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Computer Security DD2395

System Security

Arithmetic Overflow

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- It may wrap to become a very small, or negative number
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- Can lead to buffer overflows, if the integer is used to computer memory offsets, array indexes etc.
- Can lead to violation of security policies
  - X = number of pointers (references) to the data structure D
  - Reuse the memory of D only when X is 0
  - Can we have a new pointer to D if X is 4294967295 = 2^32-1?

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- Can lead to violation of security policy
- Can lead to failures
- Can lead to data corruption
    - my balance = -2147483648 SEK ~ -2 billion SEK
    - ask to borrow 1 SEK
    - my balance = +2147483647 SEK~ +2 billion SEK

Arithmetic Overflow/countermeasures

- Static analysis (e.g. symbolic execution)
- Use of special values (e.g. NaN in Java)
- Exceptions (e.g. Math.addExact(x,y) and ArithmeticException in Java)
- Numbers with arbitrary precision (e.g. Python)

Buffer Overflow - effects

- [S] Access to **S**ecret data
- [D] Corruption of program **D**ata
- [C] Unexpected transfer of **C**ontrol
- [V] Memory access **V**iolation
- [X] E**X**ecution of code chosen by attacker

S	D	C	V	X

Stack Buffer Overflow

- occurs when buffer is located on stack
  - used by Morris Worm
- local variables below saved **frame pointer** and **return address**
- overflow of a local buffer can potentially overwrite these key control elements

Example Shellcode

```
void hello(char * msg) {
  char buffer[128];
  printf("&msg adr %p\n", &msg);
  printf("msg adr %p\n", msg);
  printf("buffer adr %p\n", buffer);
  printf("enter the message for %s: \n", msg);
  printf("adr %p\n", *((void **)(buffer + 128)));
  printf("adr %p\n", *((void **)(buffer + 136)));

  gets(buffer);

  printf("message for %s is %s\n", msg, buffer);
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  return;
}

int main(int argc, char** argv) {
  char mainTag[16] = "Roberto";
  printf("main adr %p\n", &main);
  printf("hello adr %p\n", &hello);
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  hello(mainTag);
}
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```
main adr 0x4006a2
hello adr 0x400586
mainTag adr 0x7fffffffdd00

&msg adr 0x7fffffffdc58
msg adr 0x7fffffffdd00
buffer adr 0x7fffffffdc60

enter the message for Roberto:

adr 0x7fffffffdd10
adr 0x400711
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sys.stdout.write(x)
sys.stdout.write("1"*(128 - len(x)))

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sys.stdout.write("\n")
while True:
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Global Data Overflow

- can attack buffer located in global data
  - may be located above program code
- no return address
  - hence no easy transfer of control
- can target function pointers (e.g. C++ virtual tables)
- or manipulate critical data structures

Heap Overflow

- attack buffer located in heap
  - typically located above program code
  - memory requested by programs to use in dynamic data structures (e.g. linked lists, malloc)
- also possible due to dangling pointers
- no return address
- can target function pointers (e.g. C++ virtual tables)
- or manipulate critical data structures

Buffer overflow defenses

- buffer overflows are widely exploited
  - large amount of vulnerable code in use
  - despite cause and countermeasures known
- two defense approaches
  - compile-time - harden new programs
  - run-time - handle attacks on existing programs

Compile time Defenses: Language

- use a modern high-level languages with strong typing
  - you can not access to untyped memory
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S	D	C	V	X

Compile time Defenses: safe coding

- if using potentially unsafe languages e.g. C
- programmer must explicitly write safe code
  - e.g. justify why a buffer can receive n bytes
- code review
- check pointers yield by allocators
  - e.g. when allocation fails
- check to have sufficient space in all buffers

S	D	C	V	X

Compile time Defenses:
Language Extension, Safe Libraries

- proposals for safety extensions to C
  - performance penalties
  - must compile programs with special compilers
- use safer standard library variants
  - new functions, e.g. strncpy()
  - safer re-implementation of standard functions as a library, e.g. Libsafe

S	D	C	V	X

Verification

- Code verification
  - Using mathematical model
  - Proving absence of bugs
- Expensive: ~2000$ per line of code
- Verified execution platforms
  - isolation kernels
  - software fault isolation

S	D	C	V	X

Run-time Defenses: Guard Pages

- place guard memory pages
  - configured in MMU as illegal addresses
  - any access aborts process
  - can be placed between
    - stack frames and heap buffers
    - between critical regions of memory

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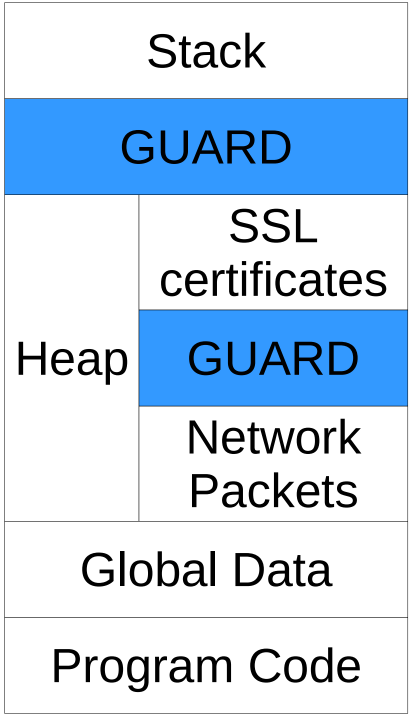

S D C V X

Control Flow Integrity

- Prevent or detect alteration of the control flow due to

    ?

Control Flow Integrity

- Prevent or detect alteration of the control flow due to
  - Modification of return pointer
  - Modification of a function pointer
- Suggestions?

Compile time Defenses: Stack protection

- add entry and exit code to check stack for signs of corruption
- use random (different for every execution) canary
  - e.g. Stackguard, Win /GS

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- Canaries were used in coal mines

  to detect the presence of

  carbon monoxide

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    - issues: recompilation, debugger support

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ReturnPtr
FramePtr
Var 1
Var 2
Par 1

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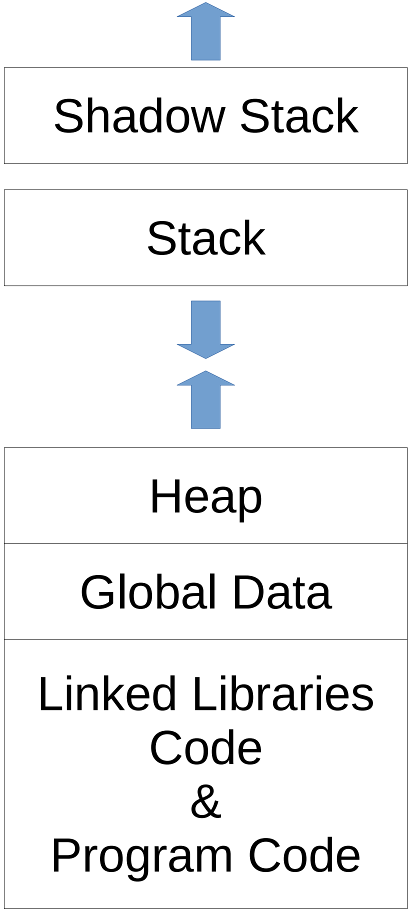
S D C V X

Compile time Defenses: Stack protection

- save/check safe copy of return address
- shadow stack
  - e.g. Stackshield, RAD
  - -fstack-protector

S	D	C	V	X



Target address encryption

- Indirect jumps (e.g. jumps to non-constants) are necessary to implement
  - Function return
  - Callbacks, Virtual methods, Exception handling

