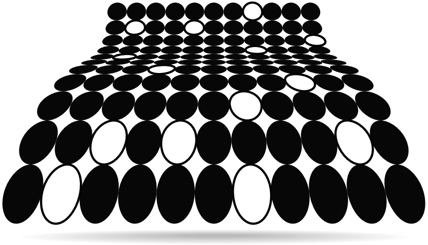

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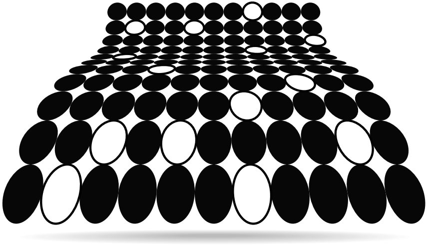

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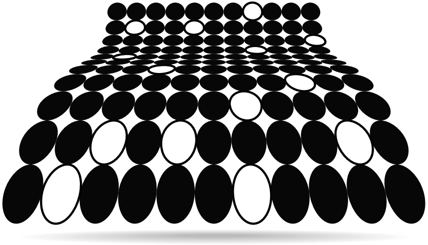

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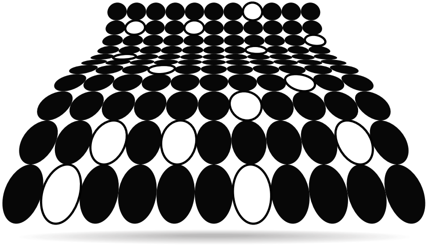

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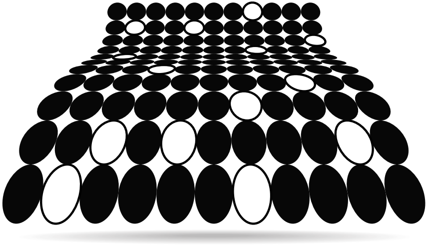

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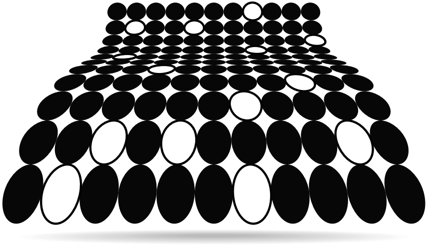

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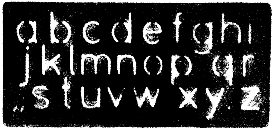
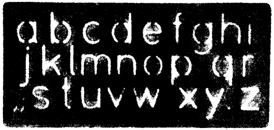


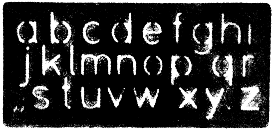

- Issue: equivalent representations make sanitization a pain




Issue: equivalent representations make sanitization a pain

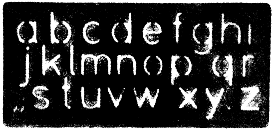
Example: equivalent Unix paths

```
/proc/self/maps
~/../../proc/self/maps
/proc/1/maps
/proc/1/./maps
/proc/1/././////maps
/proc/../proc/1/maps
...
```

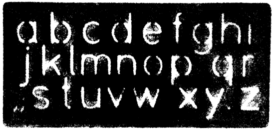


Issue: equivalent representations make sanitization a pain

| Example: equivalent Unix paths | Example: equivalent numbers |
|---|---|
| `/proc/self/maps` | `21` |
| `~/../../proc/self/maps` | `21.0` |
| `/proc/1/maps` | `+21` |
| `/proc/1/./maps` | `025` |
| `/proc/1/././////maps` | `0x15` |
| `/proc/../proc/1/maps` | `21e0` |
| ... | ... |




- Idea: make parsing more uniform
- Canonicalization before Sanitization!
- Example: canonicalizing paths using `realpath`
  - Resolve relative paths
  - Resolve symlinks:

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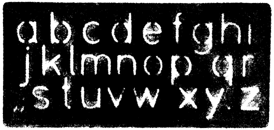


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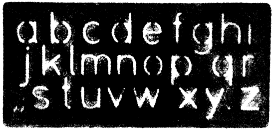


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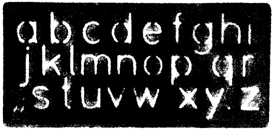


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Canonicalization before Sanitization!

