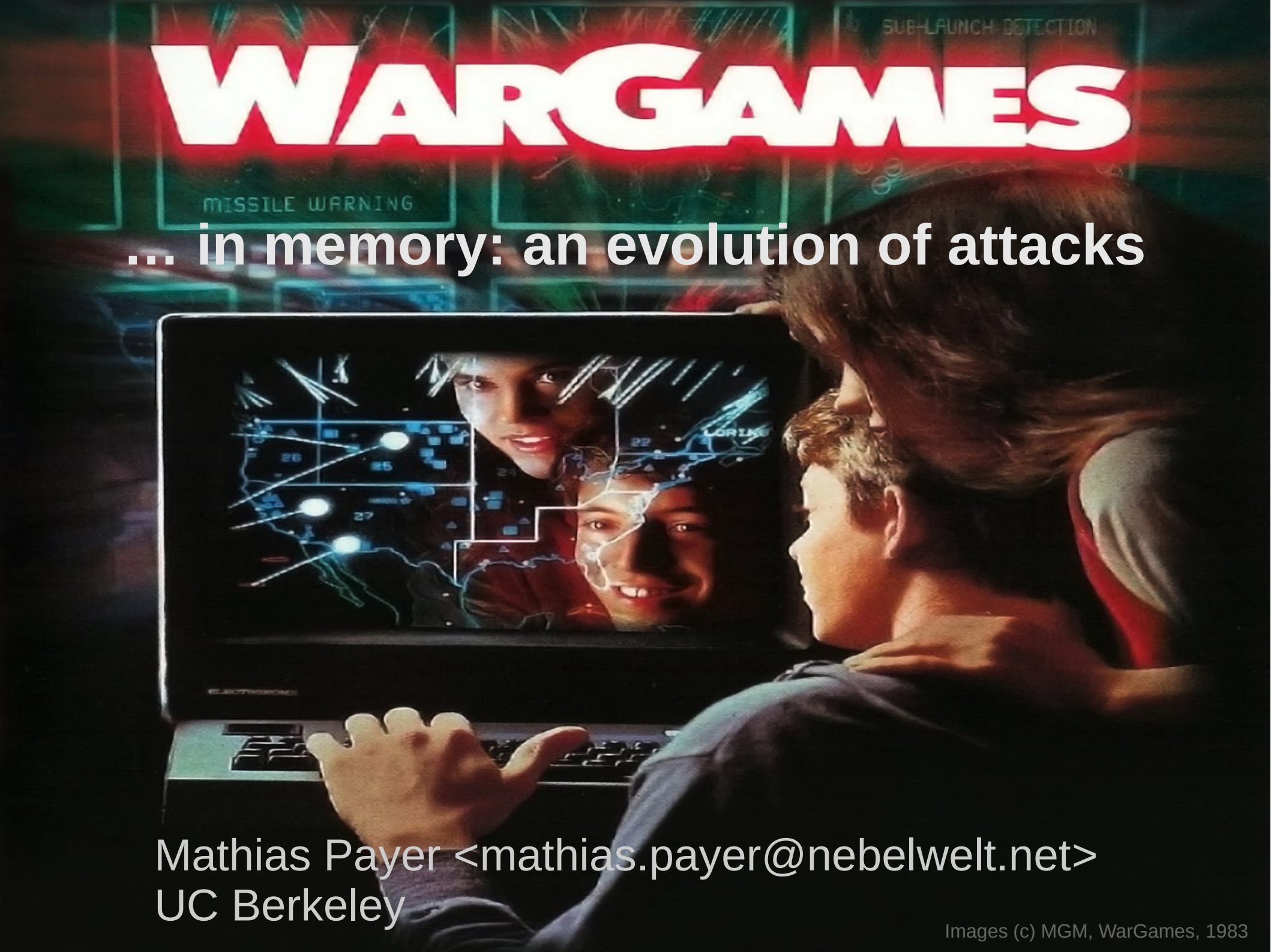
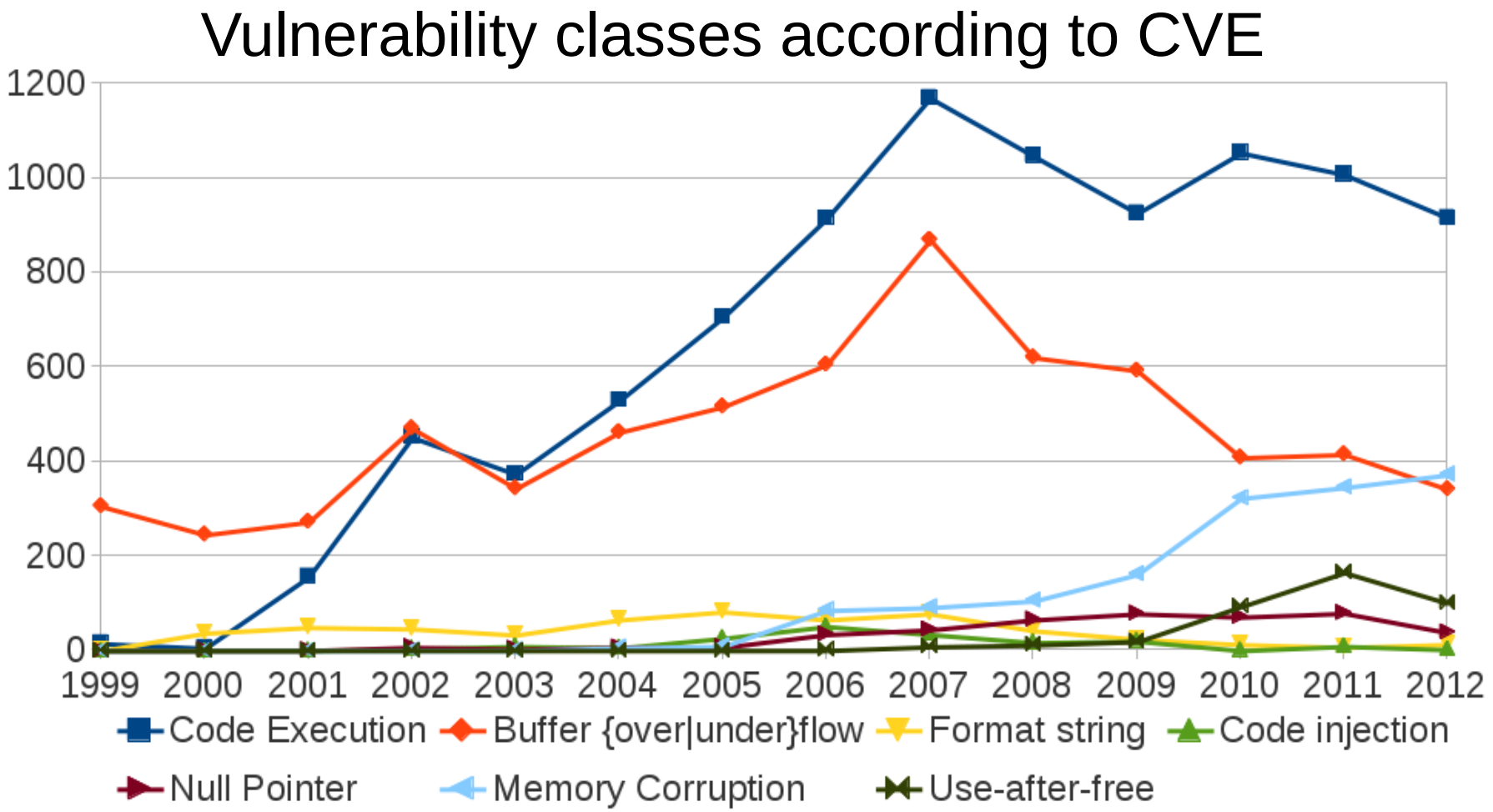


... in memory: an evolution of attacks

Mathias Payer <mathias.payer@nebelwelt.net>
UC Berkeley

Memory attacks: an ongoing war



Memory attacks: an ongoing war

David Lightman: Hey, I don't believe that any system is totally secure."

Memory attacks: an ongoing war

- Low-level languages trade type safety and memory safety for performance
  - Programmer in control of all checks
- Large set of legacy and new applications written in C / C++ prone to memory bugs
- Too many bugs to find and fix manually
  - Protect integrity through low-level security policy

Memory corruption

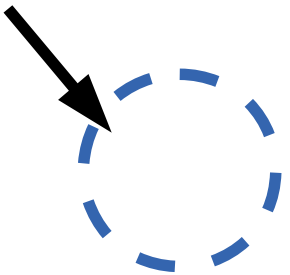
Memory corruption

- Unintended modification of memory location due to missing / faulty safety check
  - Exploitable only if address or value input dependent
  - Attacker sees all memory, controls writable memory

```
void vulnerable(int user1, int *array) {
    // missing bound check for user1
    array[user1] = 42;
}
```

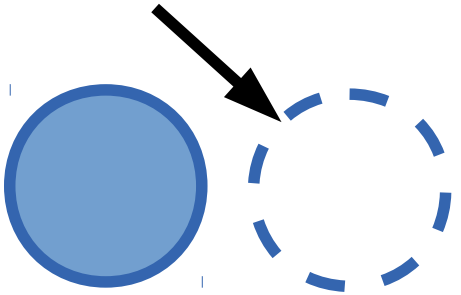
Memory safety: temporal error

```
void vulnerable(char *buf) {
    free(buf);
    buf[12] = 42;
}
```



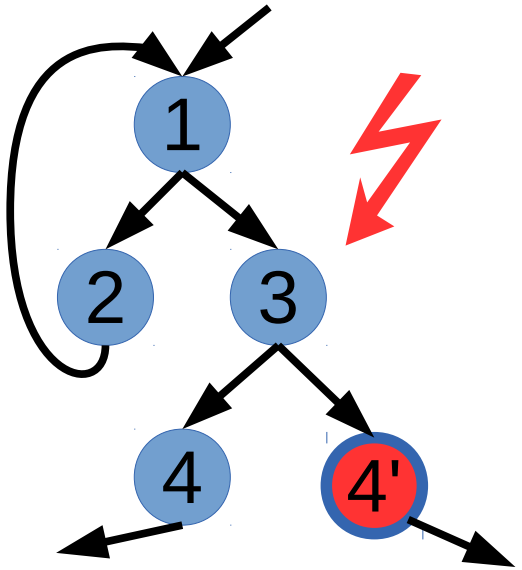
Memory safety: spatial error

```
void vulnerable() {
    char buf[12];
    char *ptr = buf[11];
    *ptr++ = 10;
    *ptr = 42;
}
```