```
int (*func1)(int) = double;    => int (*func1)(int) = double ^ key;
…                                 …
func1(15)                         int (*local_var)(int) = func1 ^ key;
                                  local_var(15);
```

Code integrity

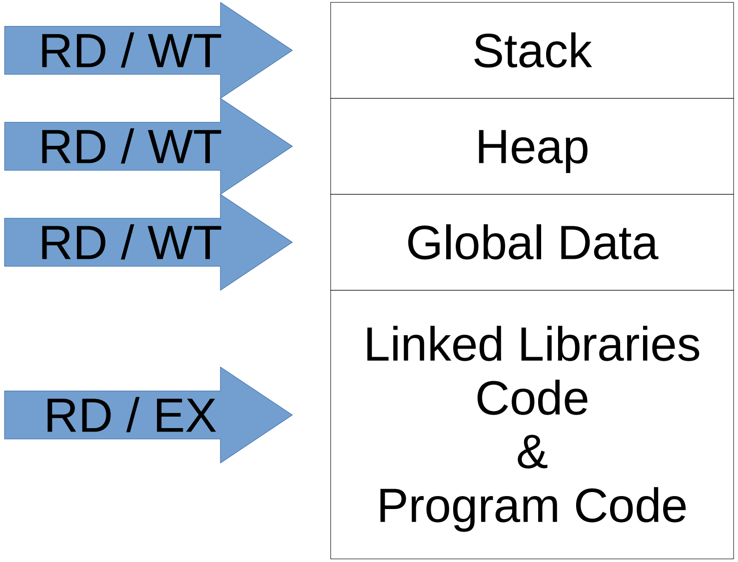
- Prevention, detection, mitigation of code injection
  - Due to a buffer controlled by the attacker (e.g. where a network packet is stored) being executed
  - Due to existing code being overwritten
- Suggestions?

Run-time Defenses: Executable Address Space Protection

- use virtual memory support to make some regions of memory non-executable
  - e.g. stack, heap, global data
  - need HW support in MMU
- long existed on SPARC / Solaris systems
- recent on x86/ARM Linux/Unix/Windows systems

S	D	C	V	X

Run-time Defenses:
Executable Address Space Protection



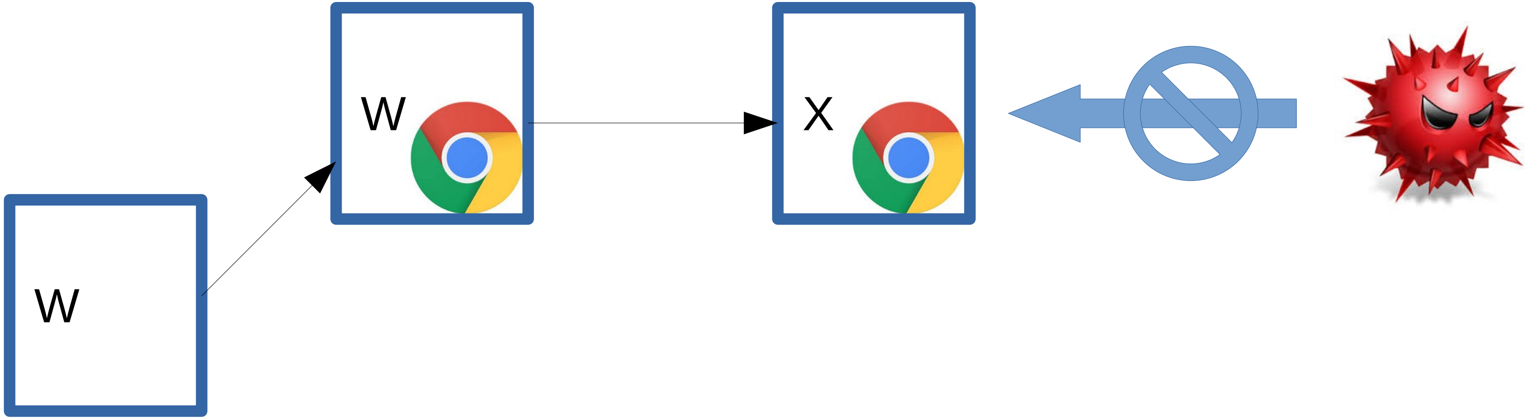
S D C V X

Run-time Defenses: Executable Address Space Protection

- issues: support for executable stack/heap code
