Why is memory safety still a concern?

Mohamed (Tarek Ibn Ziad) Hassan
https://www.cs.columbia.edu/~mtarek/
@M_TarekIbnZiad

Ph.D. Candidacy Exam
April 9th, 2020.

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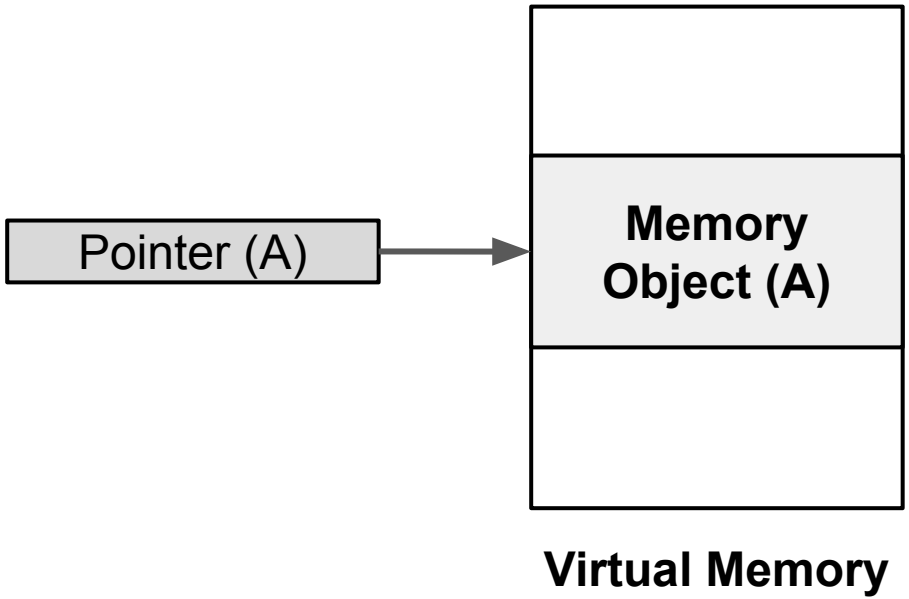
MEMORY SAFETY DEFINITION

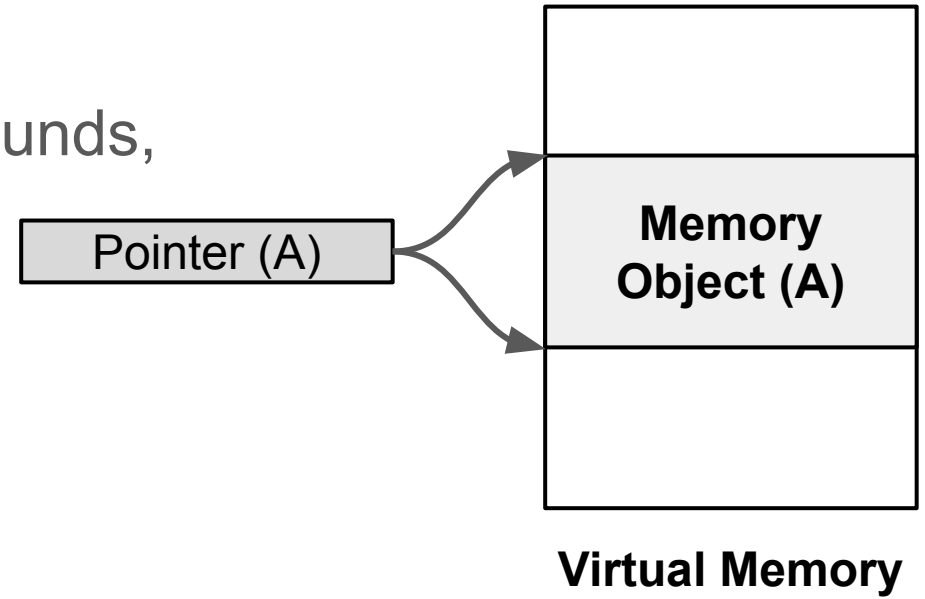
A program property that guarantees **memory objects** can only be accessed:



MEMORY SAFETY DEFINITION

A program property that guarantees **memory objects** can only be accessed:

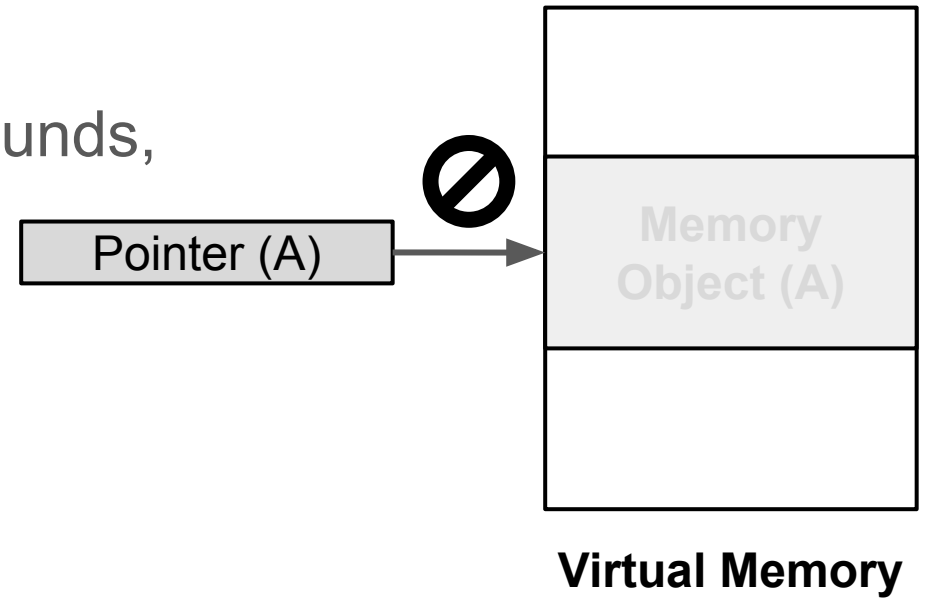
- Between their intended bounds,



MEMORY SAFETY DEFINITION

A program property that guarantees **memory objects** can only be accessed:

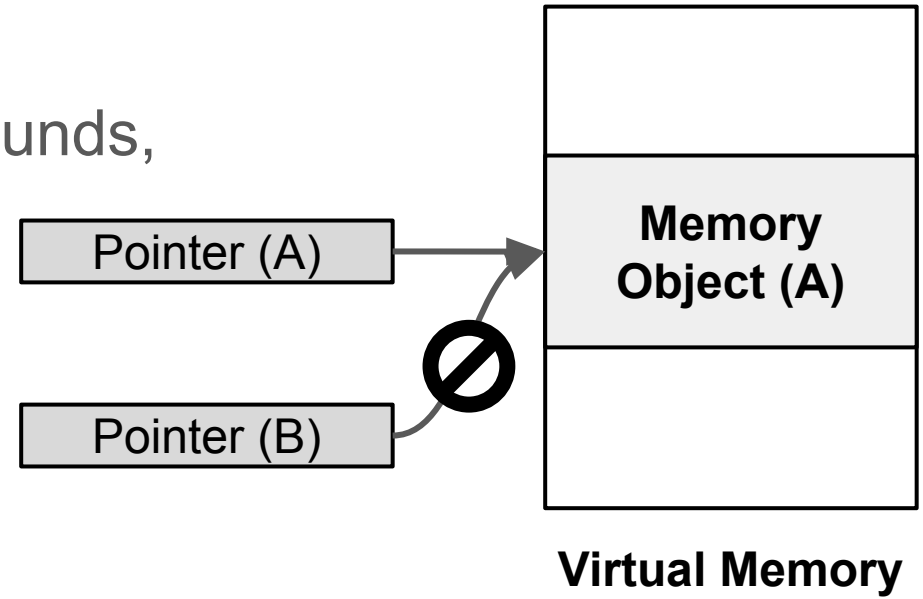
- Between their intended bounds,
- During their lifetime,



MEMORY SAFETY DEFINITION

A program property that guarantees **memory objects** can only be accessed:

- Between their intended bounds,
- During their lifetime, and
- Given their original (or compatible) type.



MEMORY SAFETY ~~DEFINITION~~ VIOLATIONS

A program property that guarantees **memory objects** can only be accessed:

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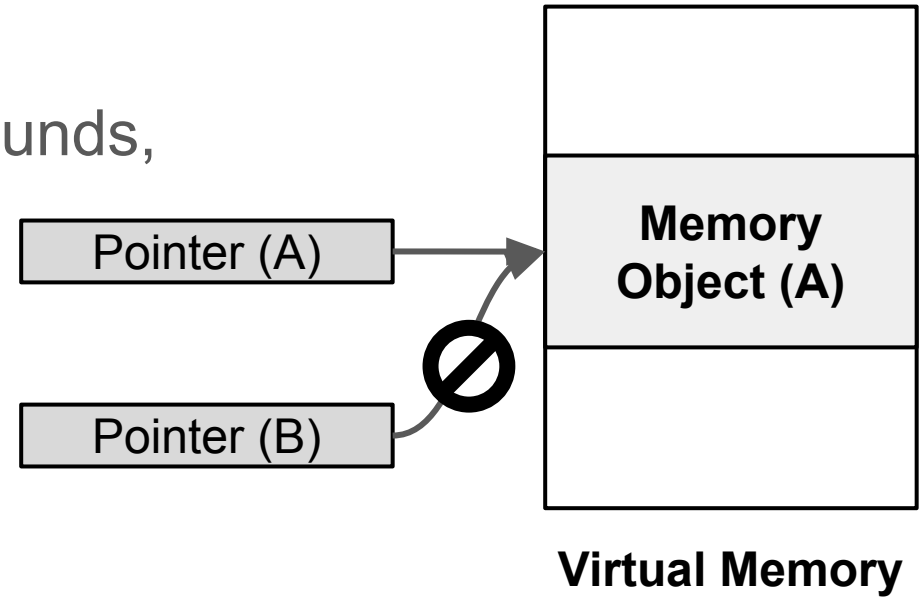


MEMORY SAFETY ~~DEFINITION~~ VIOLATIONS

A program property that guarantees **memory objects** can only be accessed:

- ~~Between their intended bounds~~, Buffer overflow
- During their lifetime, and
- Given their original (or compatible) type.

MEMORY SAFETY ~~DEFINITION~~ VIOLATIONS

A program property that guarantees **memory objects** can only be accessed:

- Between their intended bounds,
- ~~During their lifetime, and~~ Use-after-free
- Given their original
  (or compatible) type.

MEMORY SAFETY ~~DEFINITION~~ VIOLATIONS

A program property that guarantees **memory objects** can only be accessed:

- Between their intended bounds,
- During their lifetime, and
- ~~Given their original (or compatible) type.~~

Type confusion

MEMORY SAFETY IS A SERIOUS PROBLEM!

CABLE HAUNT —

Exploit that gives remote access affects ~200 million cable modems

Cable Haunt lets attackers take complete control when targets visit booby-trapped sites.

DAN GOODIN - 1/13/2020, 5:00 PM

Computing Sep 6

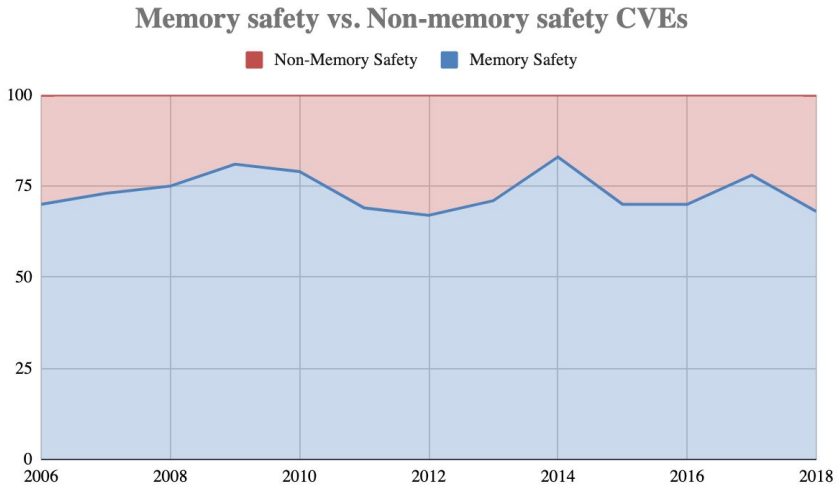
Apple says China's Uighur Muslims were targeted in the recent iPhone hacking campaign

The tech giant gave a rare statement that bristled at Google's analysis of the novel hacking operation.

EDITOR'S PICK | 42,742 views | Nov 21, 2018, 07:00am

Exclusive: Saudi Dissidents Hit With Stealth iPhone Spyware Before Khashoggi's Murder

PREVALENCE OF MEMORY SAFETY VULNS



Microsoft Product CVEs

Source: Matt Miller, Microsoft Security Response Center (MSRC) **[BlueHat 2019]**

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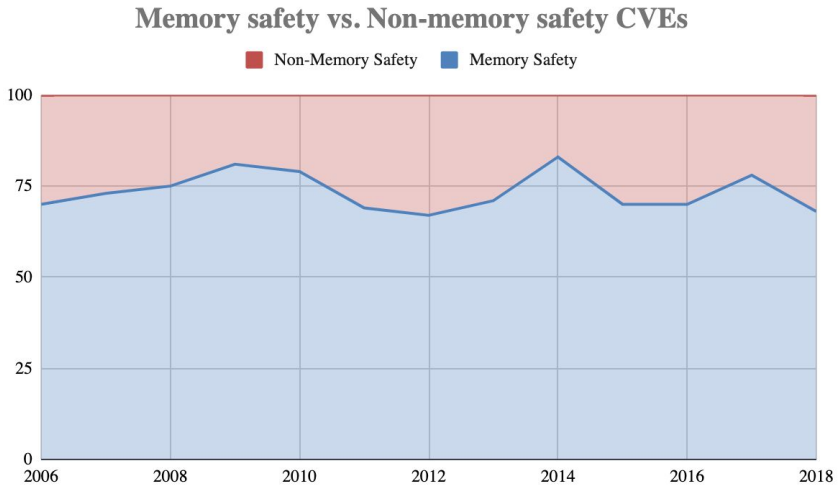

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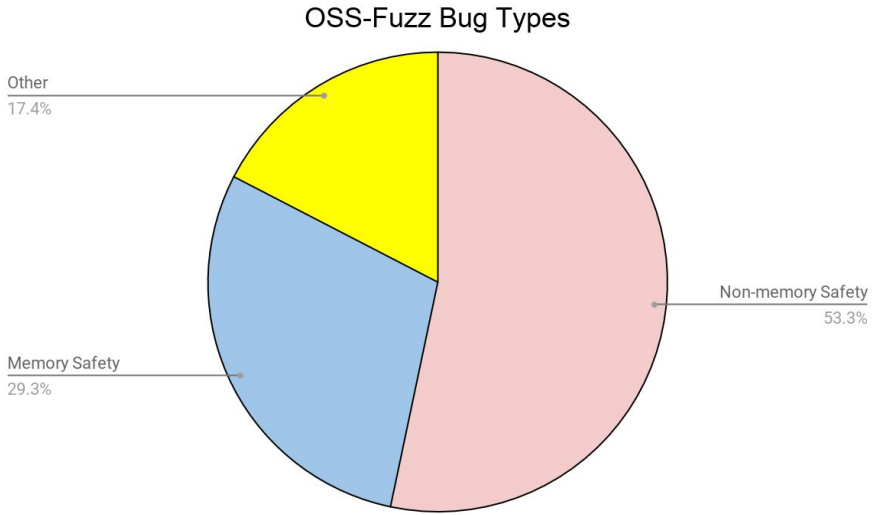
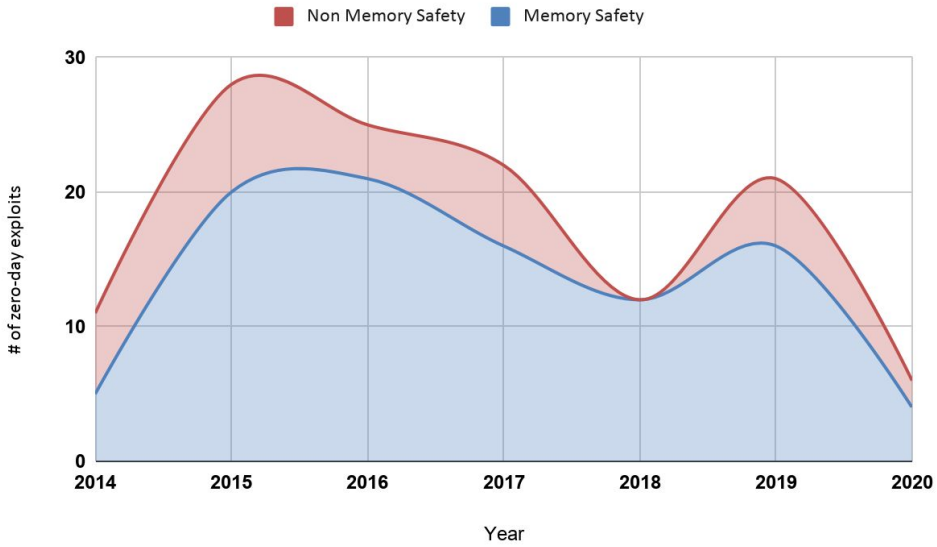


Google OSS-Fuzz bugs from 2016-2018.

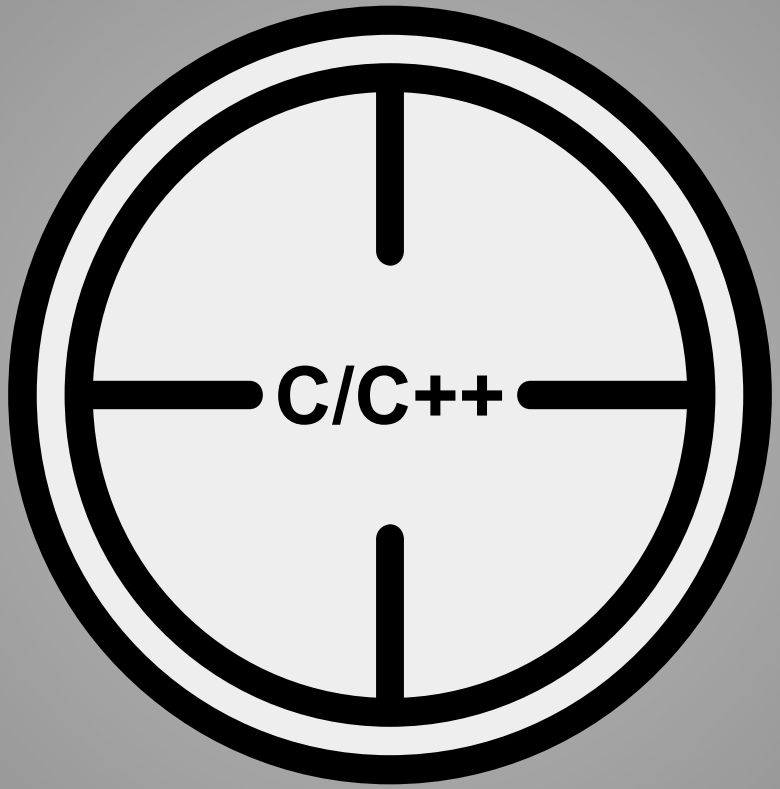
Source: https://security.googleblog.com/2018/11/a-new-chapter-for-oss-fuzz.html

ATTACKERS PREFER MEMORY SAFETY VULNS



Zero-day “in the wild” exploits
from 2014-2020

Source: Google Project Zero, 0day "In the Wild" spreadsheet. Last updated: April 3rd, 2020



C/C++ IS HERE TO STAY

- Performance.

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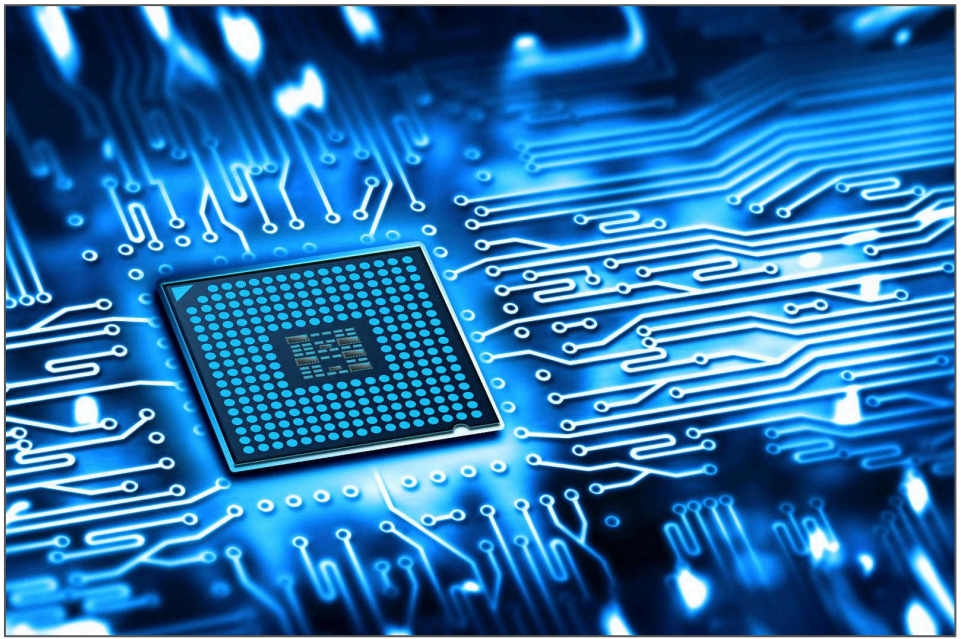

C/C++ IS HERE TO STAY

- Performance.
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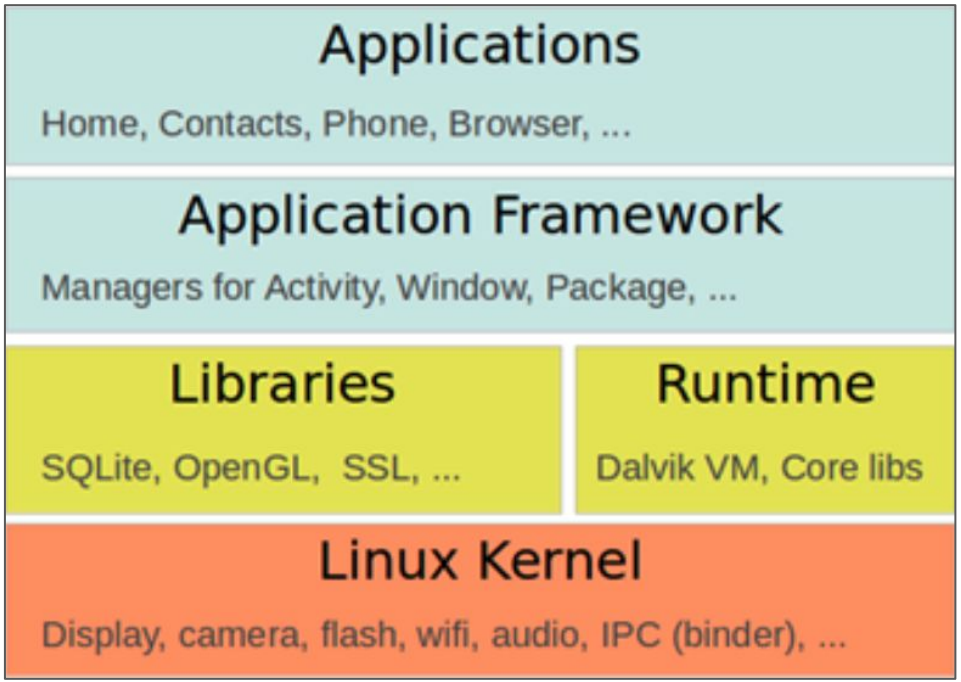
- Completeness.



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- Performance.
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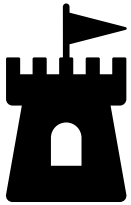
C/C++ IS HERE TO STAY

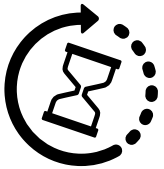
- Performance.
- Communication.
- Completeness.
- Maturity.
- Legacy code.

REST OF THE TALK

Memory Corruption Attacks & Defenses

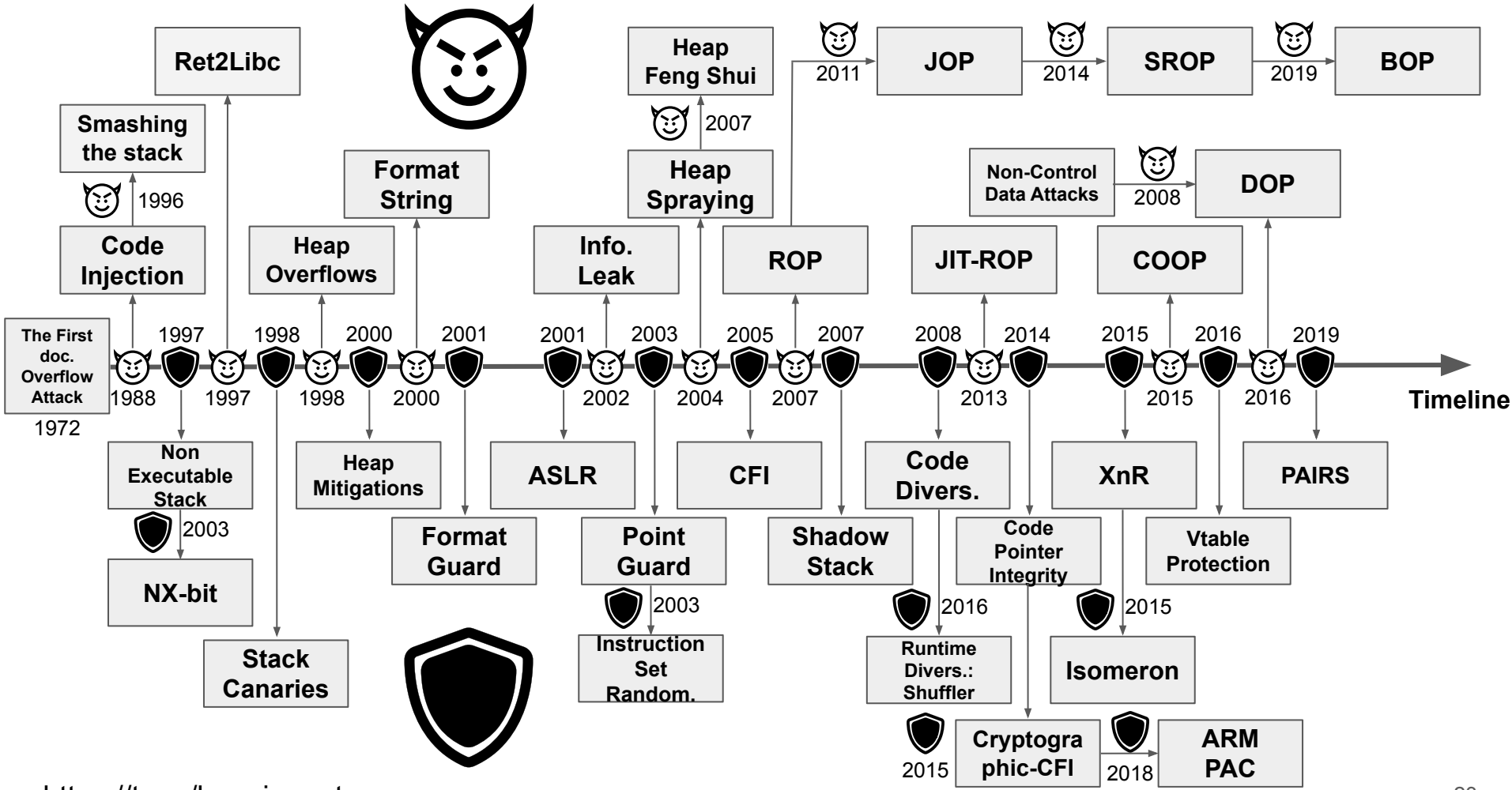


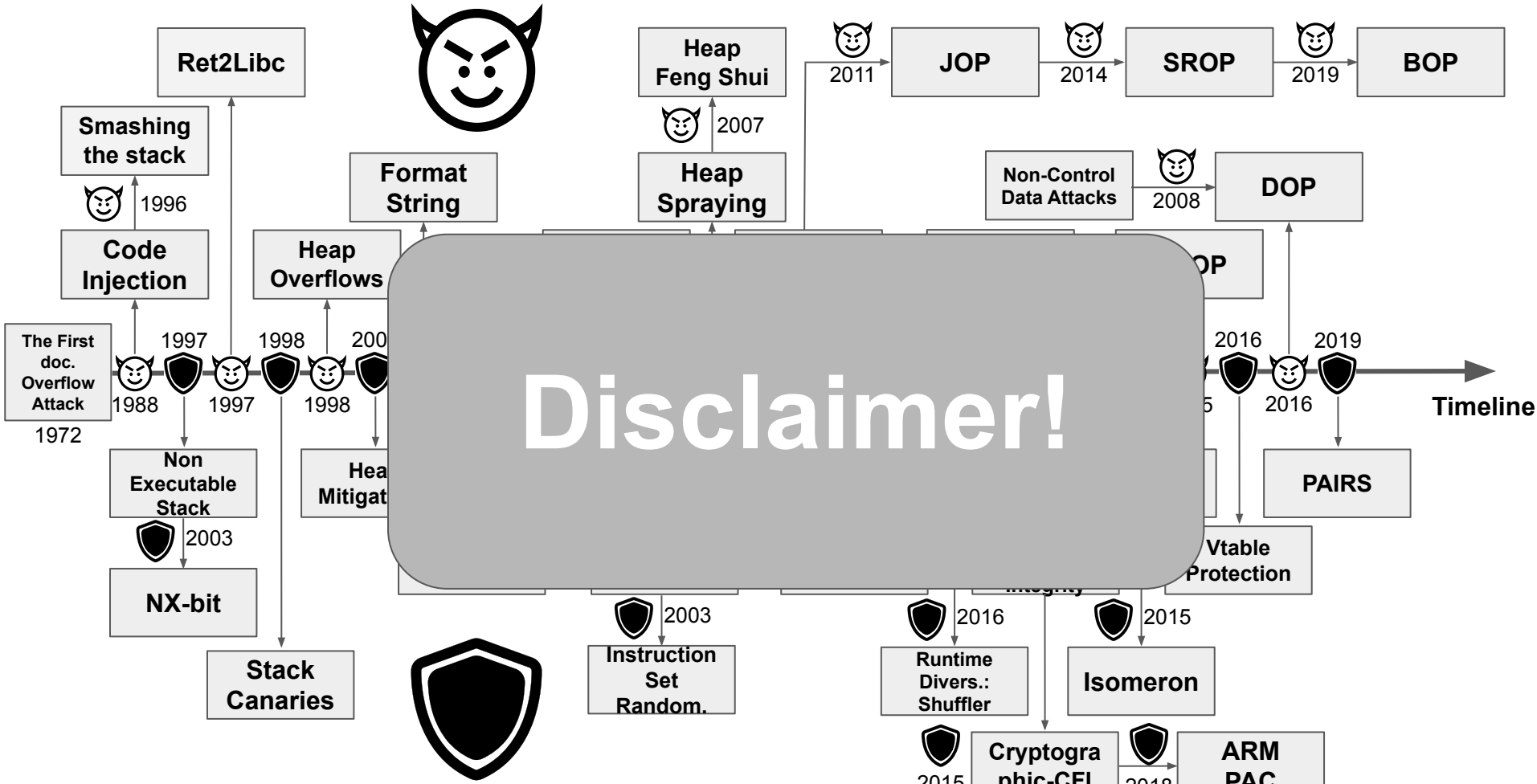
Memory Safety Techniques



Future Work Map

Memory Corruption Attacks & Defenses





The First doc. Overflow Attack

1972

Timeline

Source: James P. Anderson, Computer Security Technology Planning Study, October 1972
http://seclab.cs.ucdavis.edu/projects/history/papers/ande72.pdf

“the code performing this function does not check the source and destination addresses properly, permitting portions of the monitor to be **overlaid by the user.**

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“the code performing this function does not check the source and destination addresses properly, permitting portions of the monitor to be **overlaid by the user.** This can be used to **inject code** into the monitor that will permit the user to **seize control of the machine**”

The First doc. Overflow Attack
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Timeline

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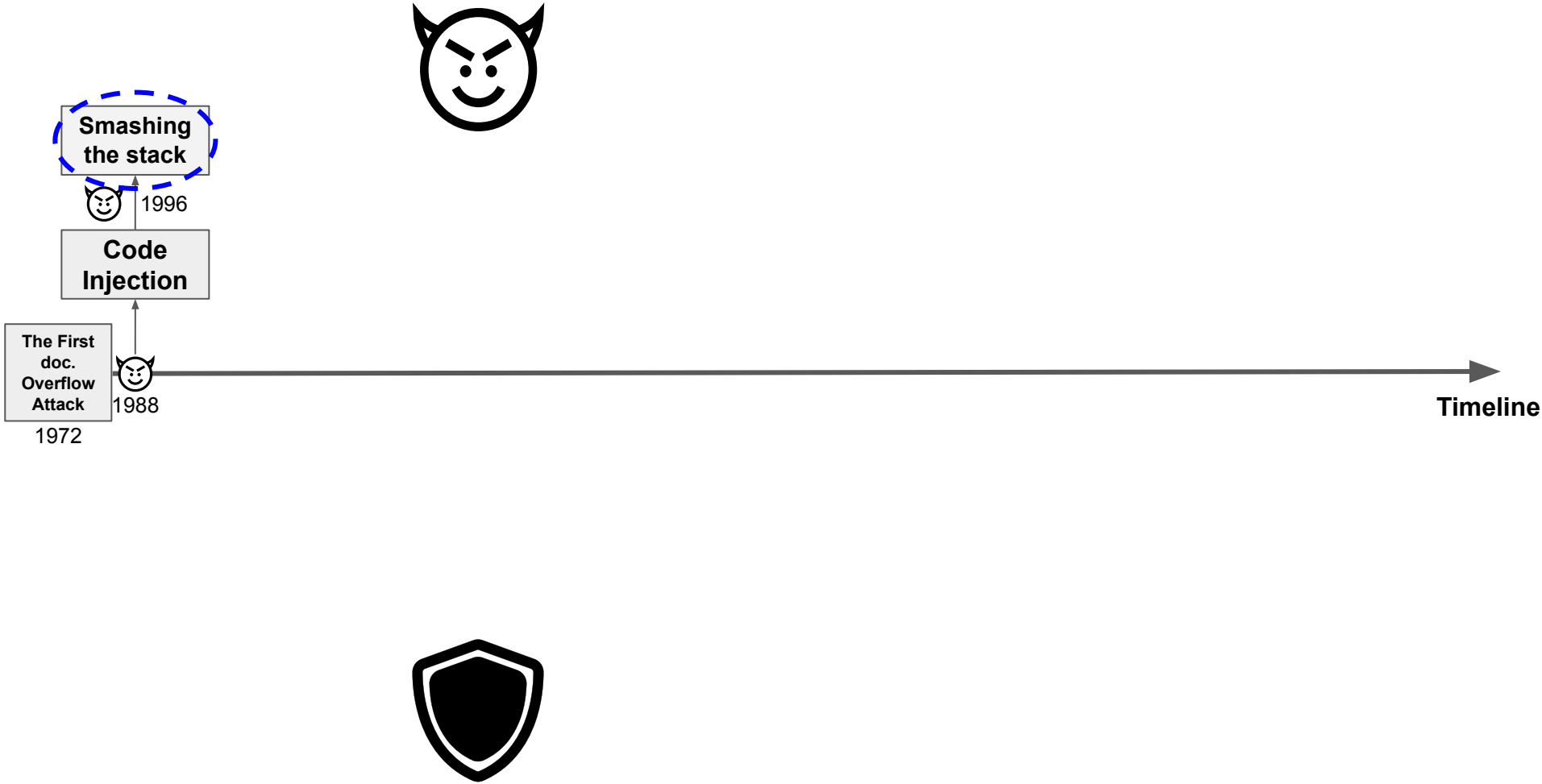

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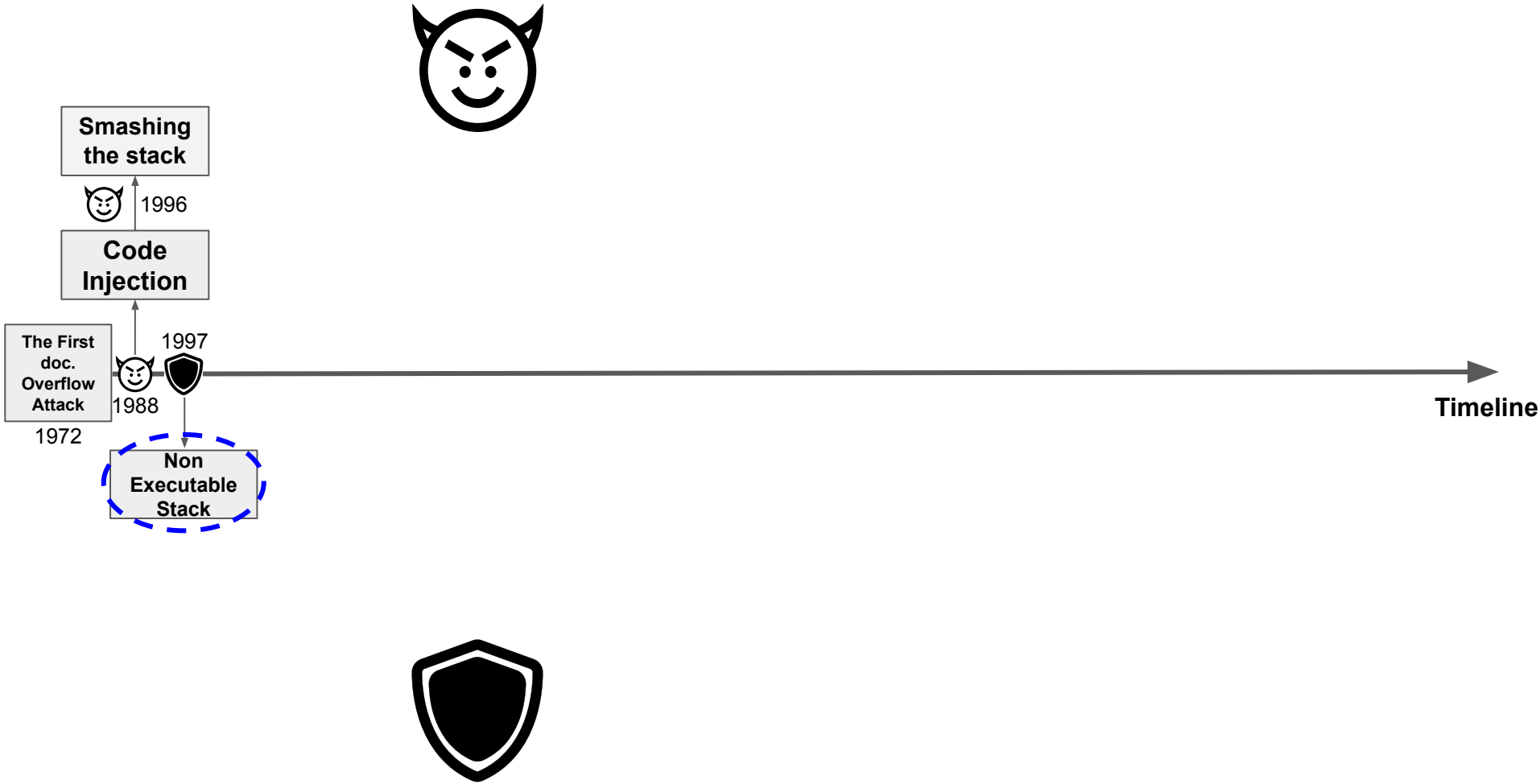