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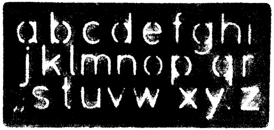
  - Resolve relative paths

    `../../etc/passwd --> /etc/passwd --> DENY`

    `./etc/passwd --> /home/ssd/etc/passwd --> ALLOW`
  - Resolve symlinks:

# Secure Data Flow: Canonicalization II

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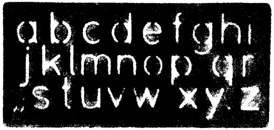

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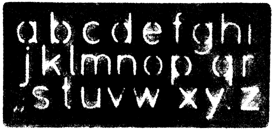
    ./etc/passwd --> /home/ssd/etc/passwd --> ALLOW
    ```

  - Resolve symlinks:

    ```
    mylink-to-passwd --> /etc/passwd --> DENY
    ```

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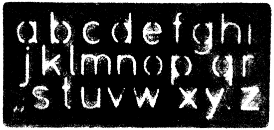


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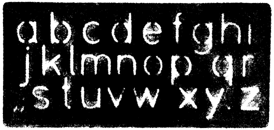


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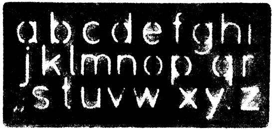


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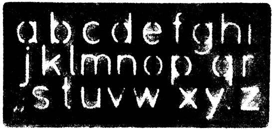


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- Cross-site scripting (HTML injection)
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Daniel Gruss, Vedad Hadzic, Andreas Kogler, Martin Schwarzl, Marcel Nageler — Winter 2021/22, www.iaik.tugraz.at

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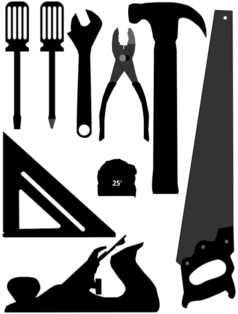


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- Memory safety
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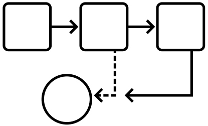

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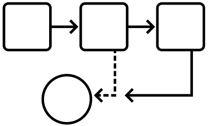

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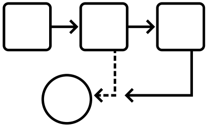

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# Secure Control Flow: Return Error Codes II



Better now?

```
1 FILE* f = fopen("report.log", "a");
2 if (NULL == f) { perror("Unable to open file"); return; }
3 assert(0 > fprintf(f, "Server started\n"));
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5 fclose(f);
```

Compiler might optimize out `asserts` (line 3)

- `fprintf` is never executed!
- Compile flag `-DNDEBUG`

Never use `assert` to check for actual error codes

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char* tmp = realloc(buffer, newsize);
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- Consider all possible error combinations
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# Secure Control Flow: Return Error Codes III

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char* tmp = realloc(buffer, newsize);
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The realloc() function returns a pointer to the newly allocated memory, which is suitably
aligned for any built-in type and may be different from ptr, or NULL if the request fails.
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### *RETURN VALUE*

If successful, the *pthread_create*() function shall return zero; otherwise, an error number shall be returned to indicate the error.

### *ERRORS*

The *pthread_create*() function shall fail if:

[EAGAIN]
: The system lacked the necessary resources to create another thread, or the system-imposed limit on the total number of threads in a process {PTHREAD_THREADS_MAX} would be exceeded.

[EPERM]
: The caller does not have appropriate permission to set the required scheduling parameters or scheduling policy.

The *pthread_create*() function may fail if:

[EINVAL]
: The attributes specified by *attr* are invalid.

The *pthread_create*() function shall not return an error code of [EINTR].