  - needed for JIT (e.g. Java) or nested functions
  - need special provisions
    - mprotect(ptr, size, (PROT_READ | PROT_EXEC);
- -z execstack
- Attacker can
  - Inject payload
  - Corrupt control flow to invoke mprotect
  - Execute the payload

Run-time monitor

- Enforce Write XOR Execute policy
- Check signature whenever a page became executable (i.e. mprotect)



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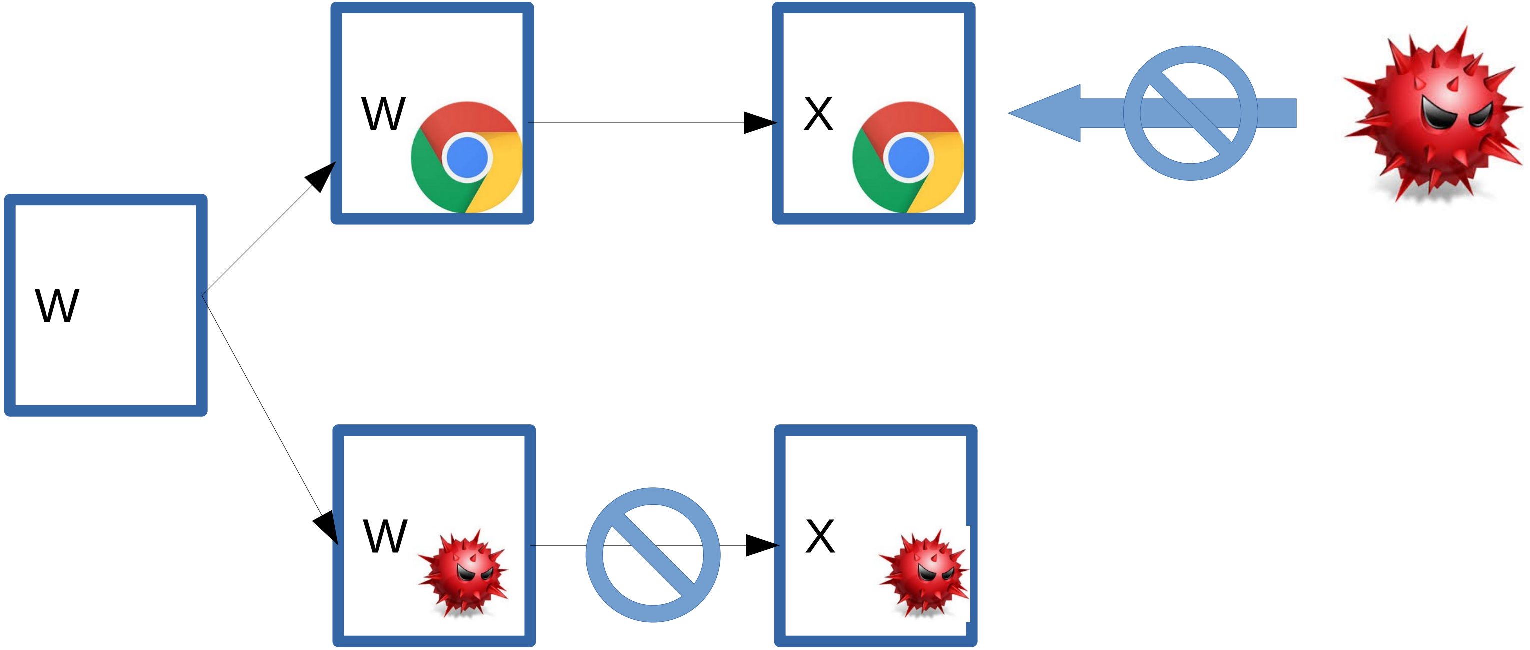

Run-time monitor

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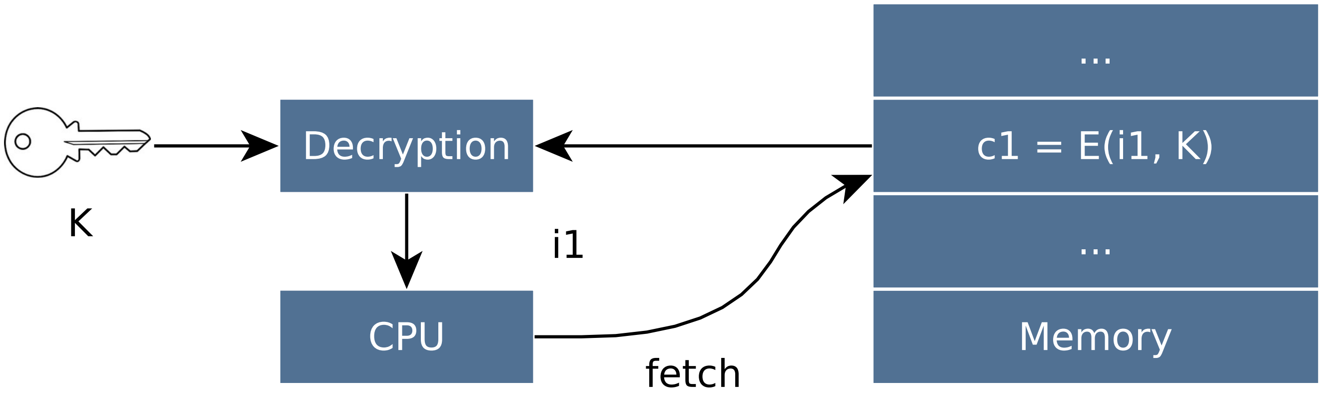
  - Keep database of valid signatures, check that SHA(page) in DB
  - Use program with certificate
    - Page = Program | Certificate
    - Certificate = Enc(SHA(Page), PR_k)
    - Check Dec(Certificate, PU_k) = SHA(Page)
  - Keep a database of binary fragments of well known malwares, check that Intersect(page, db) = empty

Instruction Set Randomization

- Make every Process's CPU unique
- If the attacker does not know the target ISA, it is impossible to produce injectable code