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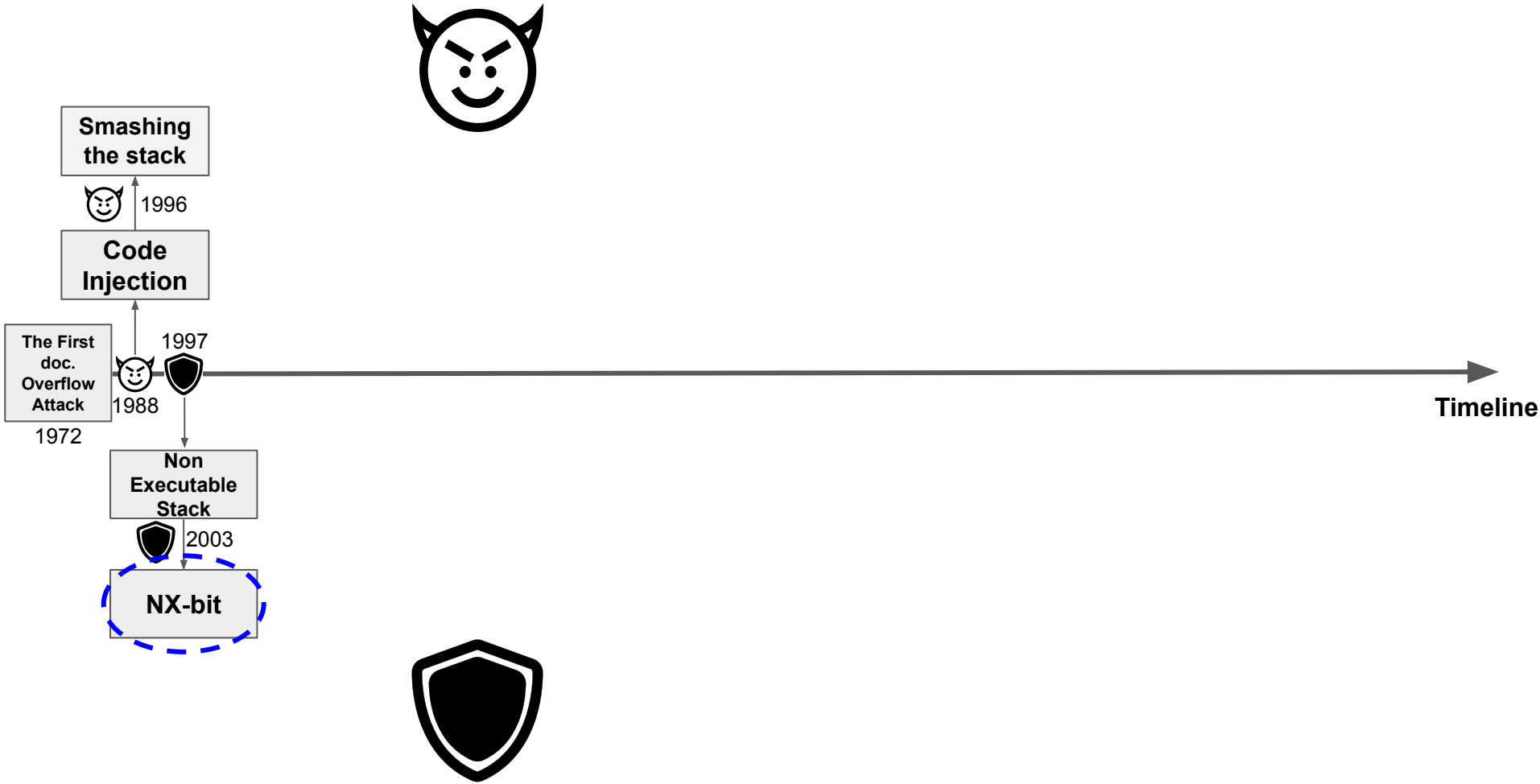

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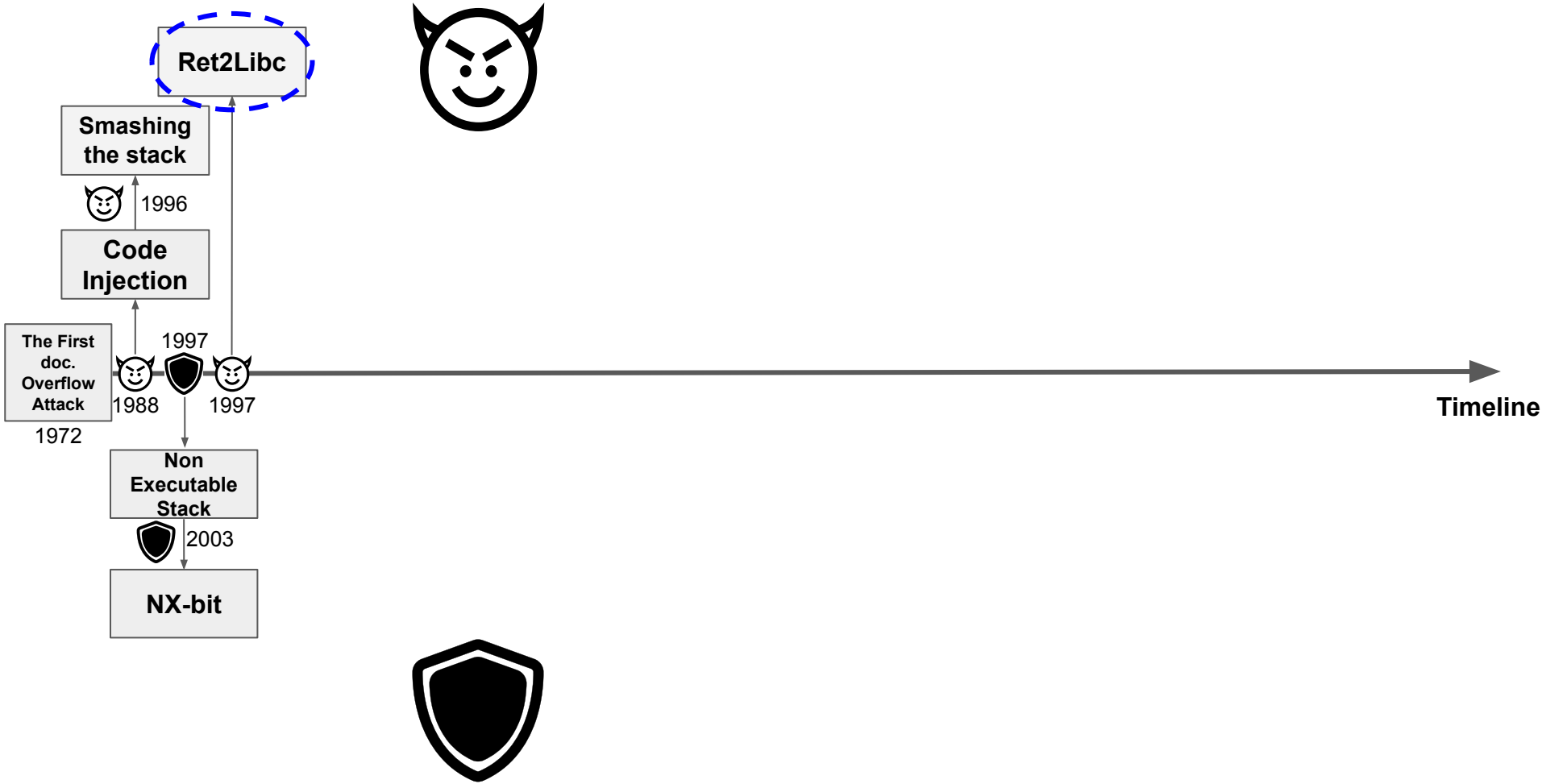

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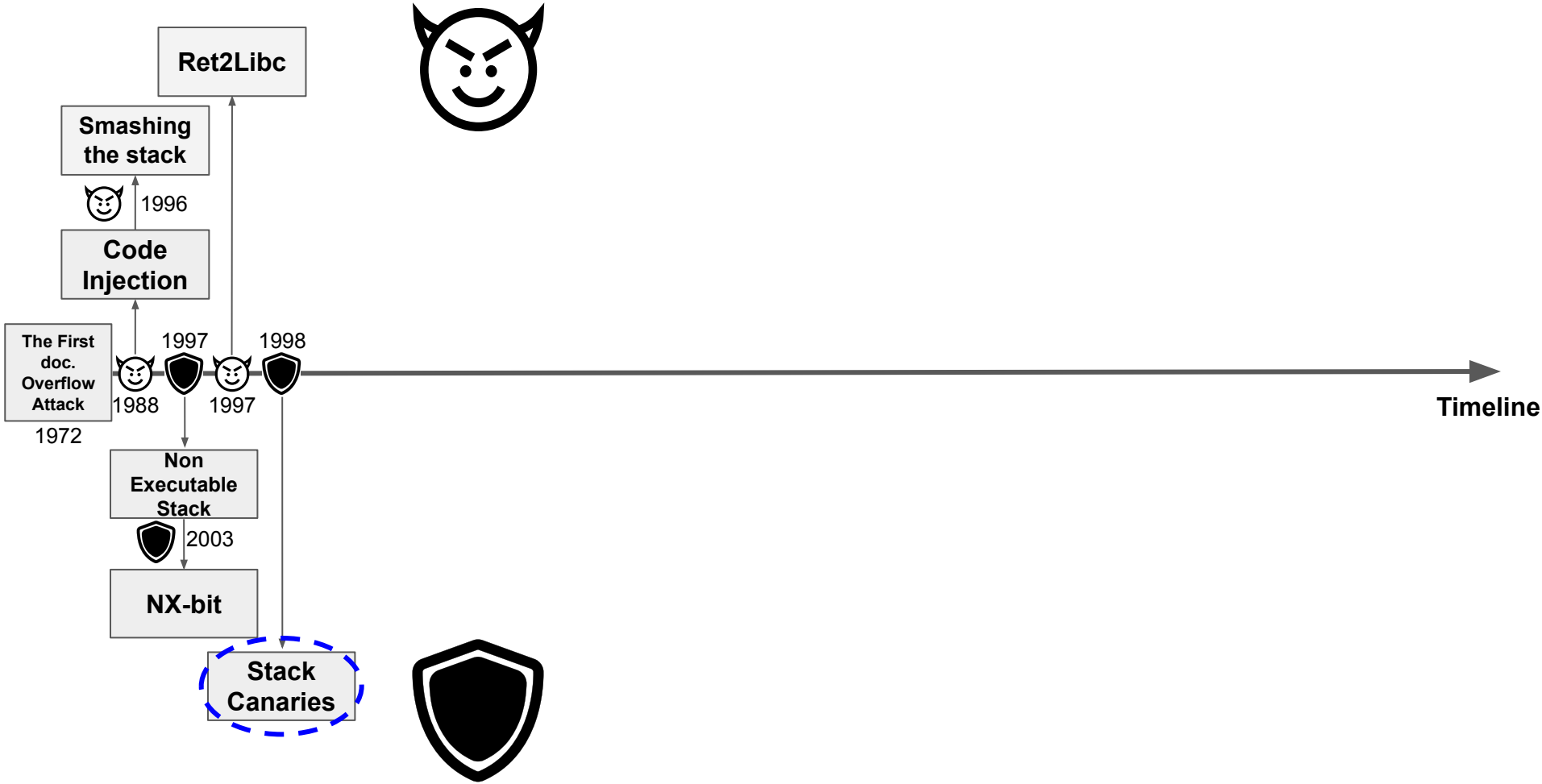

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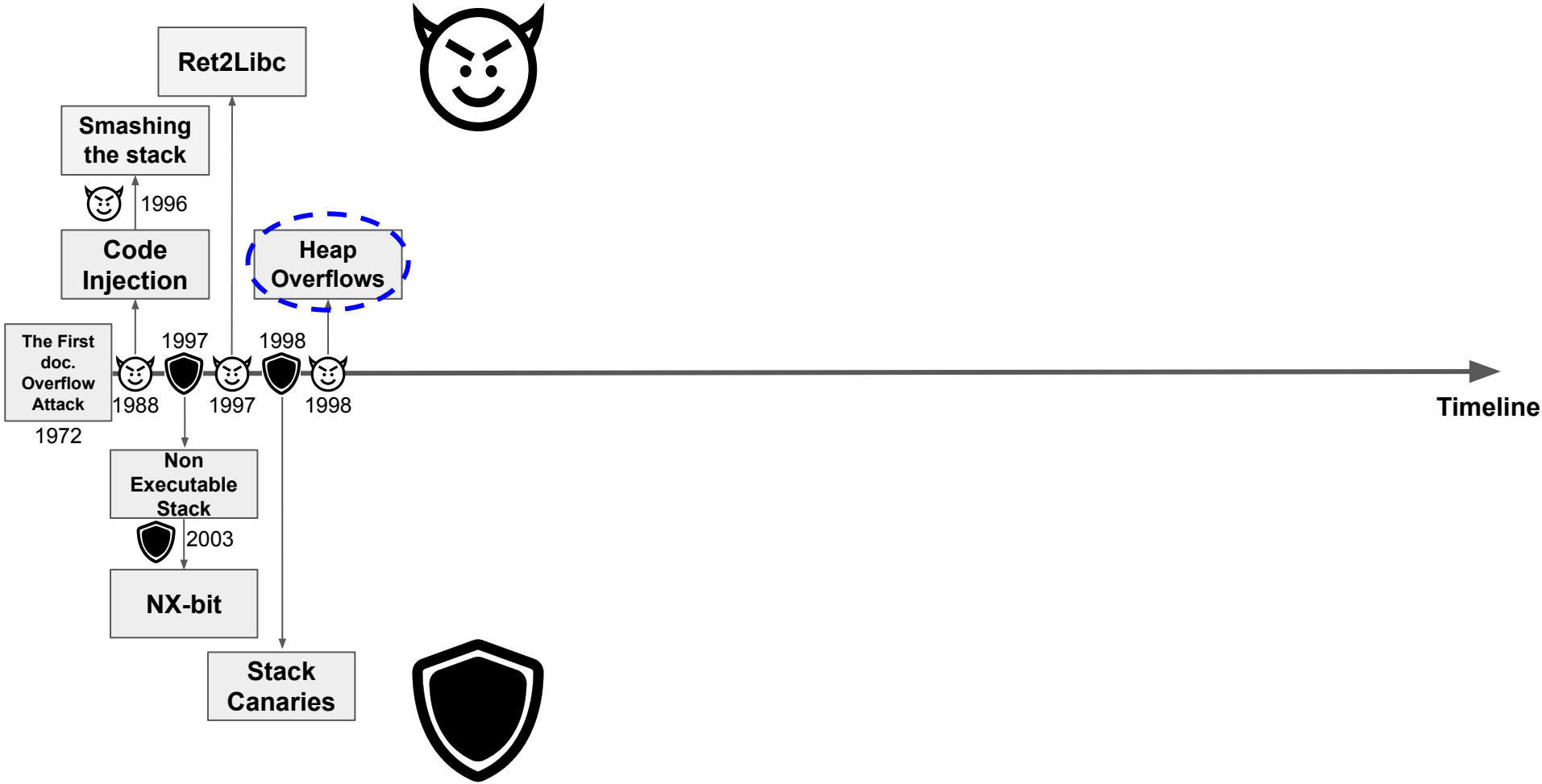

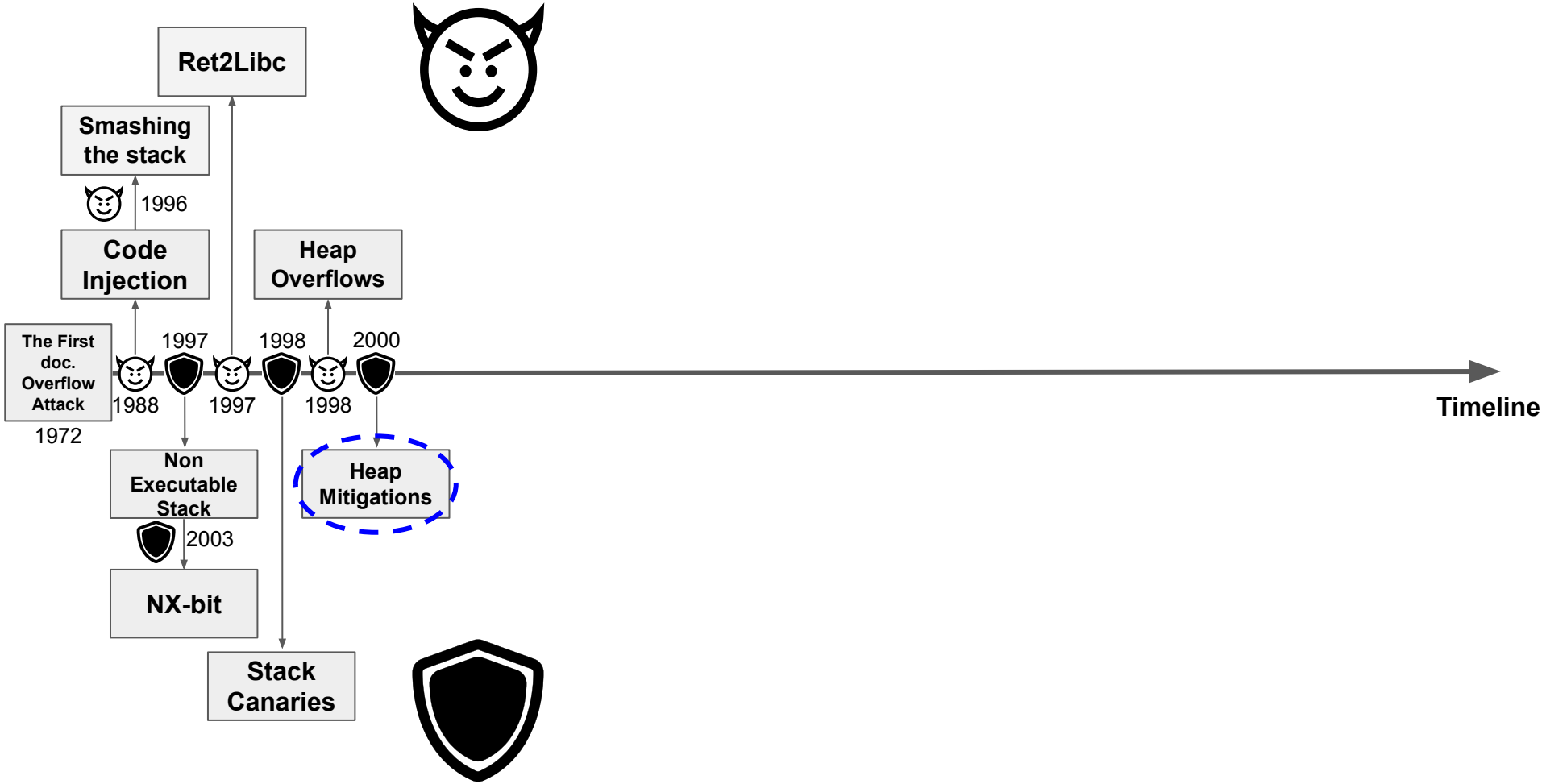

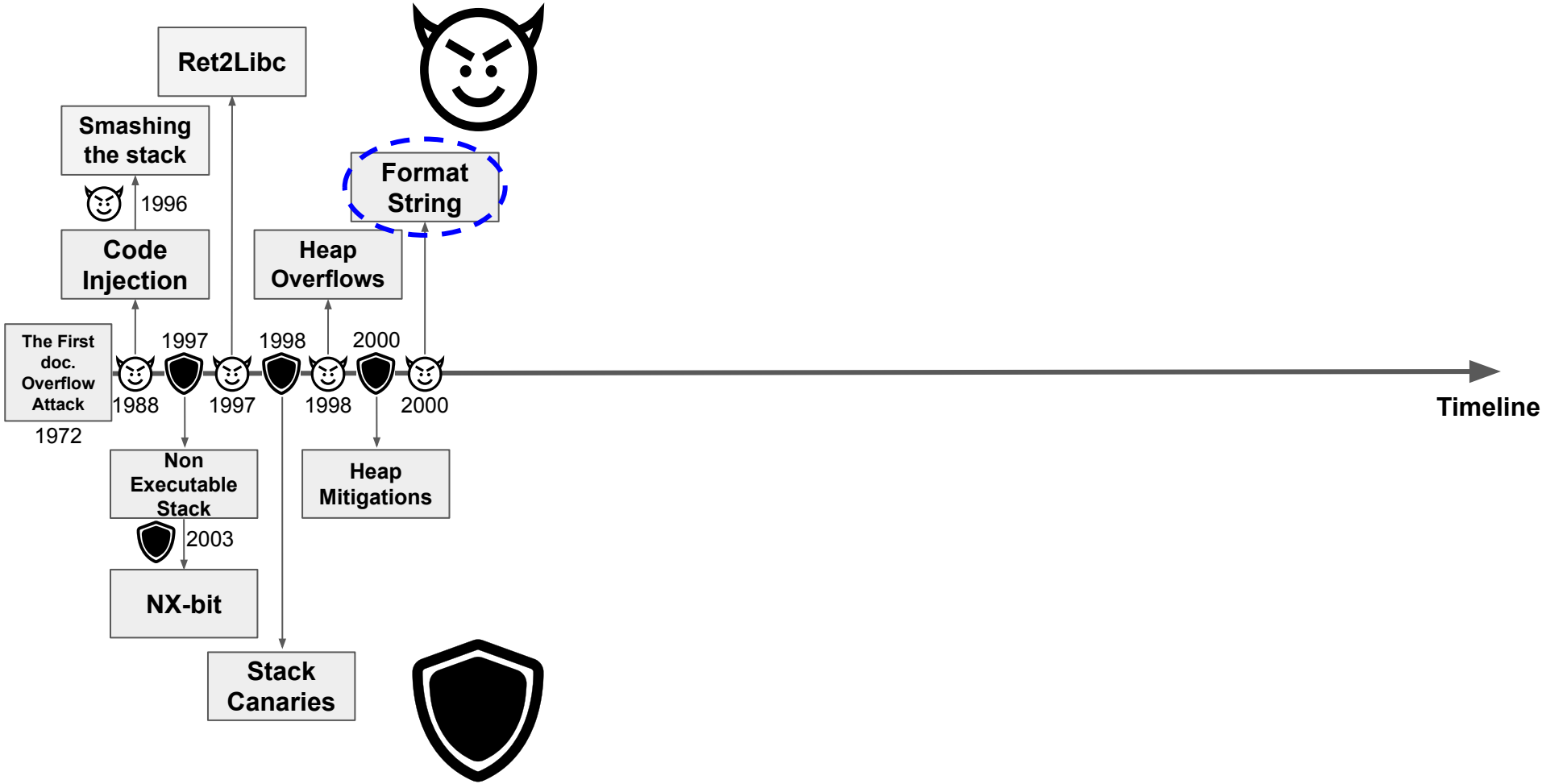

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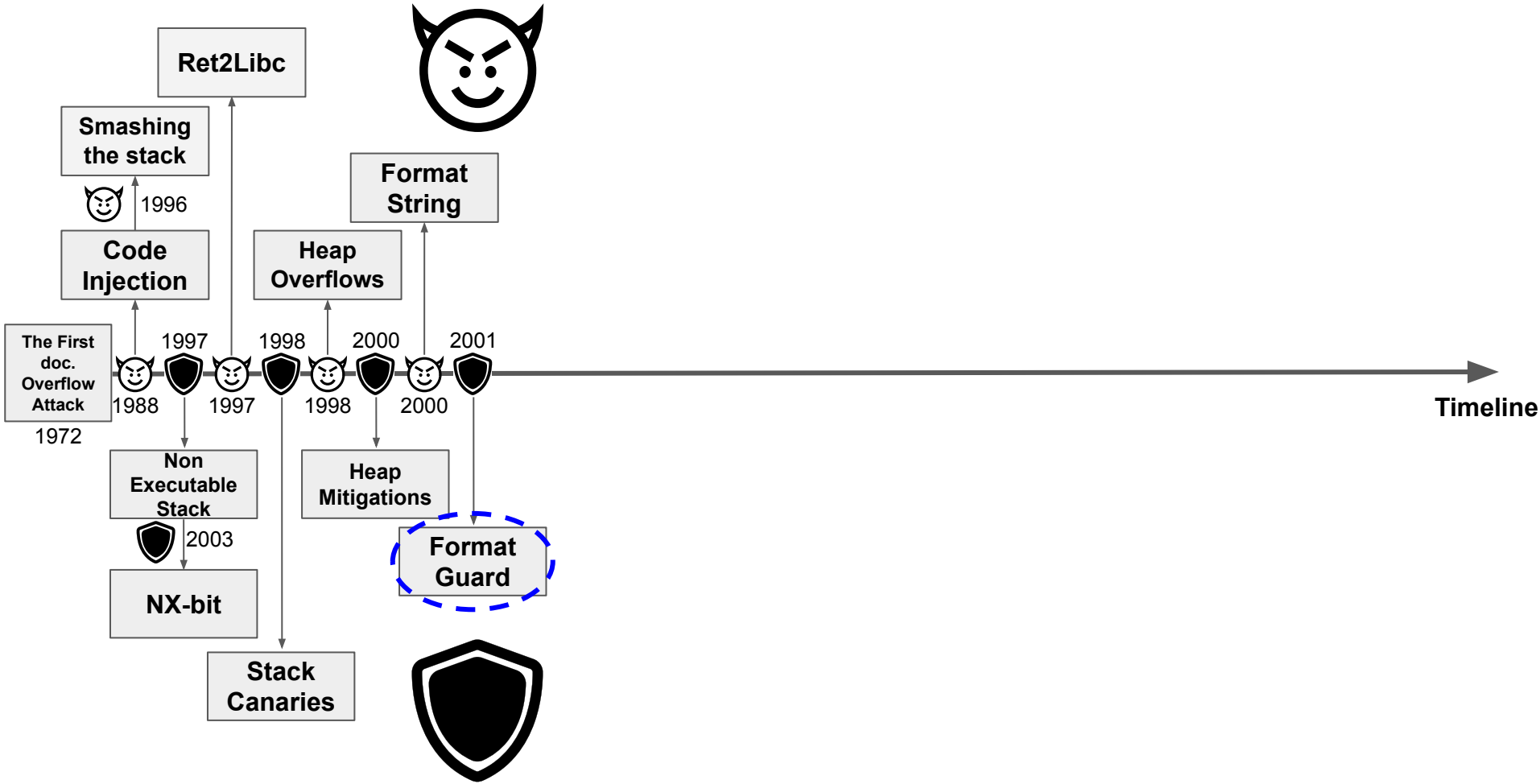

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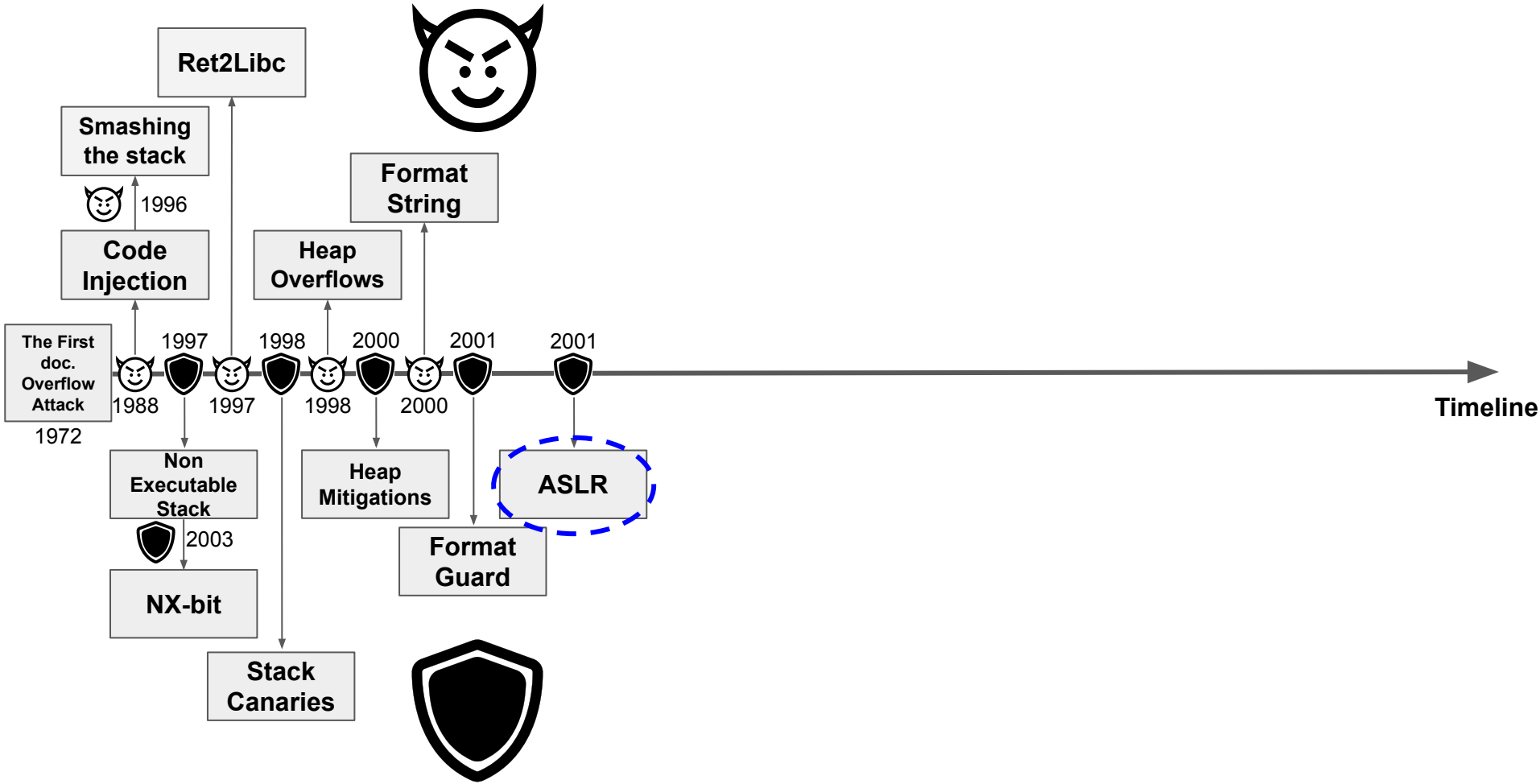
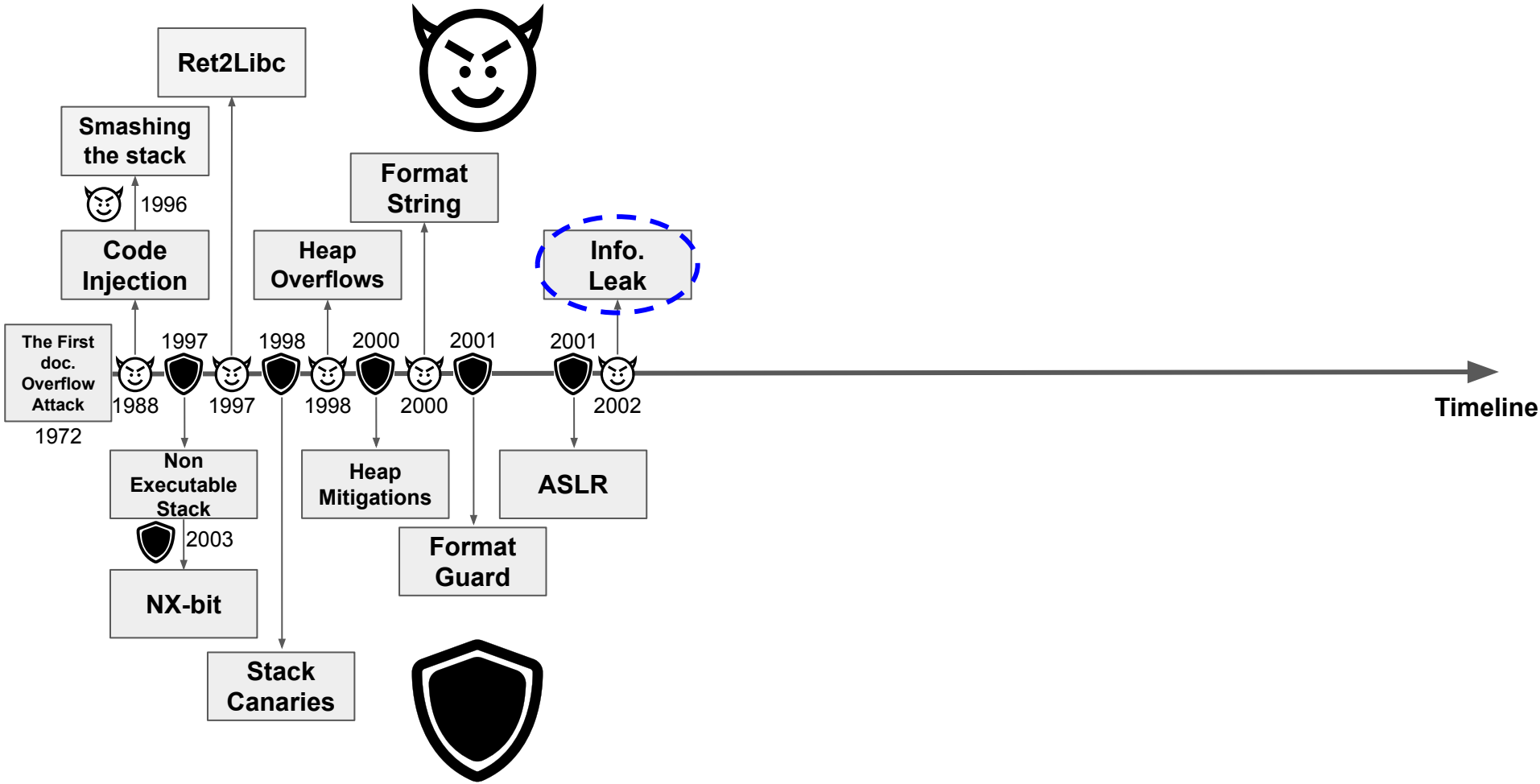


[11] PaX-Team, PaX address space layout randomization. **[2003]**



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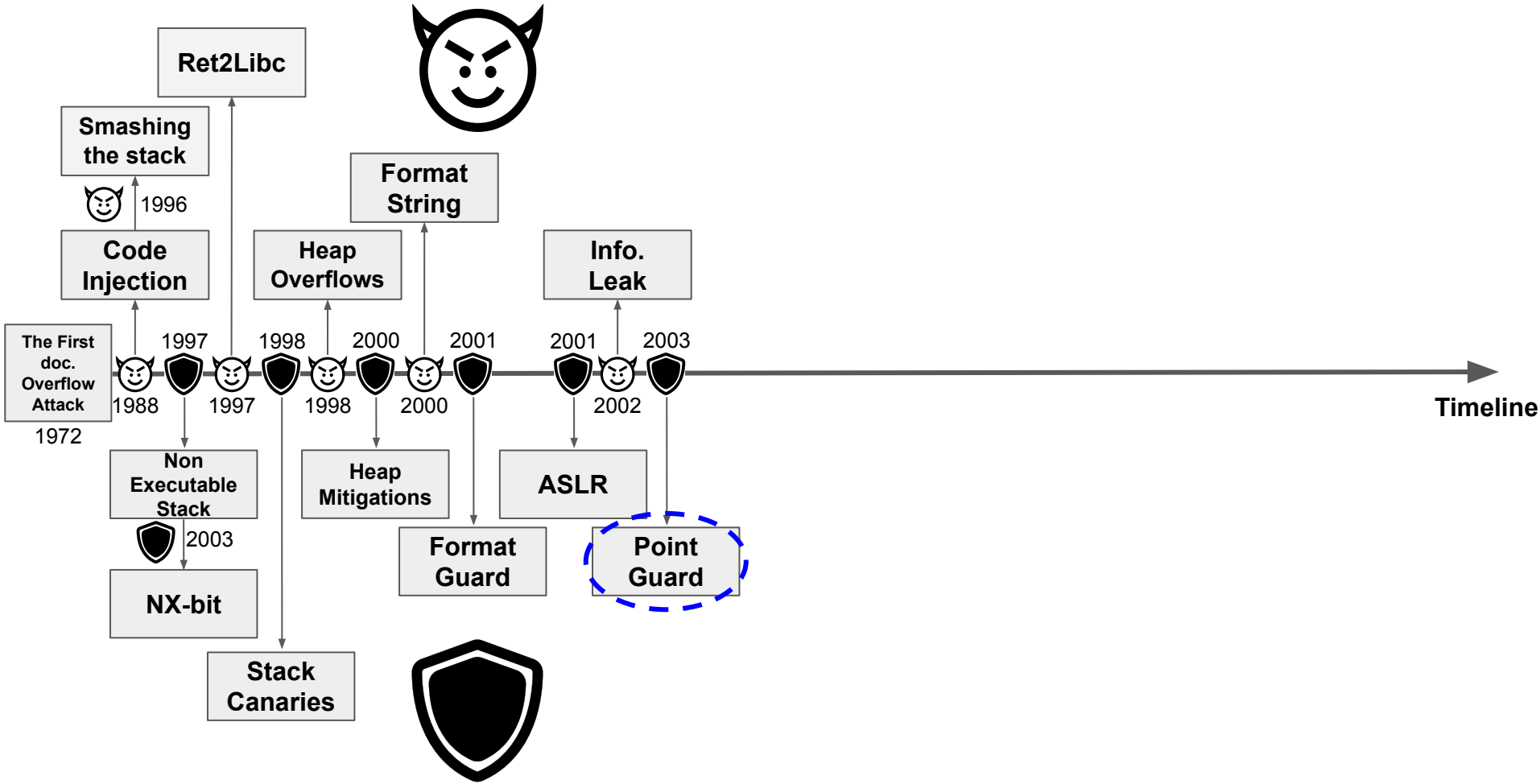