Control-flow hijacking: Attack opportunities

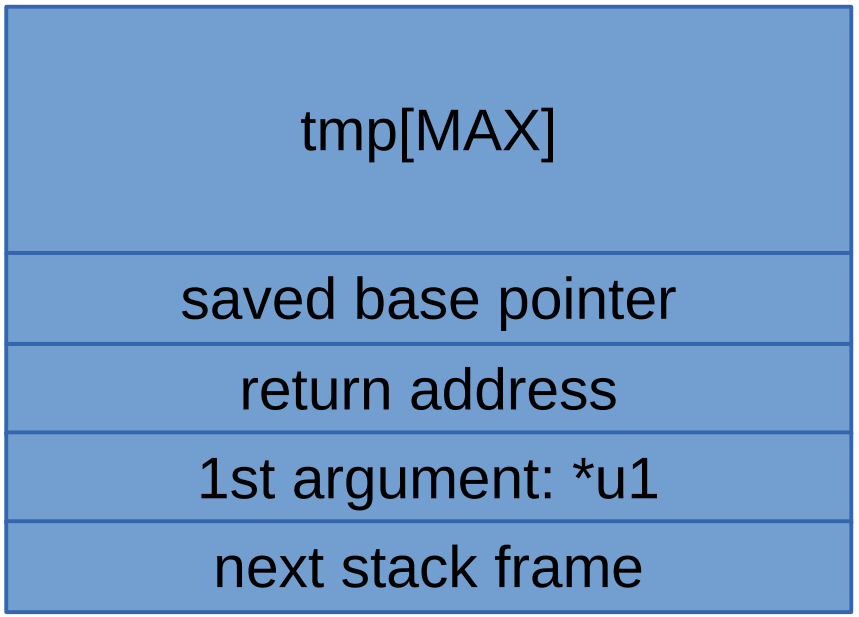
Control-flow hijack attack



- Attacker modifies ***code pointer***
  - Function return
  - Indirect jump
  - Indirect call
- Control-flow leaves static graph
- Reuse existing code
  - Return-oriented programming
  - Jump-oriented programming

Control-flow hijack attack

```
void vuln(char *u1) {
    // assert(strlen(u1)) < MAX
    char tmp[MAX];
    strcpy(tmp, u1);
    return strcmp(tmp, "foo");
}
vuln(&exploit);
```



Control-flow hijack attack

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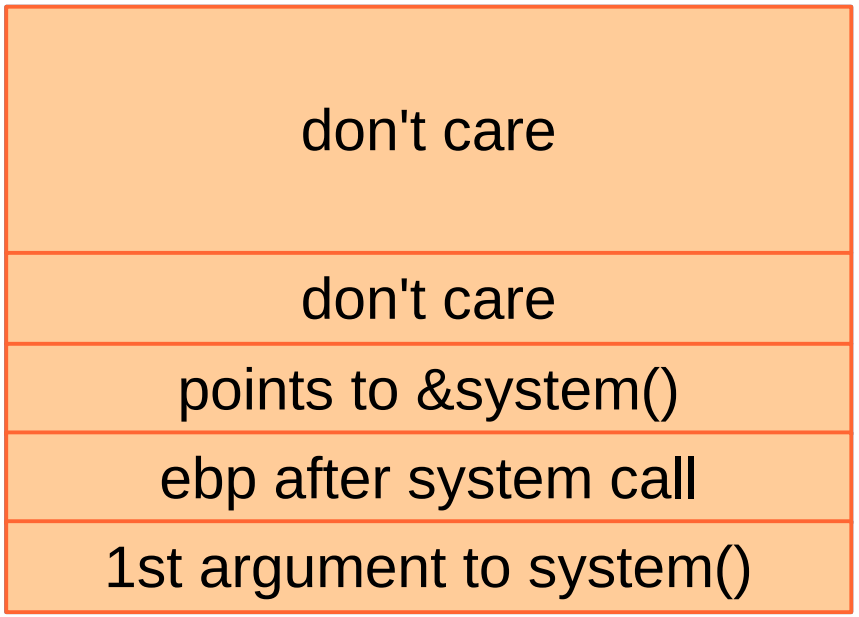
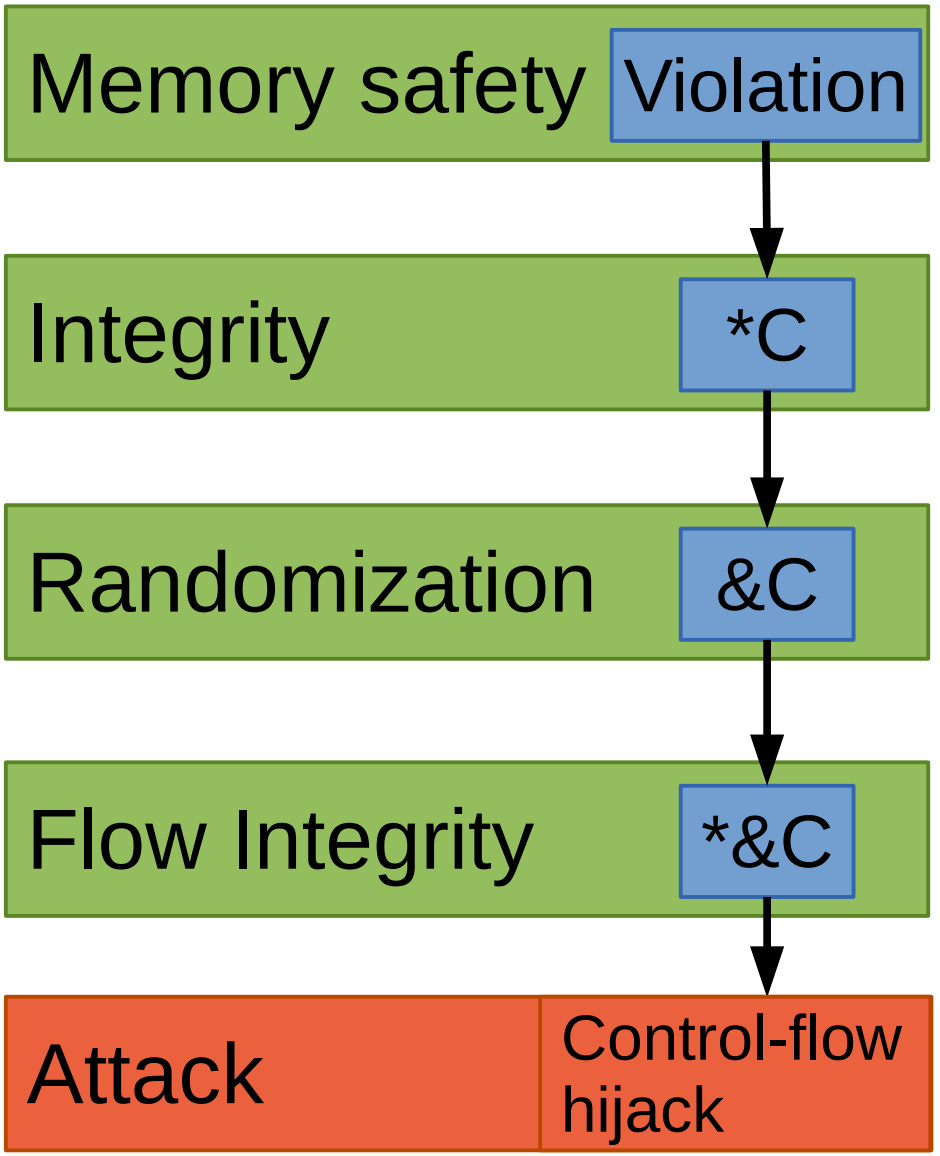
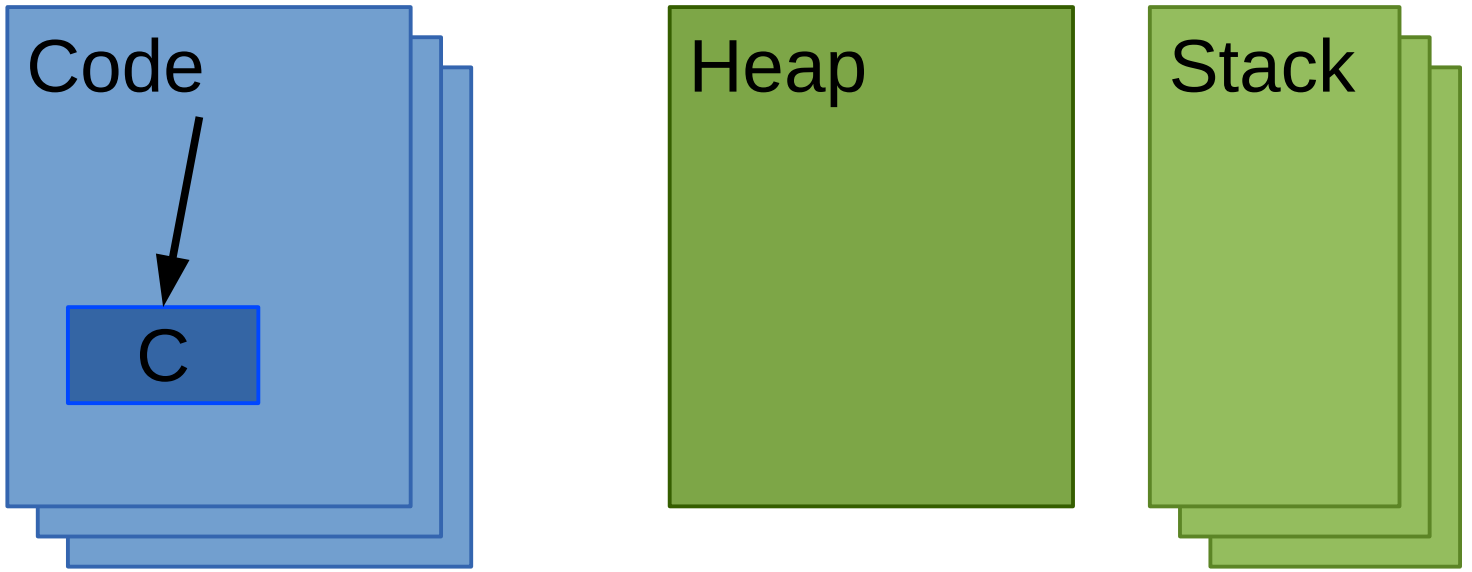