Instruction Set Randomization



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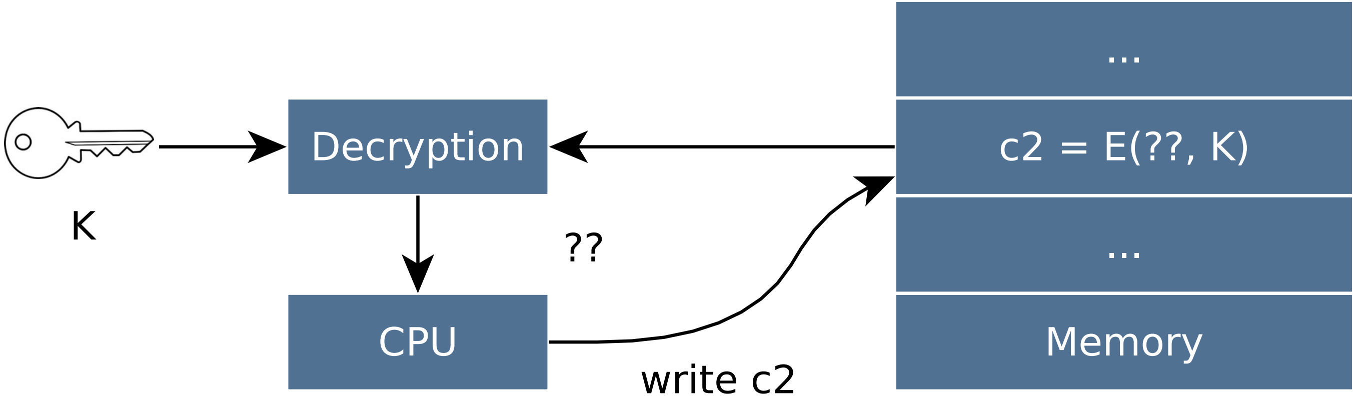


Decryption requirements

1) Cheap

    Symmetric block cyphers

2) Preserve instruction length

    No MAC

3) Support random accesses

    No Cypher Block Chaining

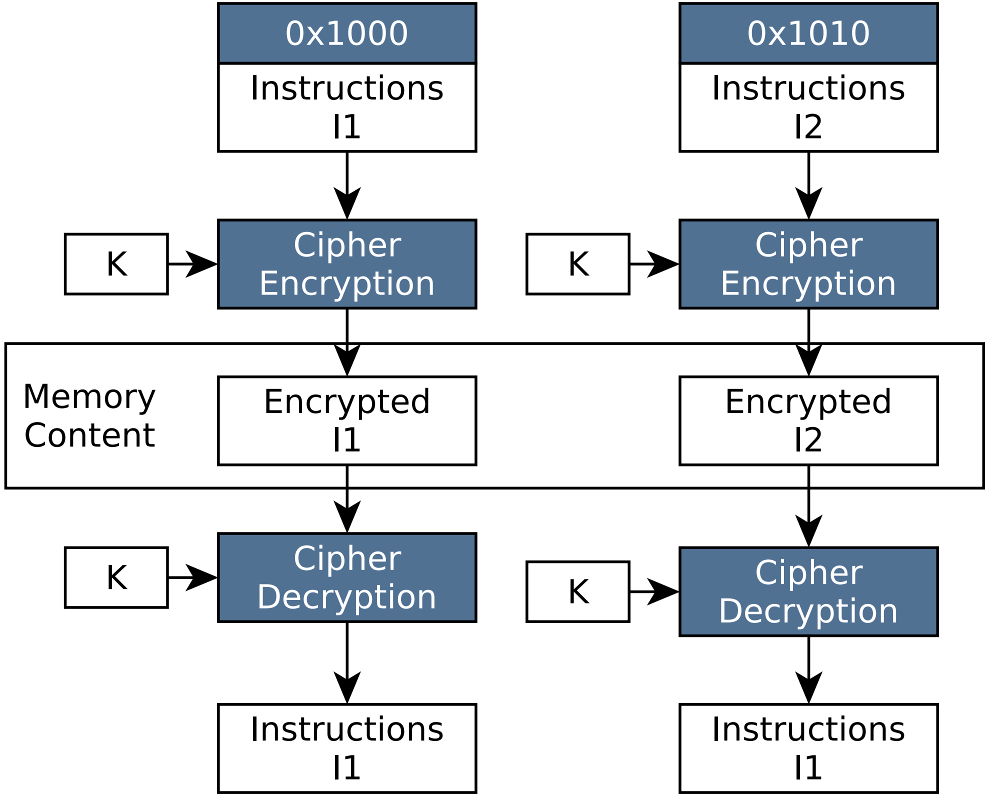
    No Cipher FeedBack

    No Output FeedBack

ISR-ECB - mode

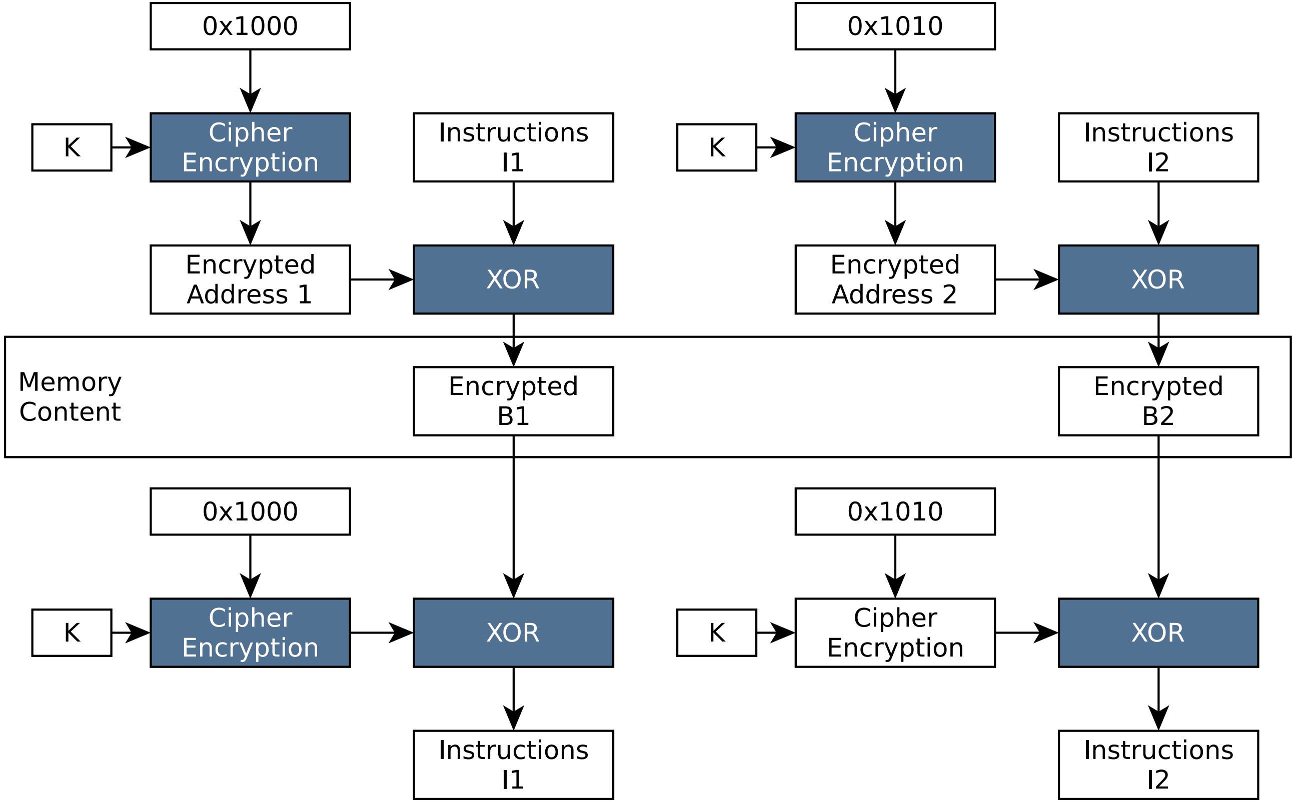
Common adopted approach

e.g. ASIST



ISR-CTR - mode

e.g. Polyglot



Diversification

- Counter attacks by making difficult for the attacker to predict the results of their activities

Run-time Defenses:
Address Space Randomization

- randomize location of key data structures
  - stack, heap, global data
  - using random shift for each process
- large virtual address range on modern systems means negligible impact
- also randomize location of standard library functions

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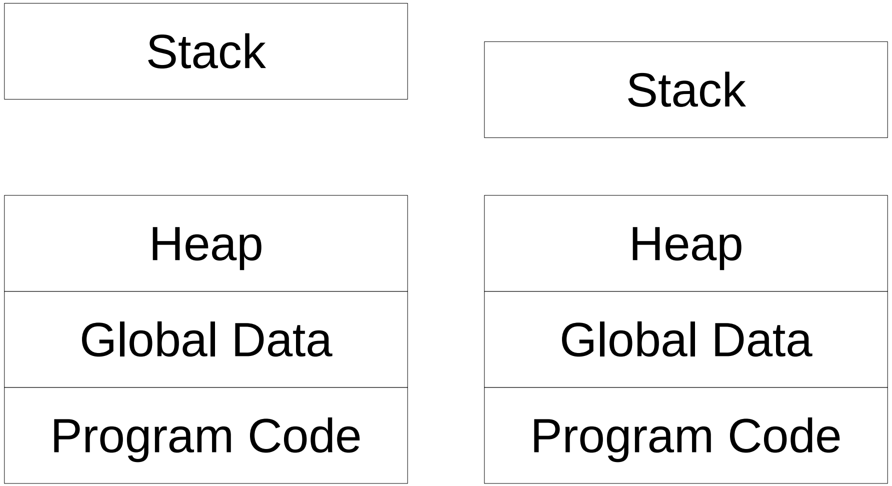