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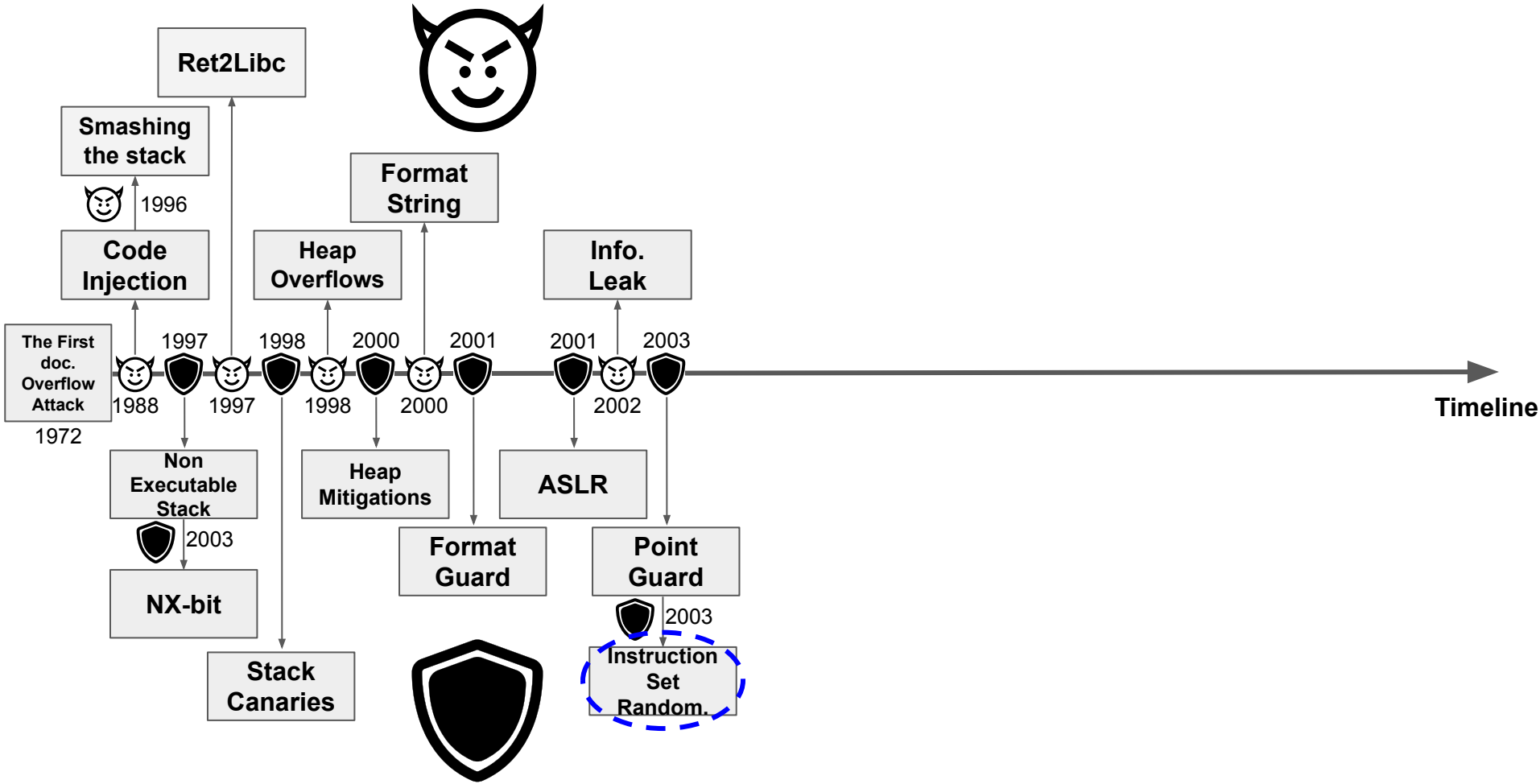

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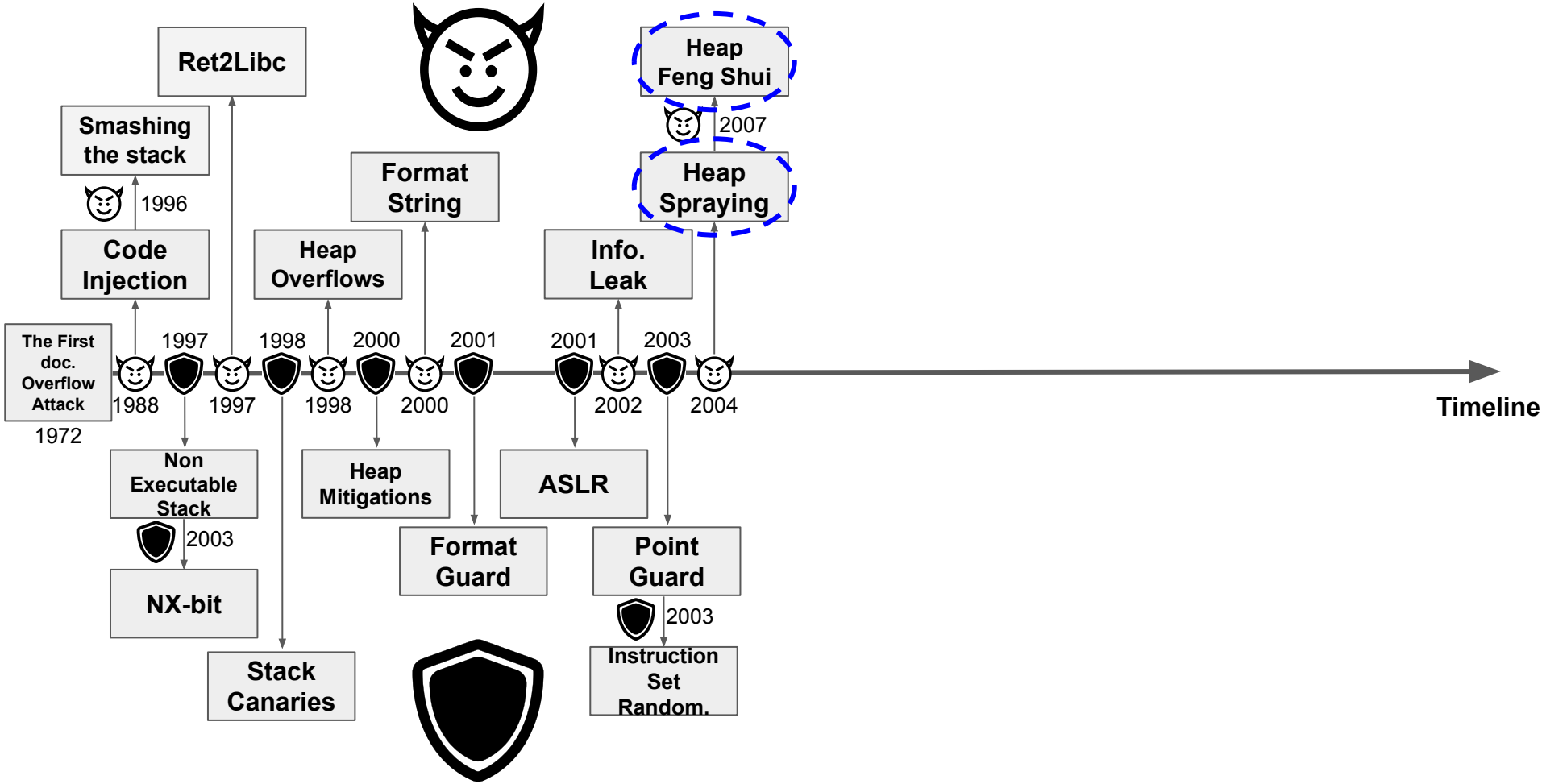
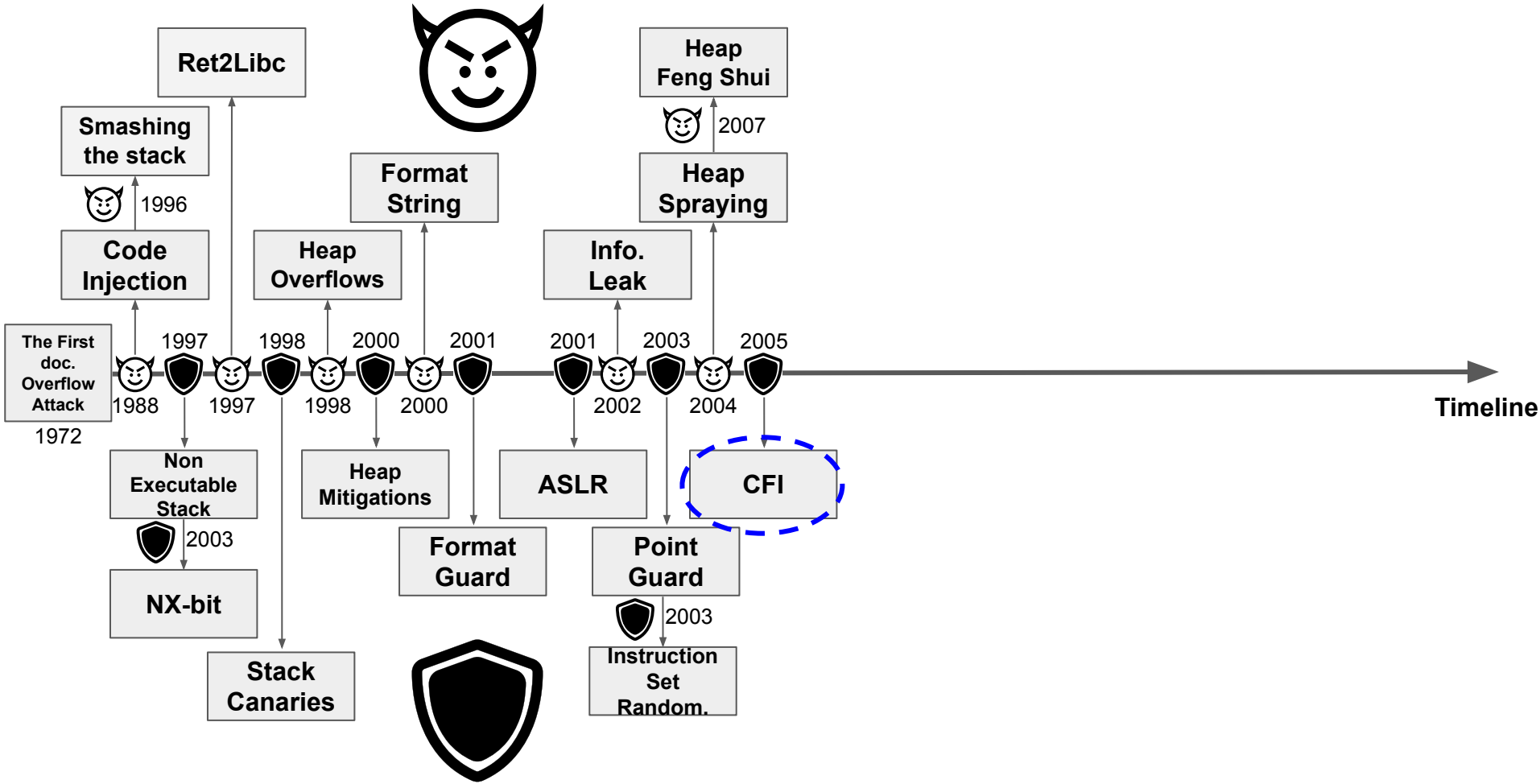
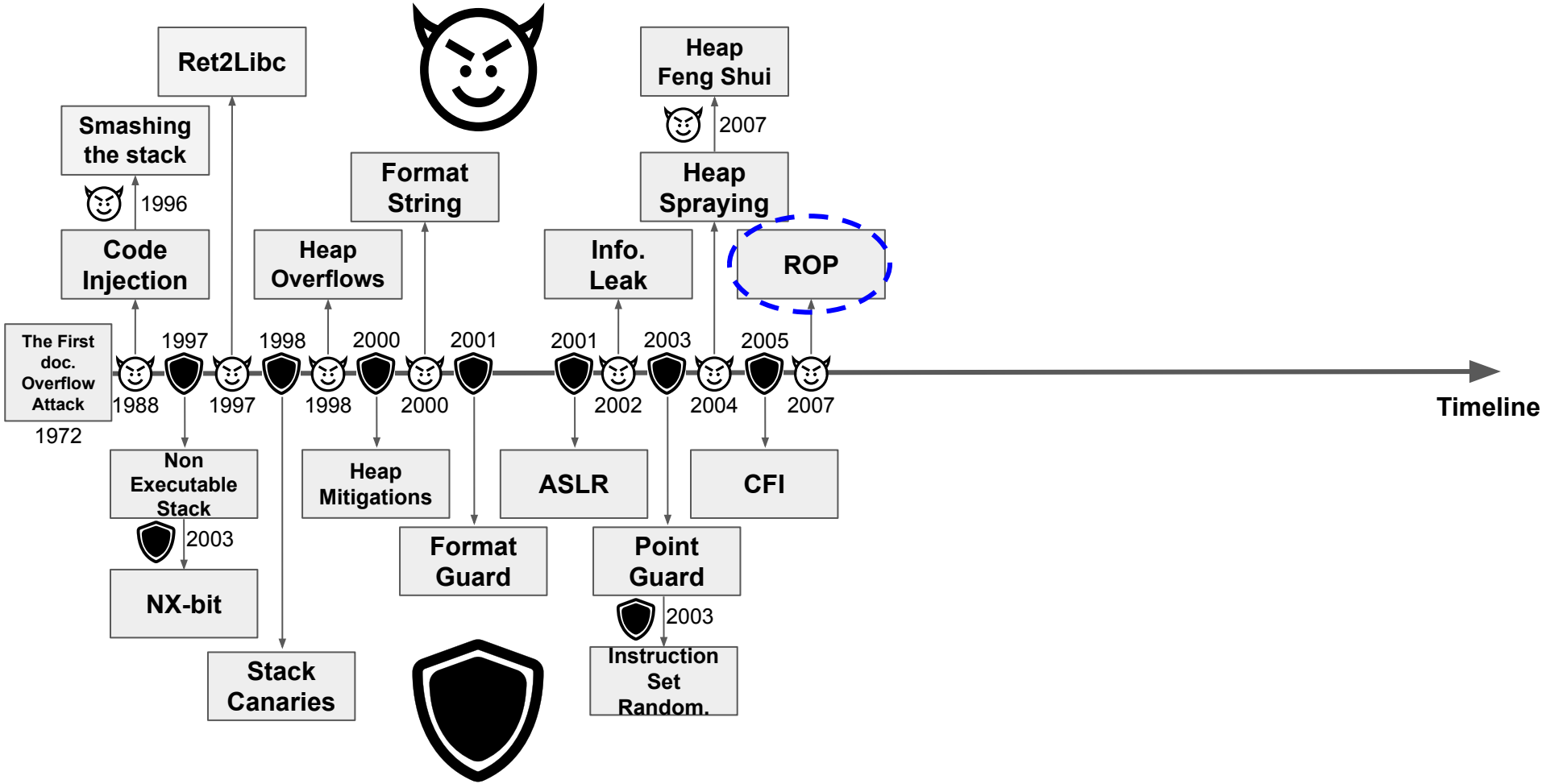




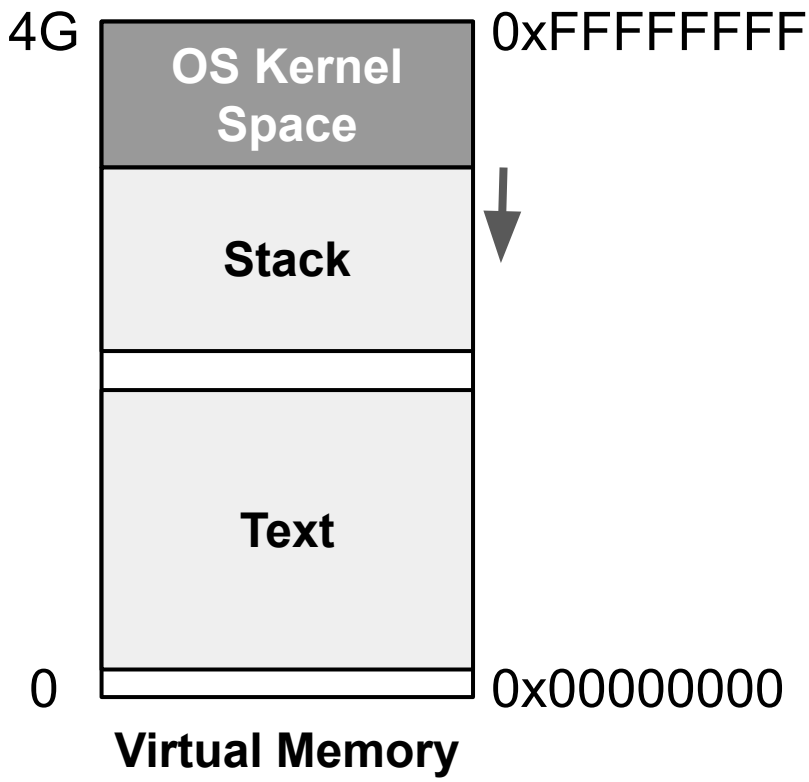
[12] Burow et. al, Control-flow integrity: Precision, security, and performance. **[ACM Surveys 2017]**



[7] Hovav Shacham. The geometry of innocent flesh on the bone. **[CCS 2007]**

RETURN ORIENTED PROGRAMMING (**ROP**)

- Attack procedures:



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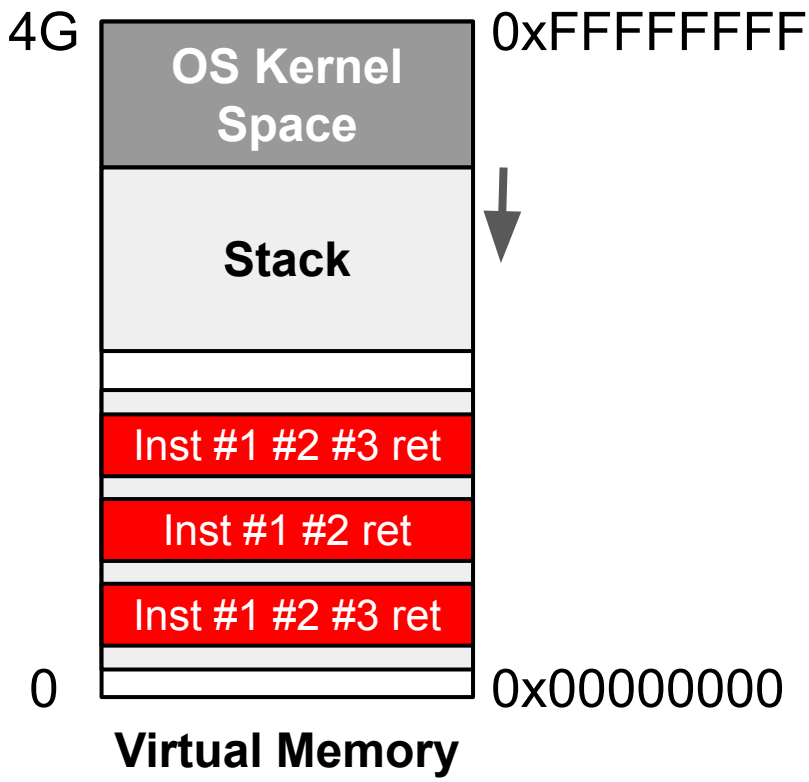

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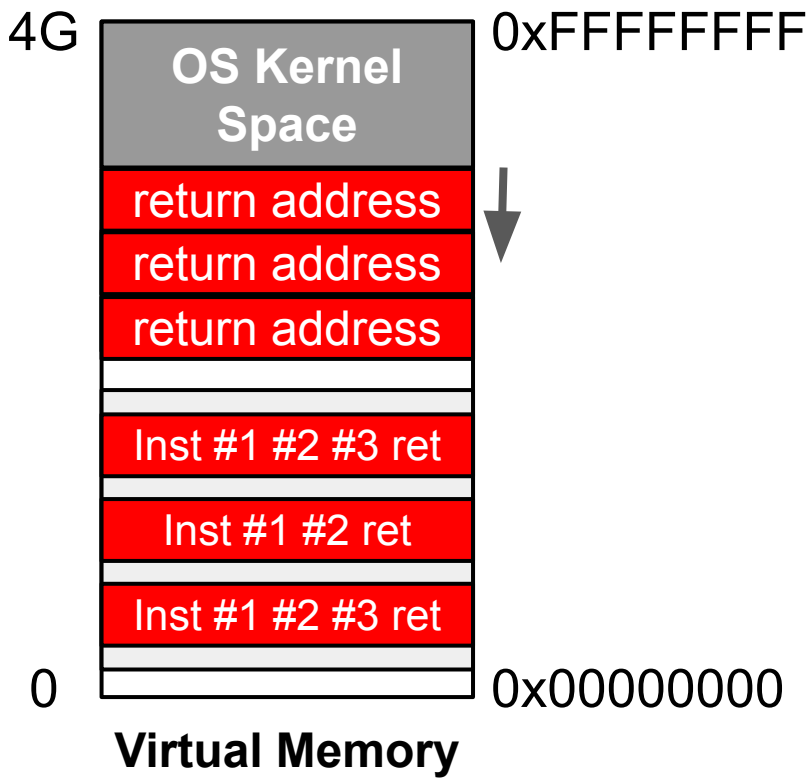
- Attack procedures:
  - Locate interesting gadgets.
  - Push sequence of gadget addresses to the stack.



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- Attack procedures:
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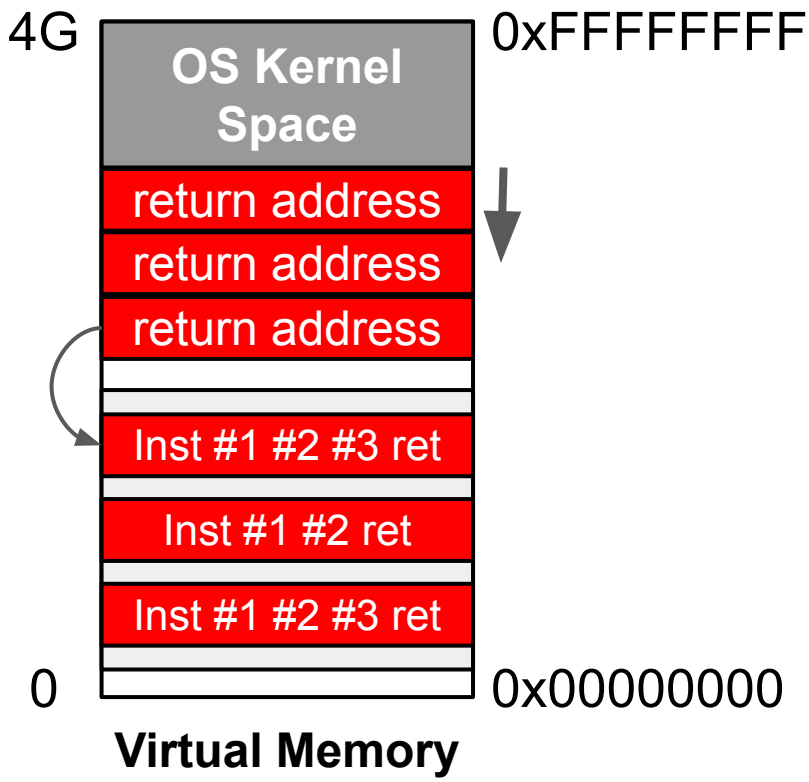
  - Push sequence of gadget addresses to the stack.
  - Run!



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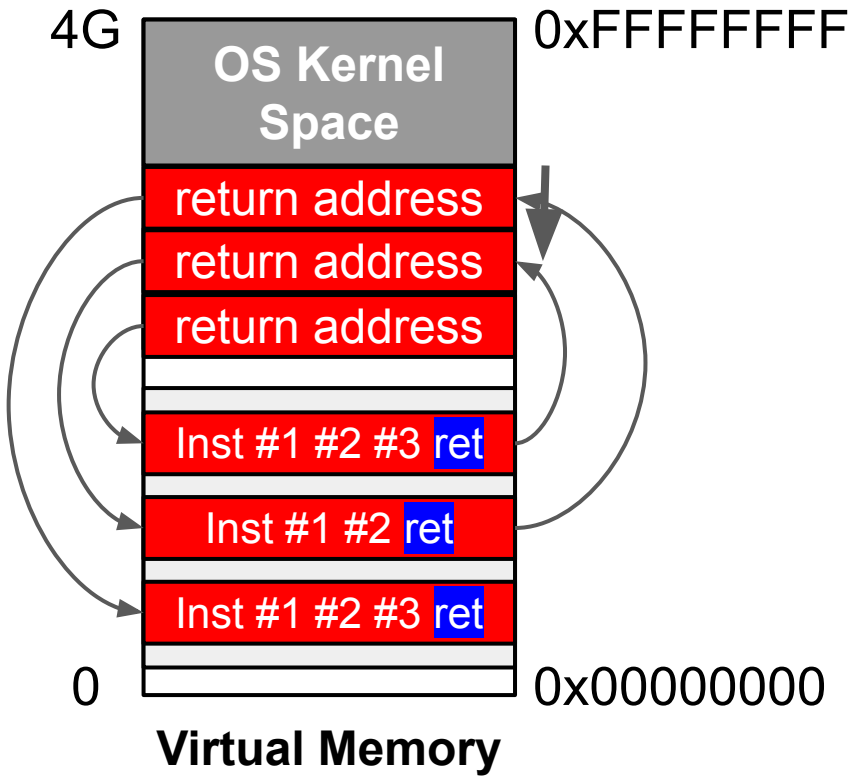

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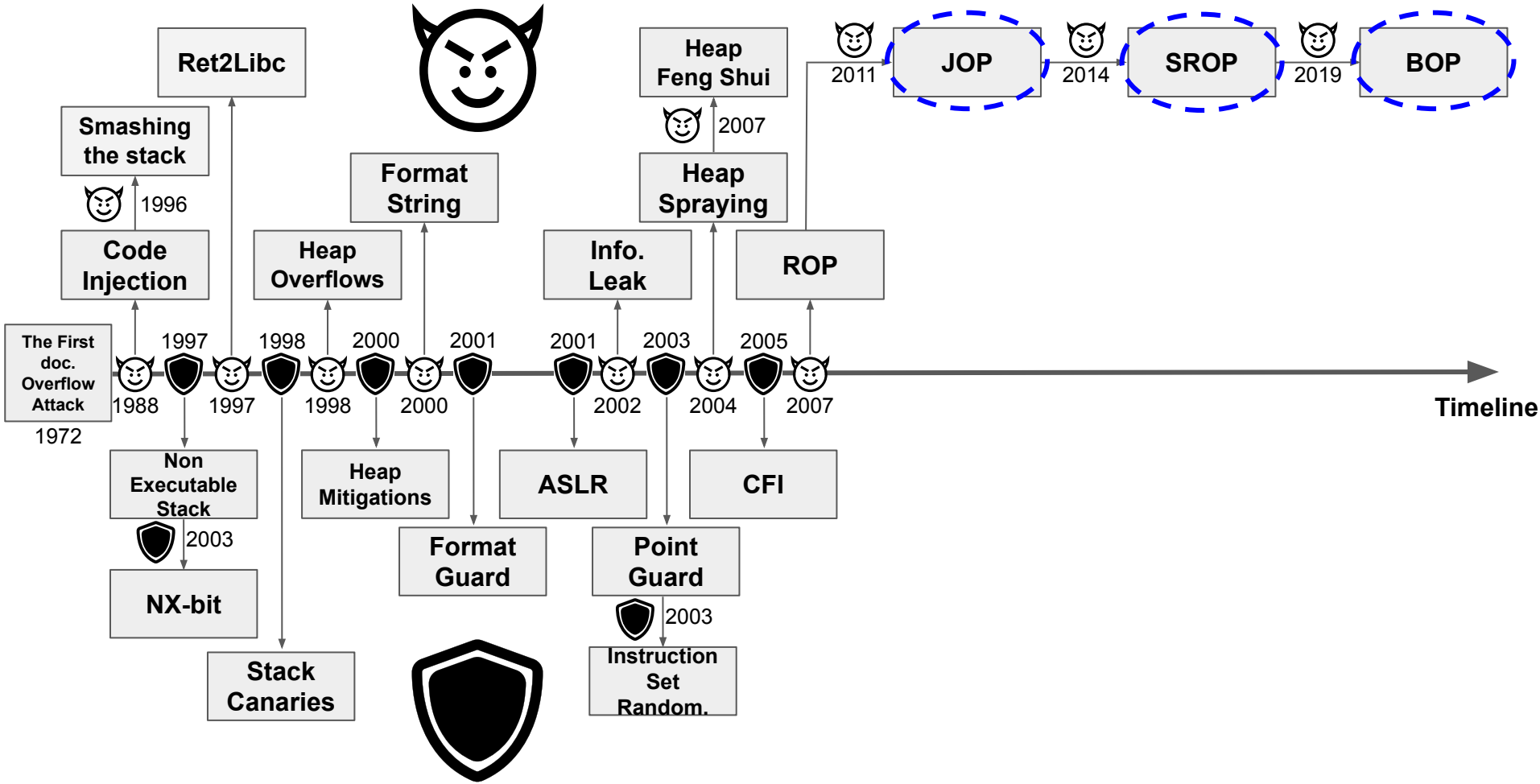

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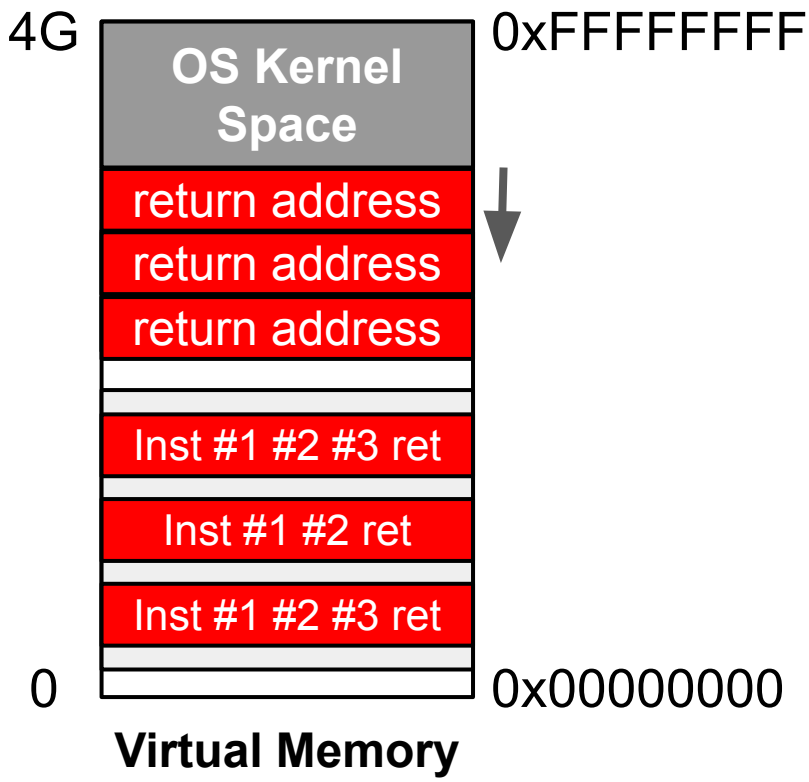
  - Locate interesting gadgets.
  - Push sequence of gadget addresses to the stack.
  - Run!
- **Mitigations**:



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RETURN ORIENTED PROGRAMMING (**ROP**)

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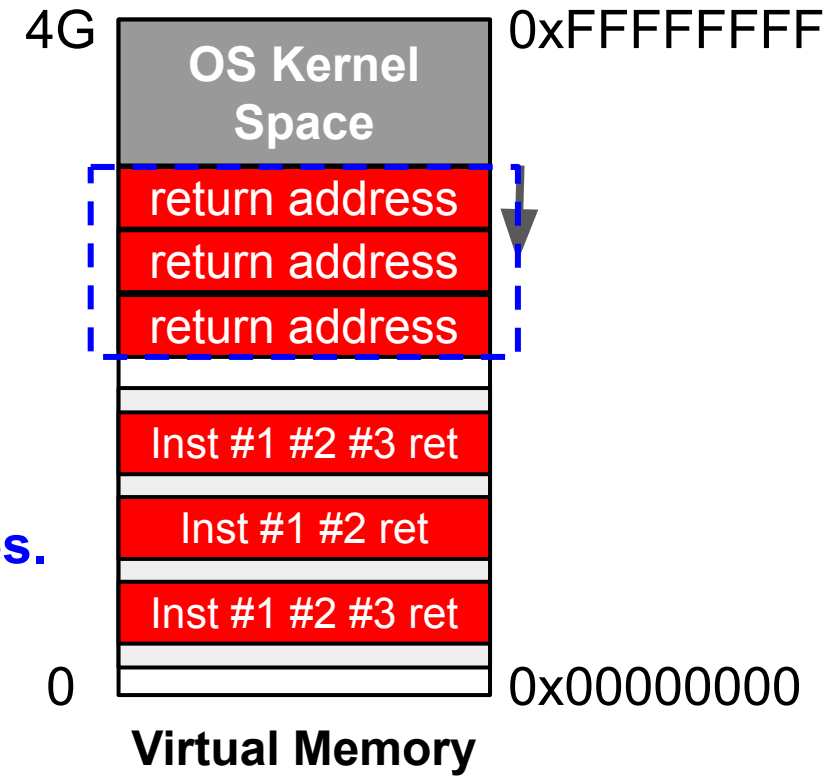
  - Locate interesting gadgets.
  - Push sequence of gadget addresses to the stack.
  - Run!
- Mitigations:
  - **Protect the return addresses.**



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- Attack procedures:
  - Locate interesting gadgets.
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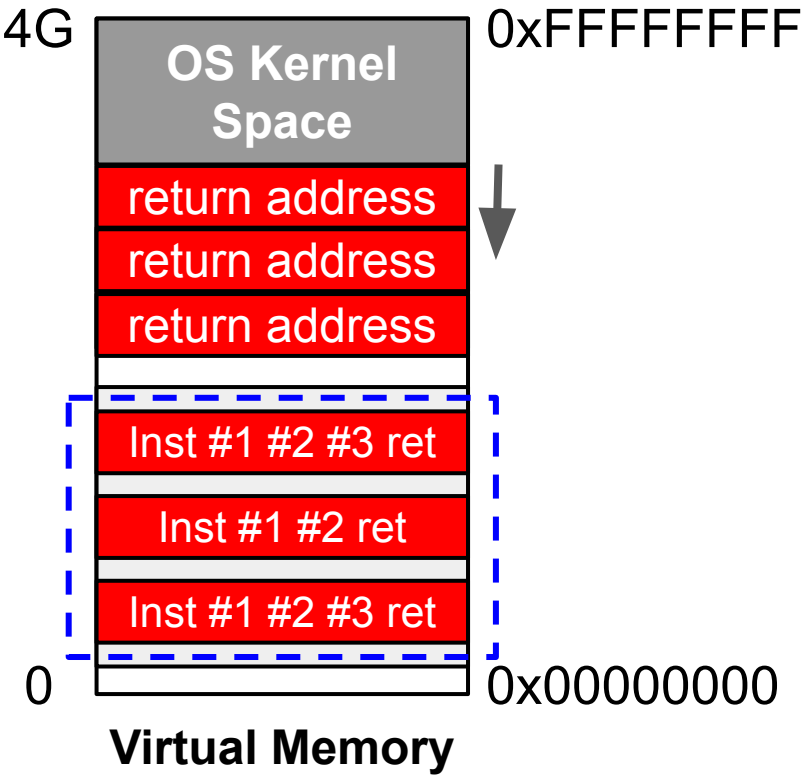
  - Run!
- Mitigations:
  - Protect the return addresses.
  - **Protect the gadgets.**



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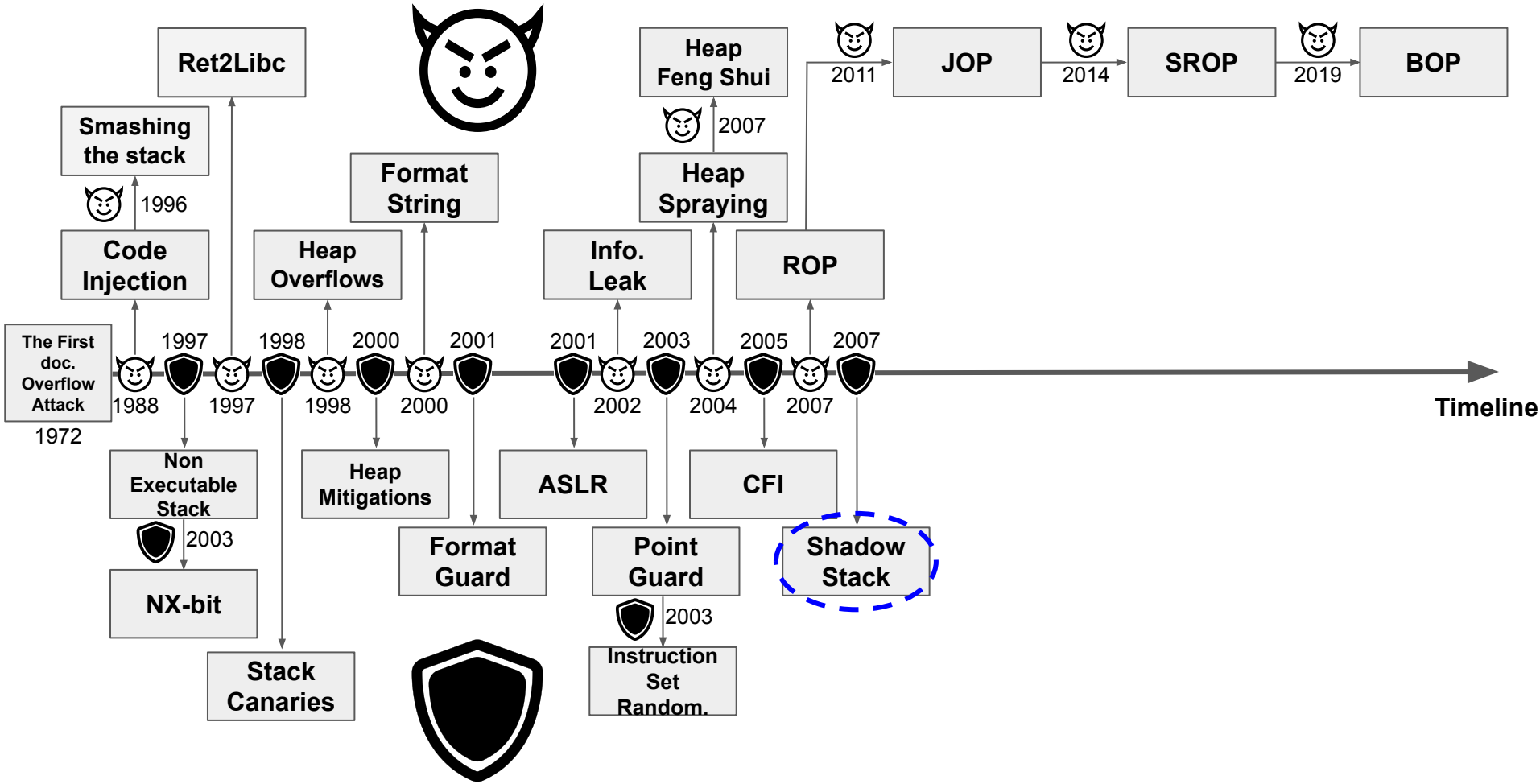