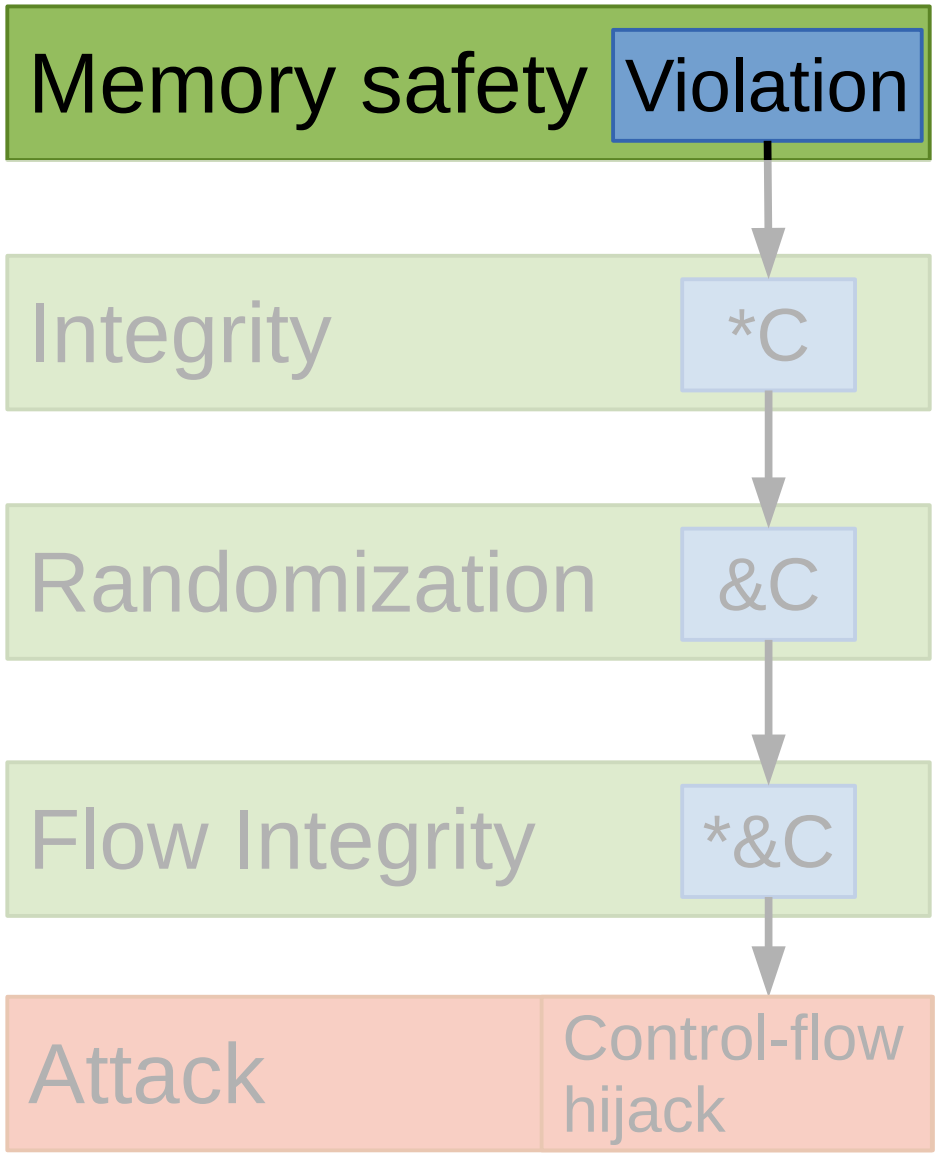
Code corruption attack



- Code modified or new code added
- Hardware protection enforces code integrity

Control-flow hijacking: Defense strategies

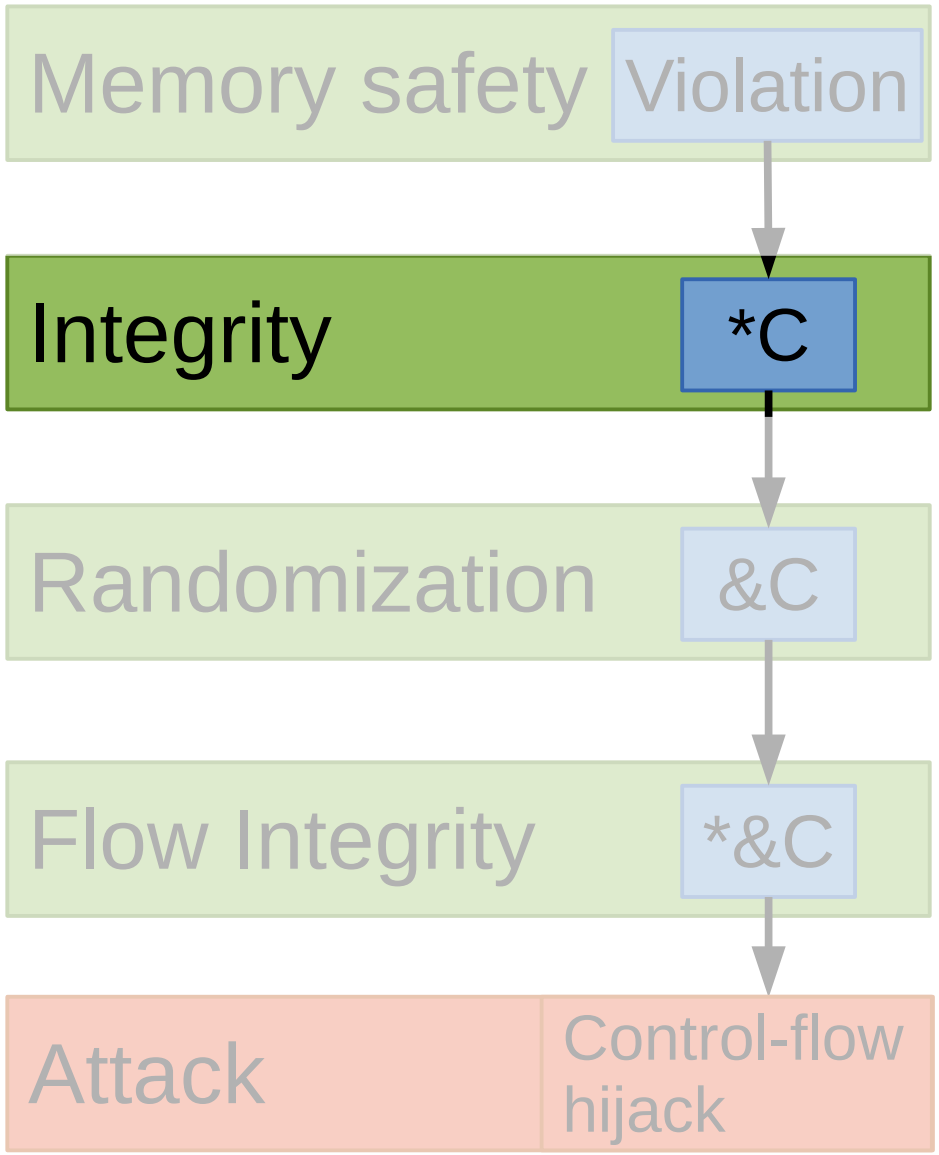
Defense strategies



Stop memory corruption

- Safe dialects of C/C++: CCured, Cyclone
- Retrofit on C/C++: SoftBounds+CETS
- Rewrite in safe language: Java/C#

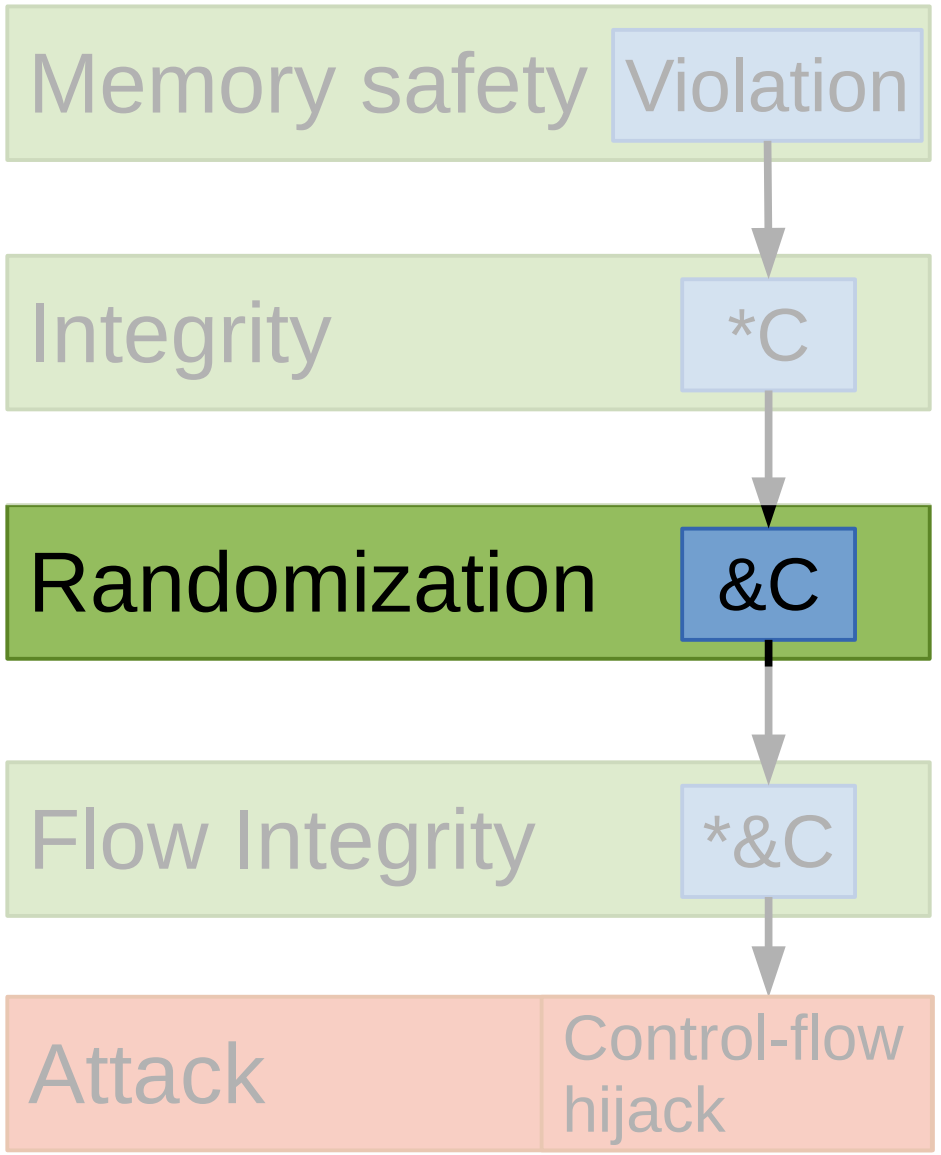
Defense strategies



Enforce integrity of reads/writes

- Write Integrity Testing
- (DEP and W^X for code)