- also randomize location of standard library functions
- echo 0 | sudo tee /proc/sys/kernel/randomize_va_space

S	D	C	V	X

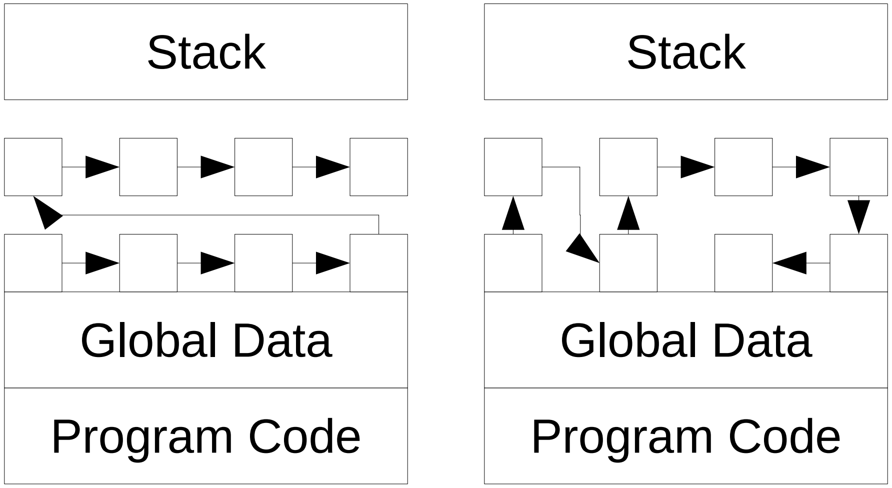
Run-time Defenses: Address Space Randomization

- Stack randomization
  - Base of the process stack is initialized by the OS and saved in a special register (Stack Pointer)
  - Different processes have different stack pointer
- Difficult for the attacker to cast a pointer to a buffer in the stack (e.g. to set the return address to a stack's buffer containing a payload)



Run-time Defenses: Address Space Randomization

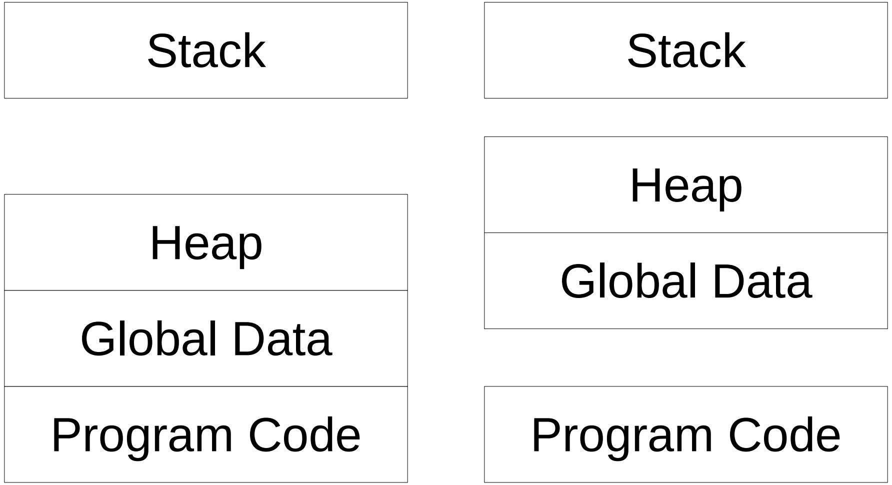
- Heap randomization
  - Dynamically allocated memory depends on OS and language runtime
    - ptr = malloc(1024);
  - OS randomizes order of allocation of virtual pages
- Difficult for the attacker to predict location of critical data-structures



Run-time Defenses: Address Space Randomization

- Global randomization
  - Programs must use indirection to access global variables