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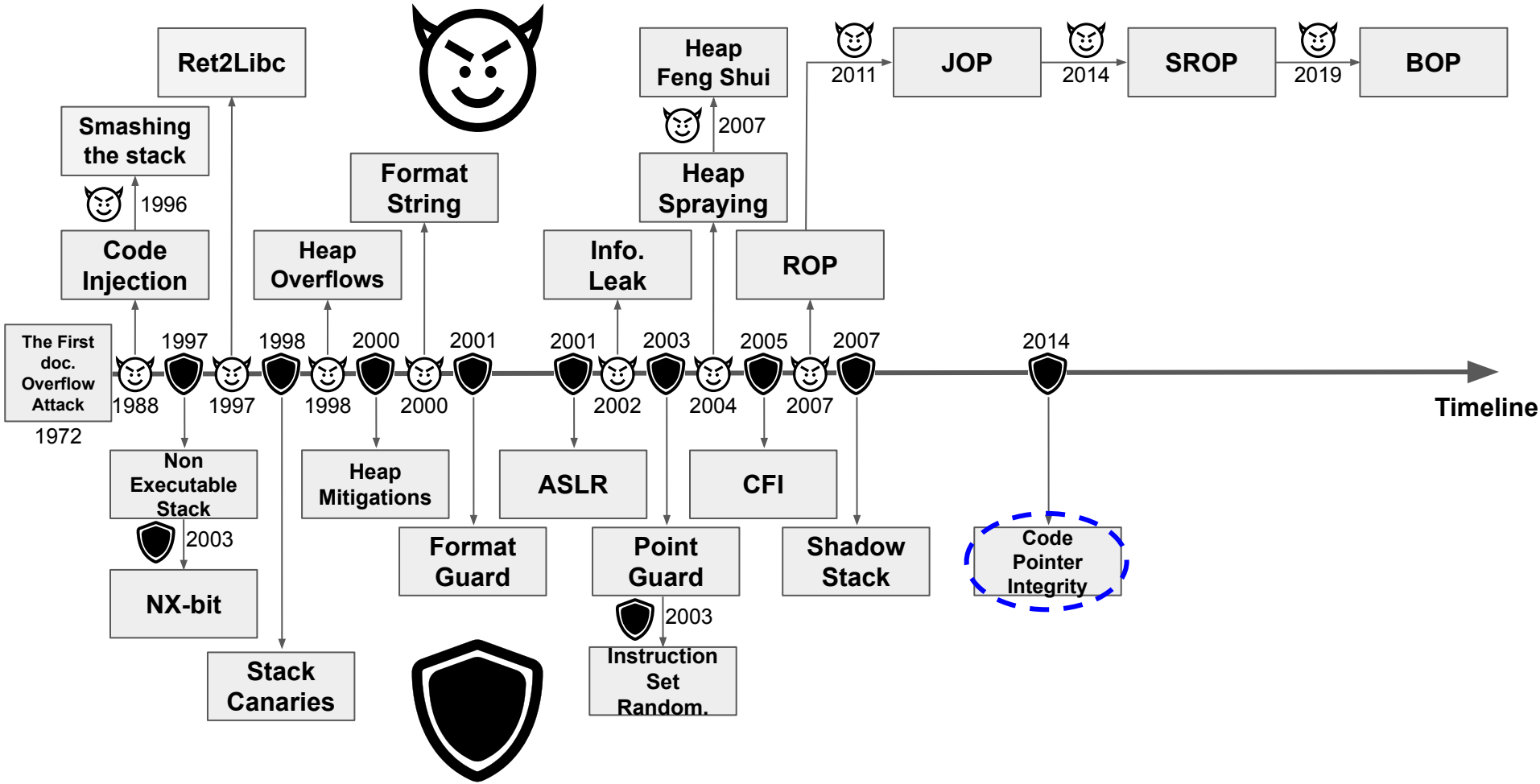
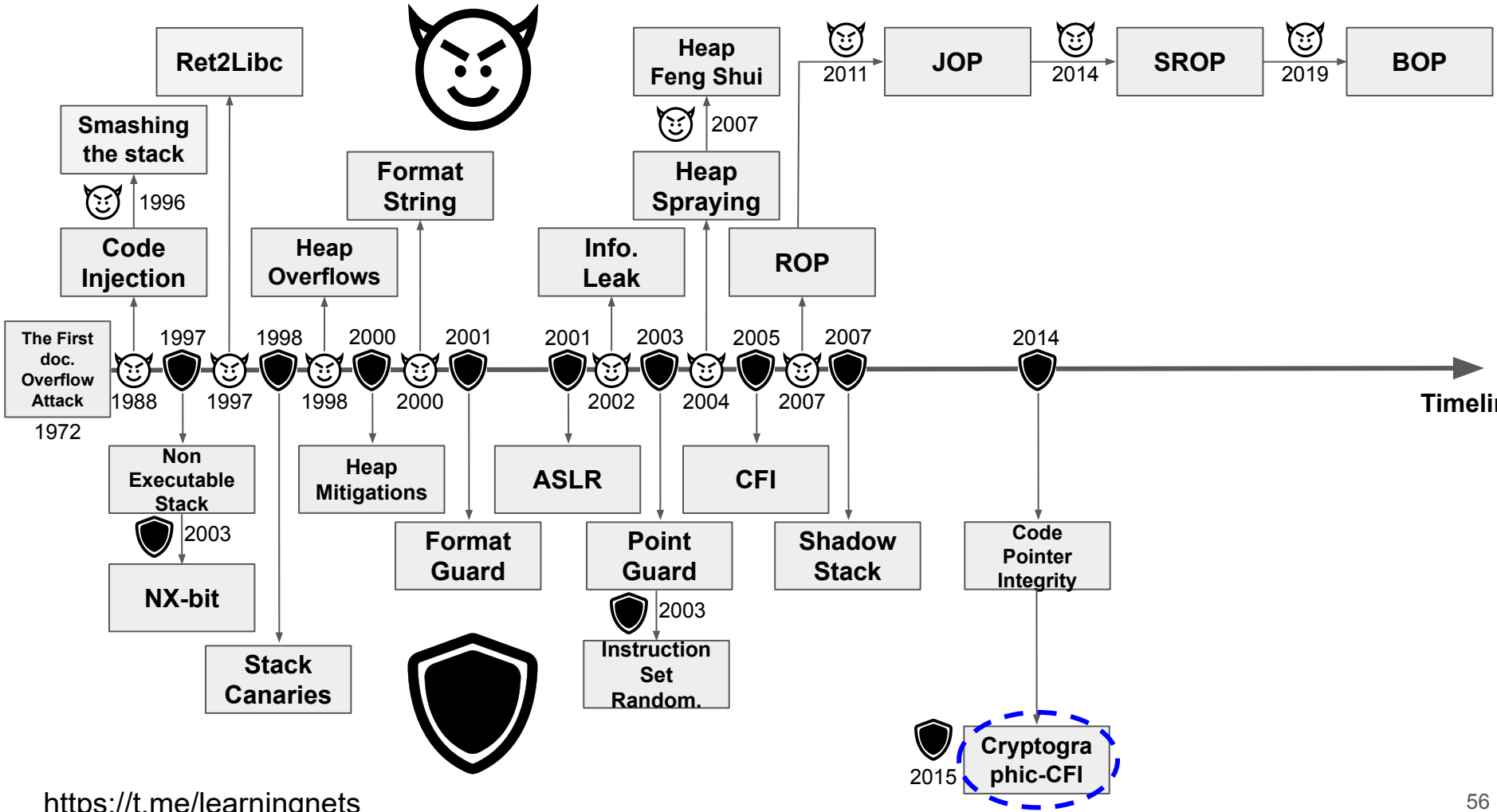
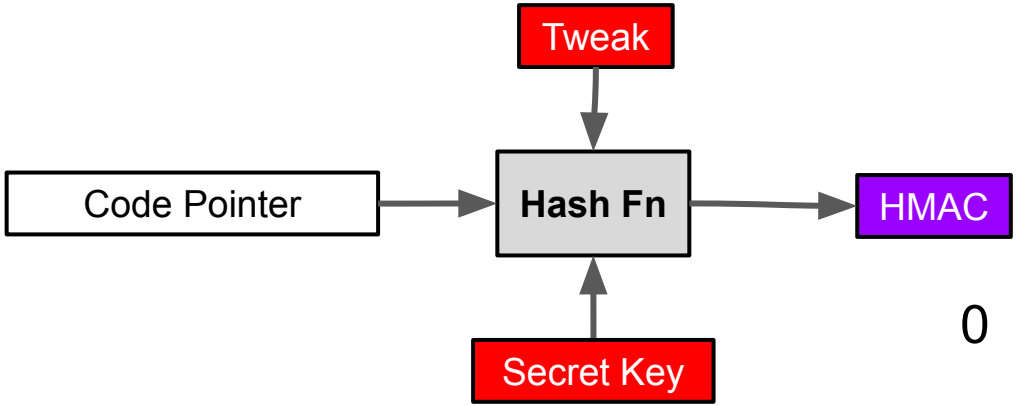


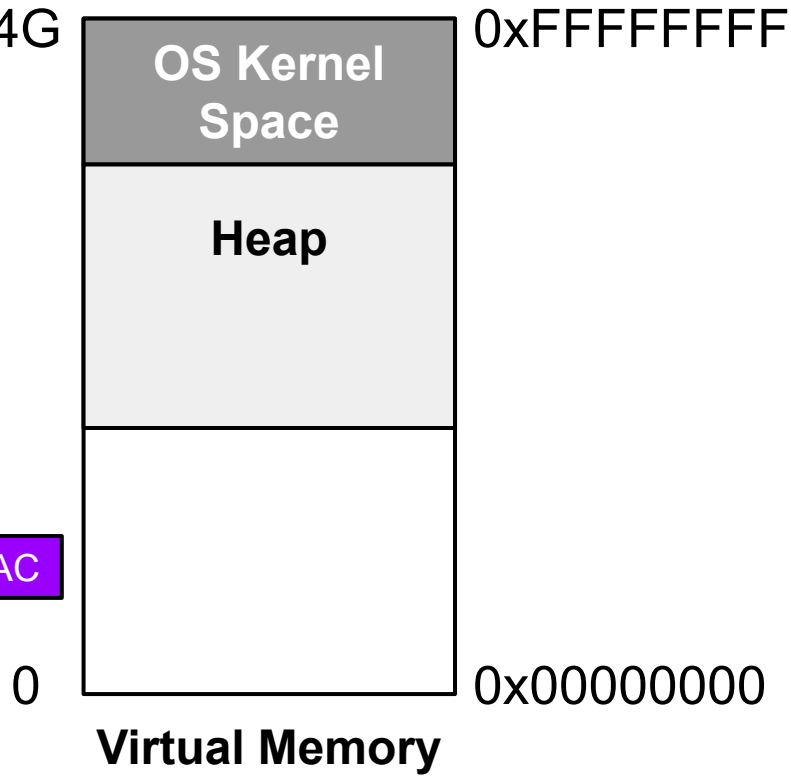
https://t.me/learningnets



CRYPTOGRAPHIC CONTROL FLOW INTEGRITY

- Create message authentication code (HMAC) for code pointers.
- Store HMAC in pointer itself.
- Verify HMAC upon pointer load.





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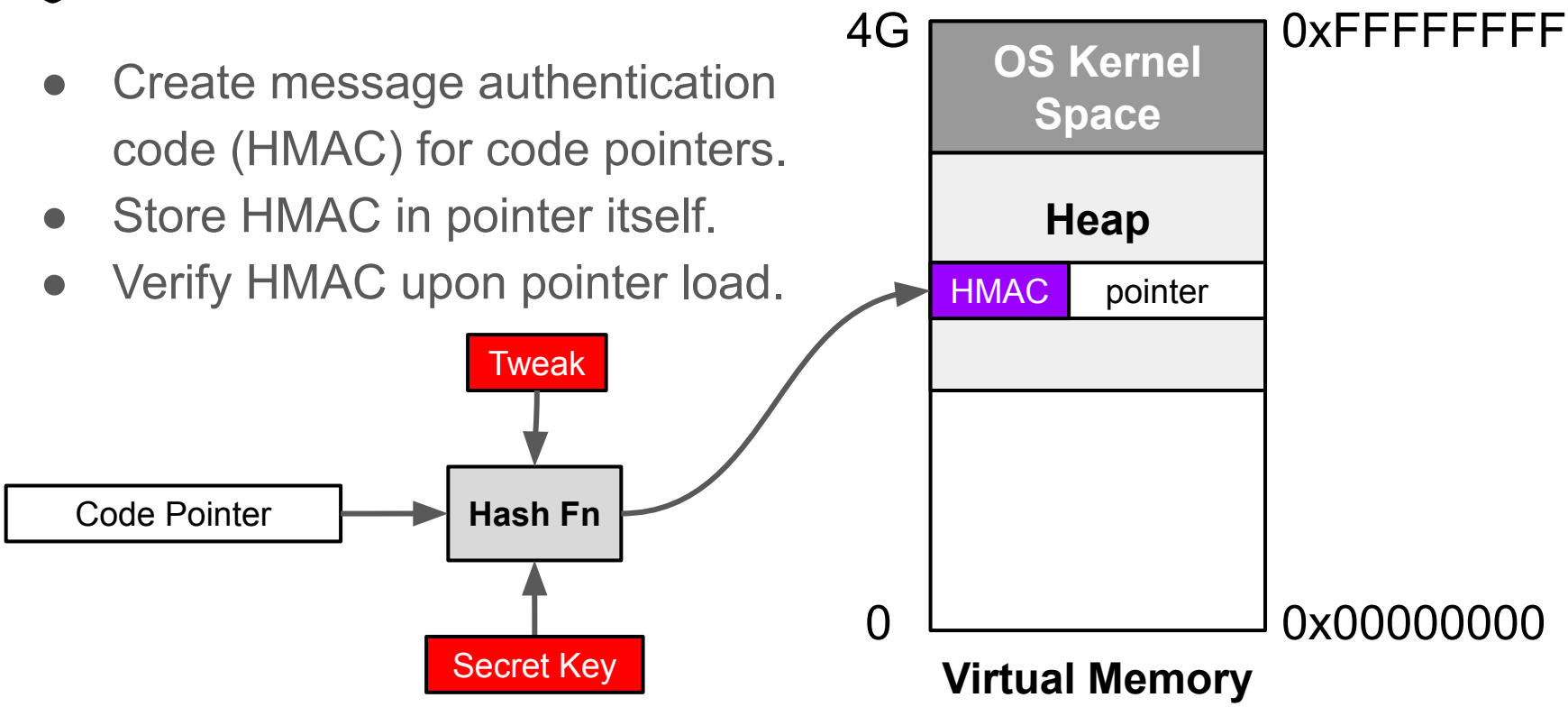

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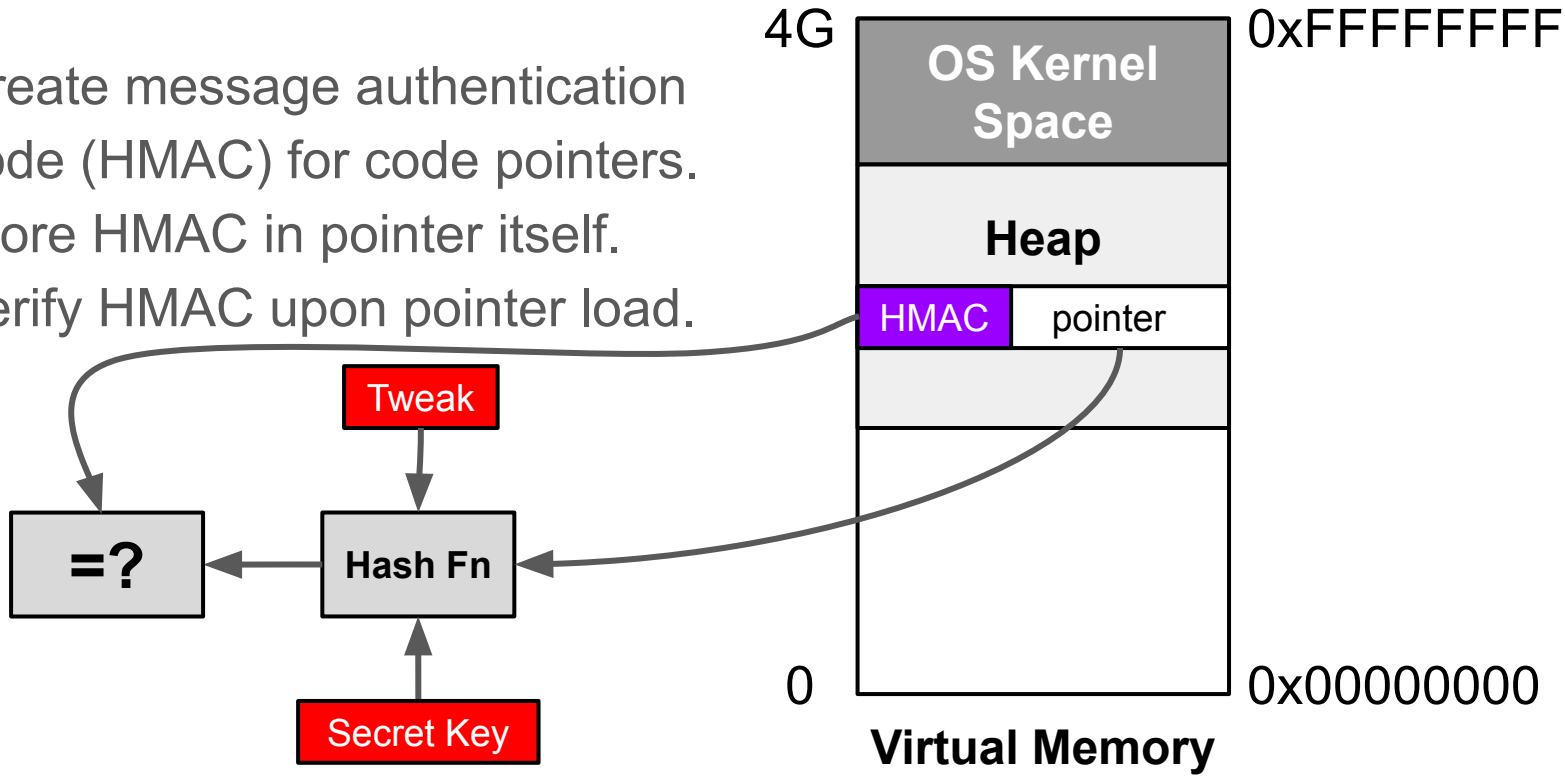

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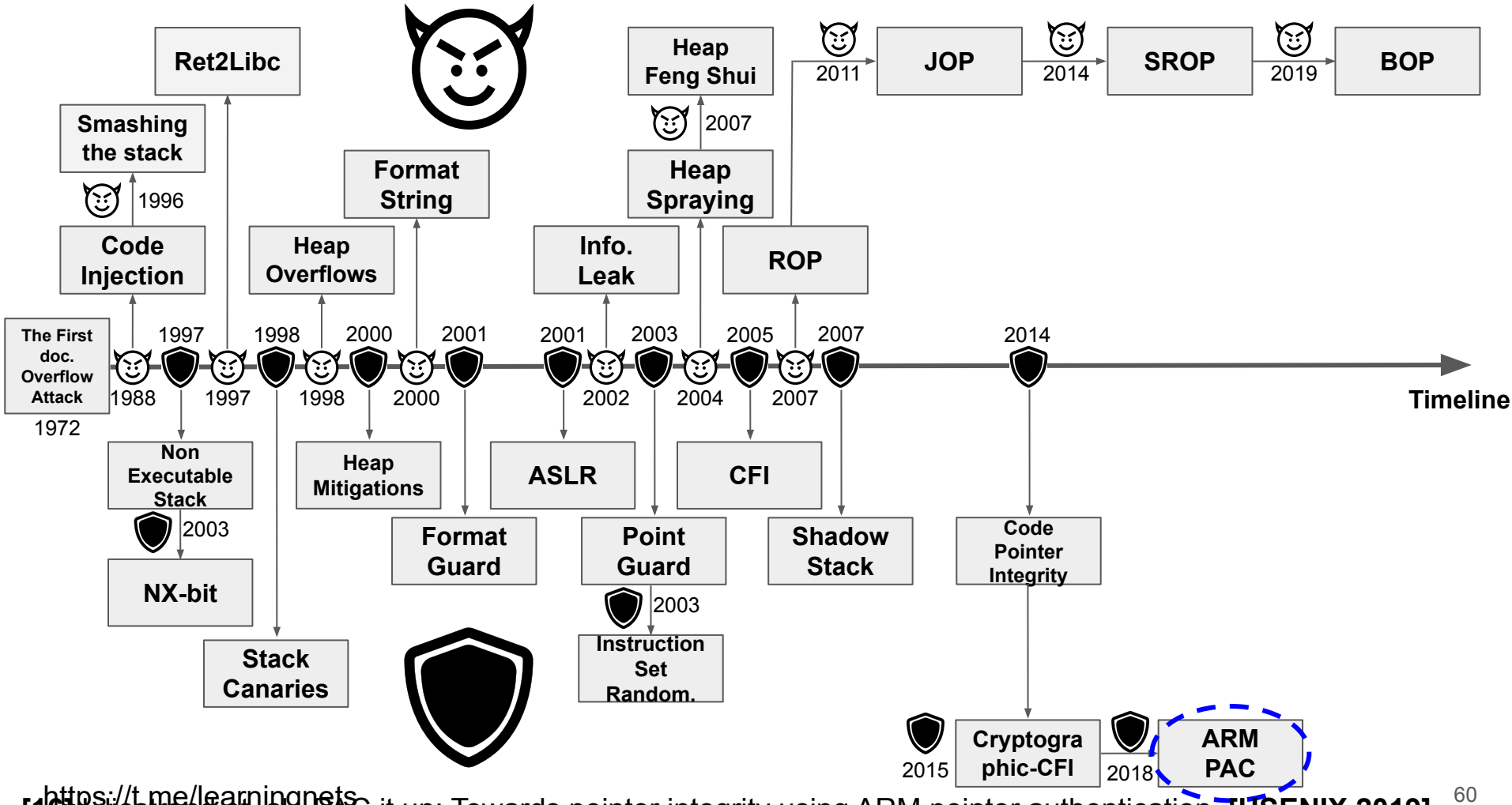

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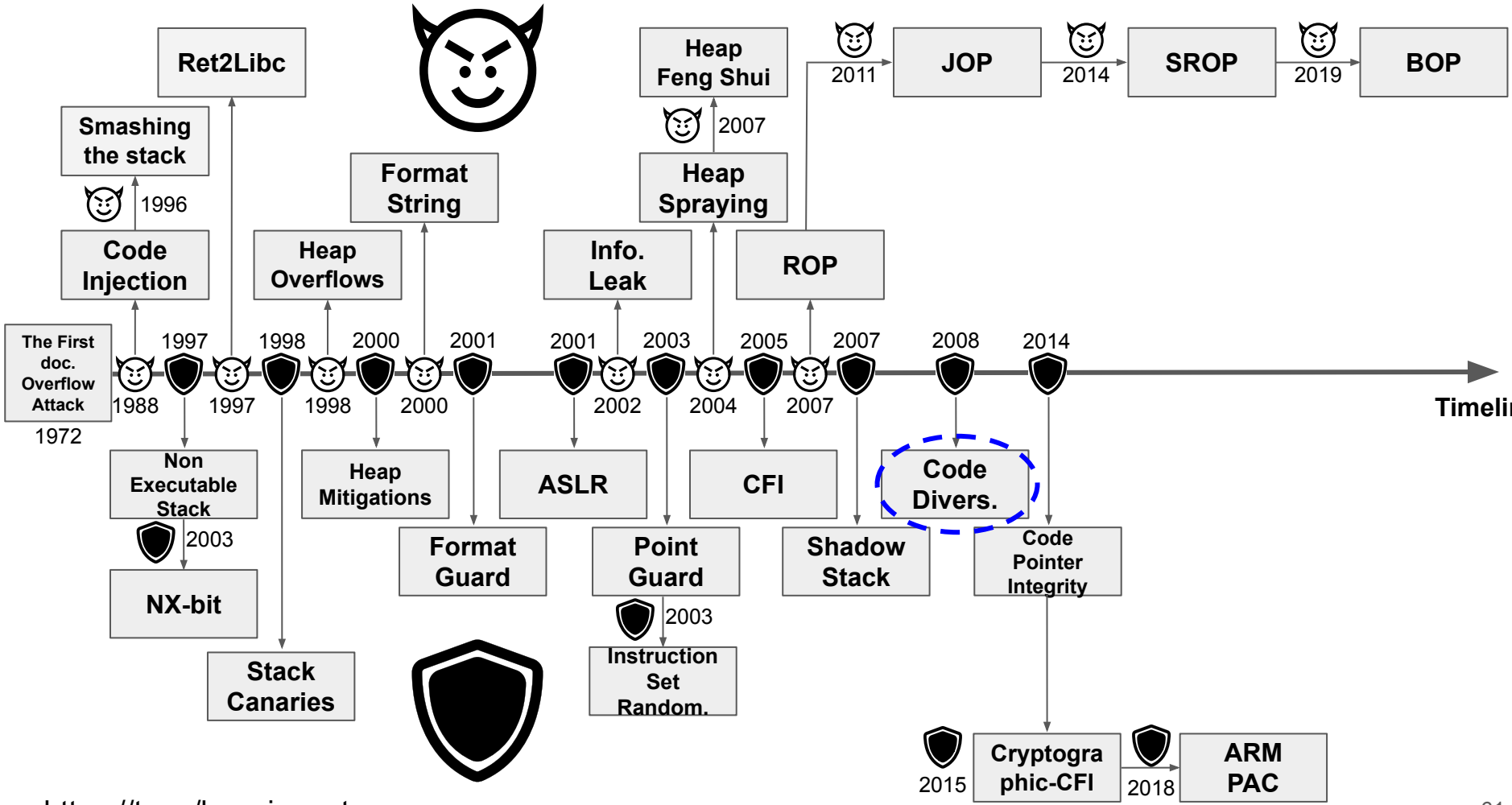

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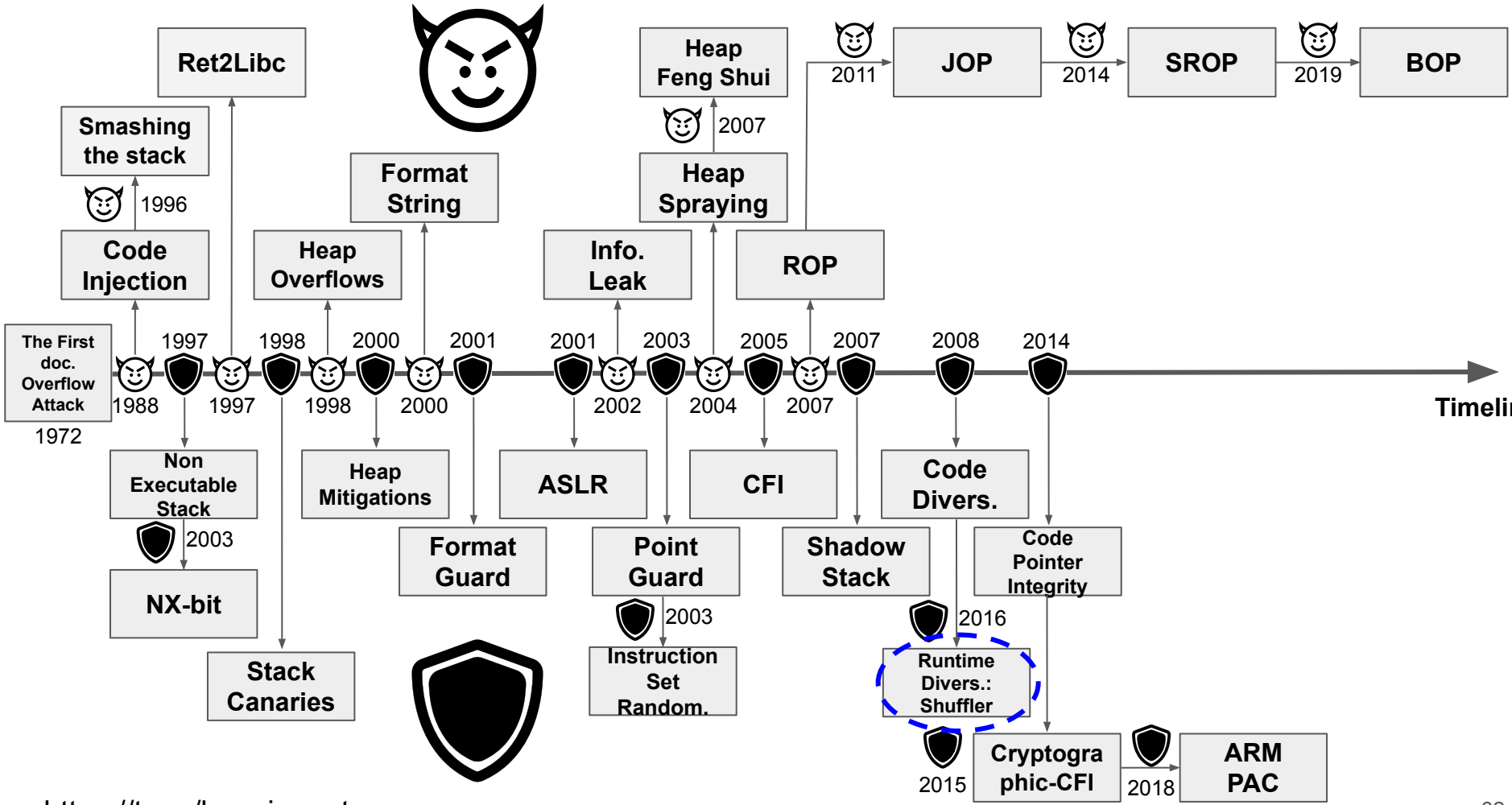
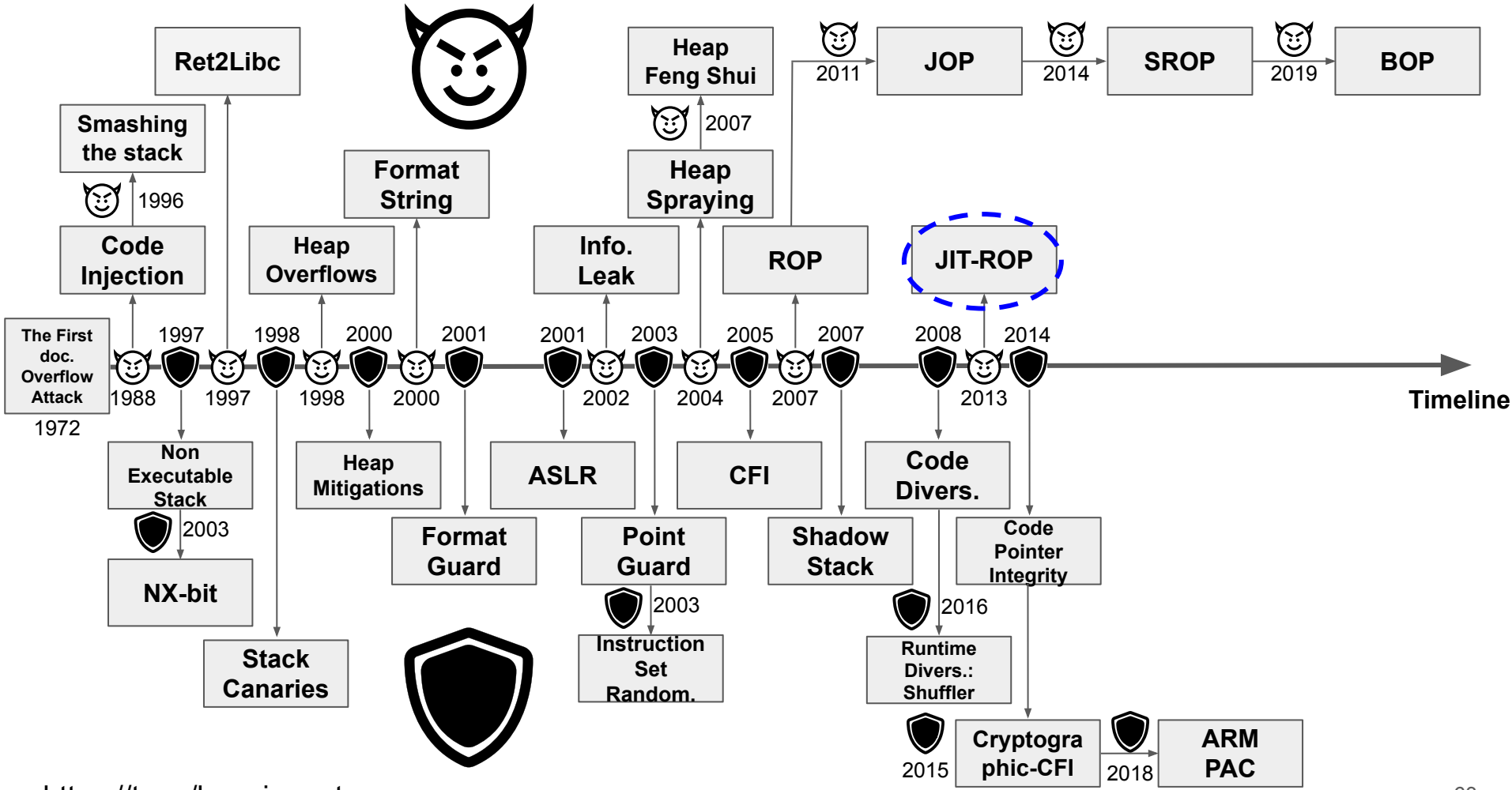
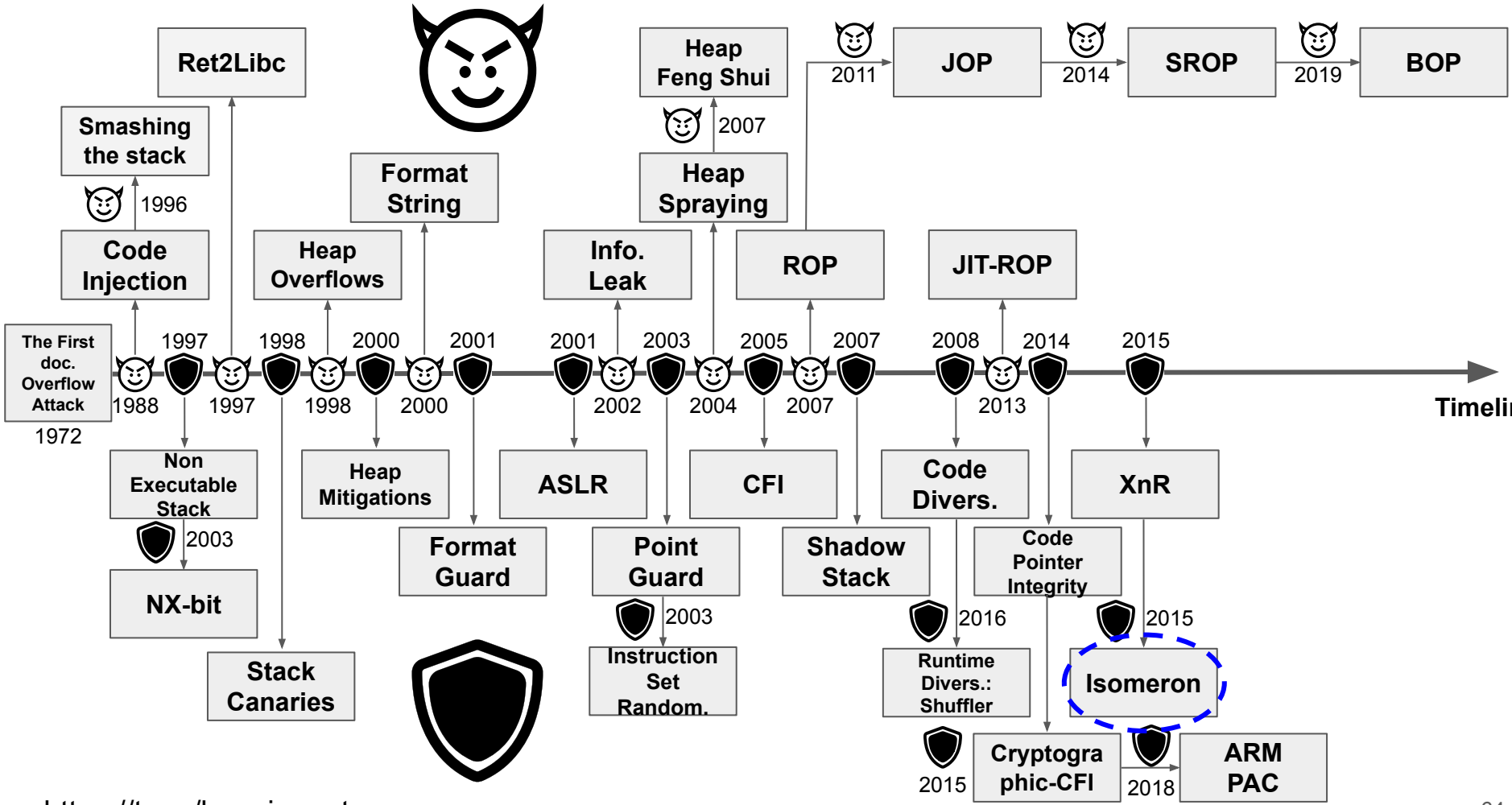


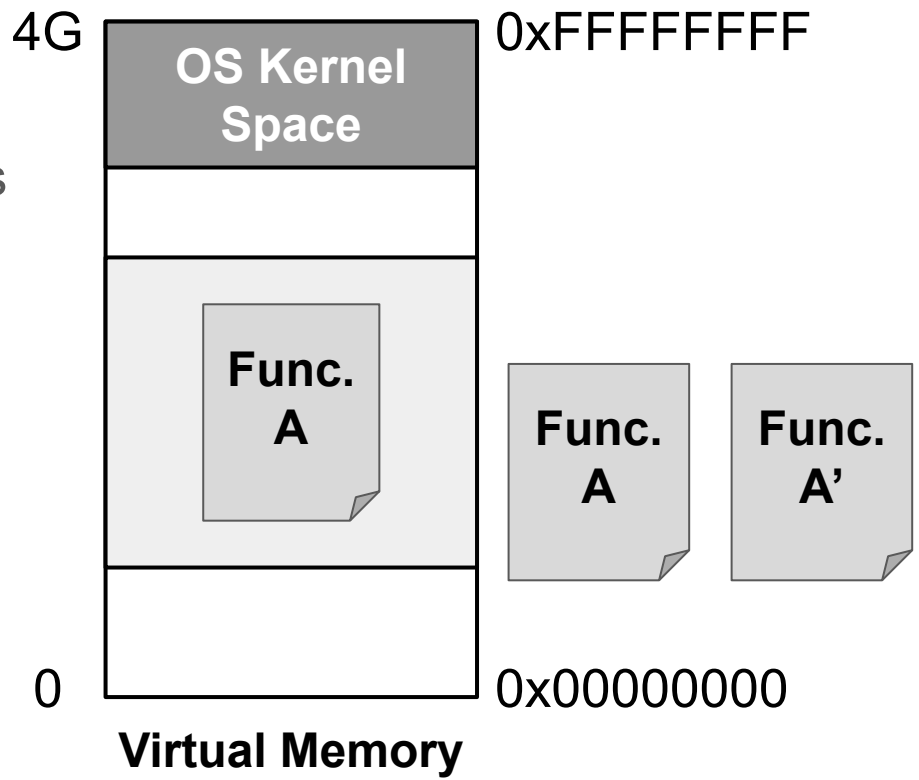


[8] Snow et. al,Just-in-time code reuse: On the effectiveness of fine-grained ASLR. **[S&P 2013]**



ISOMERON

- Main Idea:
  - Create two diversified variants of each function.