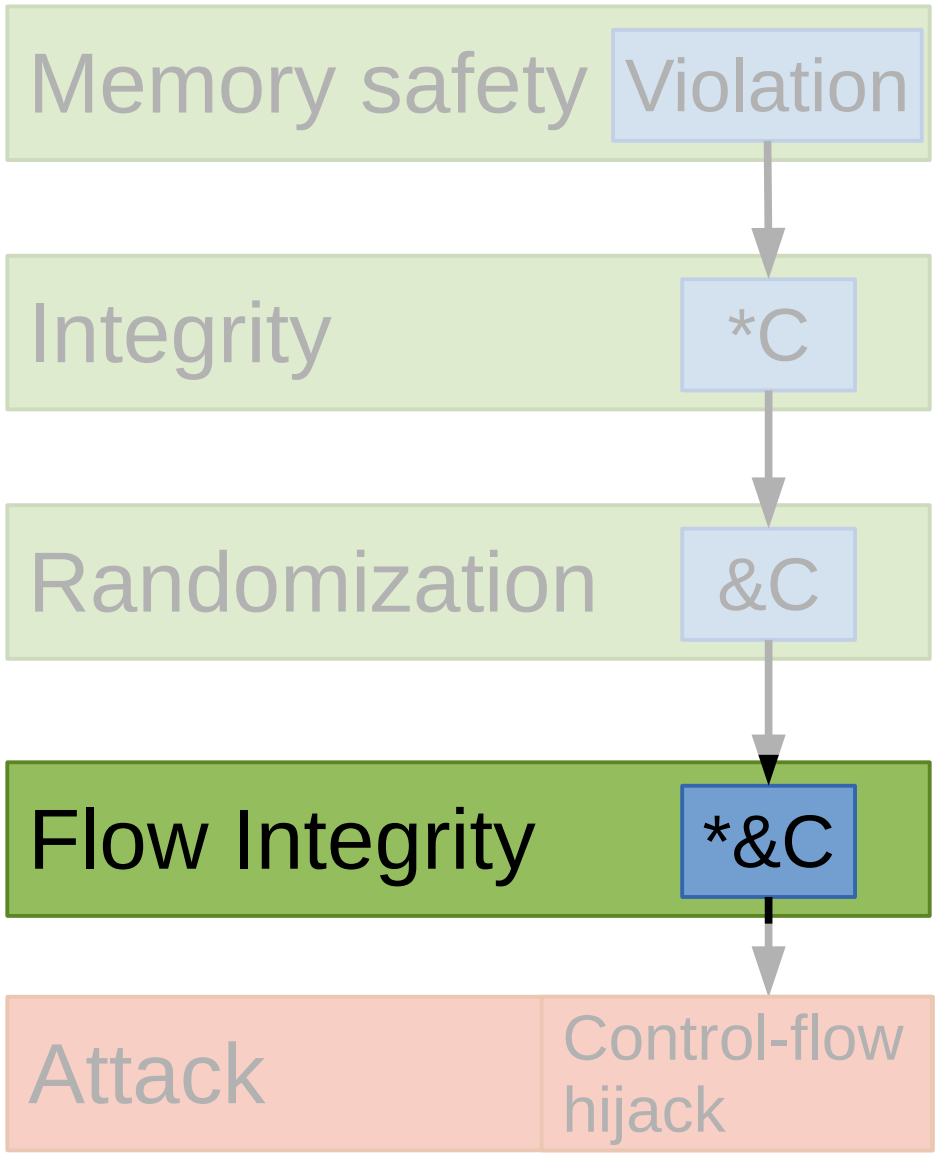
Defense strategies



Probabilistic defenses

- Randomize locations, code, data, or pointer values

Defense strategies

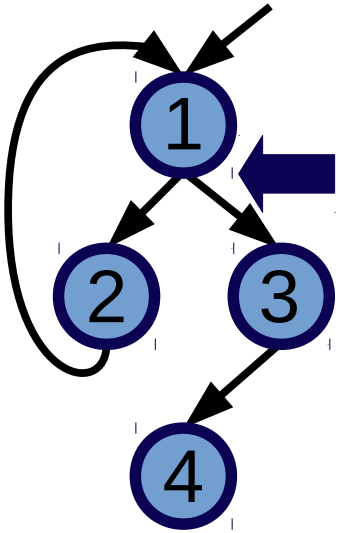


Protect control transfers

- Data-flow integrity
- Control-flow integrity

Control-Flow Integrity

- Dynamic control flow must follow the static control flow graph (CFG)
  - Use points-to analysis to get CFG
  - Runtime check if target in static set

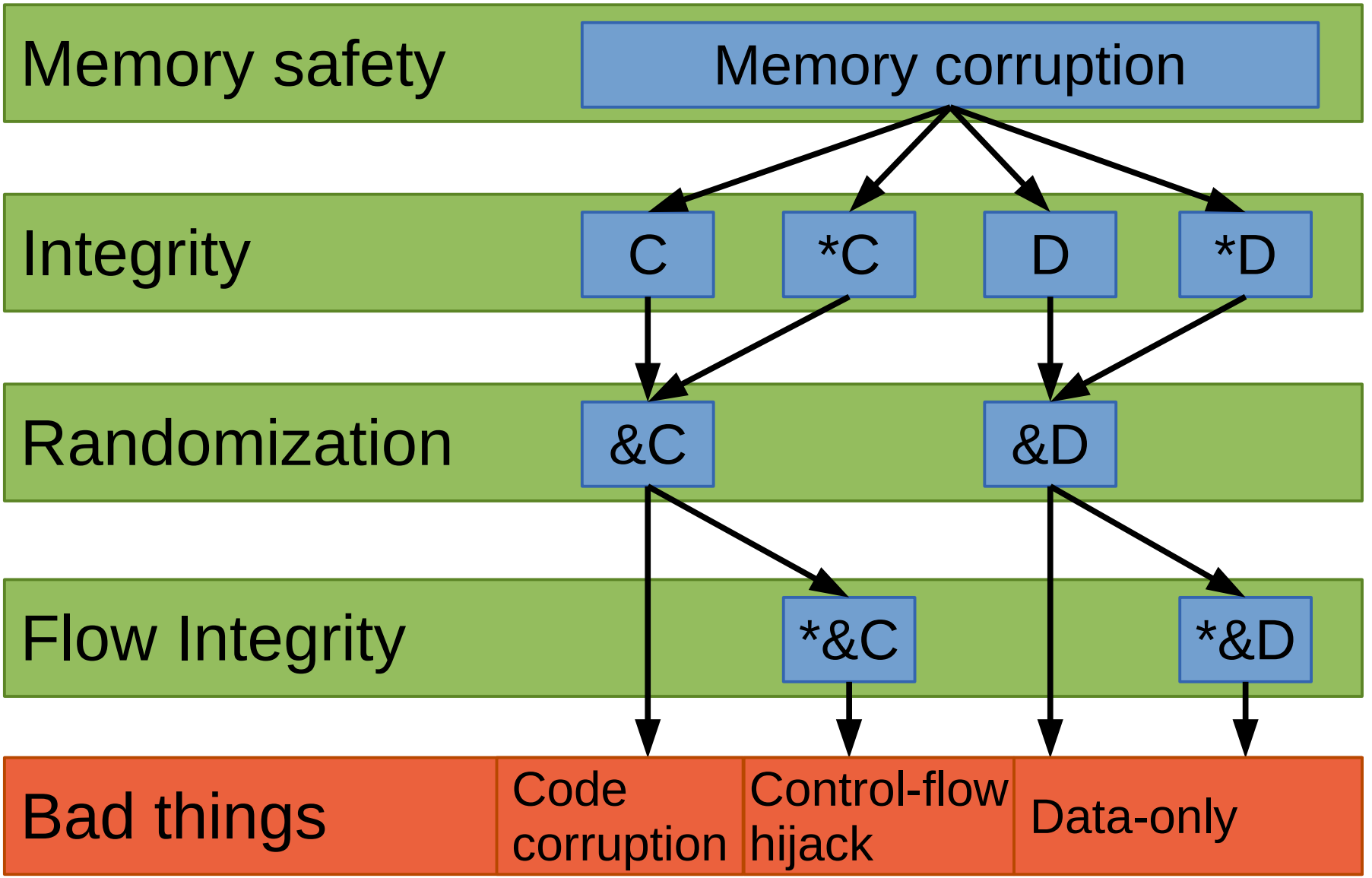


- Current implementations over-approximate
  - Imprecision of static analysis, runtime concerns
  - One set each for indirect calls, jumps, and returns

CFI: Limitations and Drawbacks

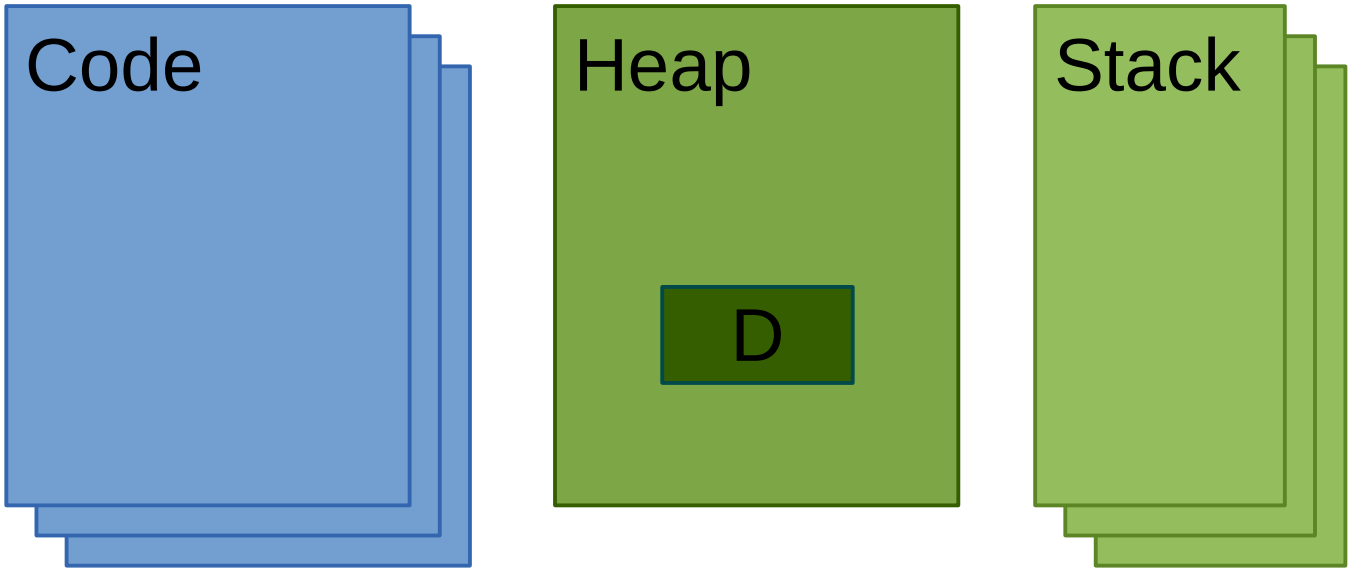
- Precision limited by static type analysis
  - Imprecision leads to ambiguities
- Static analysis must “see” all code
  - Support for dynamic libraries challenging
- Performance overhead or imprecision
  - Current implementations (greatly) over-approximate target set to achieve performance and compatibility