EXCEPTIONS
EXCEPTIONS EVERYWHERE
makeameme.org

# Secure Control Flow: Exceptions II

- Exceptions can make your code clean
- Exceptions can make your code fast
- Exceptions can make your code expensive
- \$500 million for a crashed Ariane5 rocket in 1996
  - *"The internal SRI software exception was caused during execution of a data conversion from 64-bit floating point to 16-bit signed integer value."*

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`http://sunnyday.mit.edu/nasa-class/Ariane5-report.html`

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  - Which statement can throw which exception?

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try
{
  MyClass* a = new MyClass();                // std::bad_alloc exception
  MyClass& b = dynamic_cast<MyClass&>(c); // std::bad_cast exception
}
catch (std::exception& e)
{
  std::cout << "Exception: " << e.what() << std::endl;
}
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# Secure Control Flow: C goto for the Rescue II

```c
char* resourceA = NULL;
FILE* resourceB = NULL;
void* resourceC = MAP_FAILED;
int err = SUCCESS;

resourceA = malloc(10);
if (NULL == resourceA) {
    err = ERROR_A; goto failed;
}
resourceB = fopen(...);
if (NULL == resourceB) {
    err = ERROR_B; goto failed;
}
resourceC = mmap(...);
if (MAP_FAILED == resourceC) {
    err = ERROR_C; goto failed;
}
return SUCCESS;
```

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if (MAP_FAILED == resourceC) {
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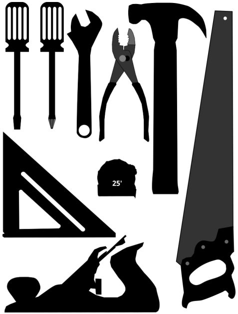
```
failed:
    if (MAP_FAILED != resourceC)
        {
        munmap(resourceC);
    }
    if (NULL != resourceB) {
        fclose(resourceB);
    }
    free(resourceA);
    return err;
```



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# Defensive Programming: Choose Appropriate Language




- C, C++
  - High control, high performance
  - Inherently unsafe in many aspects
  - Important use cases
    - C: Low-level kernel/embedded development
    - C++: High-performance application development
    - Maintenance of legacy code
    - Education
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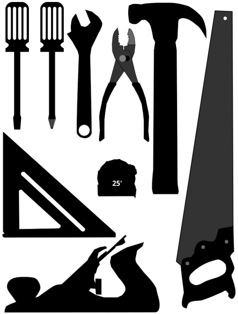


## Sub-goals

- Memory safety
- Type safety
- Integer safety
- Secure data flow
  - Input sanitization
- Secure control flow
  - Error handling

## General principles

- Choose appropriate language
- Improve code quality
  - Coding standard
  - Source code reuse
  - Portability / Assumptions
  - Documentation
  - Testing & Assertions
  - Compiler assistance

Idea: By improving code quality we

- Make code more comprehensible to us and to outsiders
- Decrease likelihood of introducing bugs
- Increase likelihood of finding bugs
- Make code maintainable
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# Improve Code Quality: Coding Standard I



- Use descriptive and consistent naming scheme,
  e.g. `local_var`, `myFunc`, `_internalFunc`, `MACRO`, `CONSTANT`
- Wrap if/else/for bodies into `{ ... }`
- Check/sanitize function parameters and return values