ISOMERON

- Main Idea:
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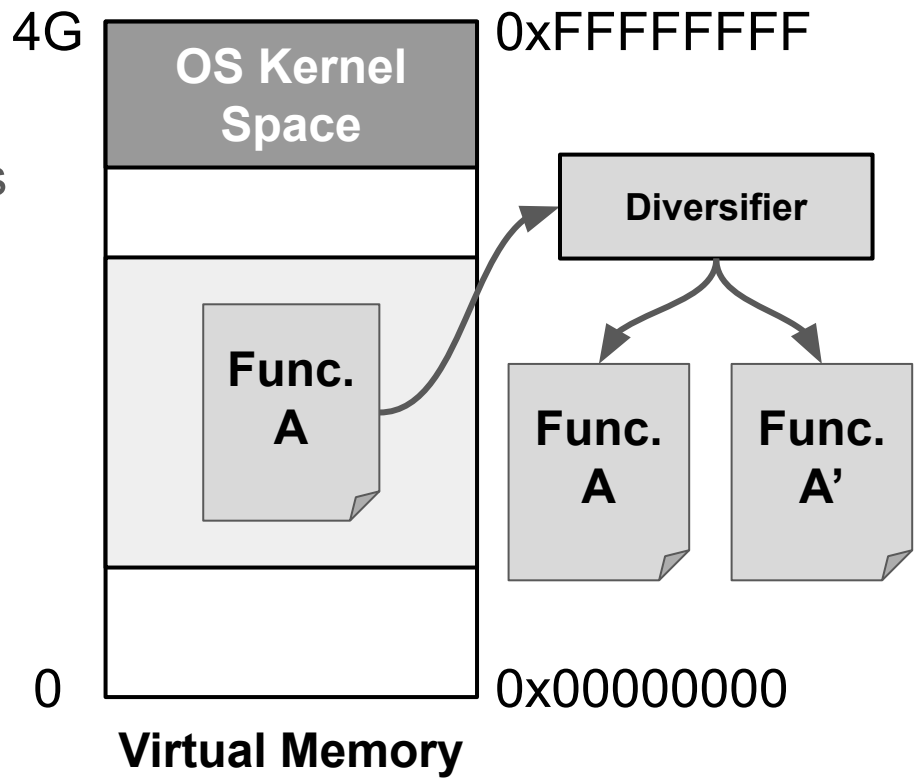

ISOMERON

- Main Idea:
  - Create two diversified variants of each function.
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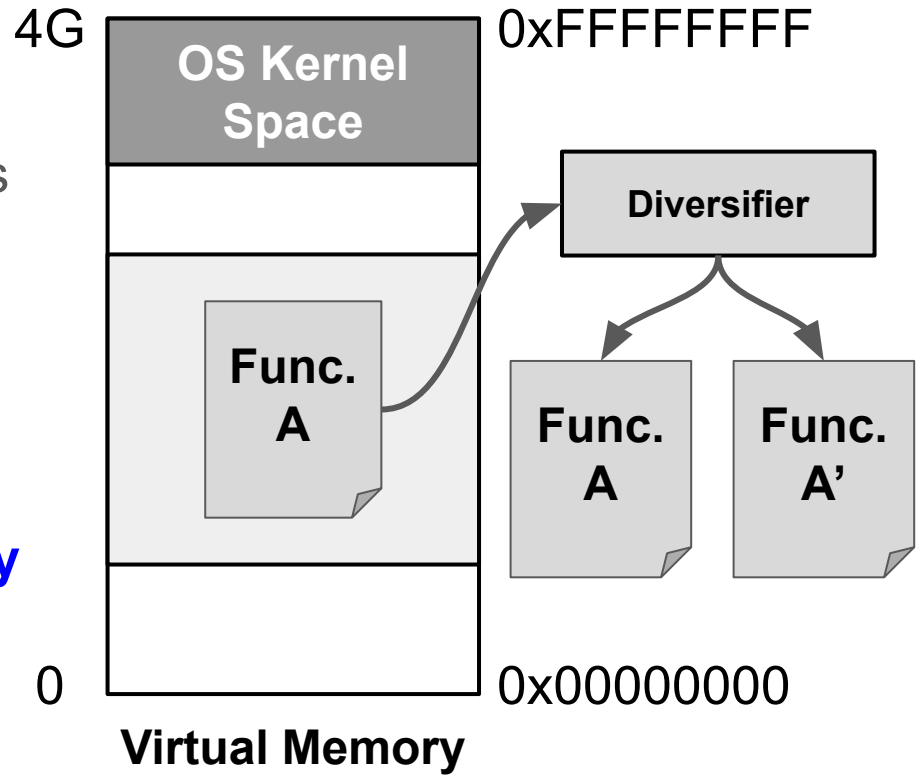
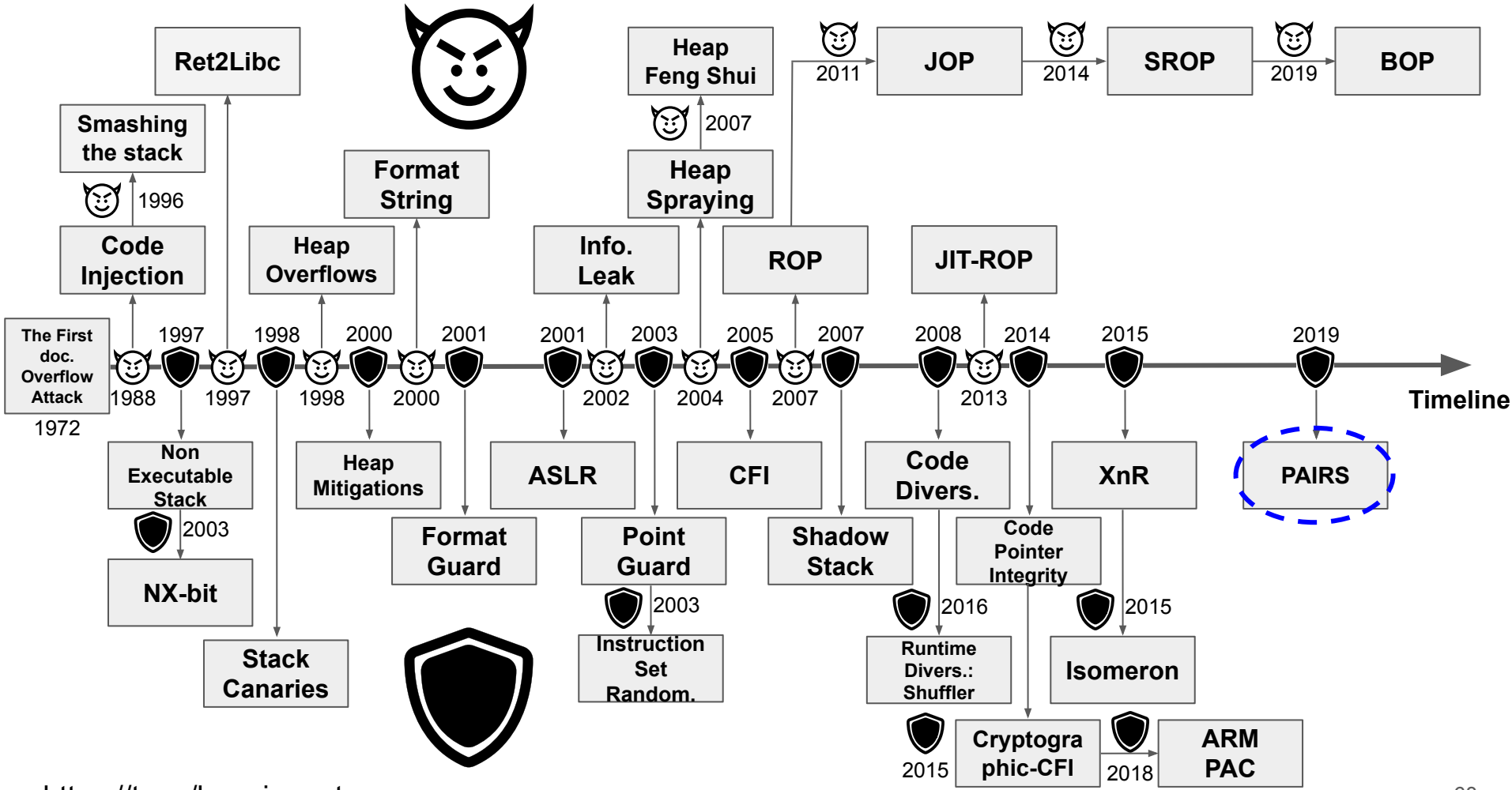
- Goal:
  - Prevent JIT-ROP from **reliably** building a gadget chain.





[2] Mohamed et. al, PAIRS: Control flow protection using phantom addressed instructions. **[arXiv 2019]**

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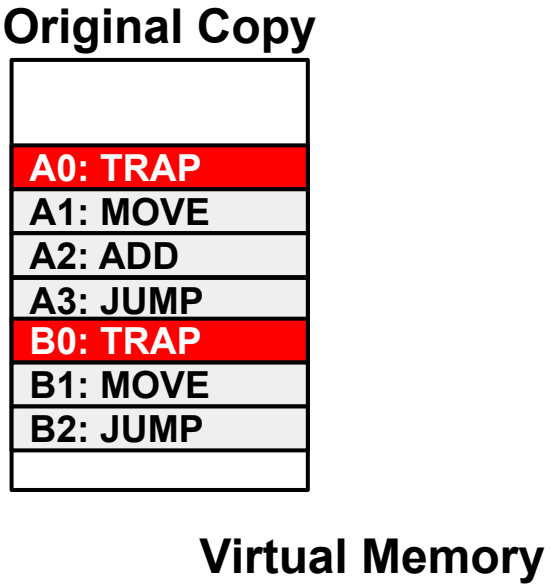

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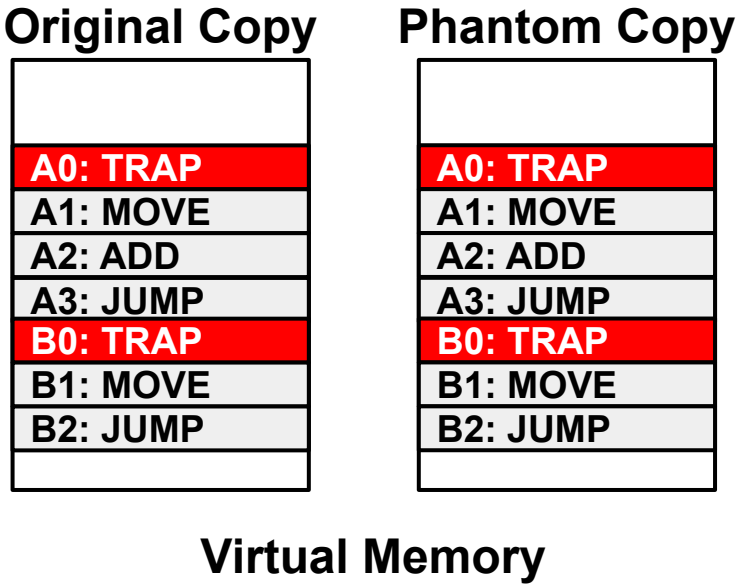

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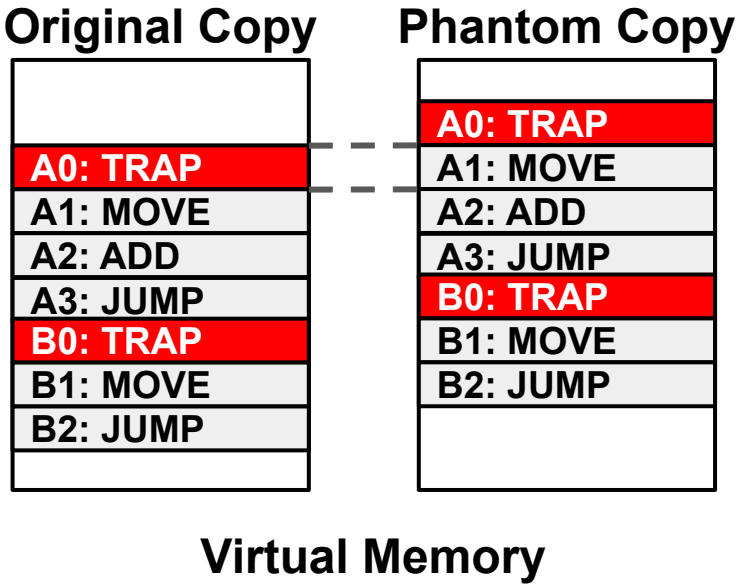

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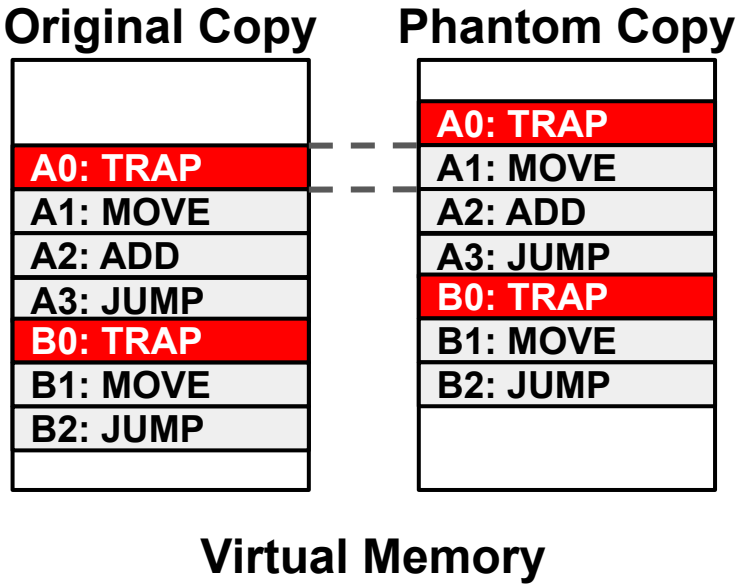

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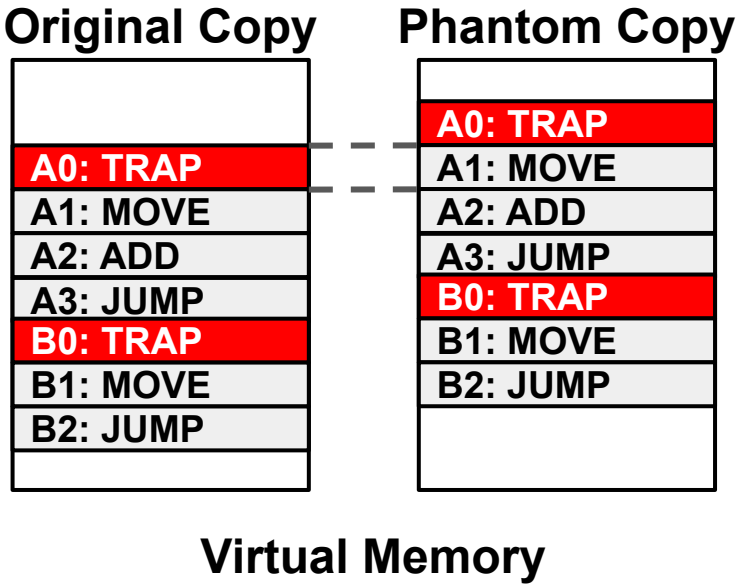

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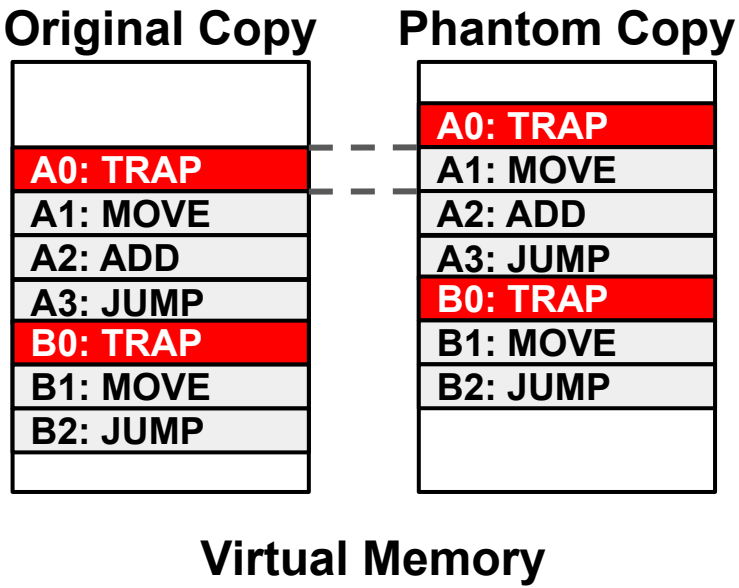
  - \+ Negligible perf. overheads.
  - \- No code pointers protection.



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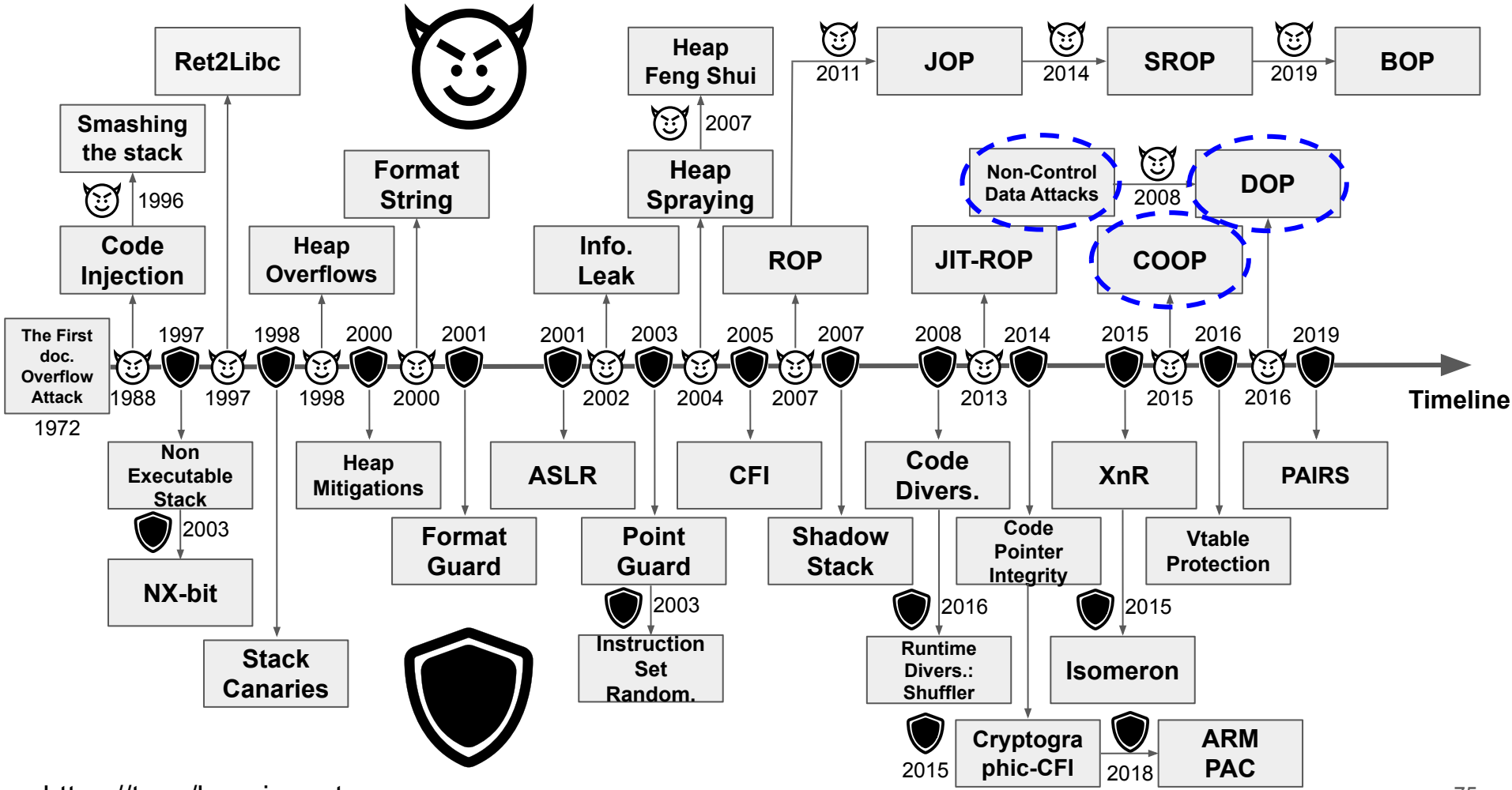
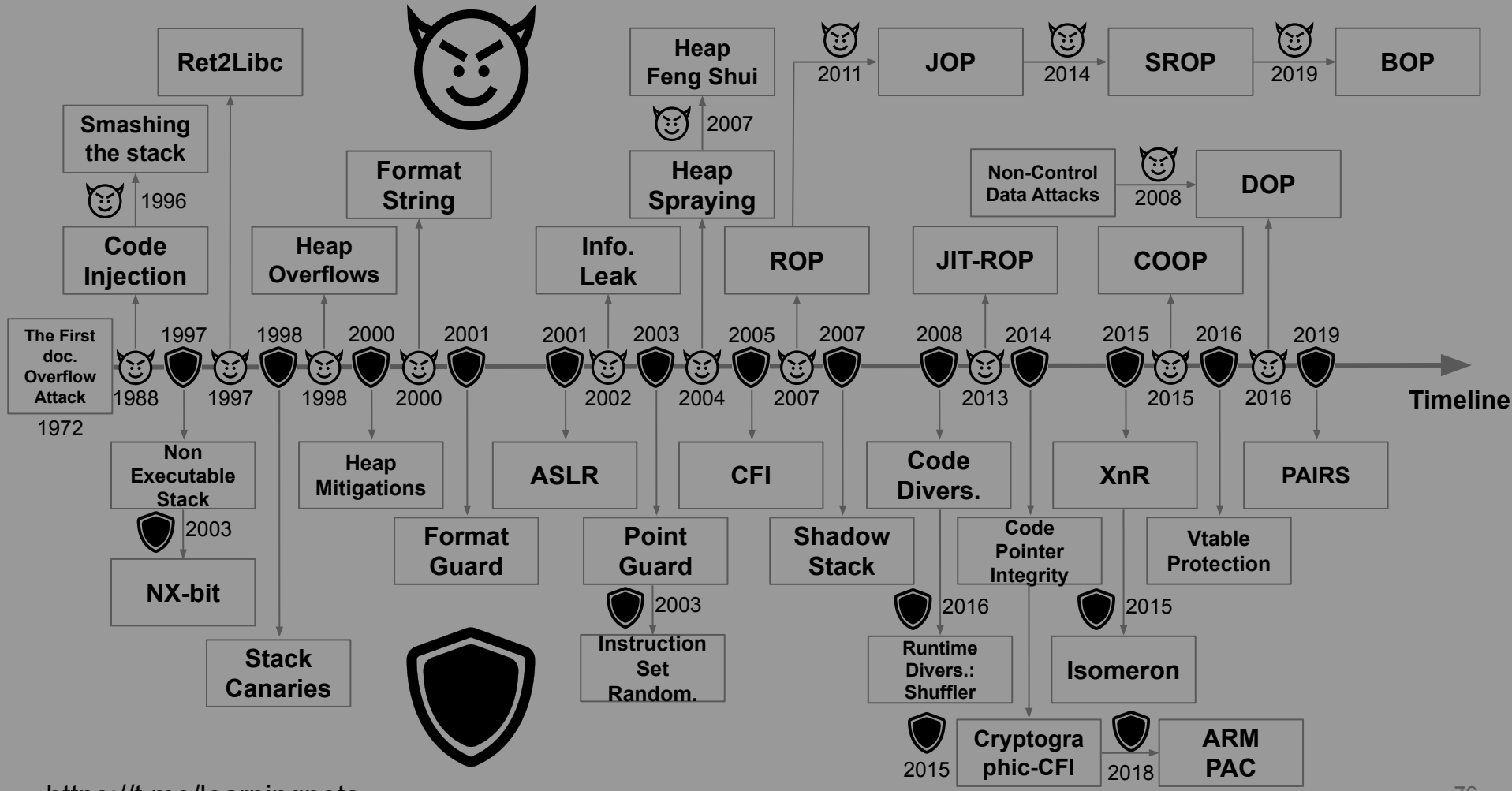
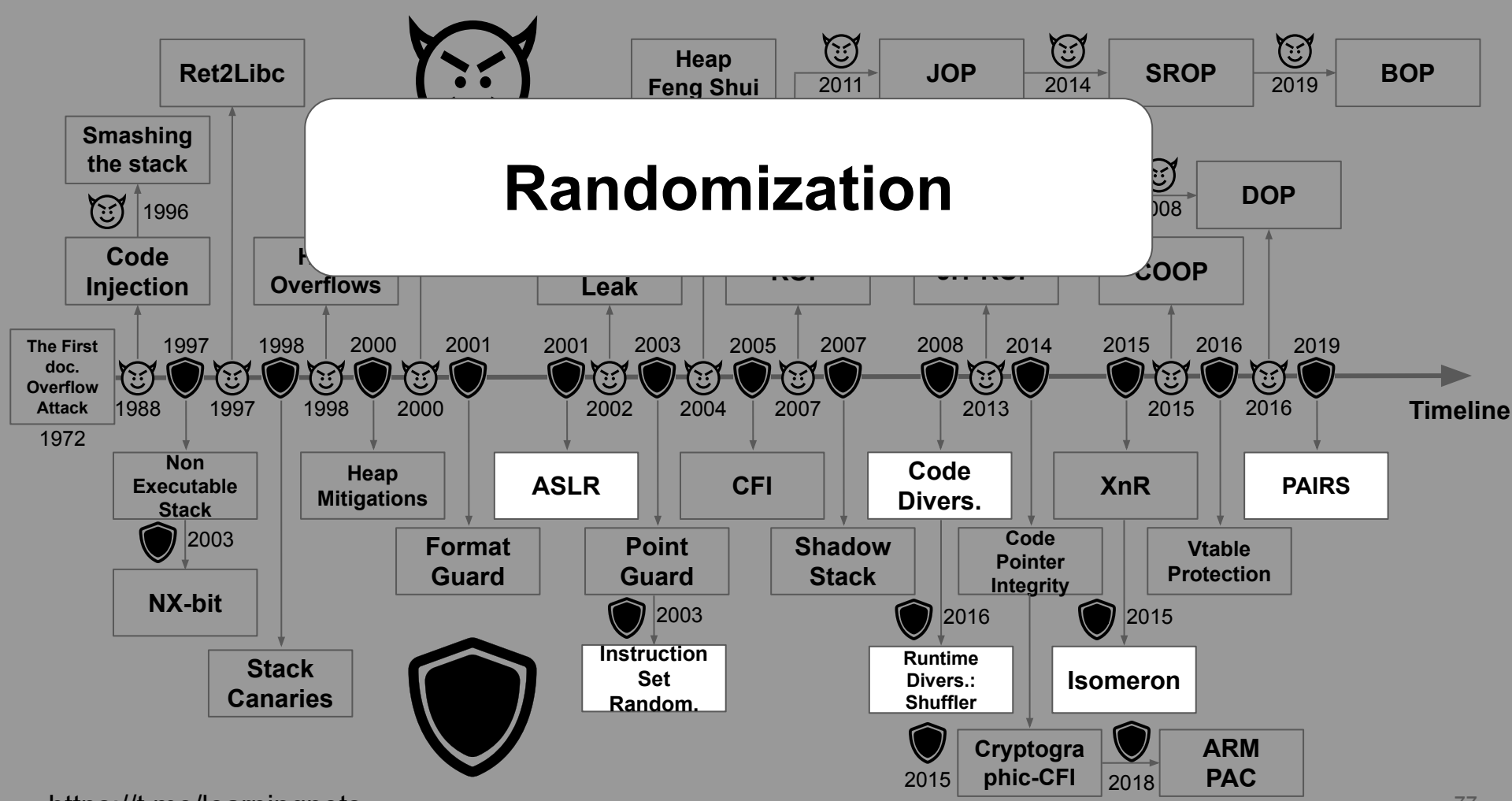
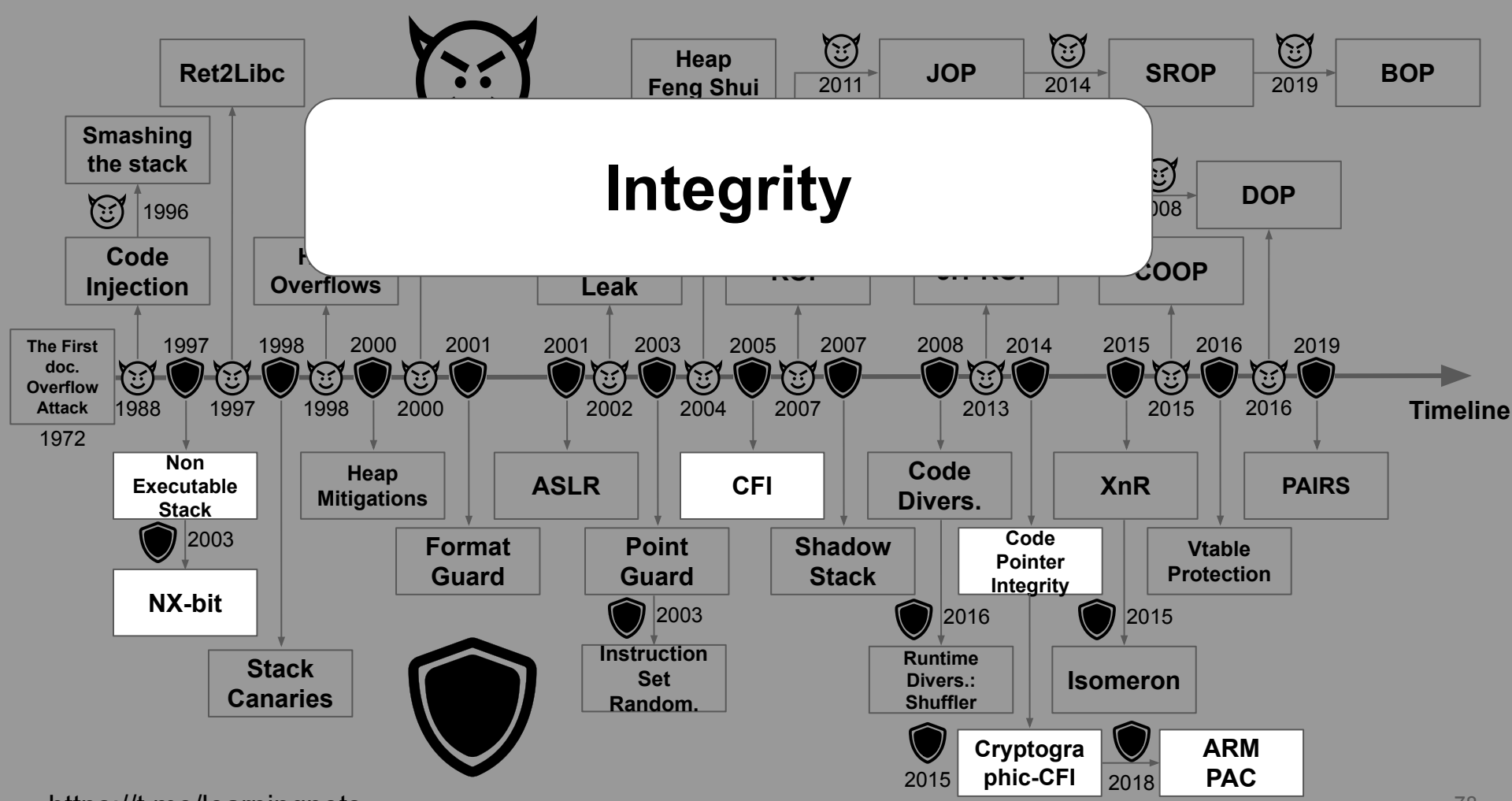
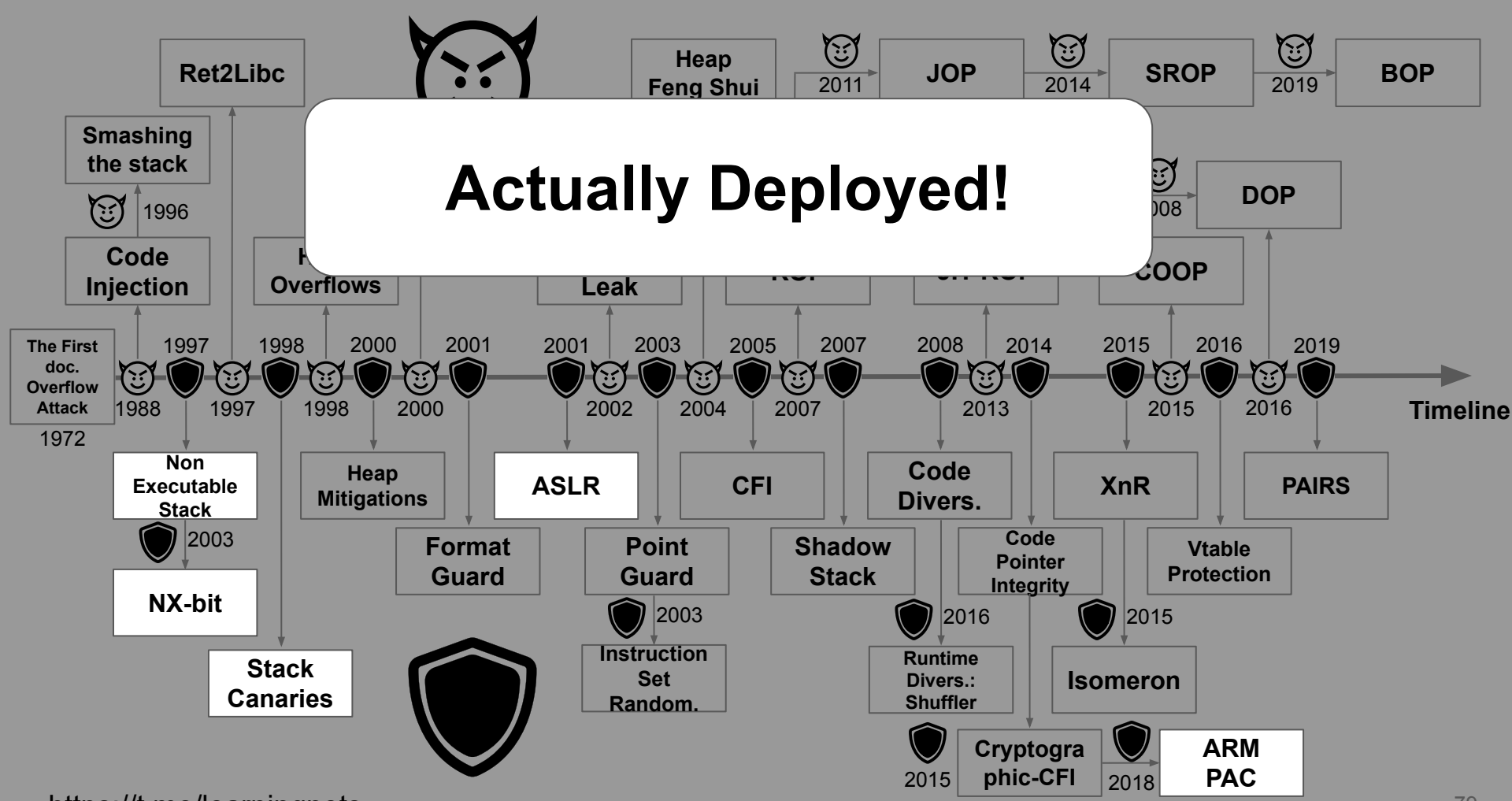