Model for memory attacks

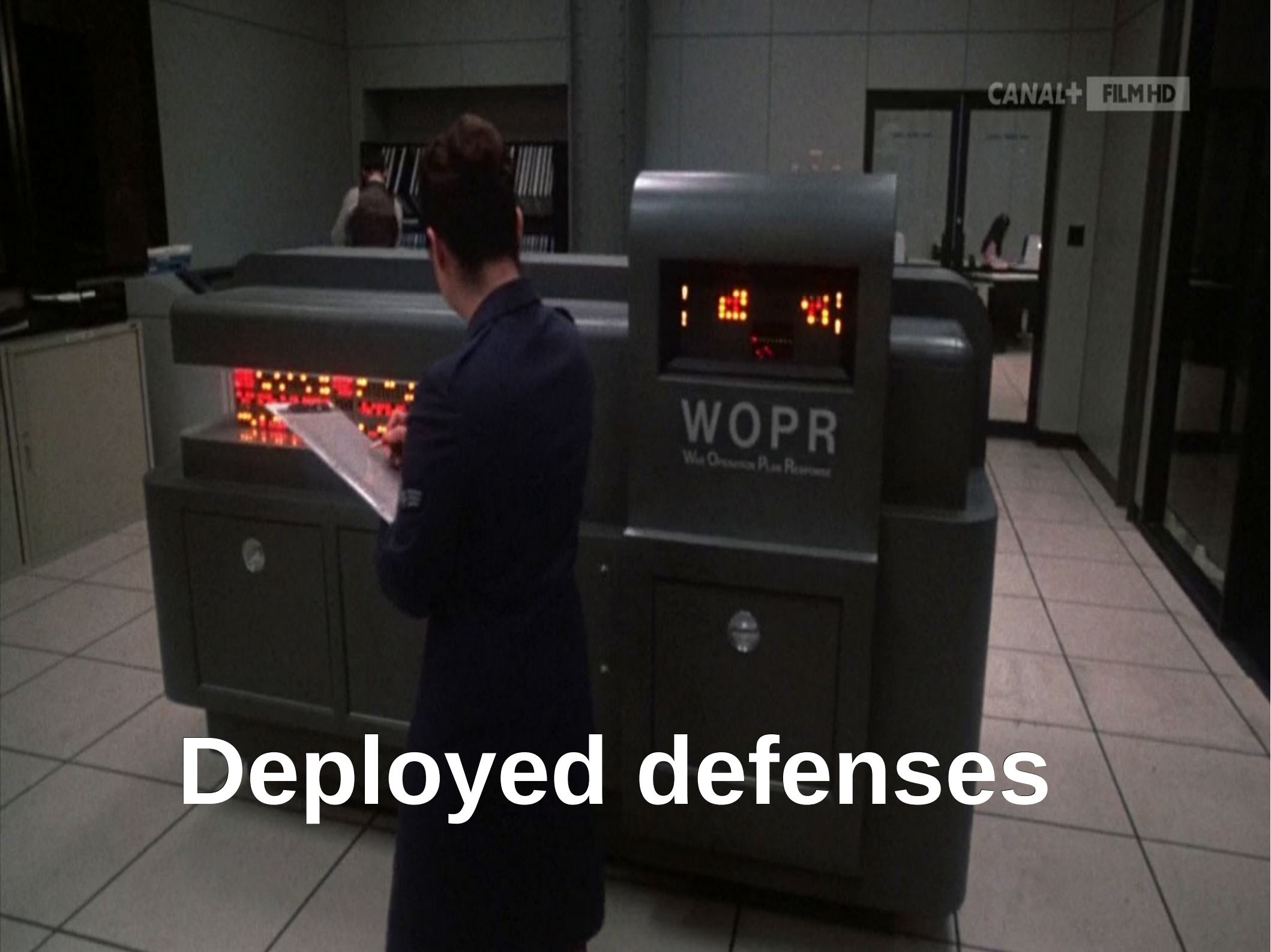


Data-only attacks

Data-only attack



- Privileged or informative data changed
  - Simple, powerful and hard to detect

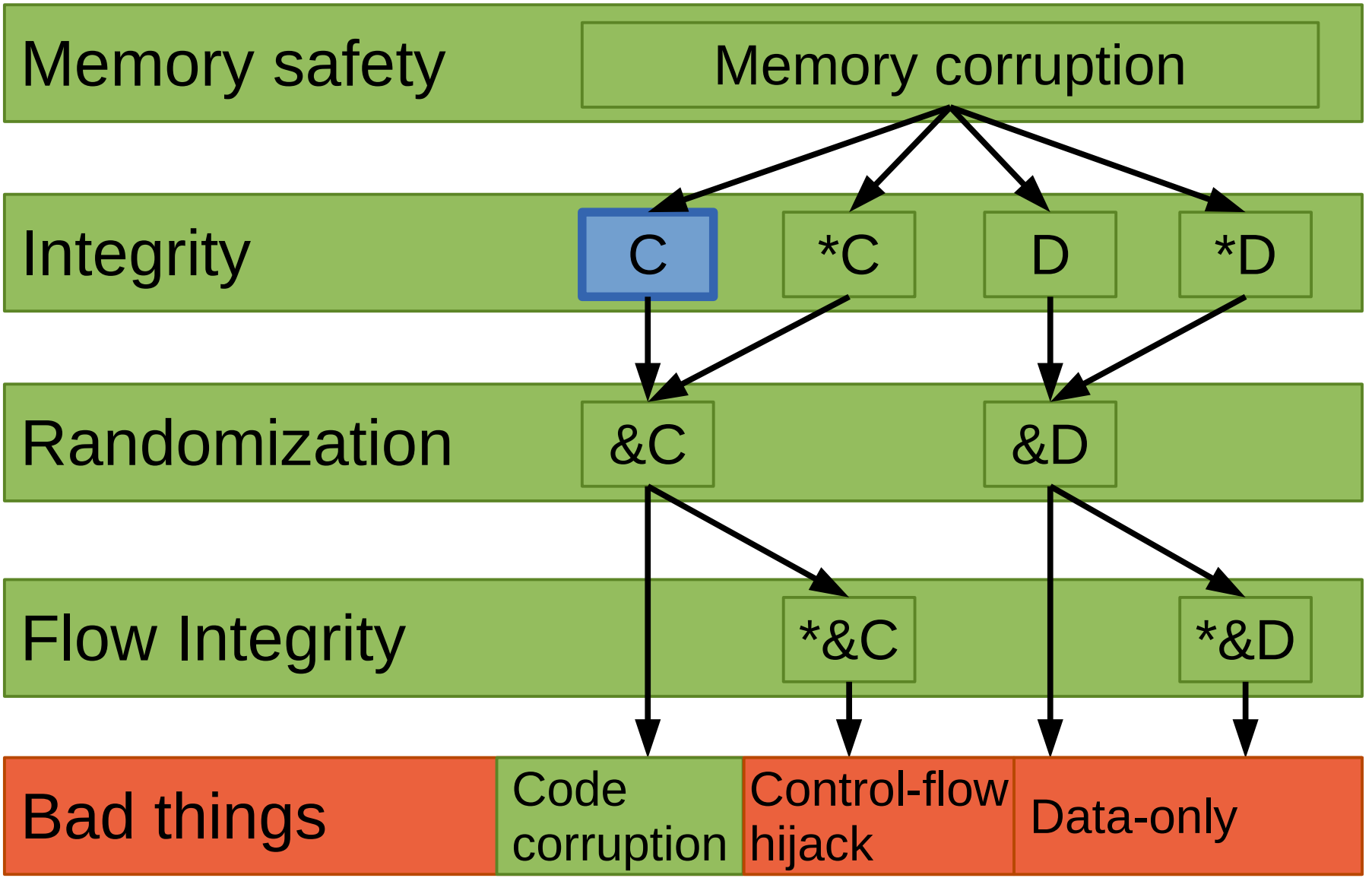


Deployed defenses

Data Execution Prevention

- Enforces code integrity on page granularity
  - Execute code if eXecutable bit set
- W^X ensures write access or executable
  - Mitigates against code corruption attacks
  - Low overhead, hardware enforced, widely deployed
- Weaknesses and limitations
  - No-self modifying code supported