```
MOV R0, 1MB
LOAD R1, [R0]
---------------------
MOV R0, &Goffset
LOAD R1, [R0]
MOV R0, 1MB
LOAD R1, [R1+R0]
```

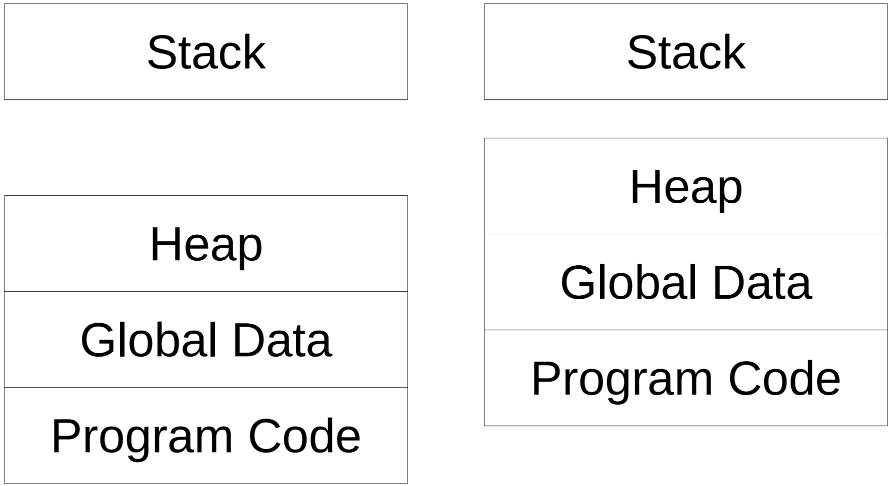


Run-time Defenses: Address Space Randomization

- Base program randomization
  - Programs must use location independent code

    1MB: JMP [1MB+2KB]

    1MB: JMP [PC + 2KB]
- Difficult for the attacker to identify addresses of useful functions and gadgets



Compile-time Defenses:
Use polymorphic technique of malware

- every instance of the application is different
  - different order of arguments