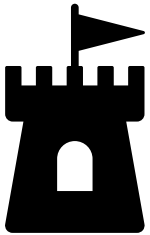
[10] Cheng et. al., Exploitation techniques and defenses for data-oriented attacks. **[SecDev 2019]**











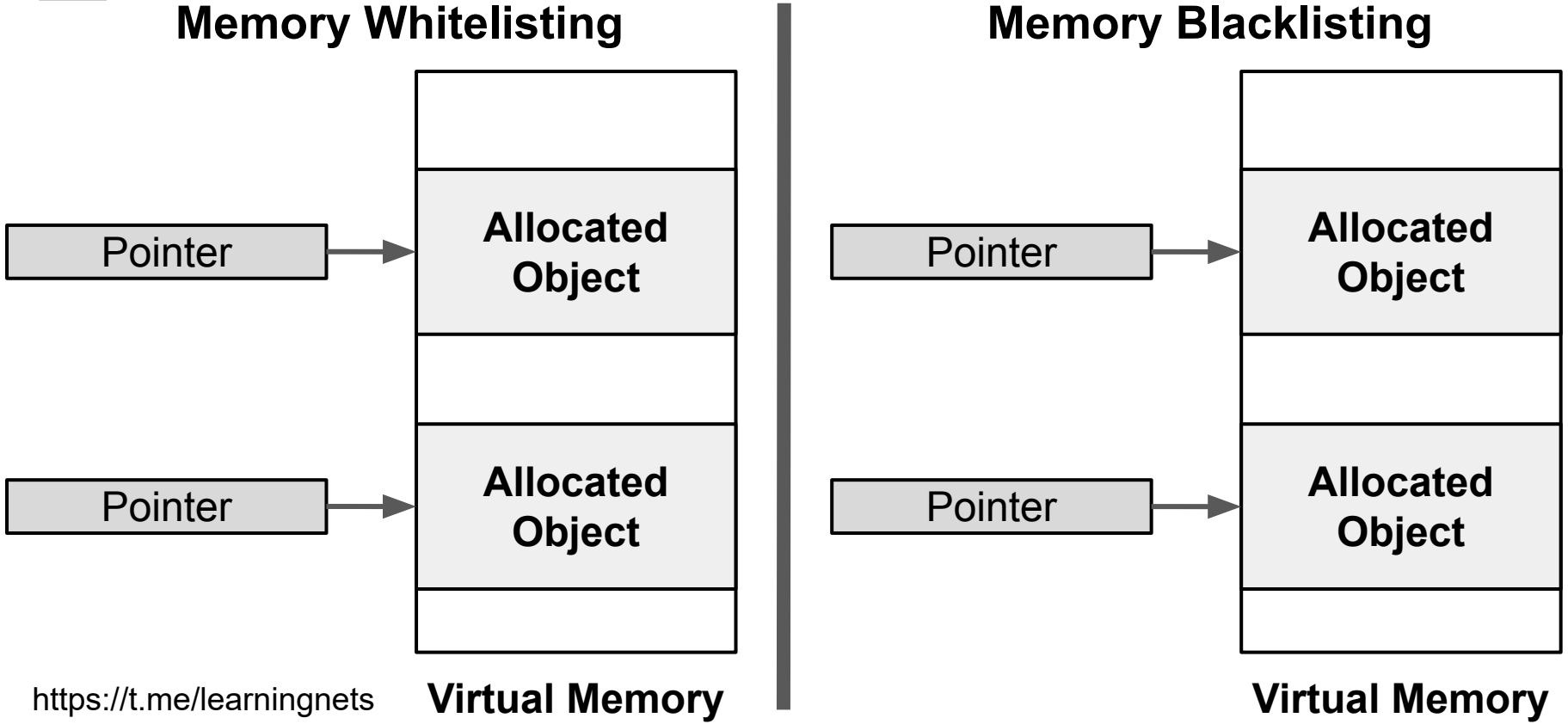
Memory Safety Techniques

MEMORY SAFETY TECHNIQUES

Spatial Memory Safety

Temporal Memory Safety

SPATIAL MEMORY SAFETY



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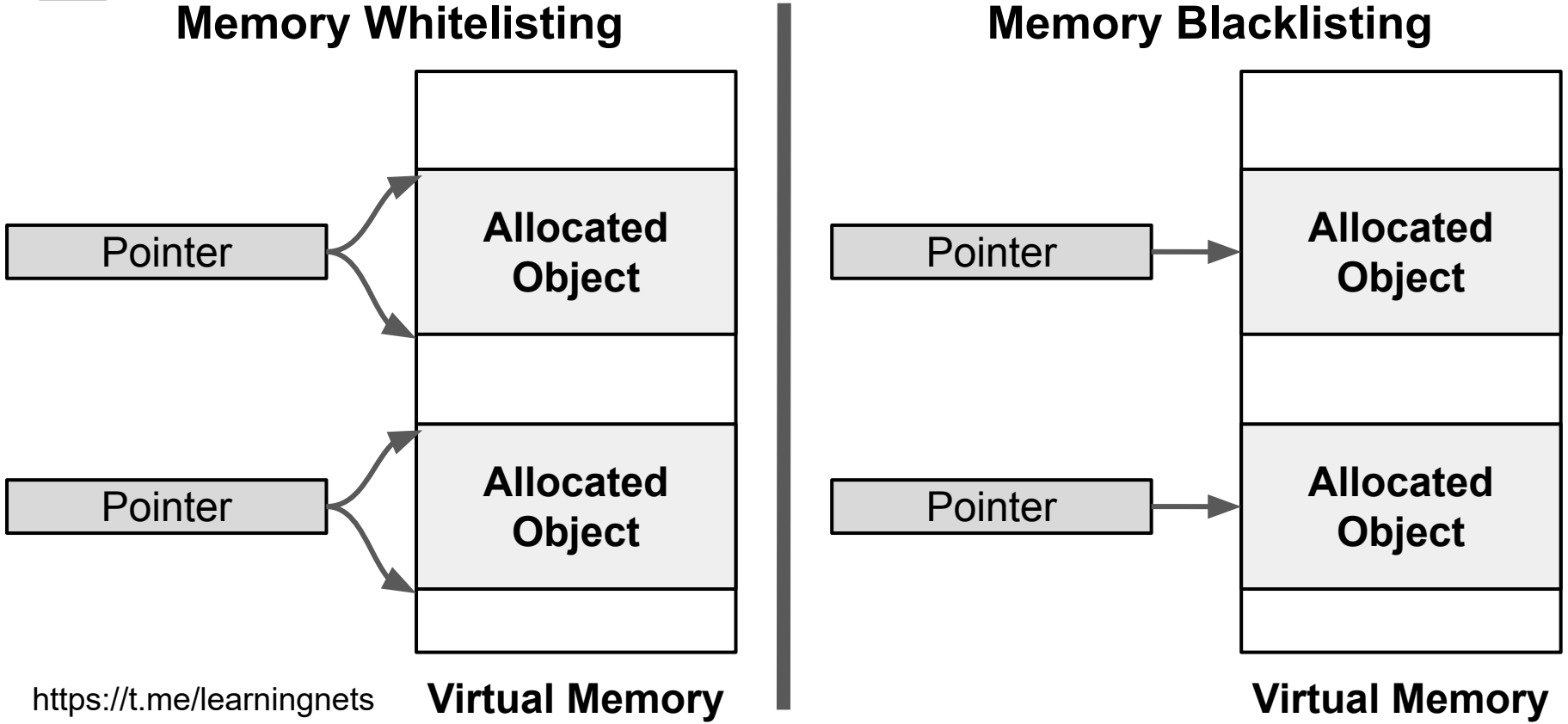
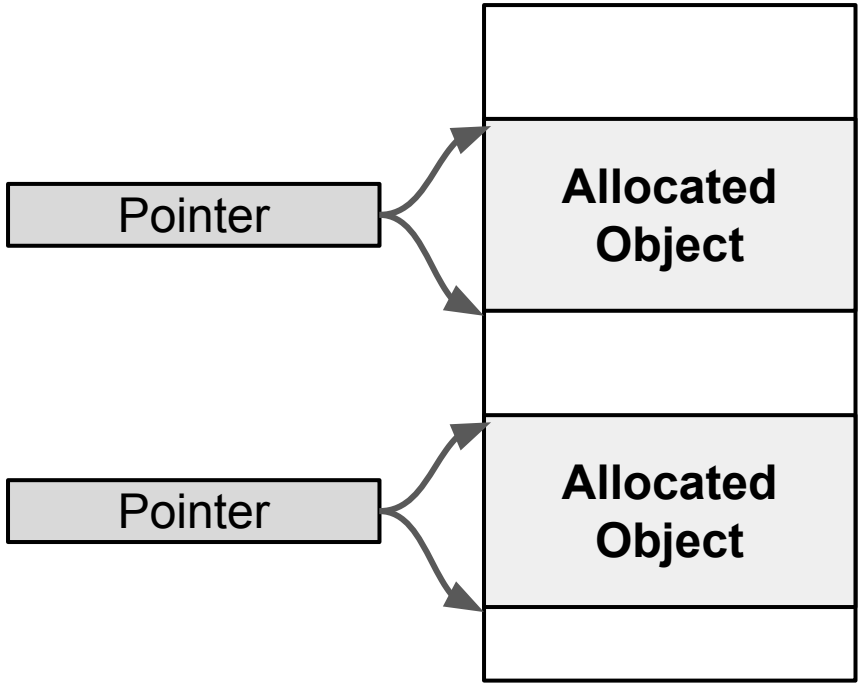
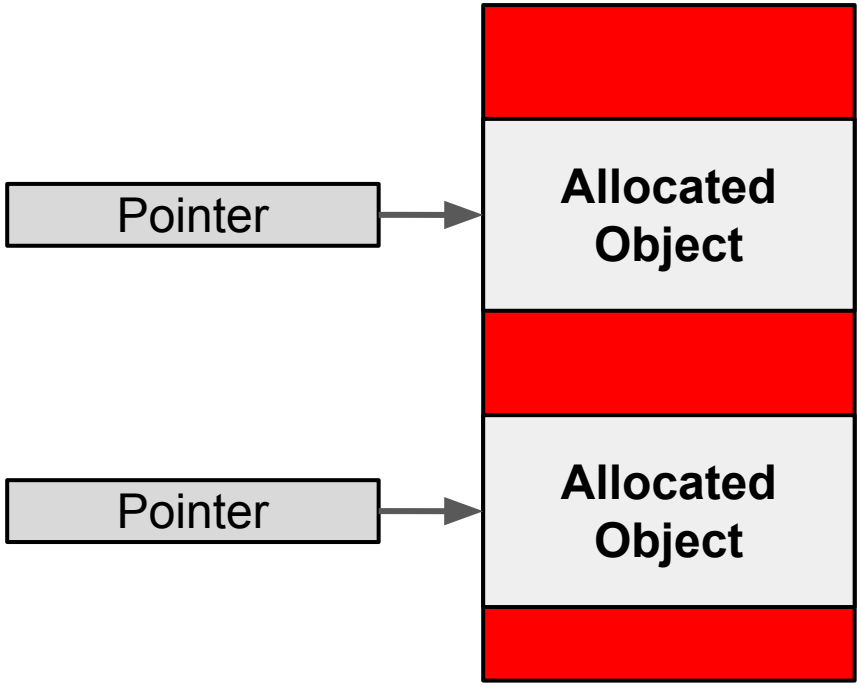


SPATIAL MEMORY SAFETY

Memory Whitelisting



Memory Blacklisting



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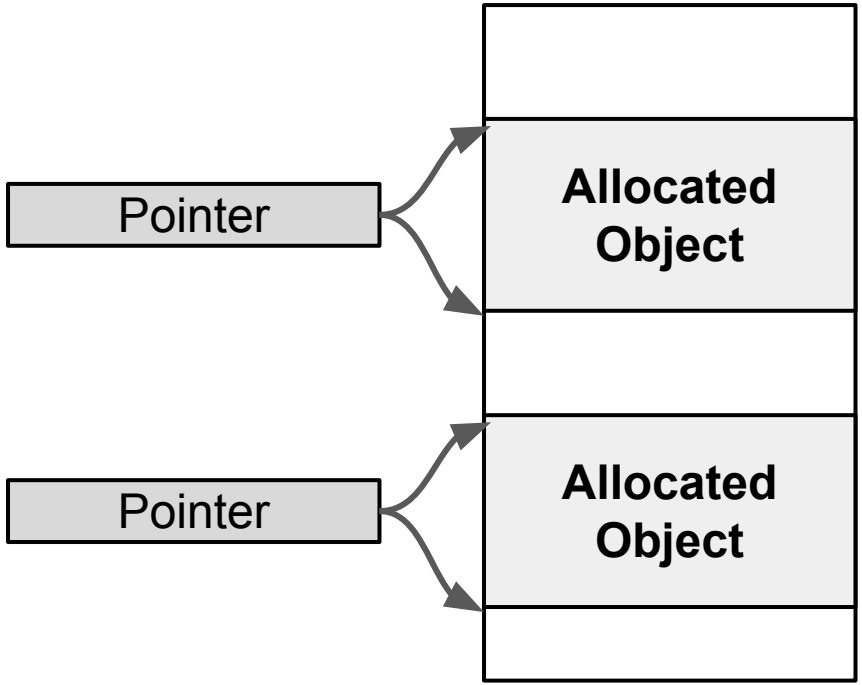

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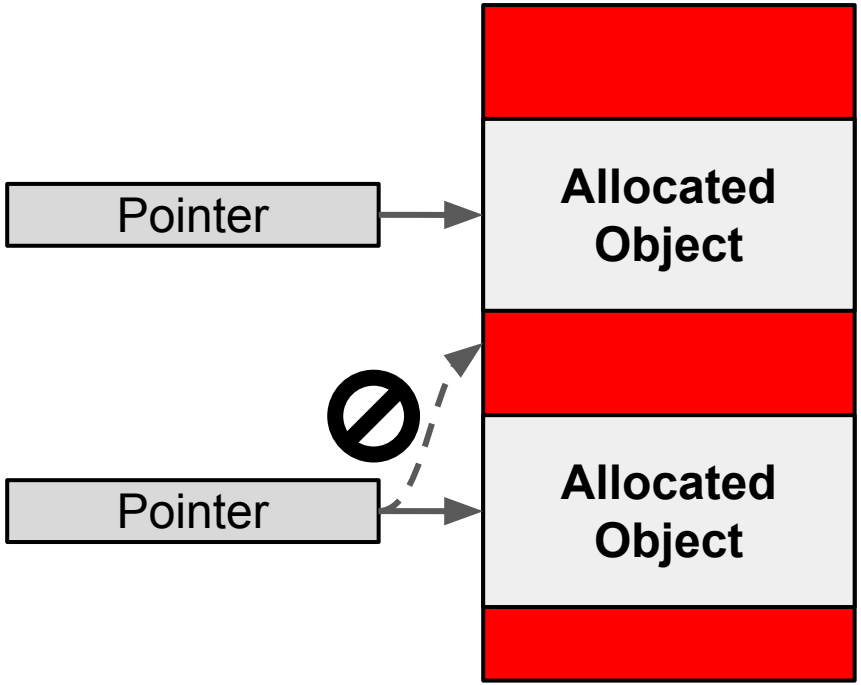

	Whitelisting		Blacklisting
	Per-object	**Per-pointer**	
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Co-joined Metadata	ARM Memory Tagging SPARC ADI		
No Metadata	Lowfat s/w	Lowfat h/w	

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  - Record bounds information for each **object** in a bounds table.
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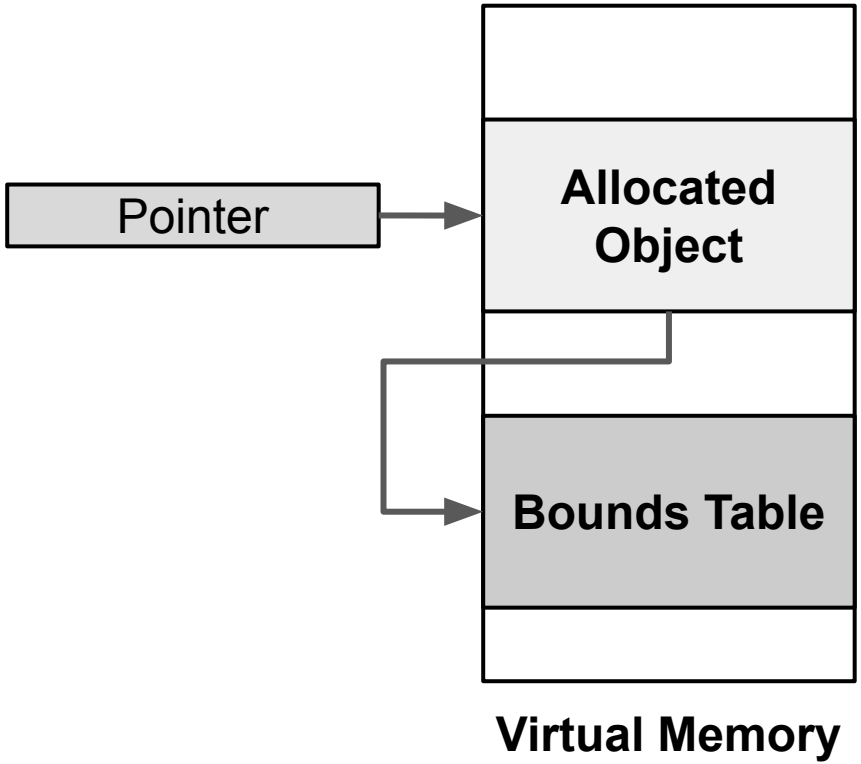

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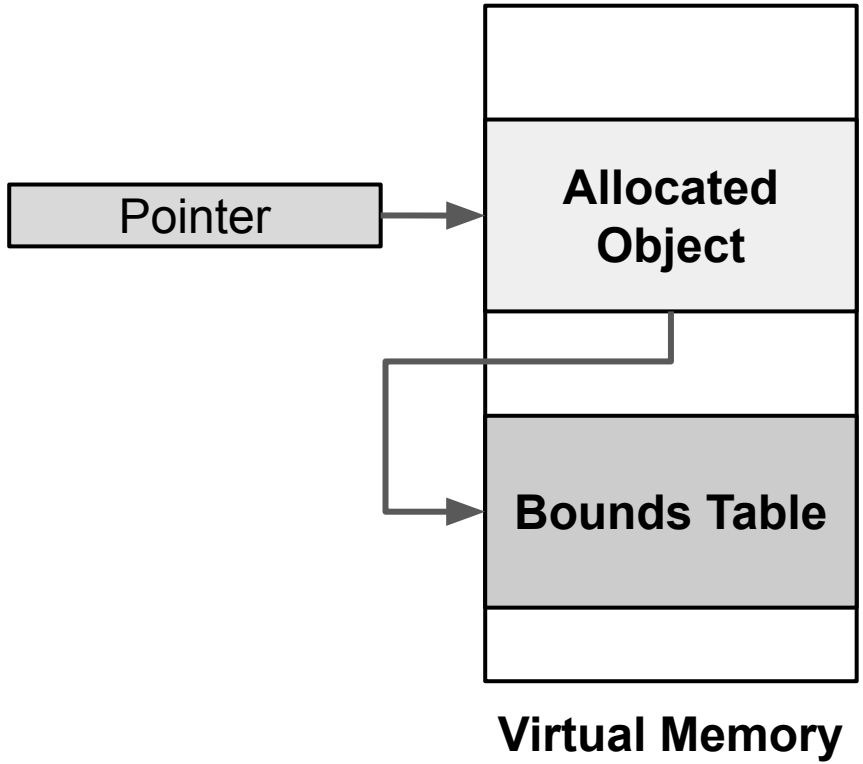

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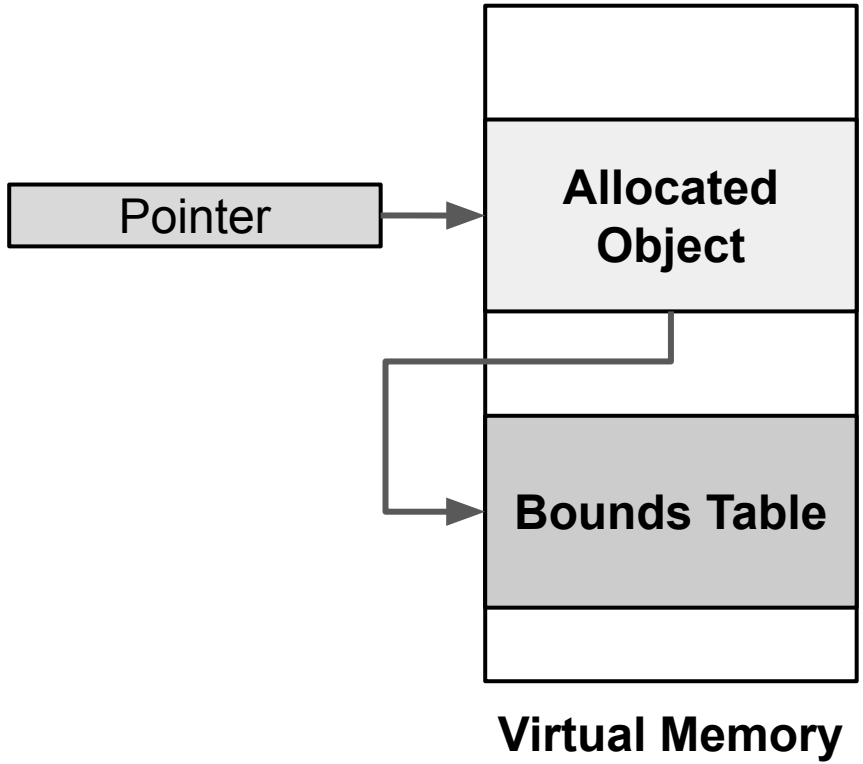

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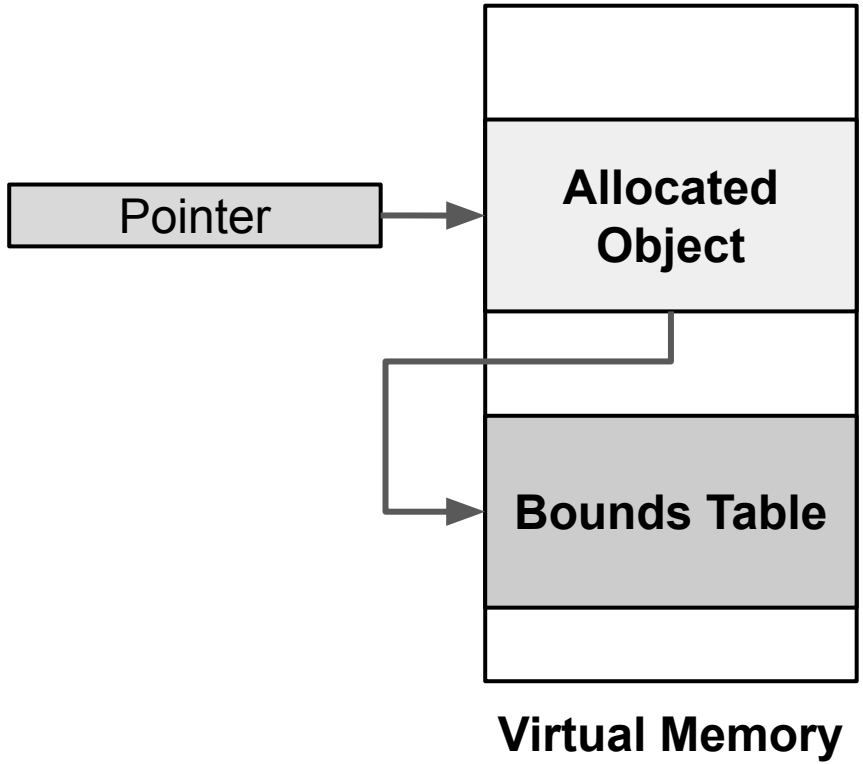
  - \- Costly range lookups.
  - \- No intra-object protection.



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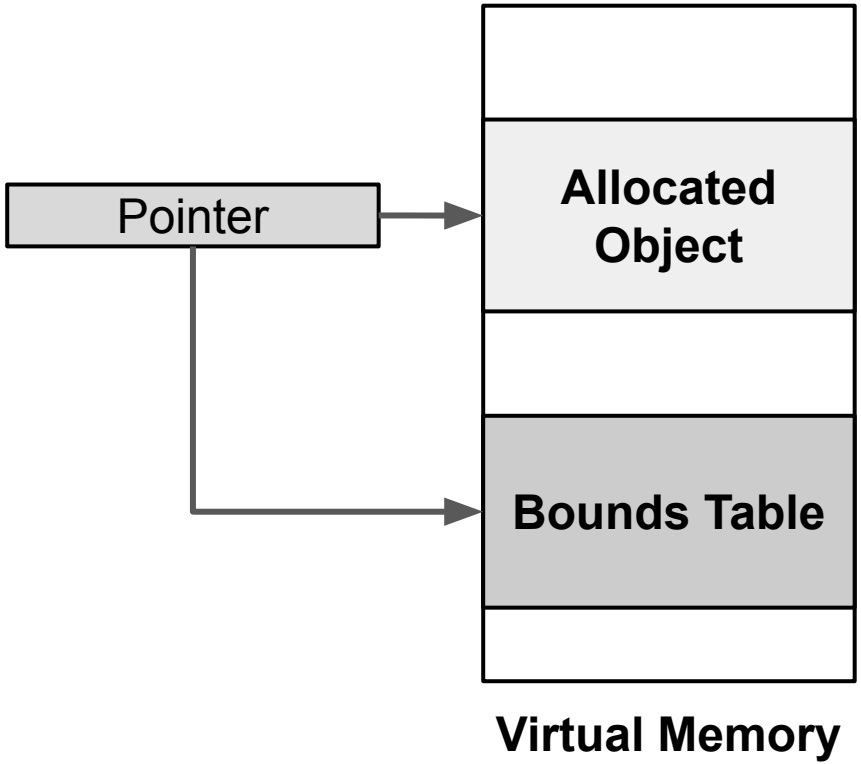

[17] Santosh Nagarakatte. Practical Low-Overhead Enforcement of Memory Safety. **[PhD Thesis 2012]**

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- Pros and Cons:
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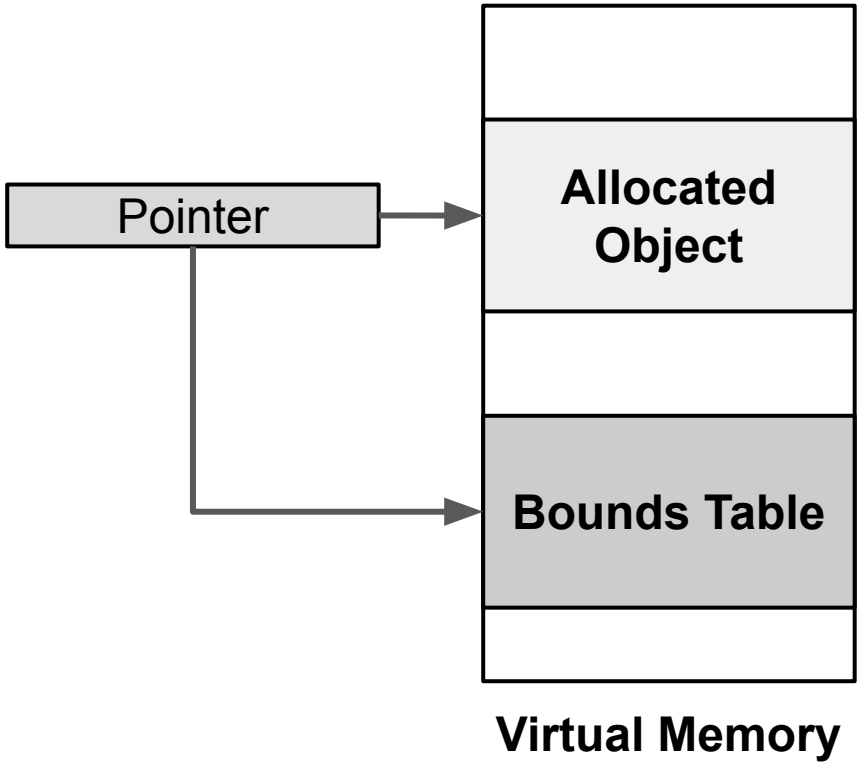

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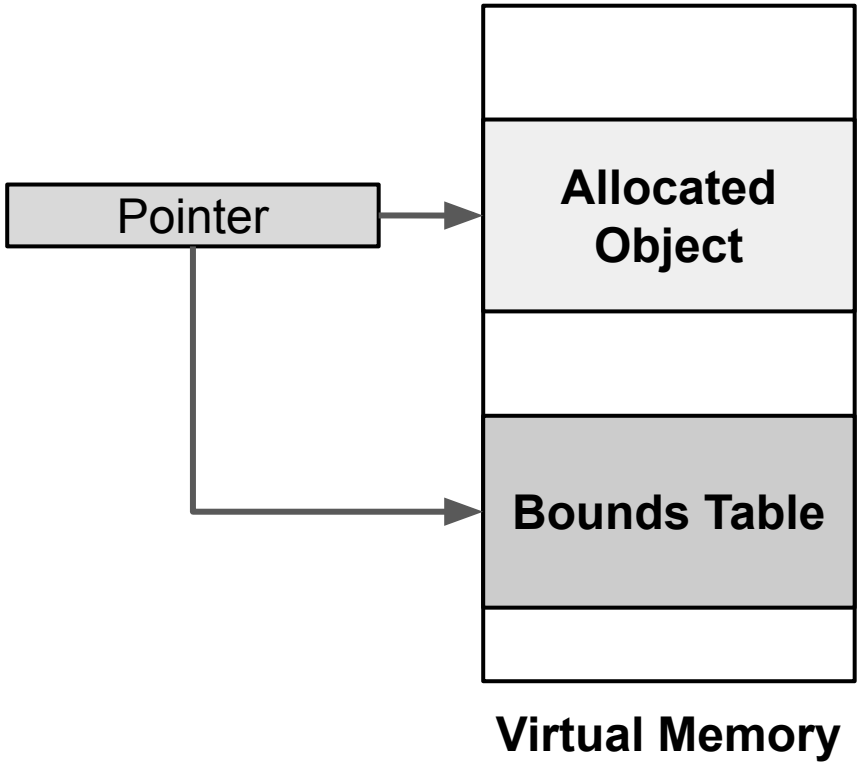
  - \- Problematic for multi-threading.



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[18] Alexandre Joannou. Optimizing the CHERI capability machine. **[PhD Thesis 2019]**

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Co-joined Metadata	ARM Memory Tagging SPARC ADI		
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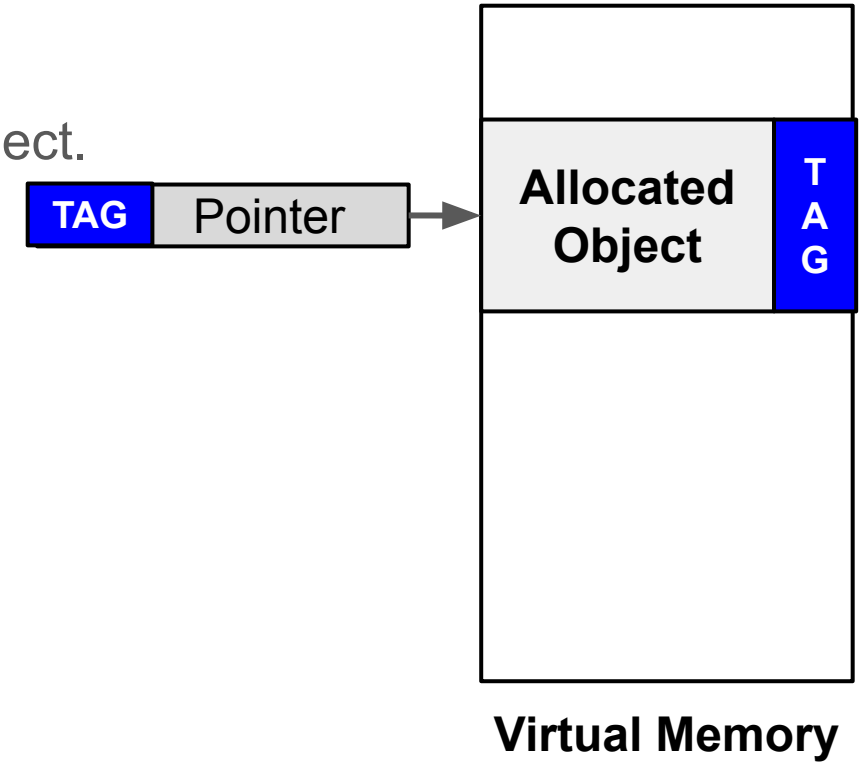
WHITELISTING: CO-JOINED METADATA

- Main Idea:
  - Assign a tag for each pointer/object.



[34] Serebryany et. al., "Memory tagging and how it improves C/C++ memory safety. **[arXiv 2018]**

WHITELISTING: CO-JOINED METADATA

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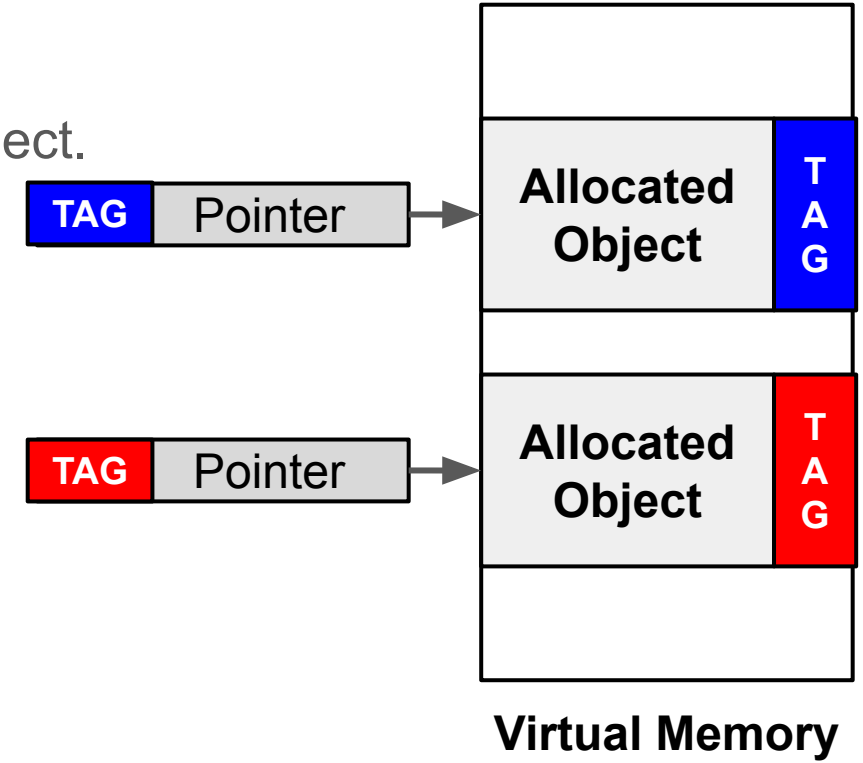

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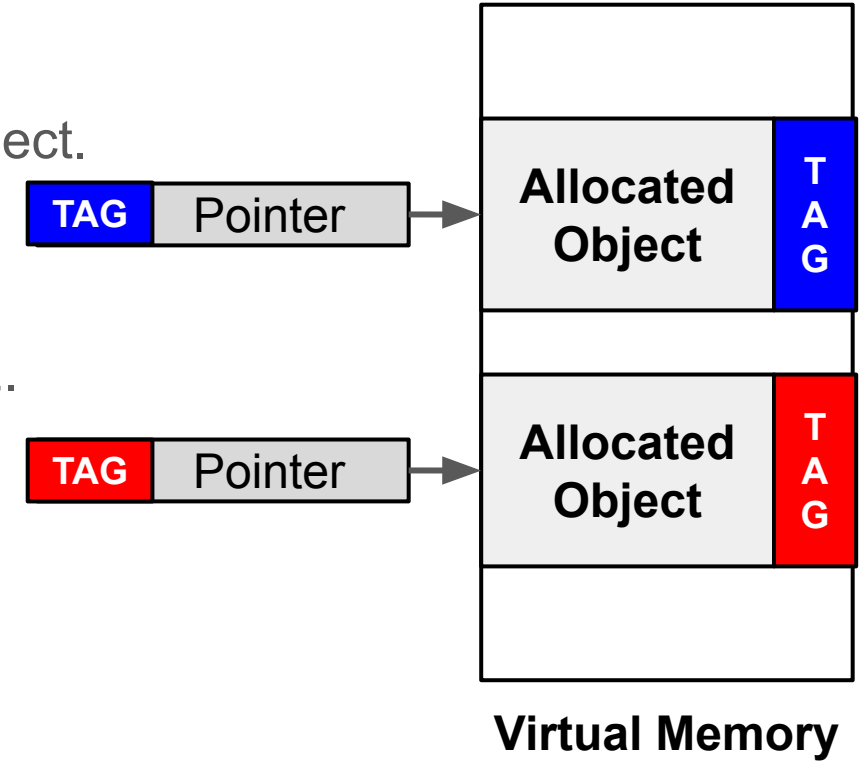

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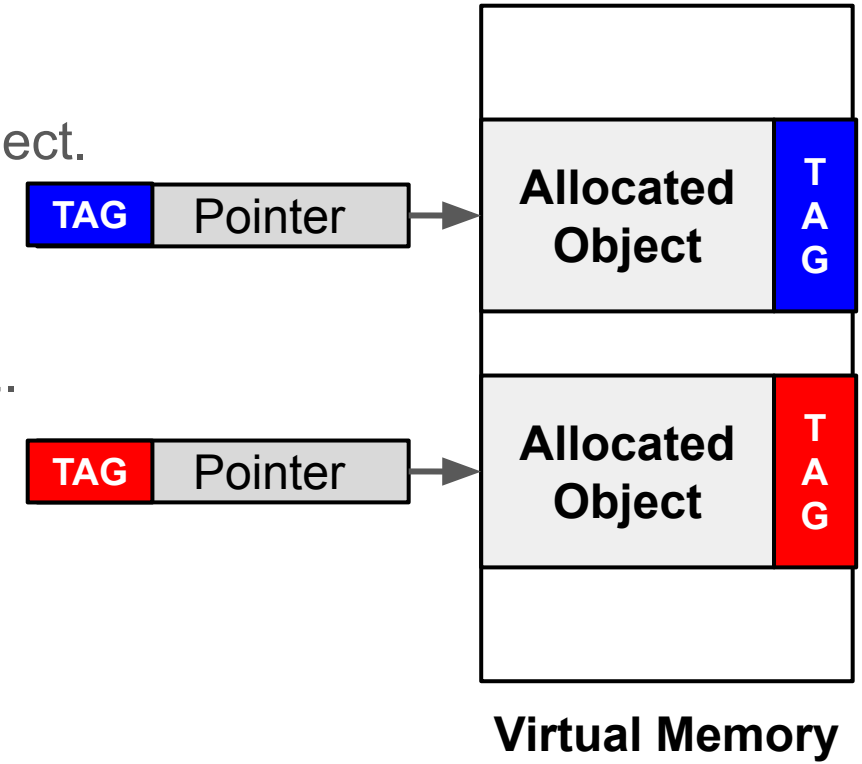

[33] Bialek et. al., Security analysis of memory tagging. **[Microsoft Research 2020]**

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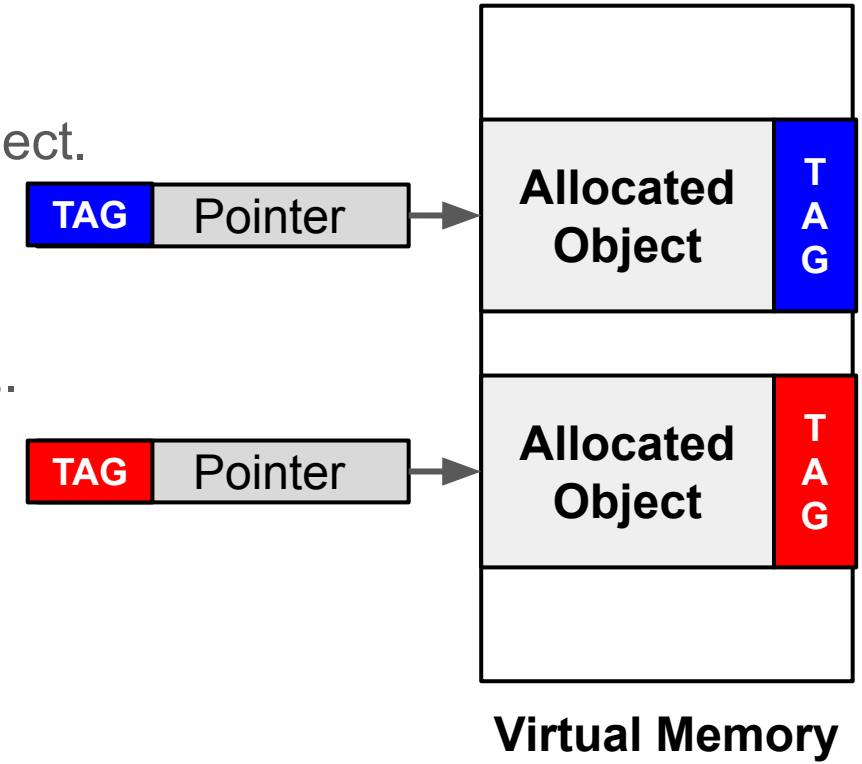

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	Whitelisting		Blacklisting
	Per-object	**Per-pointer**	
Disjoint Metadata	Compatible C Baggy Bounds	Mondrian M-machine Softbound, Hardbound Watchdog CUP, MPX	Purify Valgrind Dr. Memory Electric Fence ASan
Inlined Metadata	EffectiveSan	(aka Fat Pointers) CHERI Cyclone CheckedC	SafeMem REST CALIFORMS
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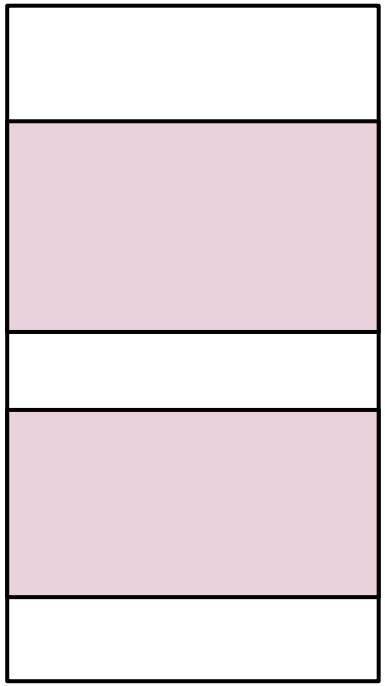
No Metadata	Lowfat s/w	Lowfat h/w	

WHITELISTING: NO METADATA (**LOWFAT**)

- Main Idea:
  - Partition the heap into equally-sized regions.