Data Execution Prevention

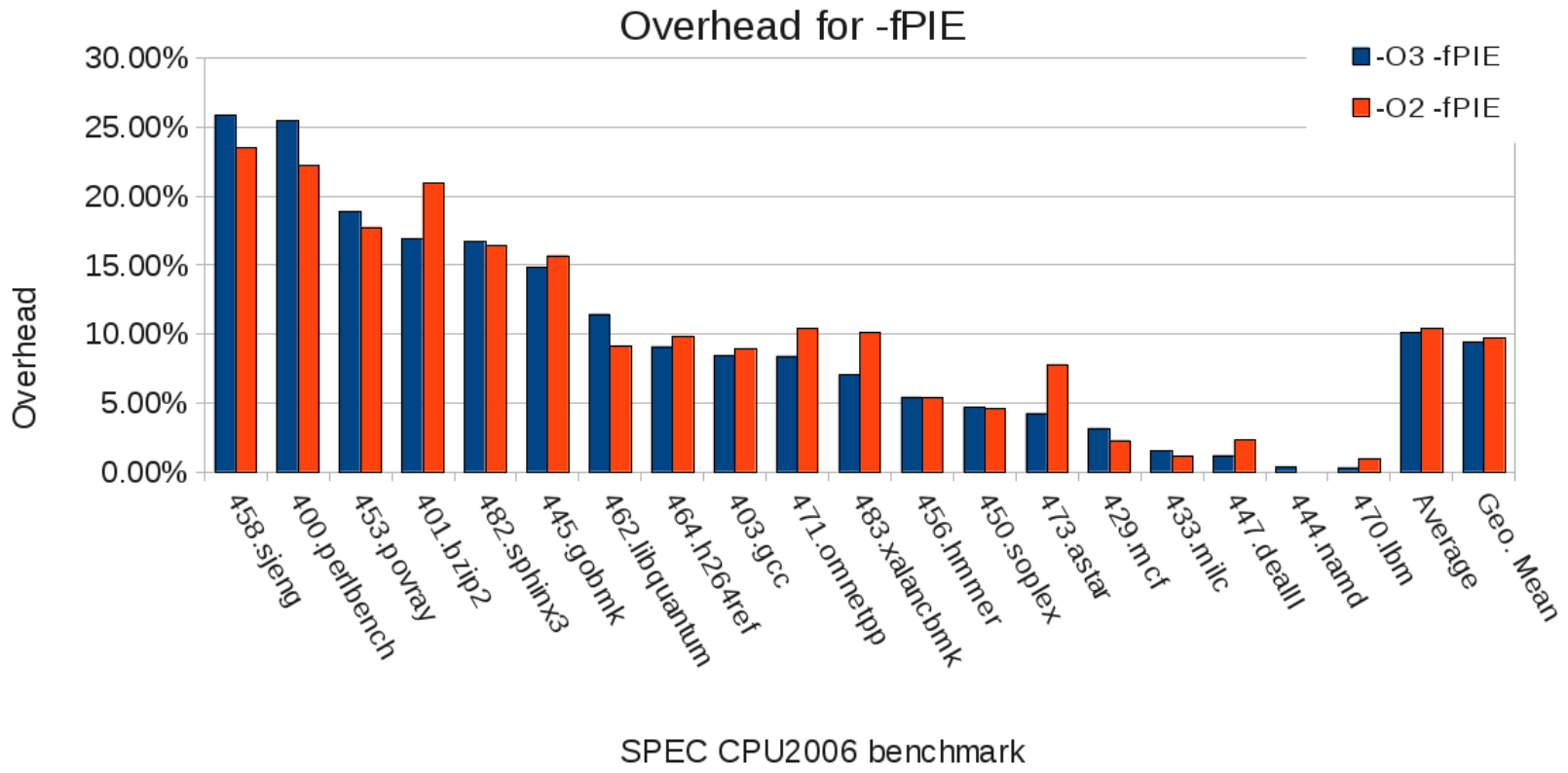


Address Space Layout Randomization

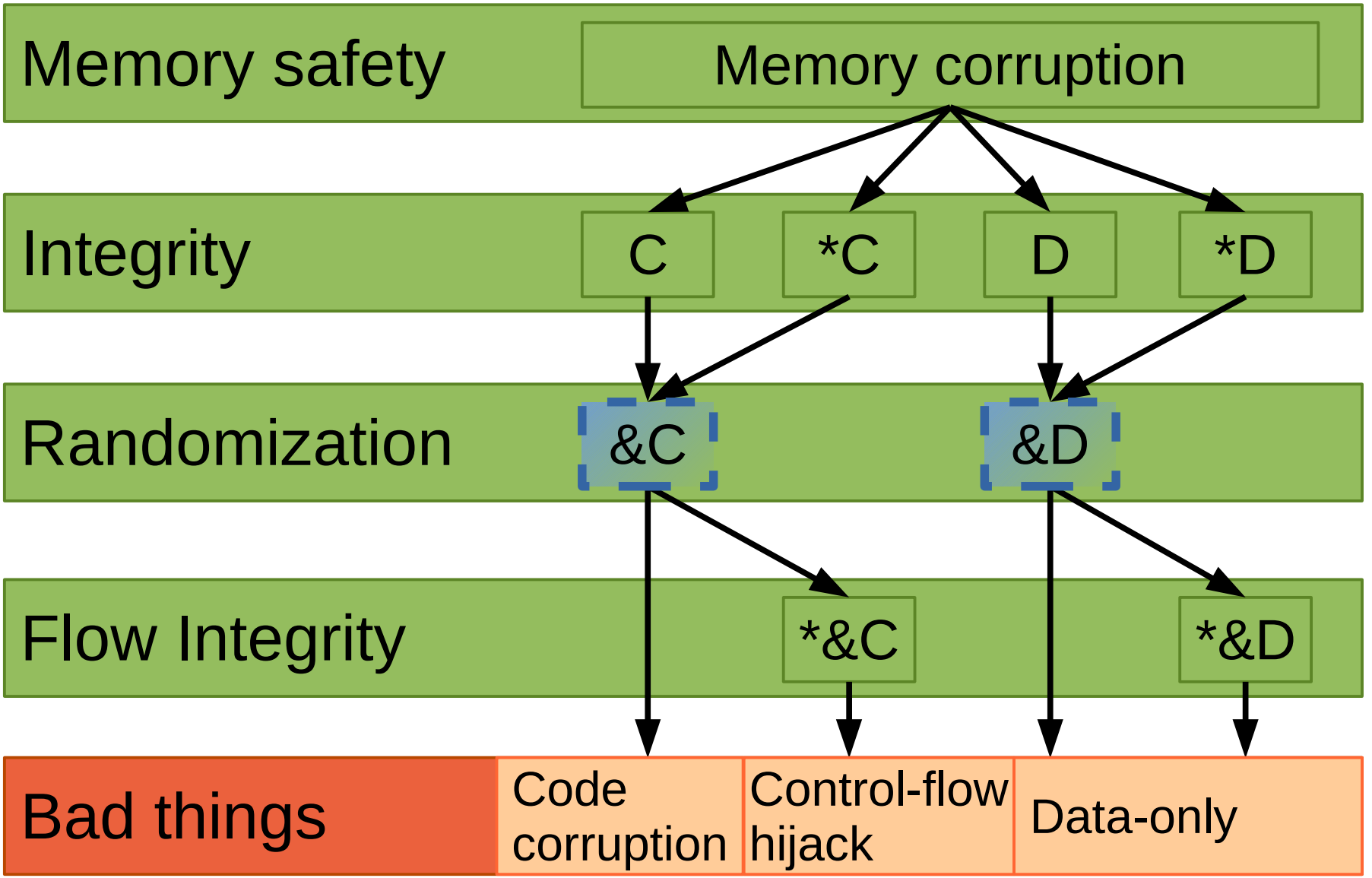
- Randomizes locations of code and data regions
  - Probabilistic defense
  - Depends on loader and OS
- Weaknesses and limitations
  - Prone to information leaks
  - Some regions remain static (on x86)
  - Performance impact (~10%)

ASLR: Performance overhead

- ASLR uses one register for PIC / ASLR code
  - Performance degradation on x86



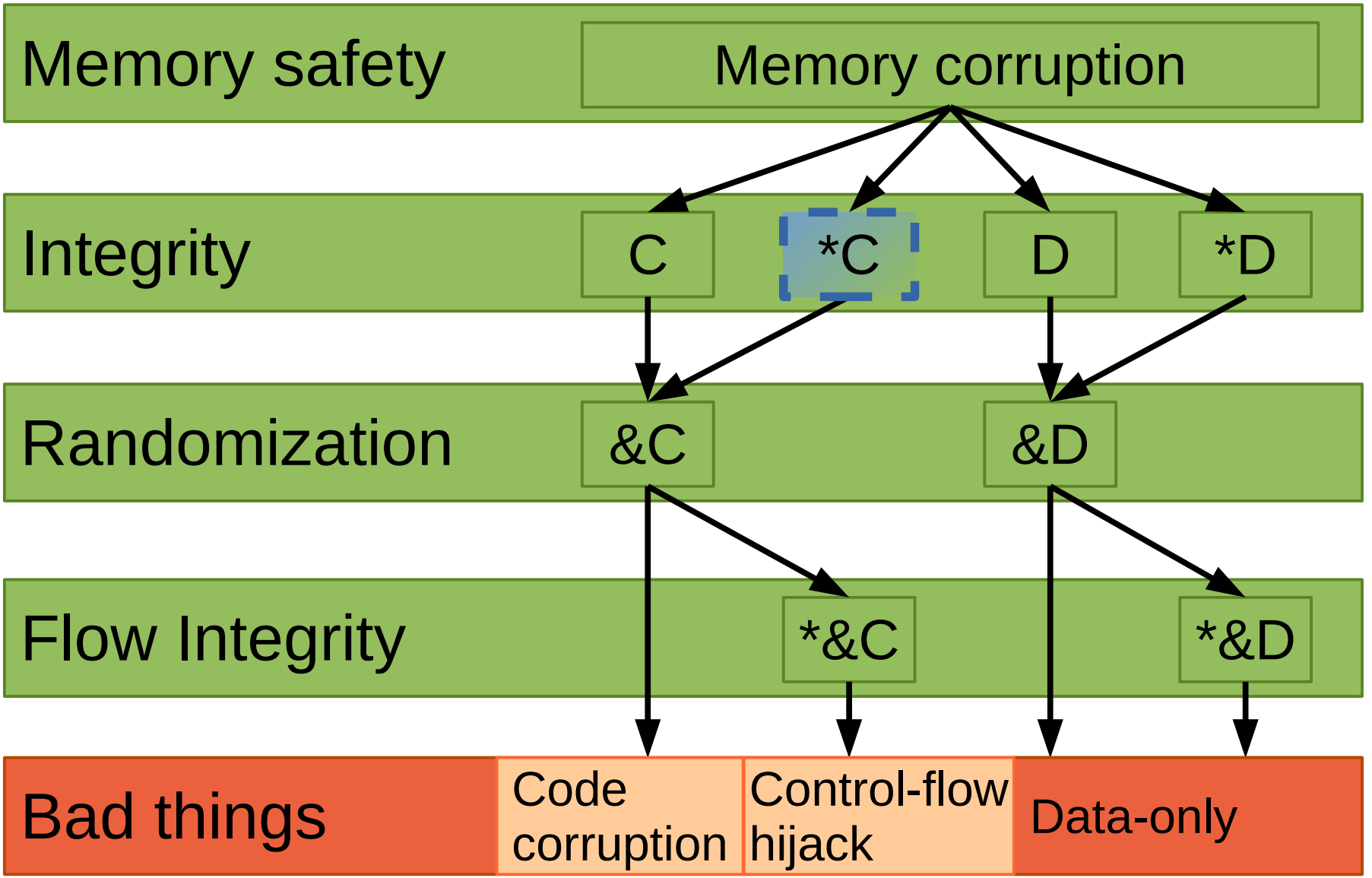
Address Space Layout Randomization



Stack canaries

- Protect return instruction pointer on stack
  - Compiler modifies stack layout
  - Probabilistic protection
- Weaknesses and limitations
  - Prone to information leaks
  - No protection against targeted writes / reads