```
int memcpy(dst, src, size) {   => int memcpy(size, src, dst) {
    …
}
memcpy(dst, src, 1024);       => memcpy(1024, src, dst);
```

Run-time Defenses:
Use polymorphic technique of malware

- every instance of the application is different
  - different order of arguments
  - different number / order of local variables

int x = y + 20; => int z = 20;
=> int x = y + z

Run-time Defenses:
Use polymorphic technique of malware

- every instance of the application is different
  - different order of arguments
  - different number / order of local variables
  - different alignment of data-structures

```
struct Book {                    => struct Book {
    char[100] tilte;                     char * text;
    Author * author;                     char[42] dummy;
    char * text;                         char[110] title;
}                                        Author * author;
                                 }
```

Run-time Defenses:
Use polymorphic technique of malware

- every instance of the application is different
  - different order of arguments
  - different number / order of local variables
  - different alignment of data-structures
  - different number of instructions

```
X = Y + 20;                  => X = (2 * Y + 40) / 2
for (int i=0; i<100; i++) {  => for (int i=0; i<100; i+=2) {
    Code(i);                        Code(i);
}                                   if (i < 100) Code (i+1);
```

Run-time Defenses:
Use polymorphic technique of malware

- every instance of the application is different
  - different order of arguments
  - different number / order of local variables
  - different alignment of data-structures
  - different number of instructions
- a buffer overflow in one instance can not be used in another one
- difficult to predict position of functions and gadgets

S	D	C	V	X

Run-time Defenses: Use polymorphic technique of malware

- every instance of the application is different
- a buffer overflow in one instance can not be used in another one
- difficult to predict position of functions and gadgets
- Use of intermediate languages (e.g. LLVM)
  - C program is compiled to IR (e.g. using CLANG)
  -
  - IR is optimized
  - IR is compiled to machine language

Run-time Defenses:
Use polymorphic technique of malware

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- Use of intermediate languages (e.g. LLVM)
  - C program is compiled to IR (e.g. using CLANG)
  - IR is transformed to add randomization
  - IR is optimized
  - IR is compiled to machine language

System security

- Low level SW (e.g. operating system) can not be written with safe languages
- It is difficult to write bug free code
- Reduce as much as possible the critical code base
    - 1 line of code = 1 liability (1 or more bugs)
- Isolate critical components from failures of the non-critical ones

System security

- Smart thermostat
  - Control heating unit
  - Keep safe limits (e.g. 15 C min)
  - Programmable
  - Wi-Fi

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- Linux 2.6.37
  - ~10 million lines of code
  - 98 vulnerabilities

System securi

Integer signedness error in the CIFSFindNext function in fs/cifs/cifssmb.c in the Linux kernel before 3.1 allows remote CIFS servers to cause a denial of service (memory corruption) or possibly have unspecified other impact via a large length value in a response to a read request for a directory.

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  - Control heating u
  - Keep safe limits (e.g. 15 C min)
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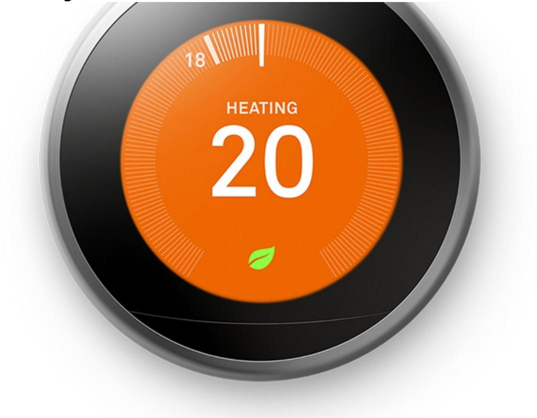
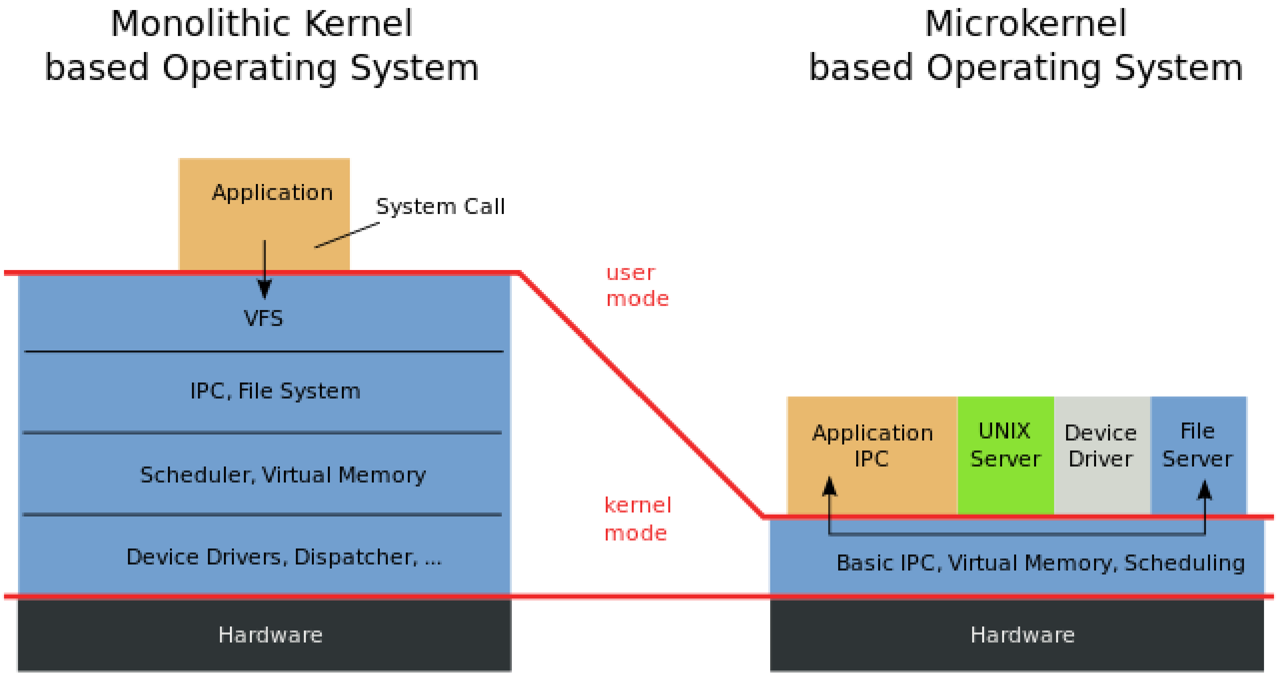


Microkernels

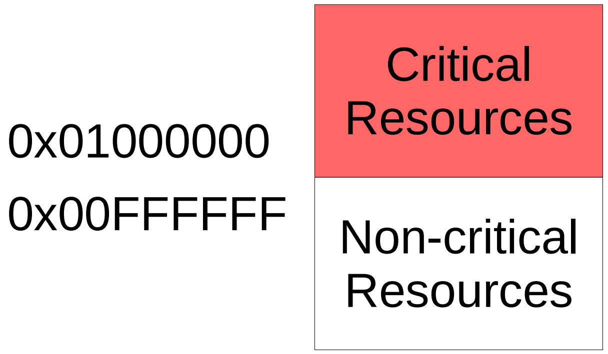
- L4 is the most famous
- “A concept is tolerated inside the microkernel only if moving it outside the kernel, i.e., permitting competing implementations, would prevent the implementation of the system's required functionality”
  - address spaces
  - threads
  - scheduling
  - inter-thread communication
- Everything else is outside the kernel (e.g. drivers)
- 15 thousands lines of code

Microkernels



Software Fault Isolation

- Sandbox non-critical code
- Google Chrome Native Client
- Modify binary to ensure that overflows can not access critical resources



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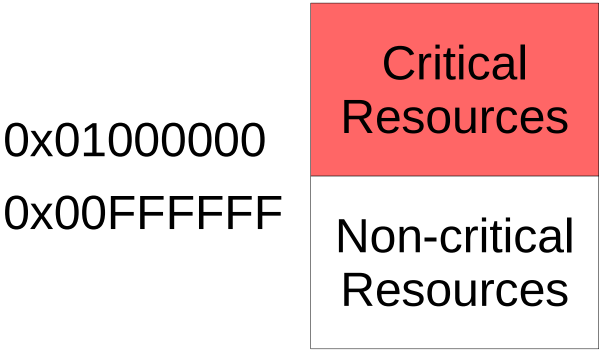
…
Store (X, Y)
...



Software Fault Isolation

- Sandbox non-critical code
- Google Chrome Native Client
- Modify binary to ensure that overflows can not access critical resources