Virtual Memory

[35] Duck & Yap, Heap bounds protection with low fat pointers. **[CC 2016]**

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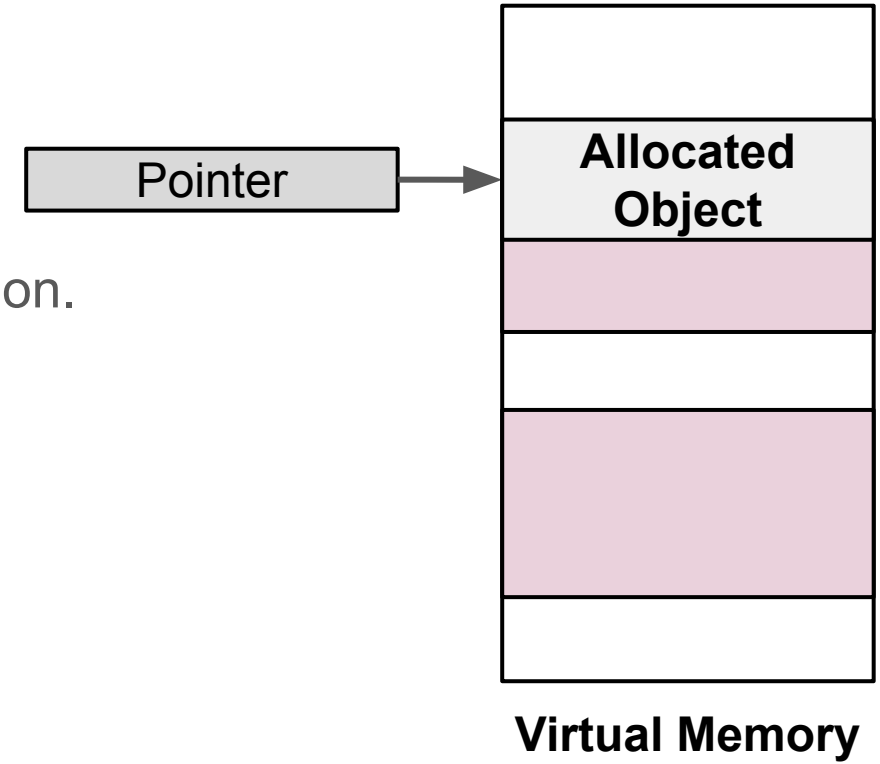

[35] Duck & Yap, Heap bounds protection with low fat pointers. **[CC 2016]**

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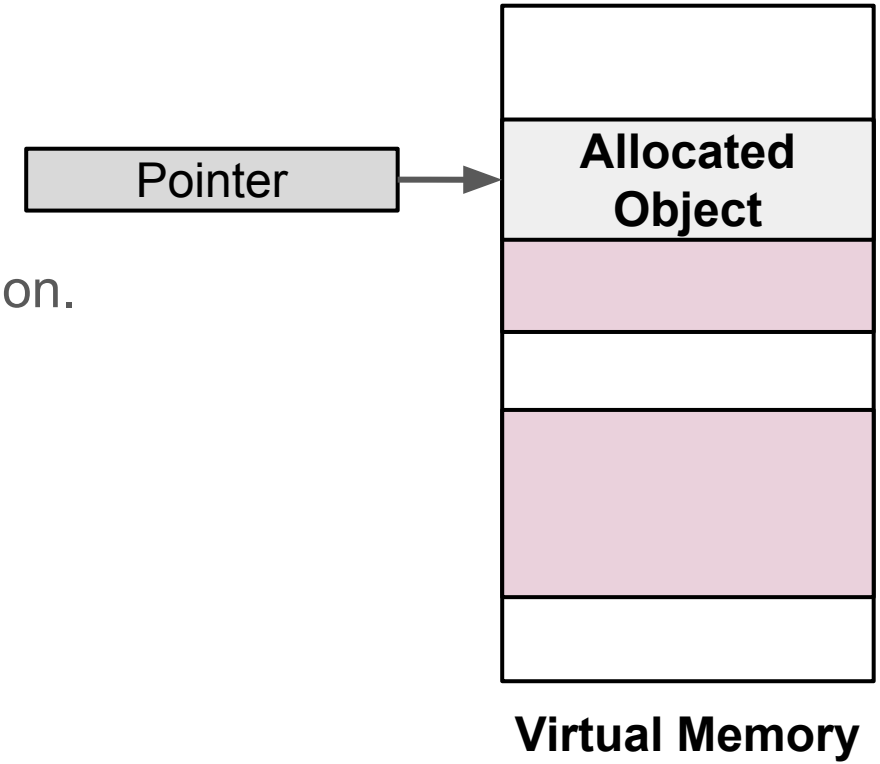

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  - \- Memory fragmentation.
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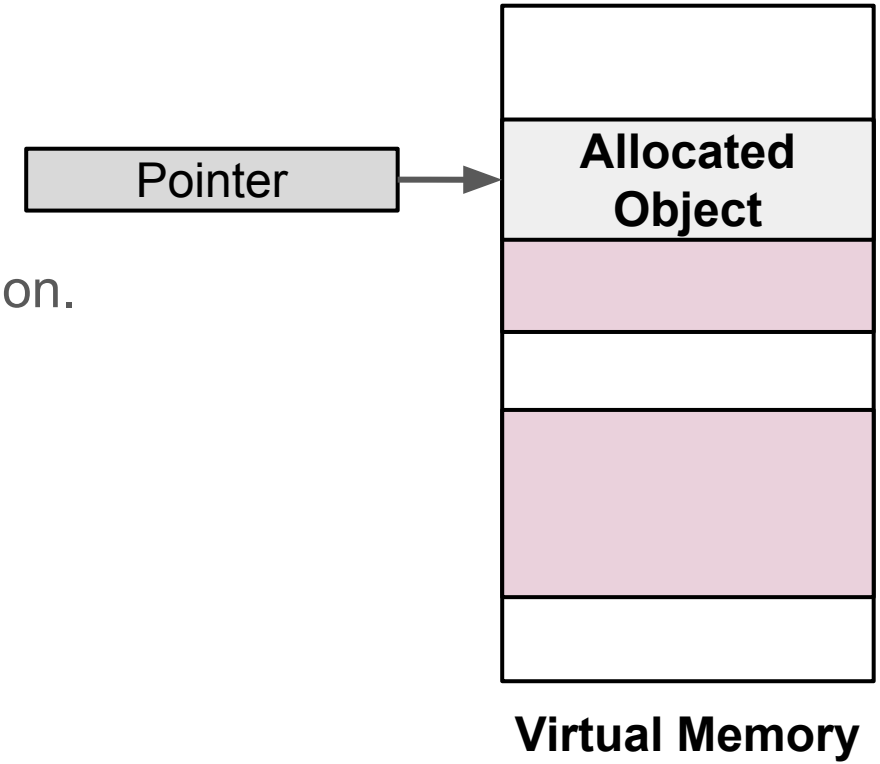

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	Whitelisting		Blacklisting
	Per-object	**Per-pointer**	
Disjoint Metadata	Compatible C Baggy Bounds	Mondrian M-machine Softbound, Hardbound Watchdog CUP, MPX	Purify Valgrind Dr. Memory Electric Fence ASan
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Co-joined Metadata	ARM Memory Tagging SPARC ADI		
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[27] Duck & Yap. EffectiveSan: type and memory error detection using dynamically typed C/C++. **[PLDI 2018]**

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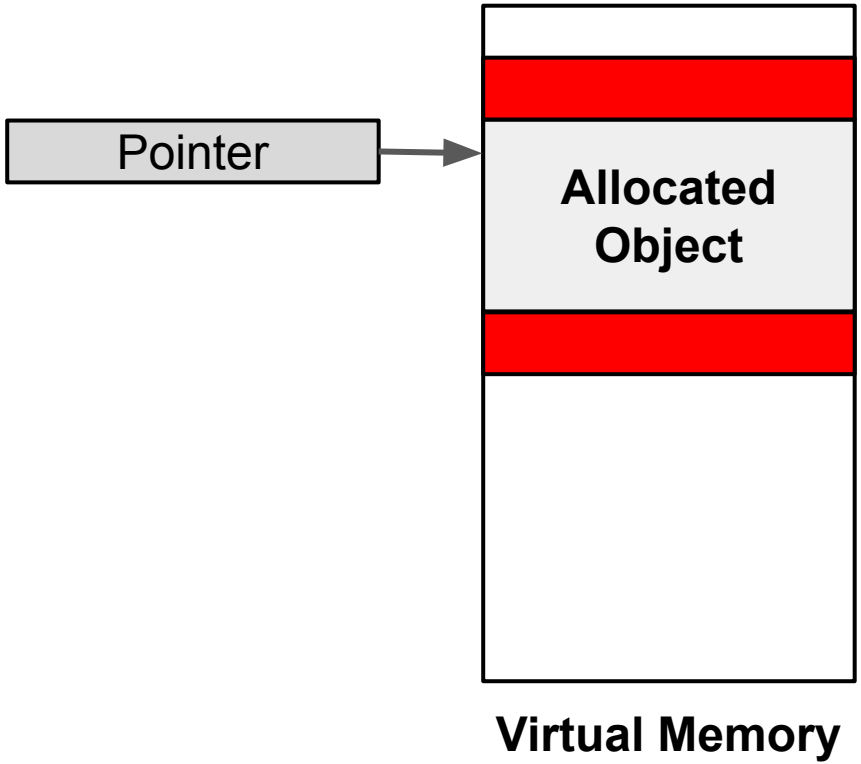
- Main Idea:
  - Guard objects with red zones.



[24] Serebryany, AddressSanitizer: a fast address sanity checker. **[USENIX ATC 2012]**

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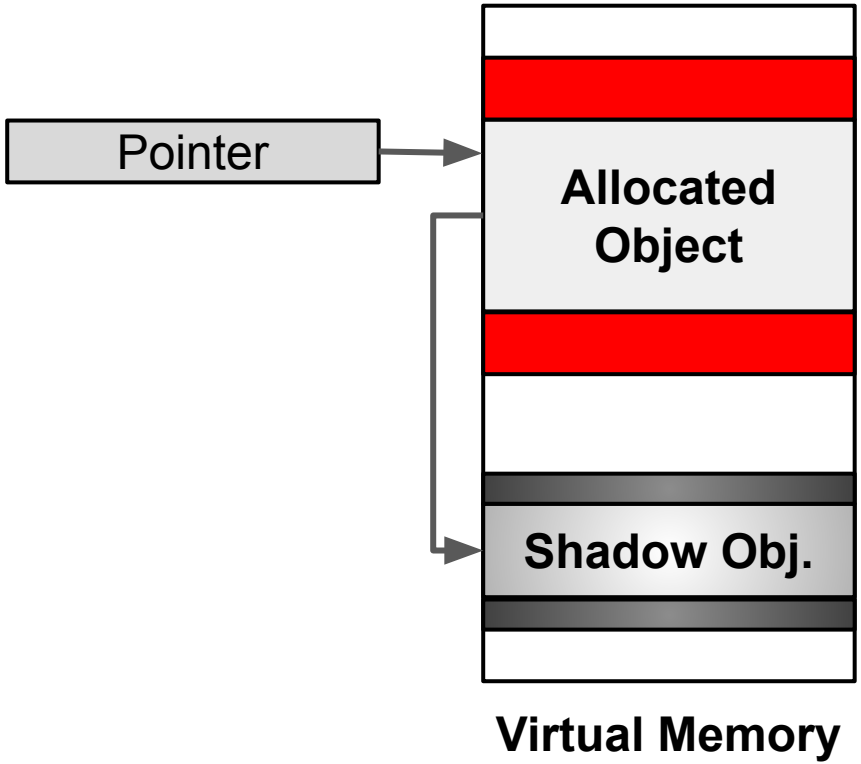

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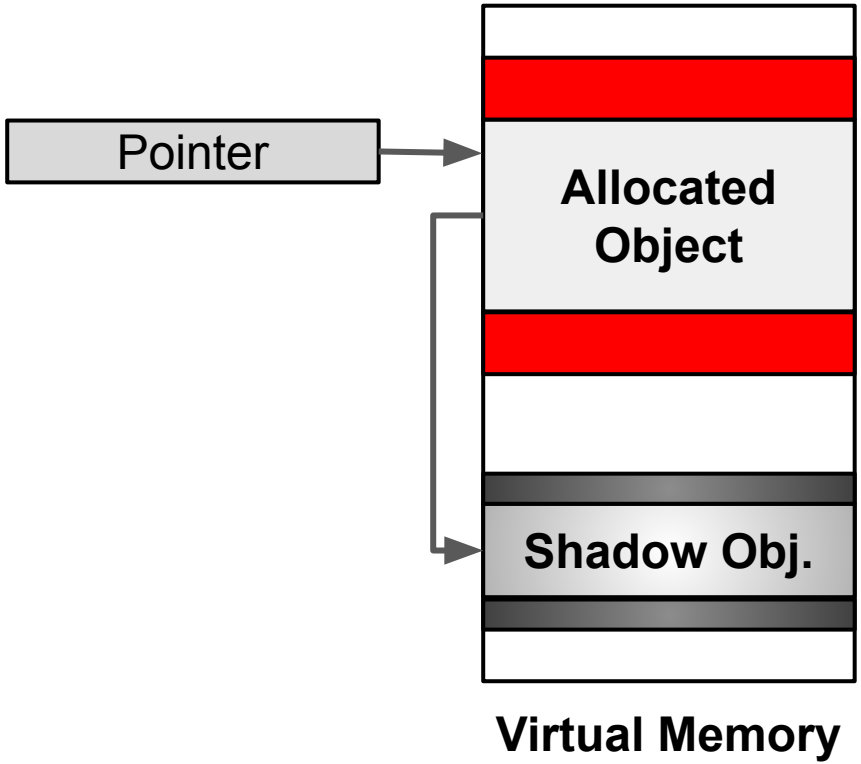

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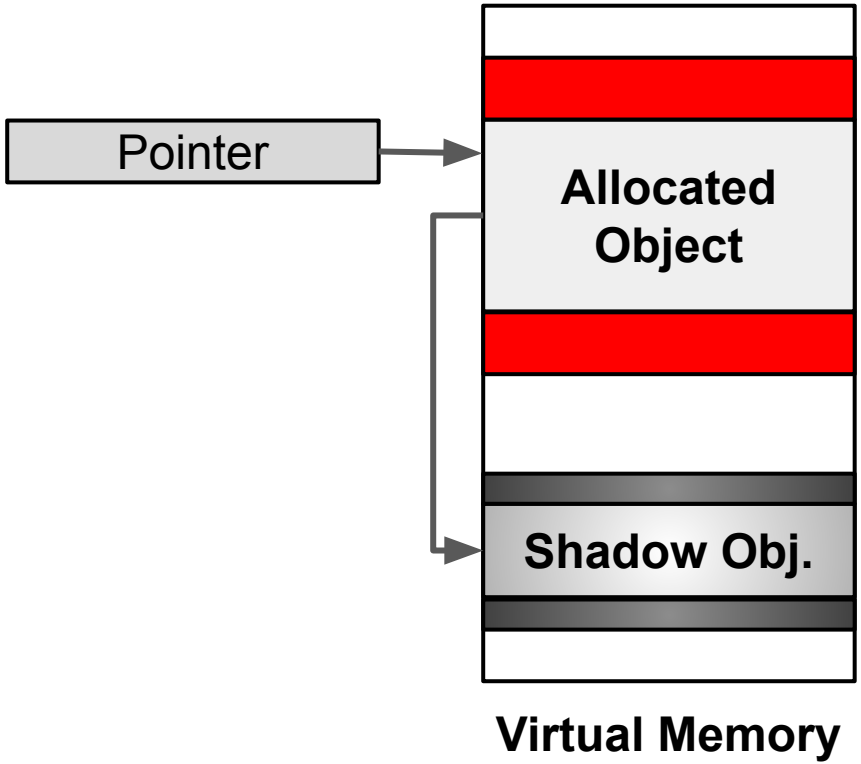

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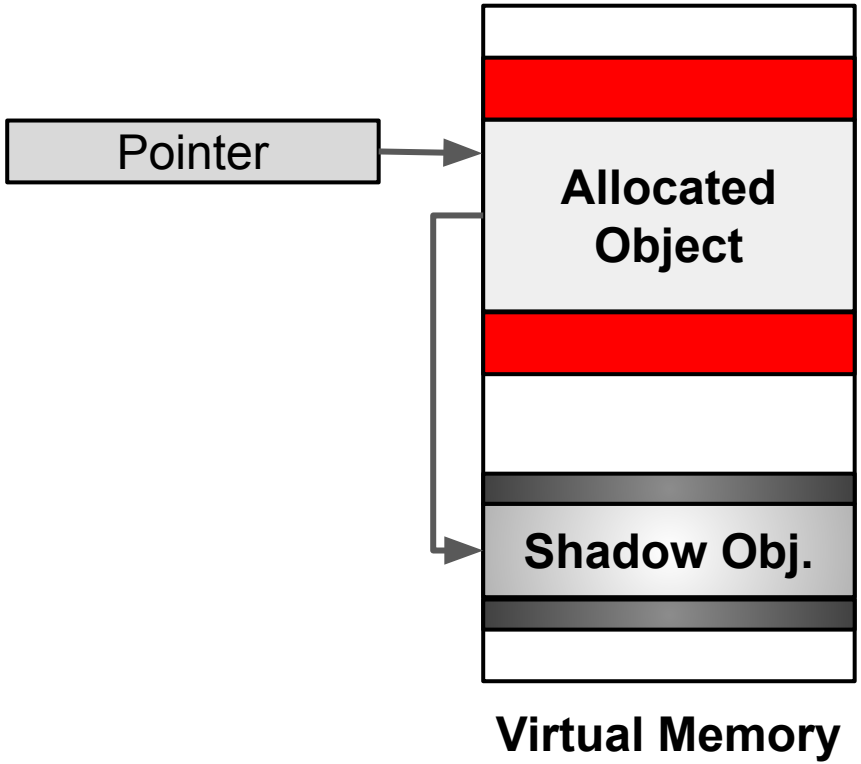

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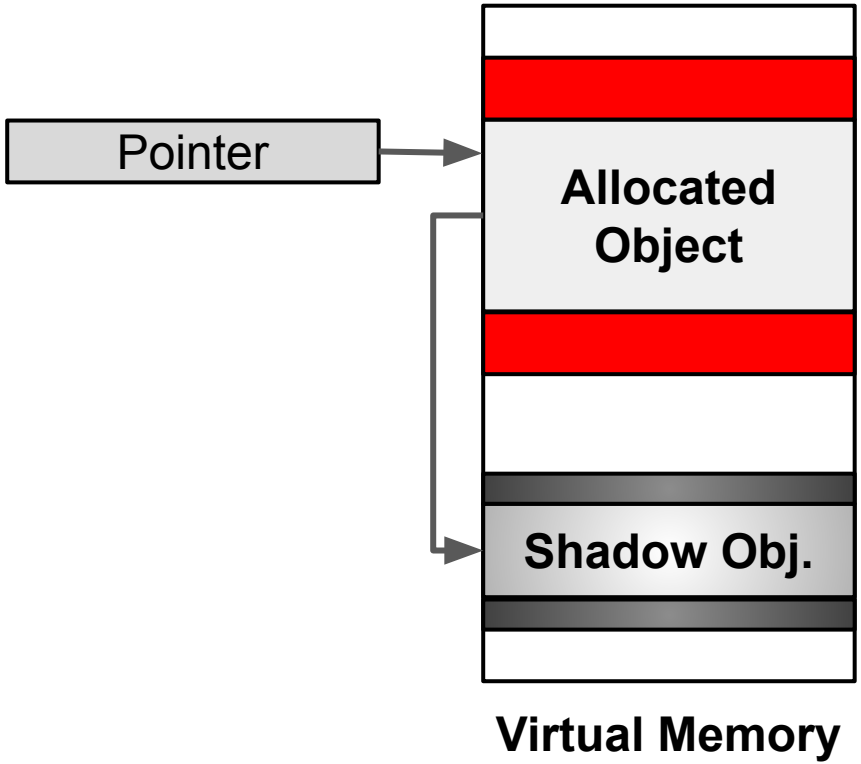
  - \- High memory footprint.
  - \- Less precise than whitelisting.



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[29] Qin et. al., SafeMem: exploiting ECC-memory for detecting memory leaks. **[HPCA 2005]**

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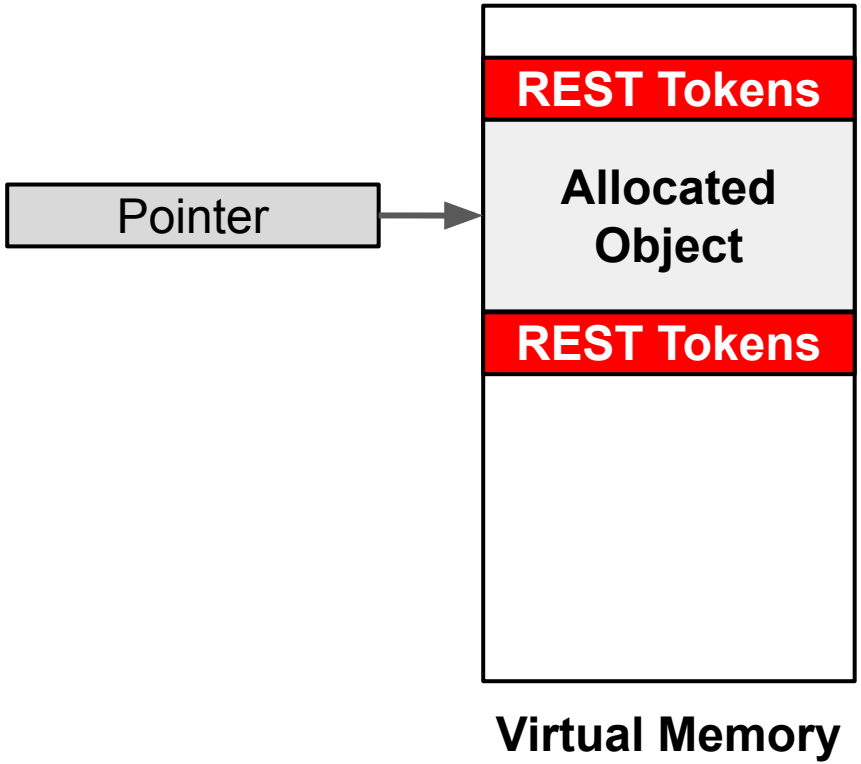

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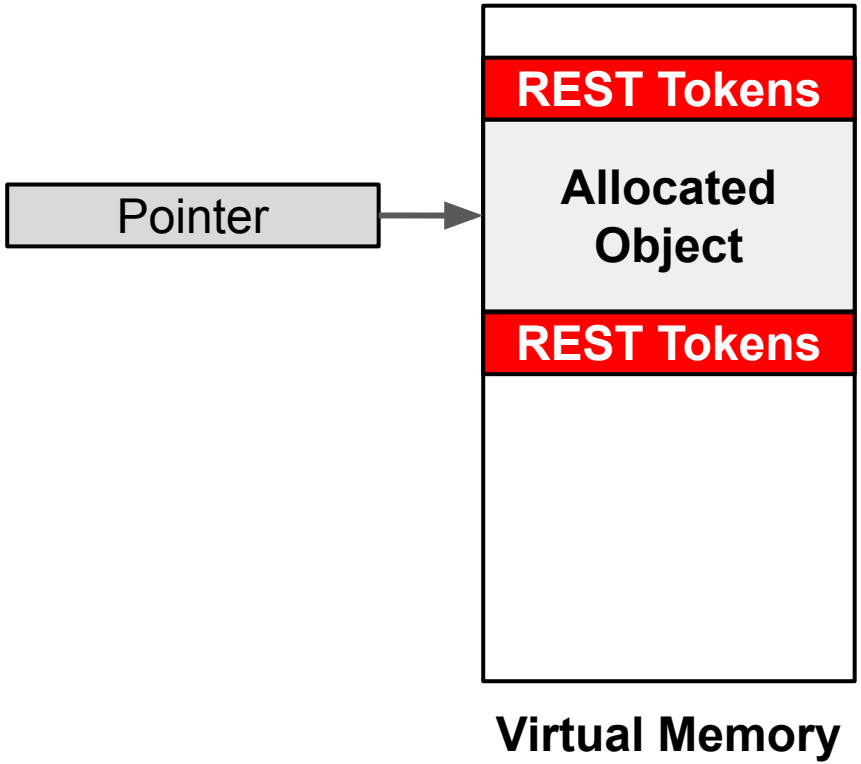

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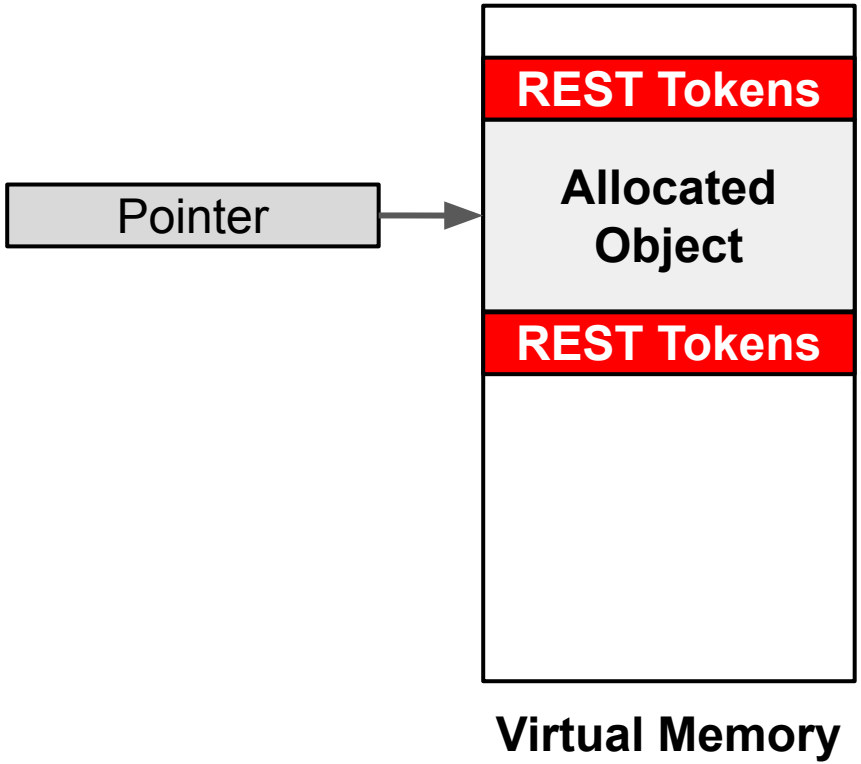

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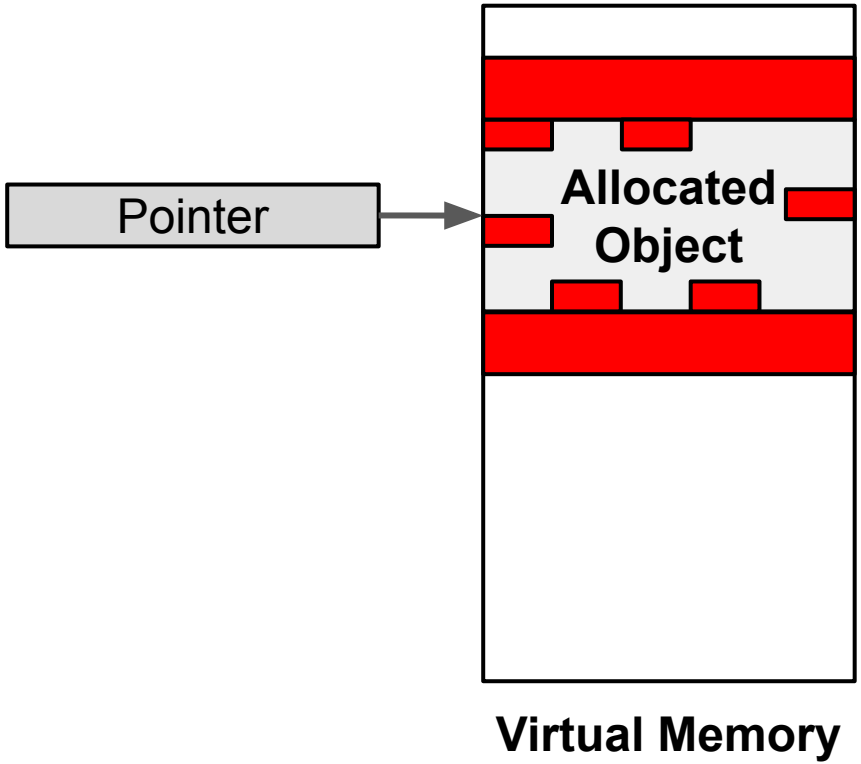

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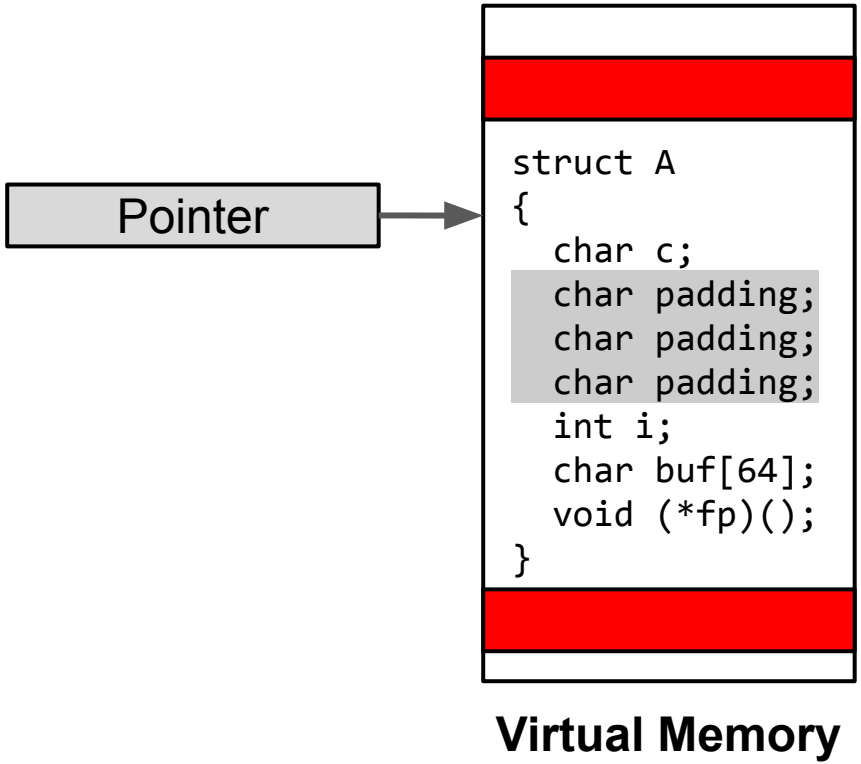

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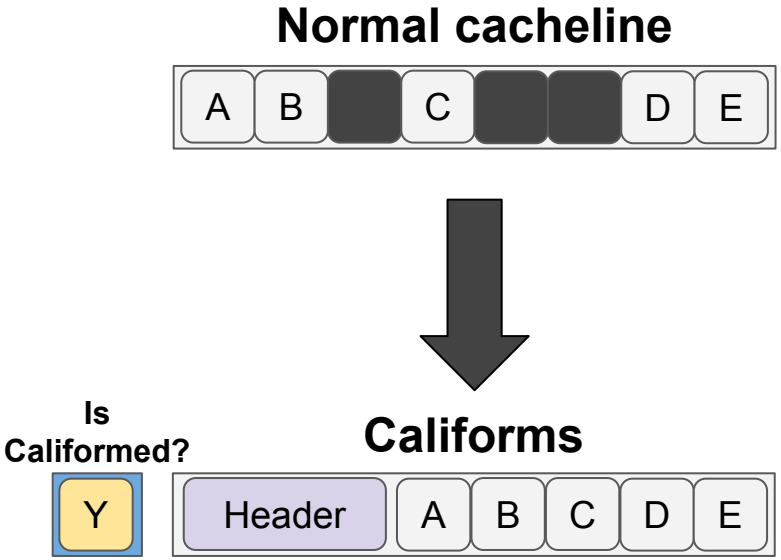

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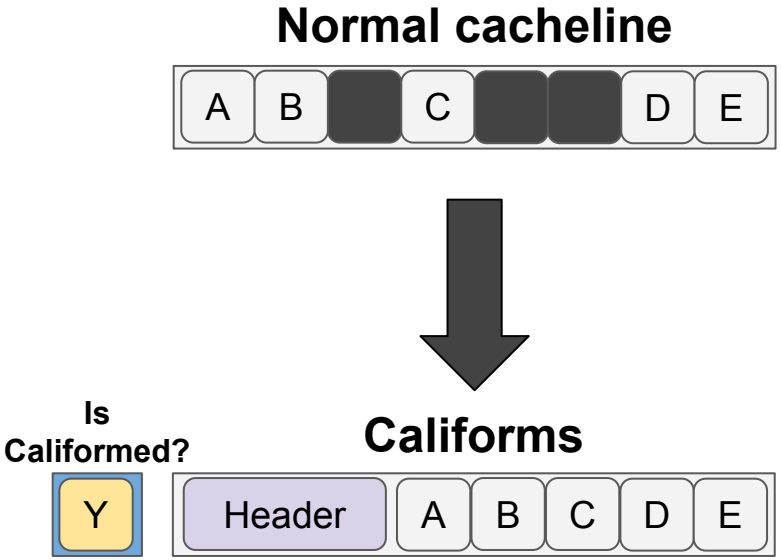

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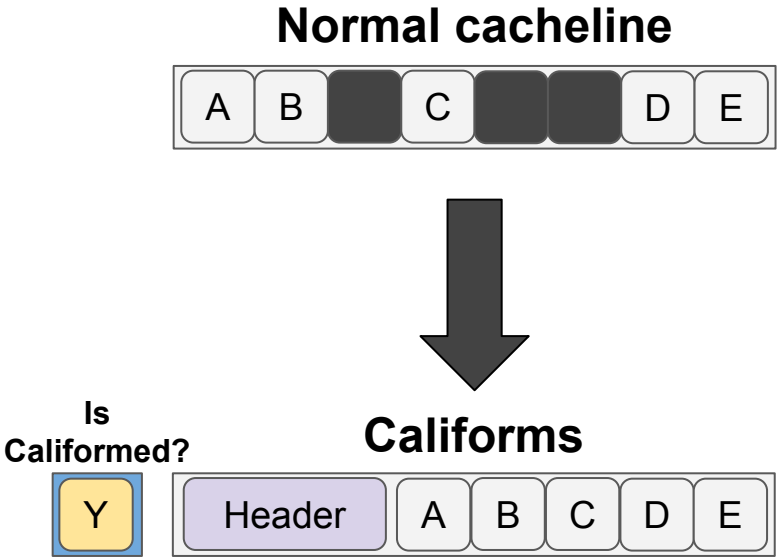
  - \- Same paddings layout for objects of the same type.