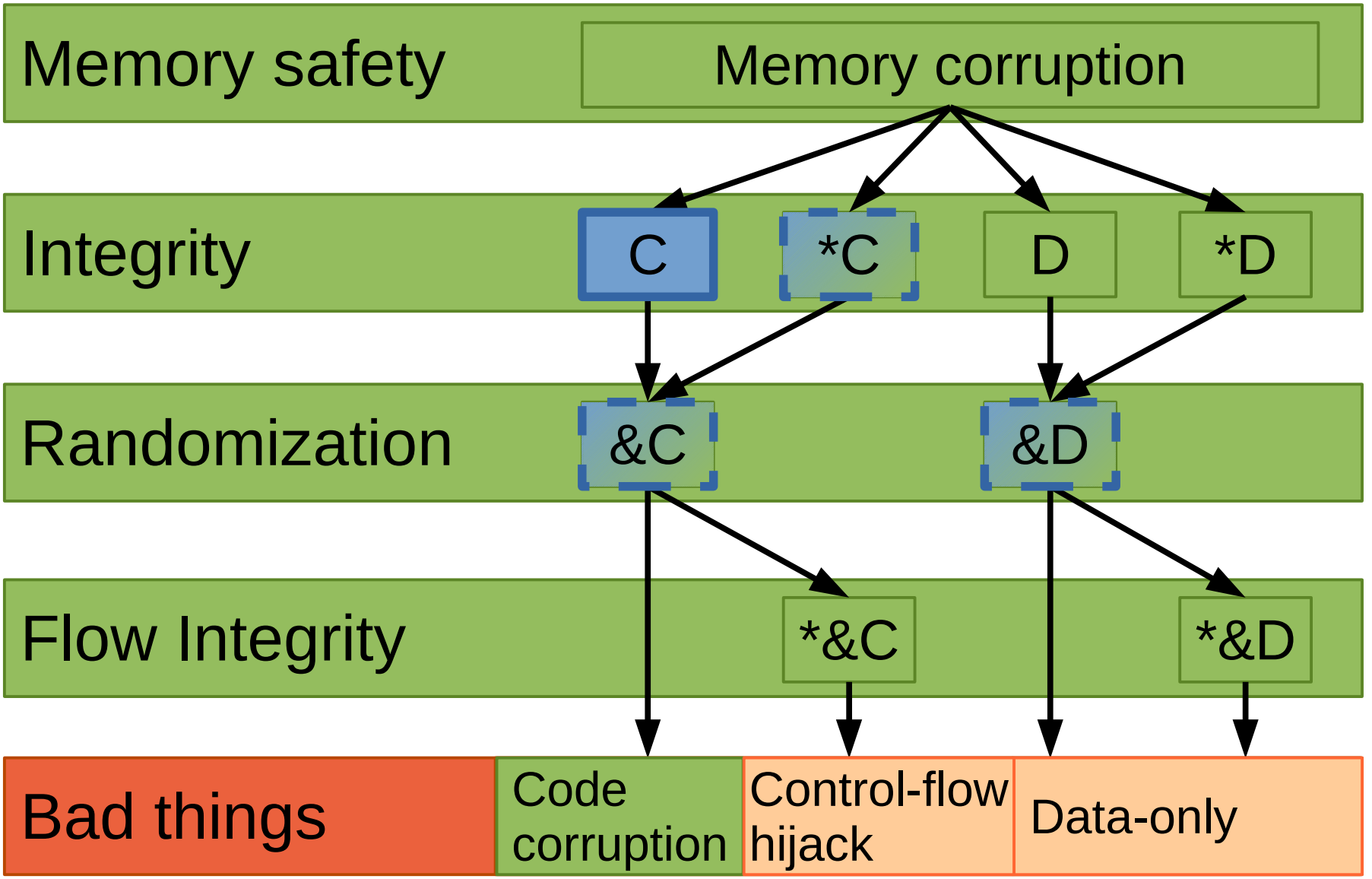
Stack canaries



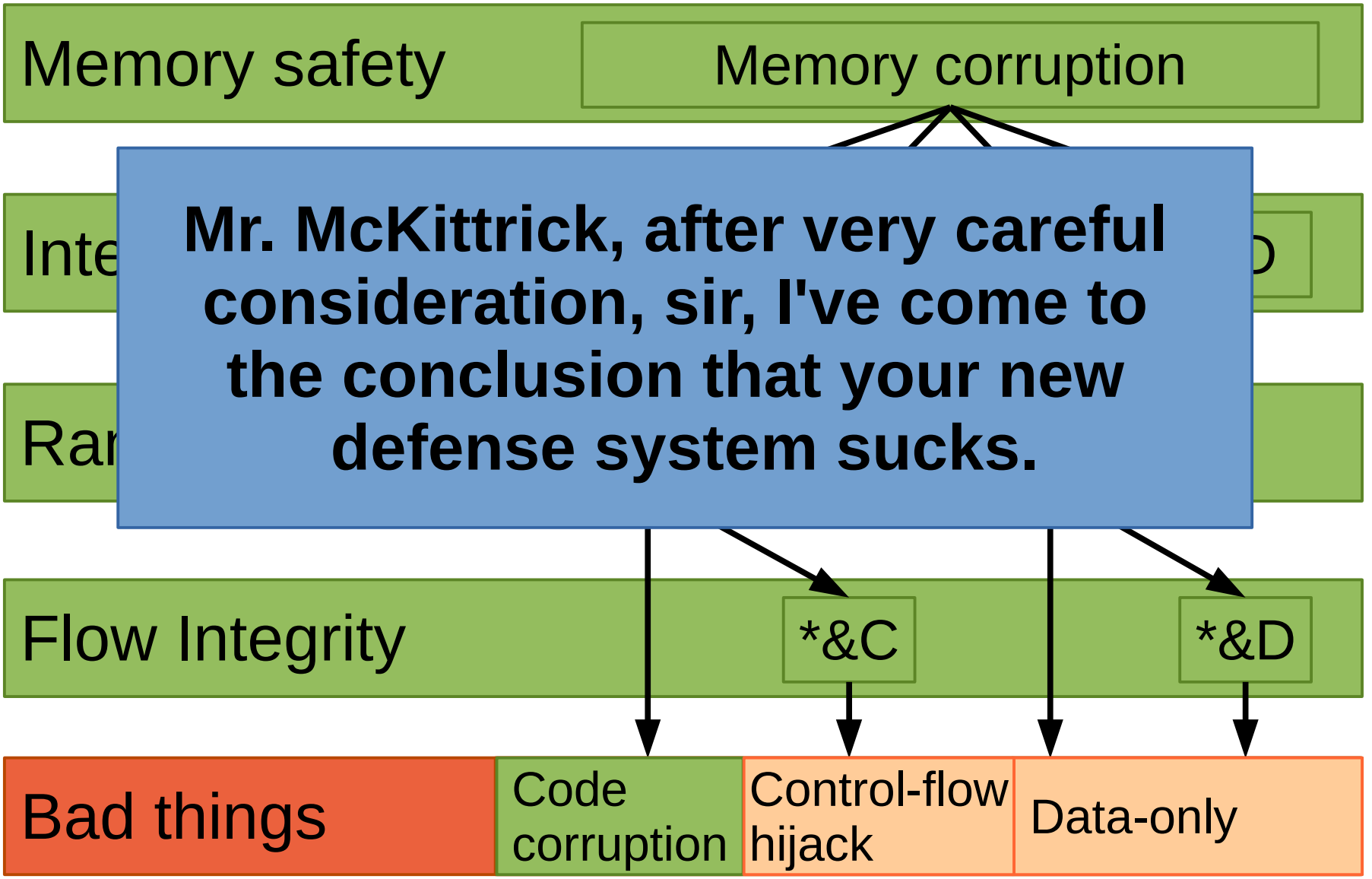
Widely deployed defenses

- Memory safety: none
- Integrity: partial
  - Code integrity: W^X
  - Code pointer integrity: canaries and safe exceptions
  - Data integrity: none
- Randomization: partial
  - Address Space Layout Randomization
- Control/Data-flow integrity: none

Widely deployed defenses

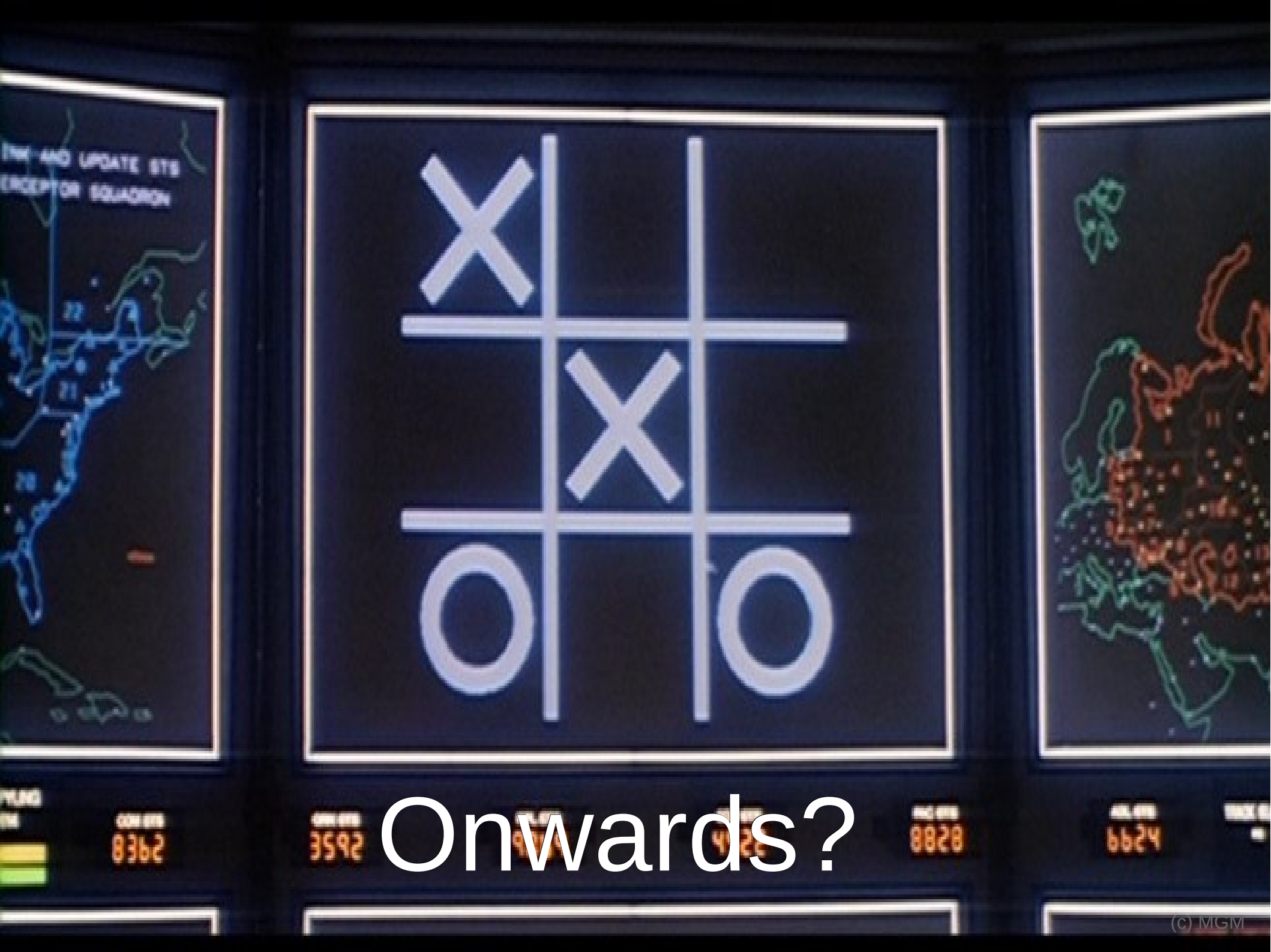


Widely deployed defenses



Why did stronger defenses fail?

- Too much overhead
  - More than 10% is not feasible
- Compatibility to legacy and source code
  - Shared library support, no code modifications
- Effectiveness against attacks
  - Protection against complete classes of attacks


Onwards?
(c) MGM

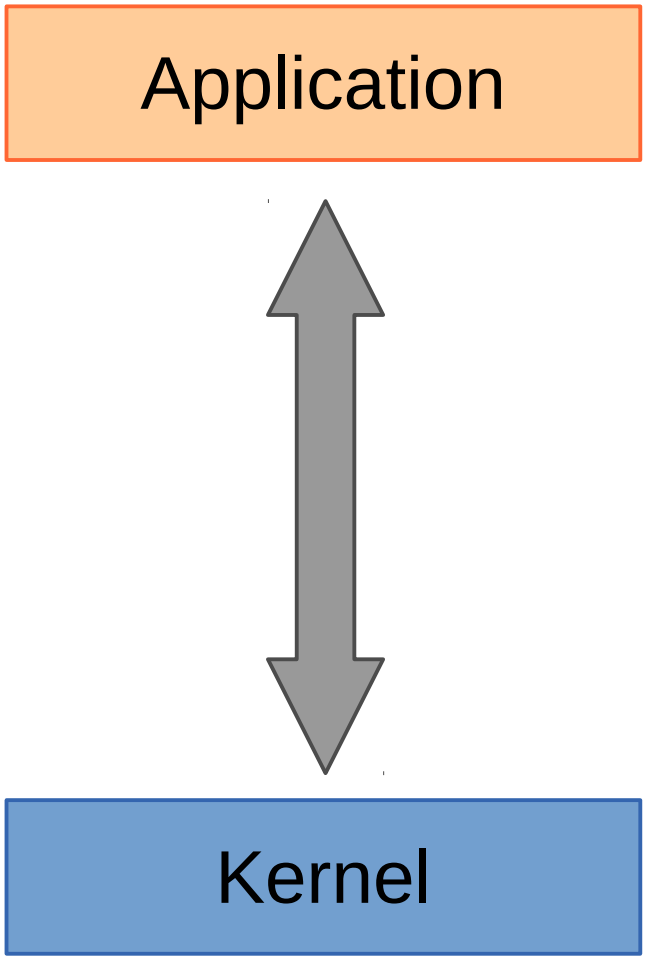
Partial? Data Integrity

- Memory safety stops control-flow hijack attacks
  - … but memory safety has high overhead
  - SoftBounds+CETS reports up to 250% overhead
- Enforce memory safety for “some” pointers
  - Compiler analysis can help
  - Tricky engineering to make it work