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```c
int readPassword(const char* path_password) {
    if (NULL == path_password) {
        return ERROR;
    }
    FILE* file_password = fopen(path_password, "r");
    if (NULL != file_password) {
        return ERROR;
    }
    ...
```

# Improve Code Quality: Coding Standard II



## Use C macros with special care

- Wrap multiple statements in `do { ... } while(0)`
- Wrap overall macro expression and each argument in `(...)`
- Copy macro parameters if used multiple times. It might be a statement with side effects e.g., `i++`
- If macro has control-flow statements (`return`, `break`, `goto`), include them in the macro name

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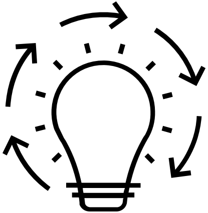
```c
#define CHECK_RETURN_ON_ERROR(stmt, err_msg) do { \
  int result = (int)(stmt); \
  if (result < 0) { \
      printf("CHECK failed with %d: %s", result, err_msg); \
      return result; \
  } \
} while(0)
```



- “Do not rewrite your own $THING”, especially
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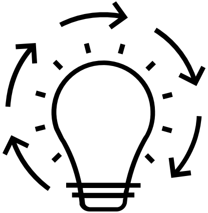
  - Crypto libraries
- Reuse **established** libraries
- Stackoverflow is not a good source code repository!



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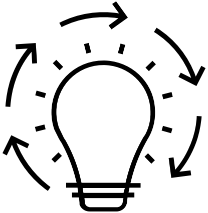

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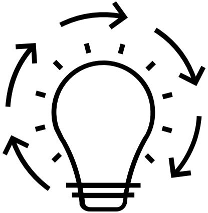

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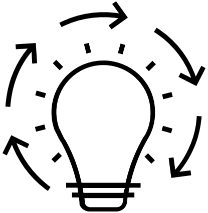

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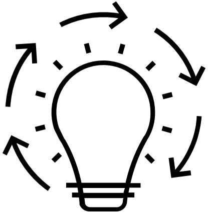
# Improve Code Quality: Intelligent Source Code Reuse



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PENTEST .BLOG

ADVISORIES OPERATING SYSTEM APPLICATION SECURITY NETWORK TOOLS

# One ring to rule them all – Same RCE on multiple Trend Micro products

October 8, 2017 Mehmet Ince Research

## One ~~ring~~ bug to rule them all – Widgets of Trend Micro's Products

Most of the Trend Micro's products have a widgets for administrator web page. Although core system written with Java/.NET, this widget mechanism had implemented with PHP. That means, they somehow need to put PHP interpreter on product whenever they decided to use widgets. Which makes it a perfect spot to what we need: a single code base, exist across the different product and awesome way to implement reliable exploit once we have an vulnerability.

For the reasons that I've mentioned above, I performed a code audit for widget system of **Trend Micro OfficeScan** product. Result is quite interesting as well as unfortunate for me. I've found 6 different vulnerability but only 2 of them is **0day**.

[...]

## Conclusion

First of all, I would like to say again, this command injection vulnerability has been patched by Trend Micro for both of these products. If you are a Trend Micro user or your organisation is using any of these products, hurry up! Patch your system.

Having same code base on different products is not something bad. I just wanted to point out that one bug within your framework can cause a massive trouble.

# Assume that your code will be reused anywhere

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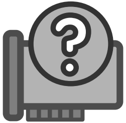

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- Make no assumptions about undefined or implementation-defined behavior
  - Signed overflows
  - Binary shift operation with a negative shift value
  - Return value of {m,c,re}alloc if size is zero (implementation-defined)
- Know undefined behavior of your programming language