```
…
Store (X, Y)
…
```

```
…
X = X & 0x00FFFFFF
Store (X, Y)
…
```

0x01000000	Critical Resources
0x00FFFFFF	Non-critical Resources

Software Fault Isolation

- Sandbox non-critical code
- Google Chrome Native Client
- Modify binary to ensure that overflows can not access critical resources

```
…
Store (X, Y)
X = X+1
Store(X+1,Y)
...
```

```
…
X = X & 0x00FFFFFF
Store (X, Y)
X = X+1
X = X & 0x00FFFFFF
Store (X, Y)
...
```

0x01000000

0x00FFFFFF

Critical Resources

Non-critical Resources

Software Fault Isolation

- Sandbox non-critical code
- Google Chrome Native Client
- Modify binary to ensure that overflows can not access critical resources

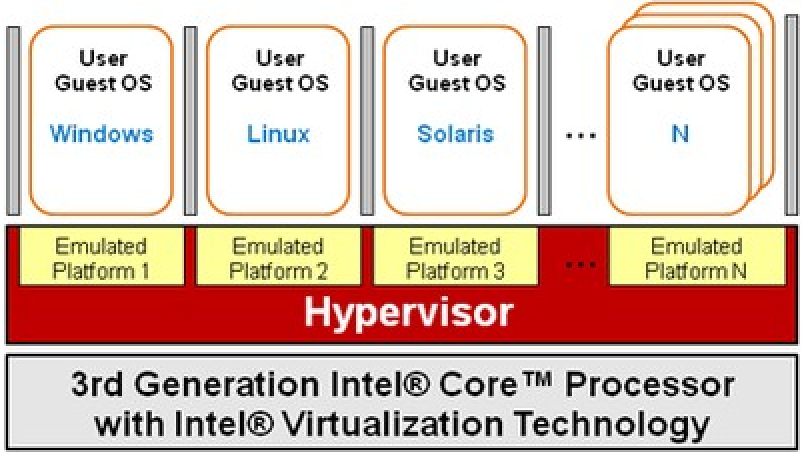
```
…
Store (X, Y)
X = X+1
Store(X+1,Y)
...
```

```
…
X = X & 0x00EFFFFF
Store (X, Y)
X = X+1
Store (X, Y)
...
```

0x01000000	Critical Resources
0x00FFFFFF	Non-critical Resources

Hypervisors

- Execute below OS
- Isolate complete OSes from each other
- Can inspect the behavior of a (possibly) buggy OS



Hypervisors

- Execute below OS
- Isolate complete OSes from each other
- Can inspect the behavior of a (possibly) buggy OS
  - Run-time monitor checking code signature
  - Behavioral monitoring
  - Resource usage analysis
  - Quarantine
  - Honeypots

Hypervisors

- Microsoft HyperV – XEN
- Paravirtualization
  - Hypervisor runs in unrestricted mode, takes control of
    - MMU (Page tables)
    - Interrupts
    - DMA configuration
  - OSes and processes run in restricted mode
  - Does not requires HW support
  - OS must be modified to invoke hypercalls to change HW configurations

Hypervisors

- Microsoft HyperV – XEN
- Paravirtualization
- Hardware assisted virtualization
  - Processes run in restricted mode
  - OSes run in unrestricted mode
  - Hypervisor runs in a new special mode
  - Two stages MMU
    - Stage 1: translates virtual addresses to intermediate one
    - Stage 2: translates intermediate addresses to physical one
  - Stage 1 configured by OS, Stage 2 configured by the hypervisor

THANKS!

Any questions?

You can find me at robertog@kth.se