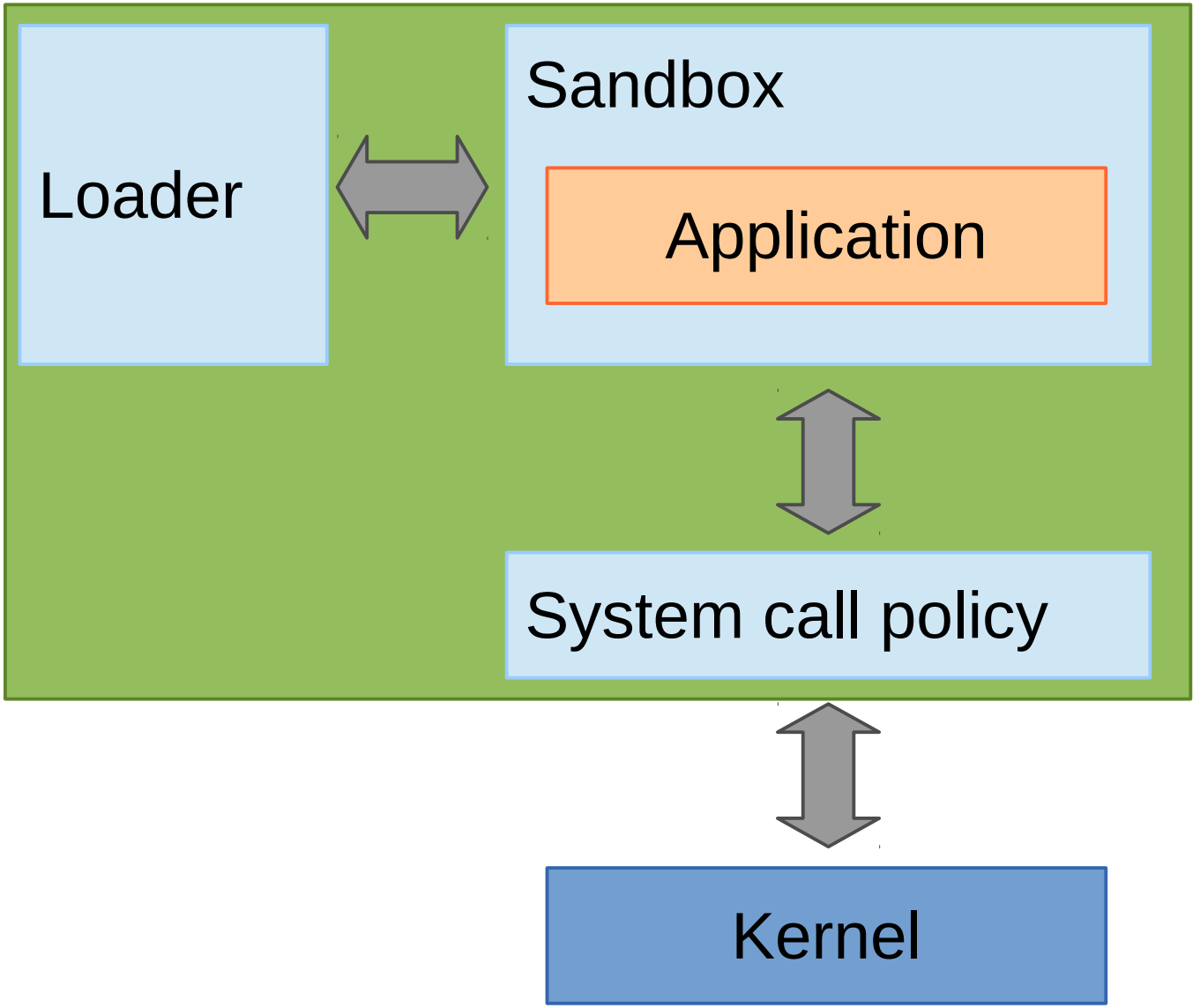
Secure execution platform

- Must support legacy, binary code
- Dynamic binary translation allows virtualization
- Leverage runtime information
  - Enables preciser security checks

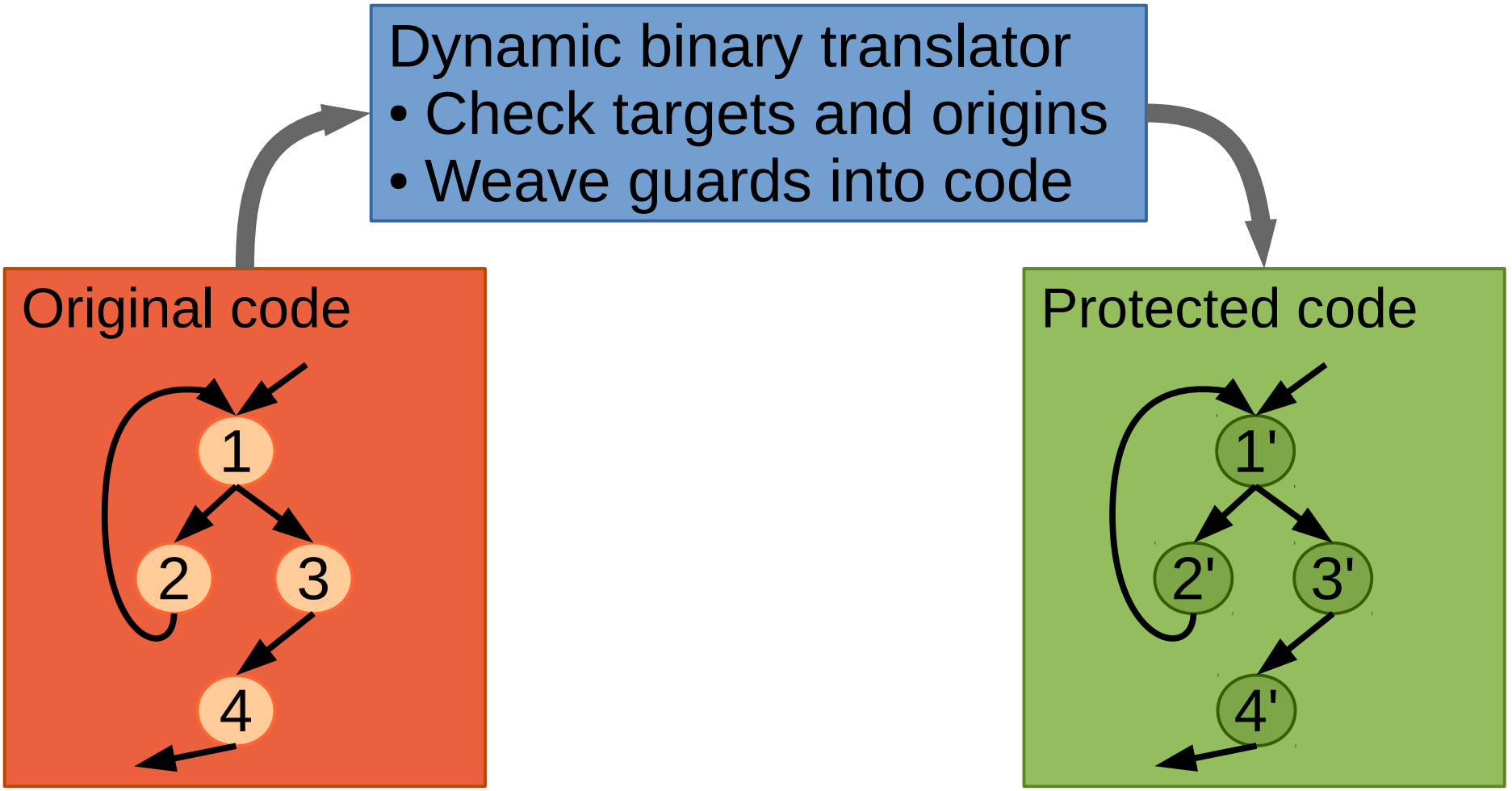
Secure execution platform

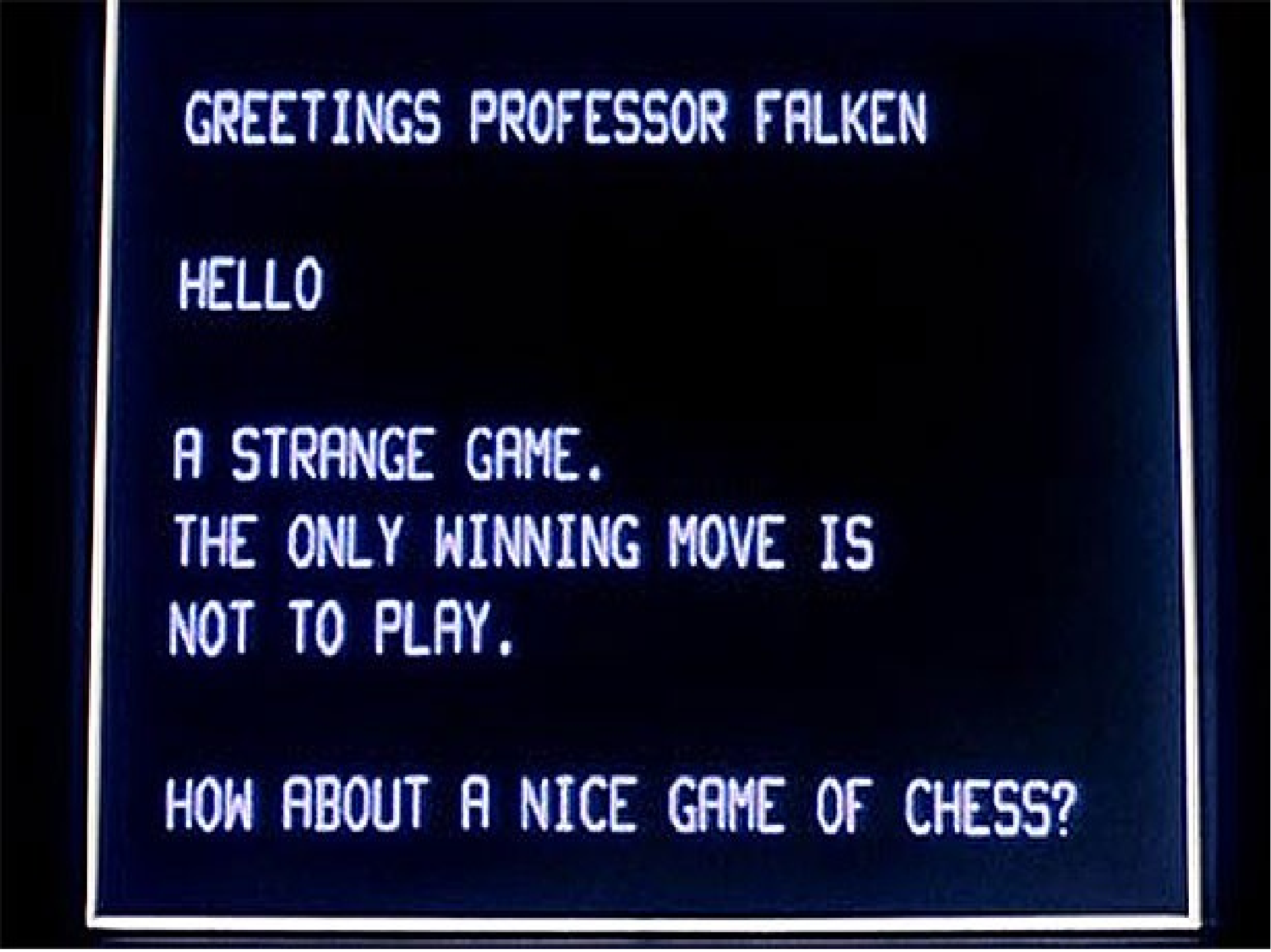


Secure execution platform



Sandbox implementation




GREETINGS PROFESSOR FALKEN
HELLO
A STRANGE GAME.
THE ONLY WINNING MOVE IS
NOT TO PLAY.
HOW ABOUT A NICE GAME OF CHESS?

Conclusion

- Low level languages are here to stay
  - We need protection against memory vulnerabilities
  - Performance, legacy, compatibility
- Mitigate control-flow hijack attacks
  - Secure execution platform for legacy code
- Future directions: strong policies for data

If the winning move is not to play then we need to change the rules of the game!

http://nebelwelt.net