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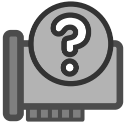
  See no. 51, 52, 53...



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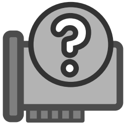

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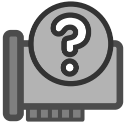

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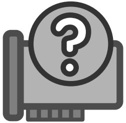
# Improve Code Quality: Portability & Assumptions I



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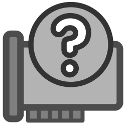
**Daniel Gruss**, **Vedad Hadzic**, **Andreas Kogler**, **Martin Schwarzl**, **Marcel Nageler** — Winter 2021/22, www.iaik.tugraz.at



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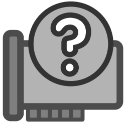

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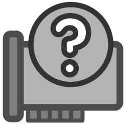

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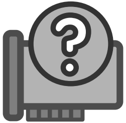

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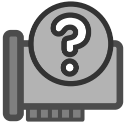

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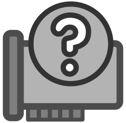

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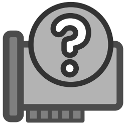

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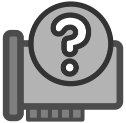

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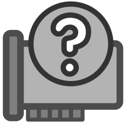

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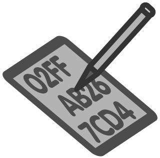


- Write documentation
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  - Assumptions about input parameters (e.g. overlapping buffers in `memcpy`/`memmove`)
  - Assumptions about architecture, stdlib version, etc.
  - Error behavior
  - Globally visible side-effects (global and static variables)
  - Multithreading safety

# Improve Code Quality: Documentation




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  - Error behavior
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  - Multithreading safety

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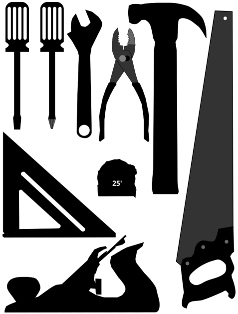


### Sub-goals

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### General principles

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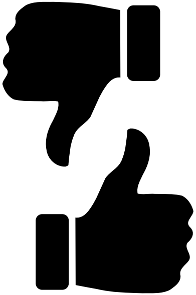
# Improve Code Quality: Testing & Assertions I



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- When to use asserts and when not?
- Idea: Asserts reflect invariants of a program
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- Asserts are good for testing
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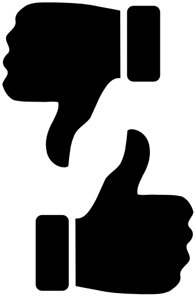
  - No performance penalty
  - `-DNDEBUG` compiler flag
  - Do not rely on asserts for security!



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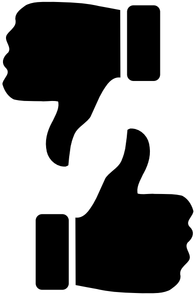

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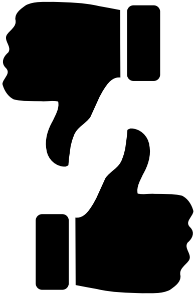

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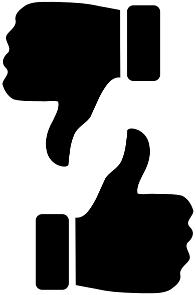

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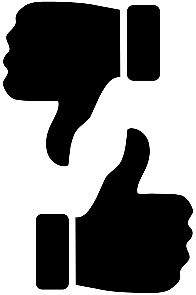

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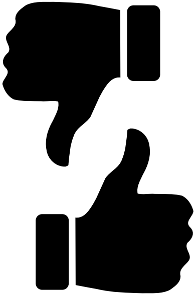

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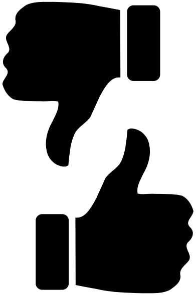

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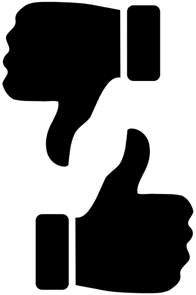

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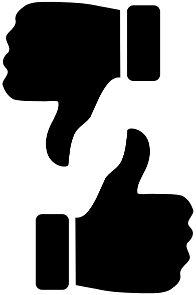

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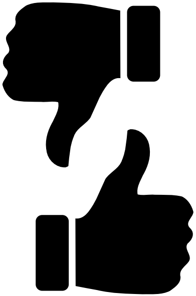
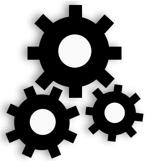


```c
#define TYPE_A   0
#define TYPE_B   1
#define TYPE_MAX 2

typedef struct {
    unsigned int type;
    size_t pos;
    int data[100];
} struct_t;

void print(struct_t* s)
  assert(s->type < TYPE_MAX); // type must always be valid
  size_t s_len =  sizeof(s->data) / sizeof(s->data[0]);
  assert(s->pos < s_len);    // pos must always be smaller than len
  for (size_t i = 0; i < s->pos; i++) {
      printf("Data: %d\n", s->data[i]);
  }
}
```

# Improve Code Quality: Compiler Support I



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- Turn warnings into errors `-Werror`
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  `https://gcc.gnu.org/onlinedocs/gcc/Integer-Overflow-Builtins.html`
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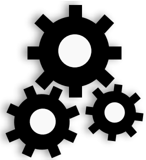

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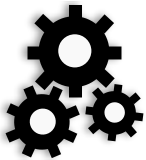

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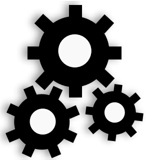

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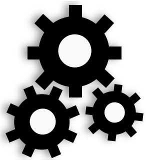

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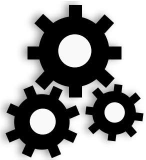

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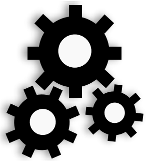
- -D_FORTIFY_SOURCE=2
- Compiler adds extra checks to detect buffer overflows
- Compiler internally replaces calls to regular string functions with known-length string functions
- Not always possible



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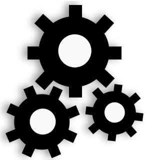

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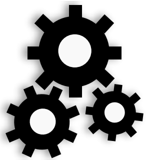

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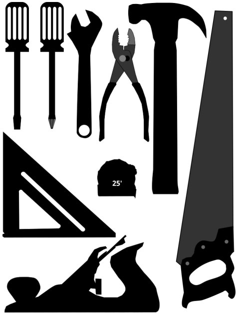
# Summary & Outlook

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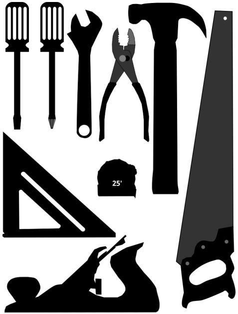


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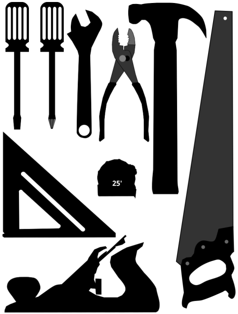


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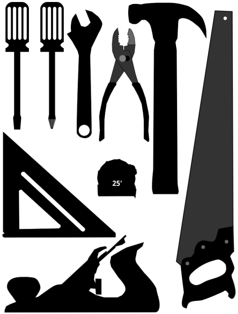


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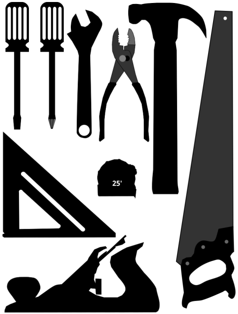


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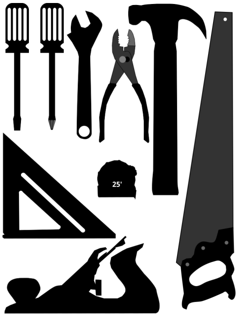


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# Defense In Depth: Outlook

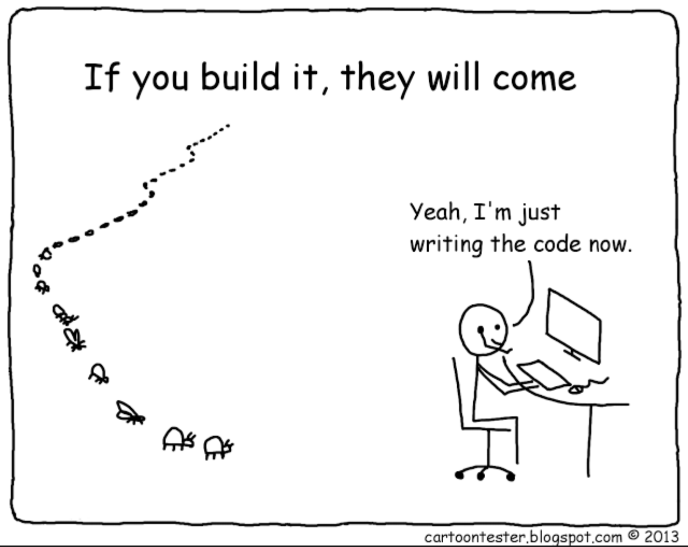
**Attacker's perspective**

- Vulnerability discovery ☑
- Exploitation ☑
- Privilege elevation (soon)

**Defender's perspective**

- Vulnerability prevention (today) ☑
- Exploit prevention (next time)
- Privilege minimization (next time)

# Questions?


If you build it, they will come
Yeah, I'm just writing the code now.
cartoontester.blogspot.com © 2013