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	Whitelisting		Blacklisting	Randomized Allocators
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[20] Berger and Zorn, DieHard: Probabilistic memory safety for unsafe languages. **[PLDI 2006]**

MEMORY SAFETY TECHNIQUES

Spatial Memory Safety

Temporal Memory Safety

Naive Solution	Never use `Free()`

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Garbage Collection (GC)	**Regular**	Hardware Accelerated GC
	Conservative	MarkUs

[37] Mass et. al., A hardware accelerator for tracing garbage collection. **[ISCA 2018]**

Naive Solution		Never use `Free()`
Garbage Collection (GC)	**Regular**	Hardware Accelerated GC
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Memory Quarantining		Valgrind, ASan, REST, Califorms, CHERIvoke

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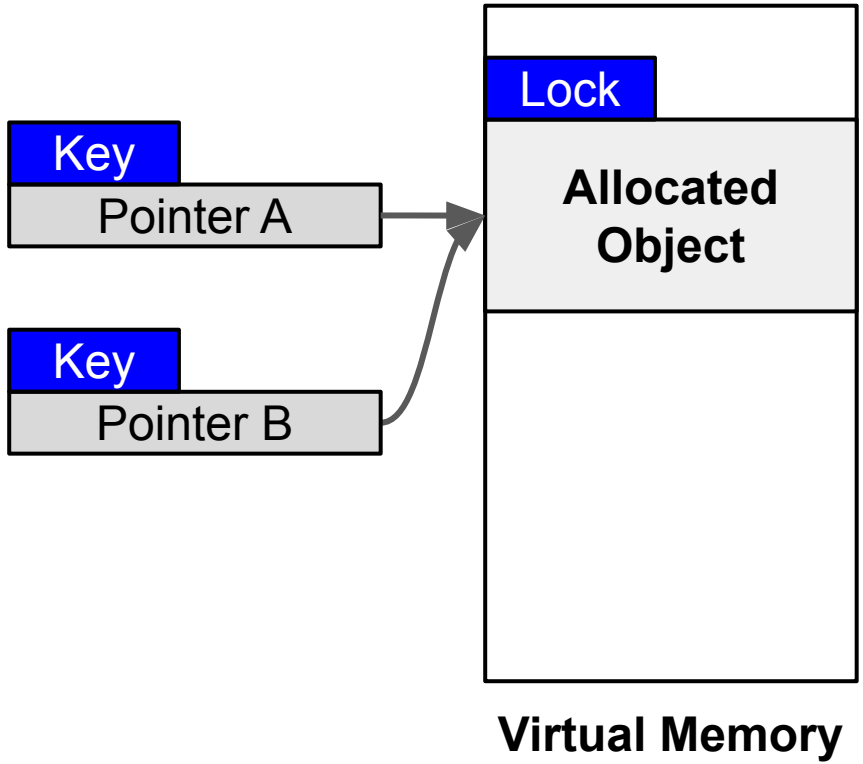
Lock & Key	**Explicit**	**Change Lock**	CETS, CUP
	Implicit	**Change Lock**	Electric Fence, Oscar
		Revoke key	DangNull, DangSan, BOGO

LOCK & KEY: EXPLICIT LOCK CHANGE (**CETS**)

- Main Idea:
  - Use unique Lock per object.
  - Pass Lock to pointers as a key.
  - Propagate keys on pointer **arithmetic**.
  - Check on pointer **dereference**.



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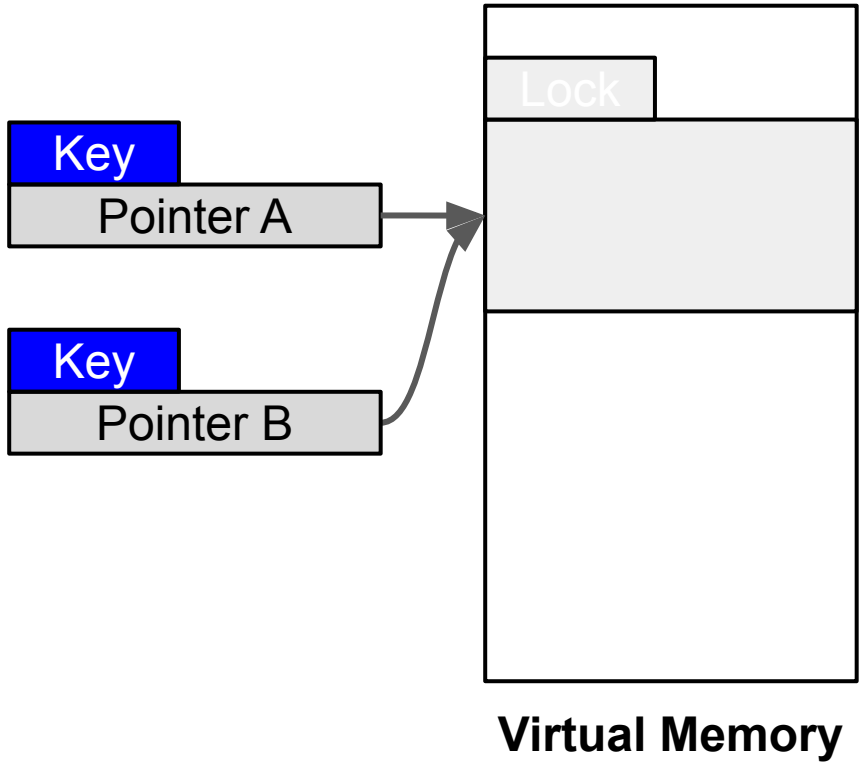

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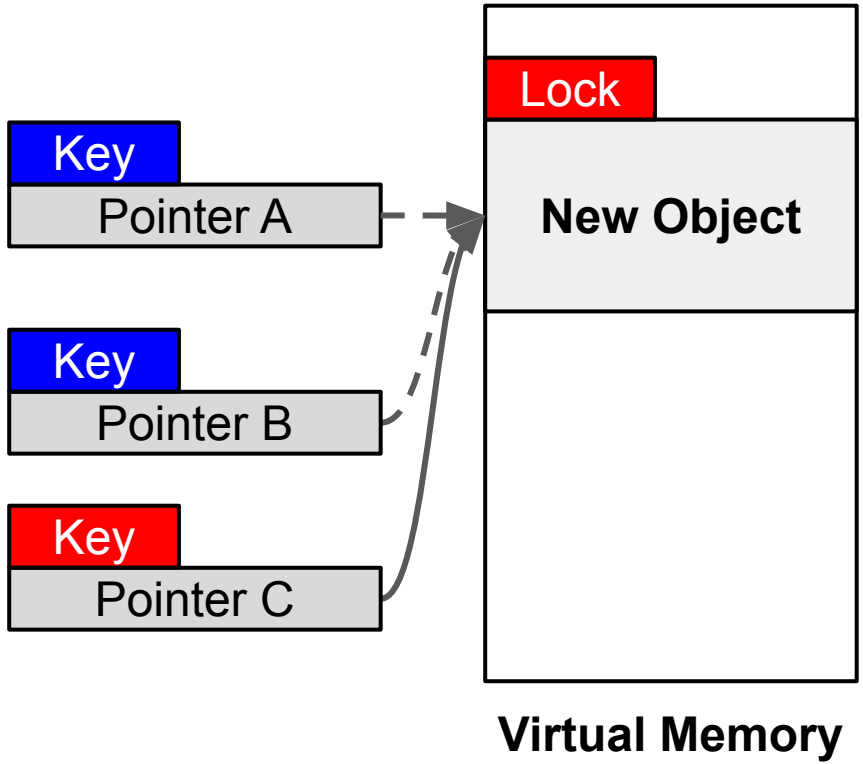

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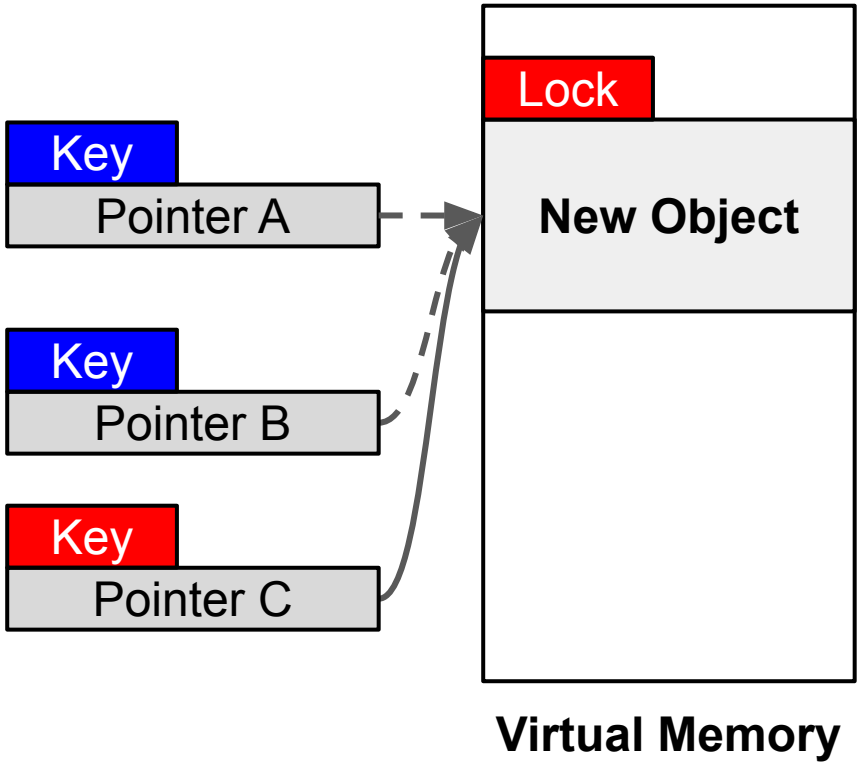
  - Propagate keys on pointer **arithmetic**.
  - Check on pointer **dereference**.
- Pros and Cons:
  - \+ Simple bounds checking.
  - \- High performance overheads.



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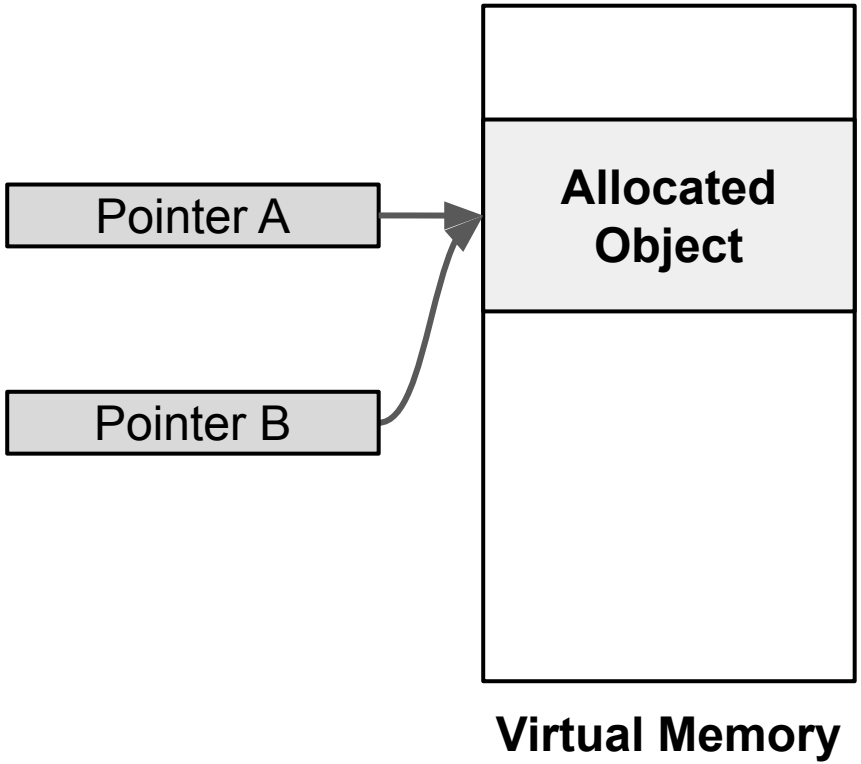

[39] Dang et. al., Oscar: A practical page-permissions-based scheme. **[USENIX 2017]**

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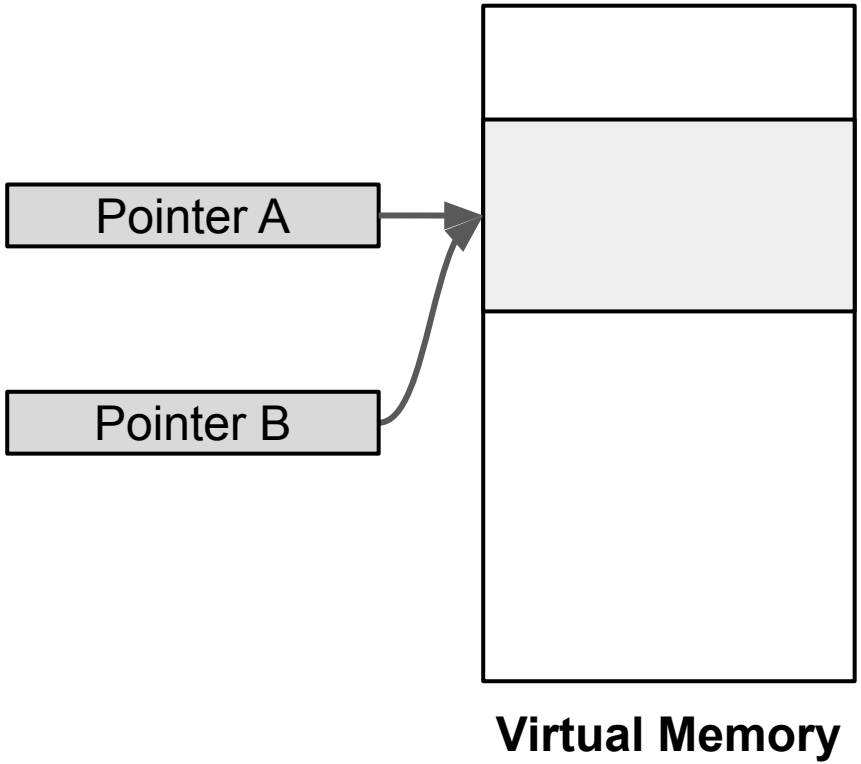

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- Main Idea:
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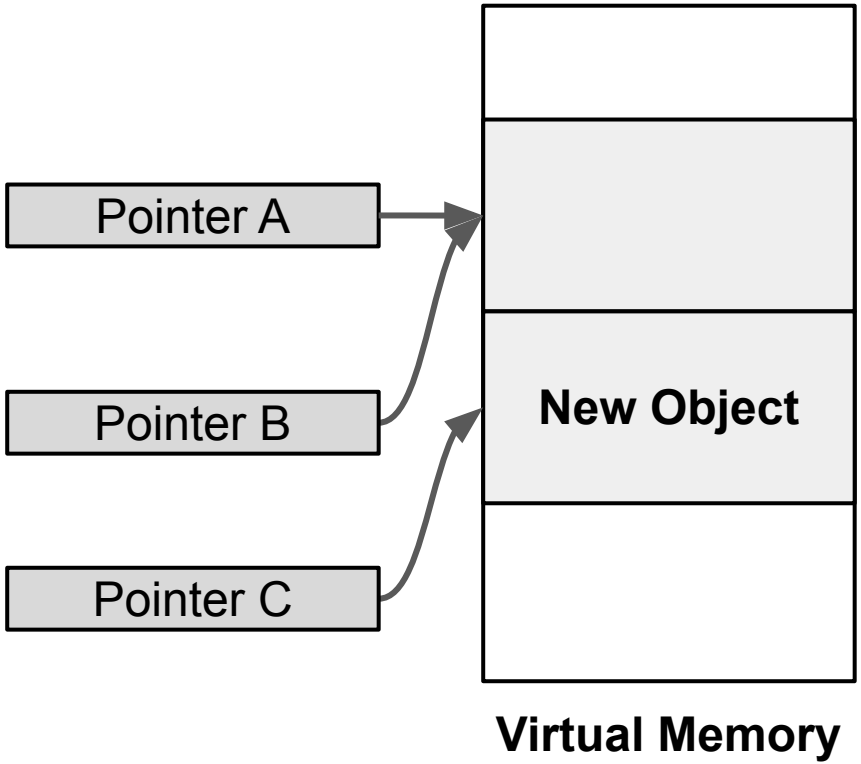
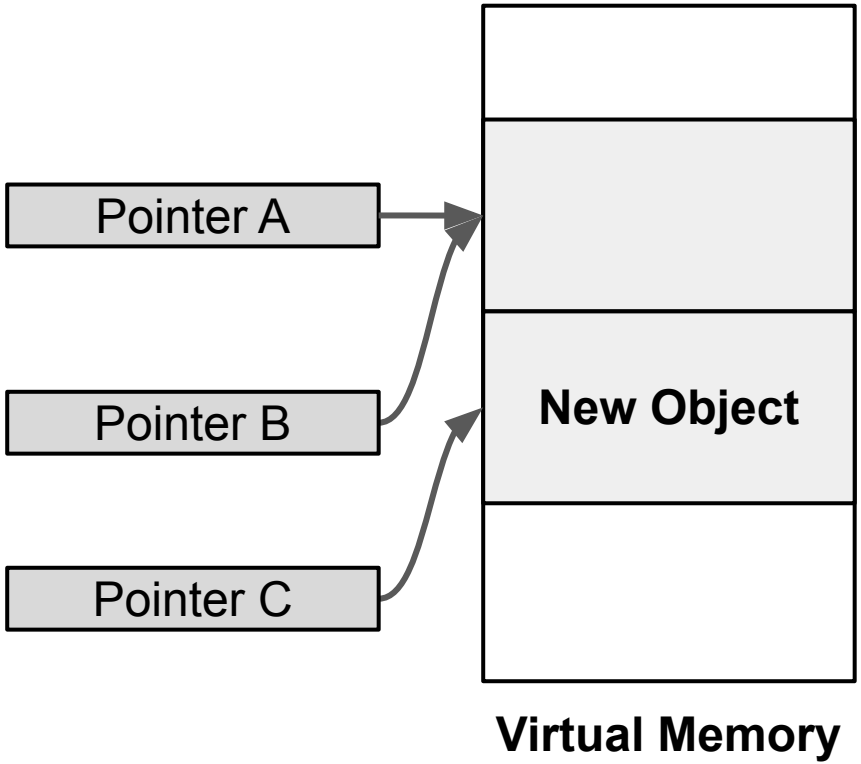
  - Mark virtual addresses as inaccessible upon free.
  - Never reuse virtual addresses.



[39] Dang et. al., Oscar: A practical page-permissions-based scheme. **[USENIX 2017]**

LOCK & KEY: IMPLICIT LOCK CHANGE

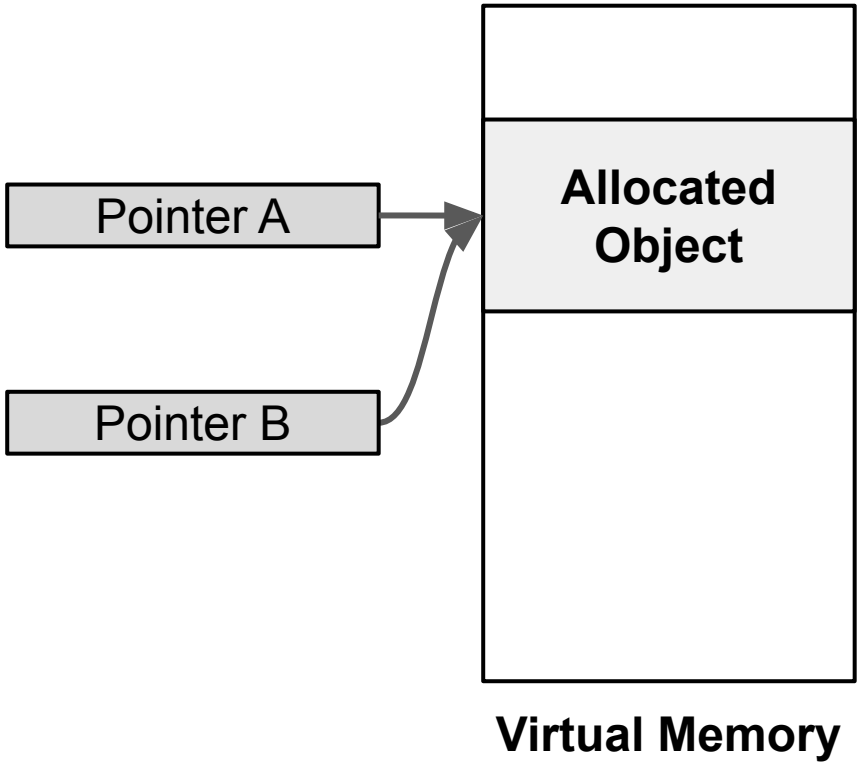
- Main Idea:
  - Use object address as a lock.
  - Mark virtual addresses as inaccessible upon free.
  - Never reuse virtual addresses.
- Pros and Cons:
  - \+ No per-pointer overheads.
  - \- High TLB overheads.



[39] Dang et. al., Oscar: A practical page-permissions-based scheme. **[USENIX 2017]**

LOCK & KEY: IMPLICIT KEY REVOCATION

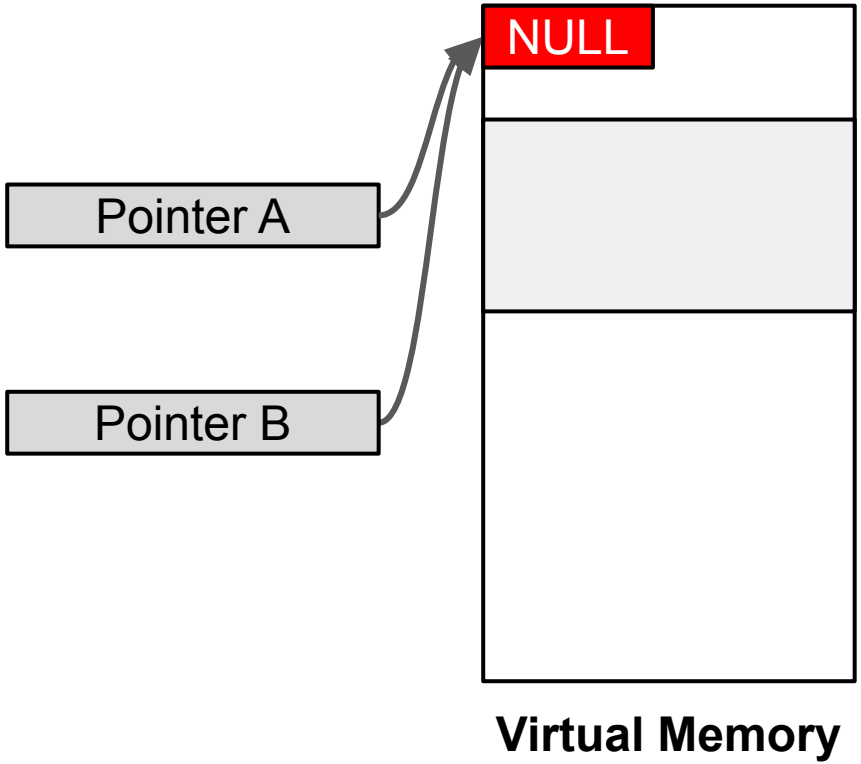
- Main Idea:
  - Use pointer value as a key.



[5] Song et. al., SoK: Sanitizing for security. **[S&P 2019]**

LOCK & KEY: IMPLICIT KEY REVOCATION

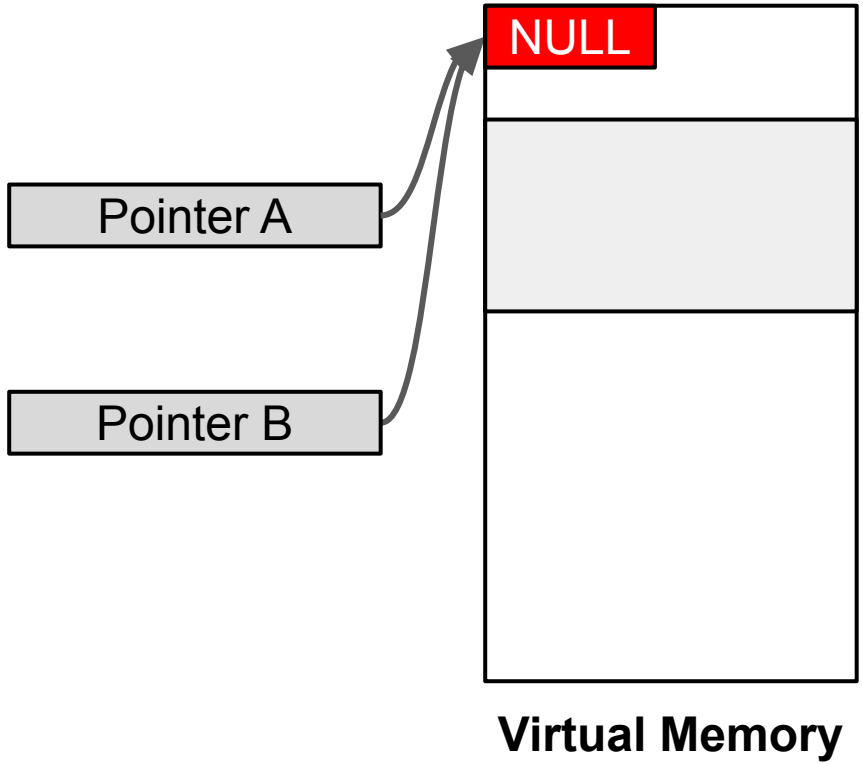
- Main Idea:
  - Use pointer value as a key.
  - Nullify pointers upon `Free()`.



[5] Song et. al., SoK: Sanitizing for security. **[S&P 2019]**

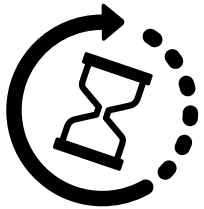
LOCK & KEY: IMPLICIT KEY REVOCATION

- Main Idea:
  - Use pointer value as a key.
  - Nullify pointers upon `Free()`.
- Limitations:
  - Overheads are proportional to the number of pointers.
  - May miss dangling pointers stored in registers.



[5] Song et. al., SoK: Sanitizing for security. **[S&P 2019]**

<table>
<tr><td colspan="3">Naive Solution</td><td>Never use <code>Free()</code></td></tr>
<tr><td rowspan="2">Garbage Collection (GC)</td><td colspan="2">Regular</td><td>Hardware Accelerated GC</td></tr>
<tr><td colspan="2">Conservative</td><td>MarkUs</td></tr>
<tr><td colspan="3">Memory Quarantining</td><td>Valgrind, ASan, REST, Califorms, CHERIvoke</td></tr>
<tr><td rowspan="3">Lock & Key</td><td rowspan="1">Explicit</td><td>Change Lock</td><td>CETS, CUP</td></tr>
<tr><td rowspan="2">Implicit</td><td>Change Lock</td><td>Electric Fence, Oscar</td></tr>
<tr><td>Revoke key</td><td>DangNull, DangSan, BOGO</td></tr>
</table>



Future Work Map

FUTURE WORK MAP

Created via: https://azgaar.github.io/Fantasy-Map-Generator/

LOW-COST MEMORY SAFETY SOLUTIONS

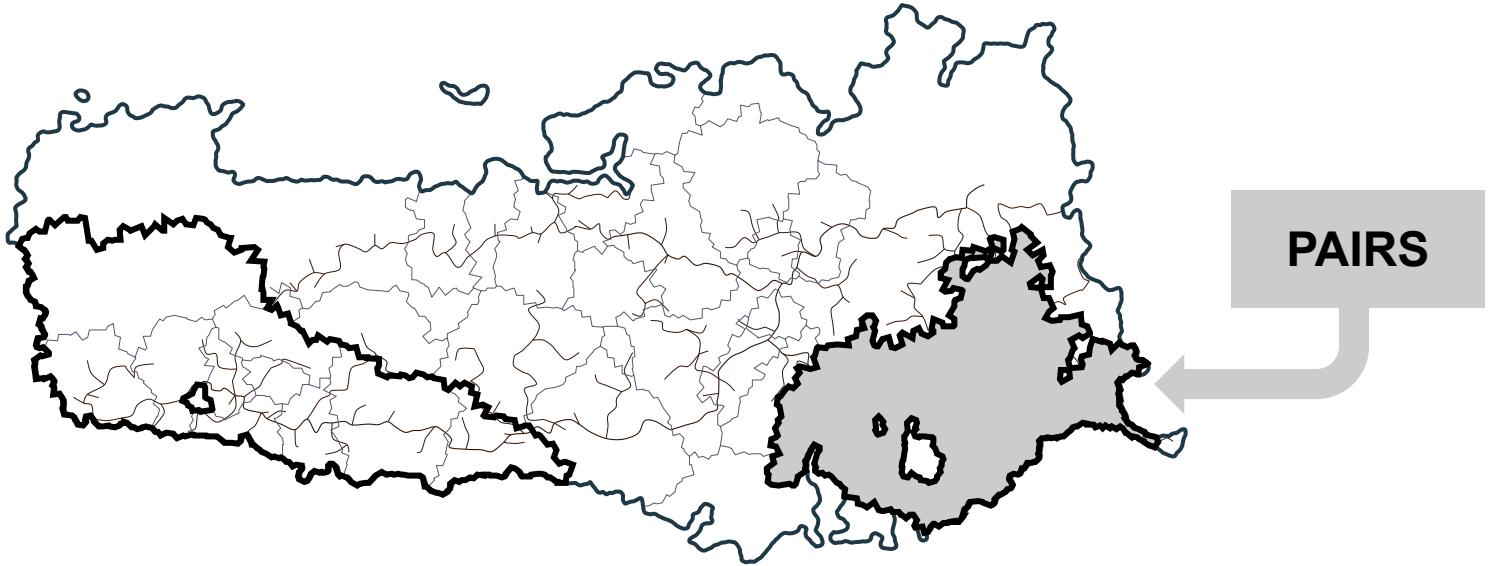
Created via: https://azgaar.github.io/Fantasy-Map-Generator/

LOW-COST MEMORY SAFETY SOLUTIONS

Hiroshi Sasaki, Miguel A. Arroyo, **Mohamed Tarek Ibn Ziad**, Koustubha Bhat, Kanad Sinha, and Simha Sethumadhavan, Practical byte-granular memory blacklisting using Califorms, **[MICRO 2019] [IEEE Micro Top Picks Honorable Mention]**

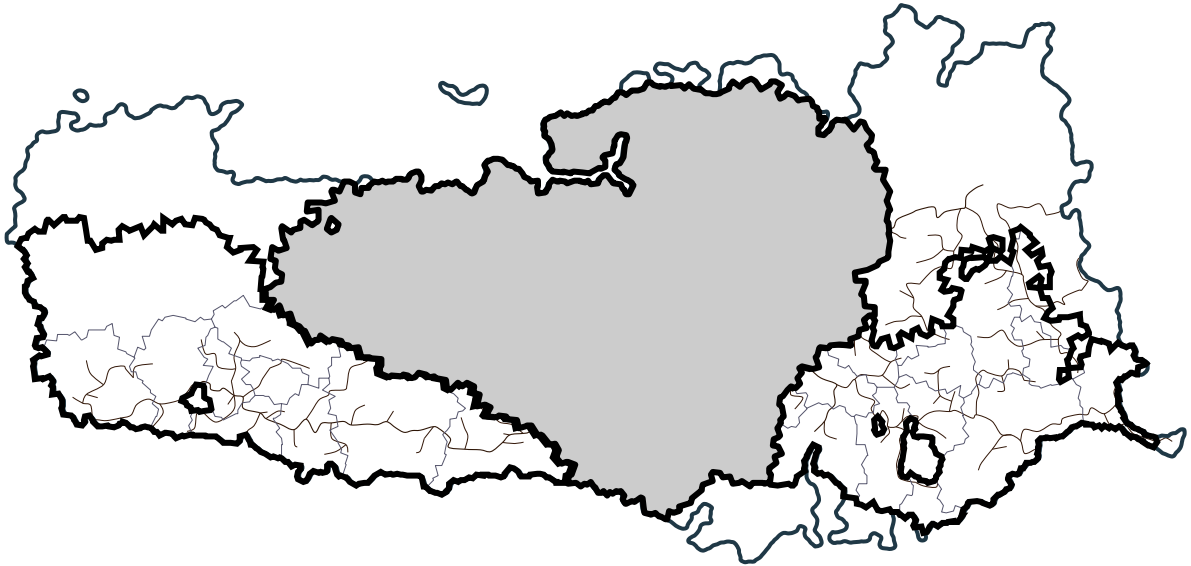
PROTECTING NON-64 BIT SYSTEMS

PROTECTING NON-64 BIT SYSTEMS

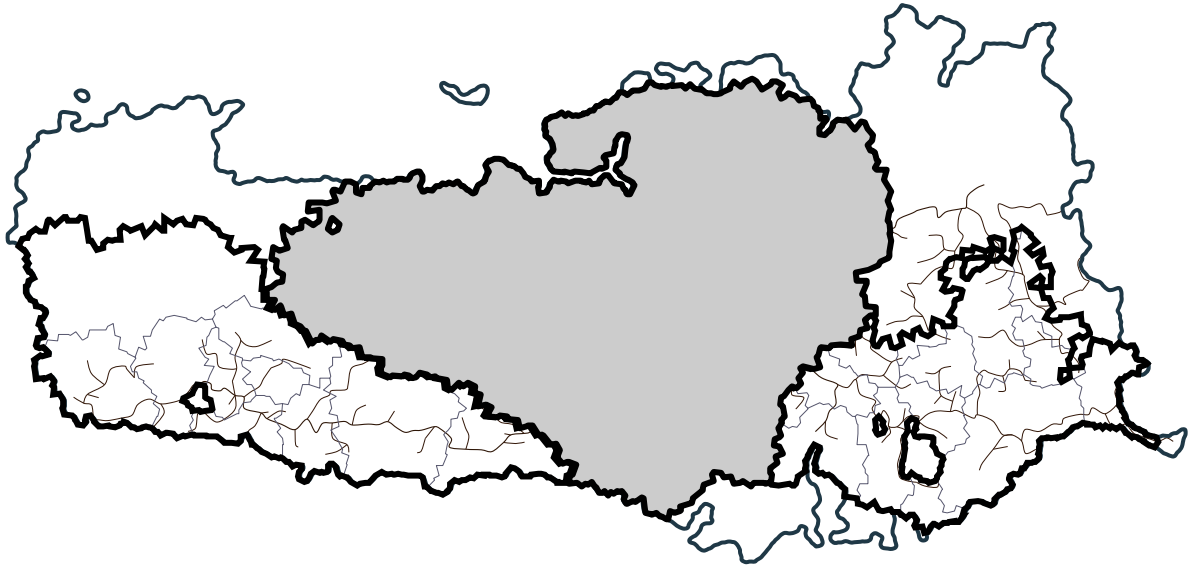


Mohamed Tarek Ibn Ziad and Evgeny Manzhosov, Practical Software Security on Heterogeneous Systems on Chips. **[Qualcomm Innovation Fellowship Finalists 2020]**

COHESIVE MEMORY SAFETY SOLUTIONS



COHESIVE MEMORY SAFETY SOLUTIONS



Mohamed Tarek Ibn Ziad, Miguel A. Arroyo, and Simha Sethumadhavan, SPAM: Stateless Permutation of Application Memory. **[Submitted to USENIX 2020]**

Why is memory safety still a concern?

Mohamed (Tarek Ibn Ziad) Hassan

Ph.D. Candidacy Exam
April 9th, 2020.

Why is memory safety still a concern?

Mohamed (Tarek Ibn Ziad) Hassan

QUESTIONS?

https://www.cs.columbia.edu/~mtarek/

@M_TarekIbnZiad

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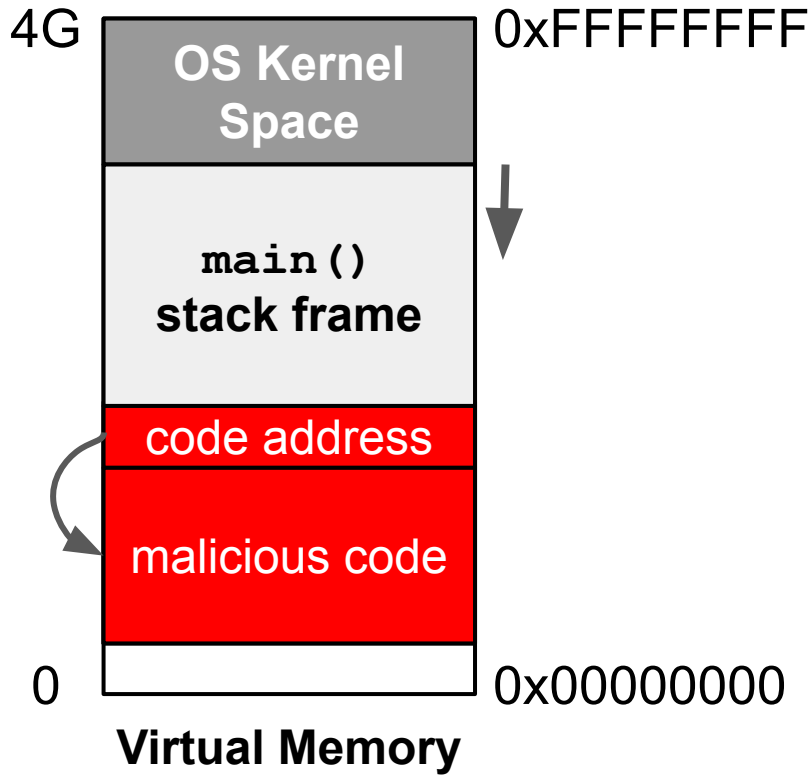
Supplementary Slides

CODE INJECTION

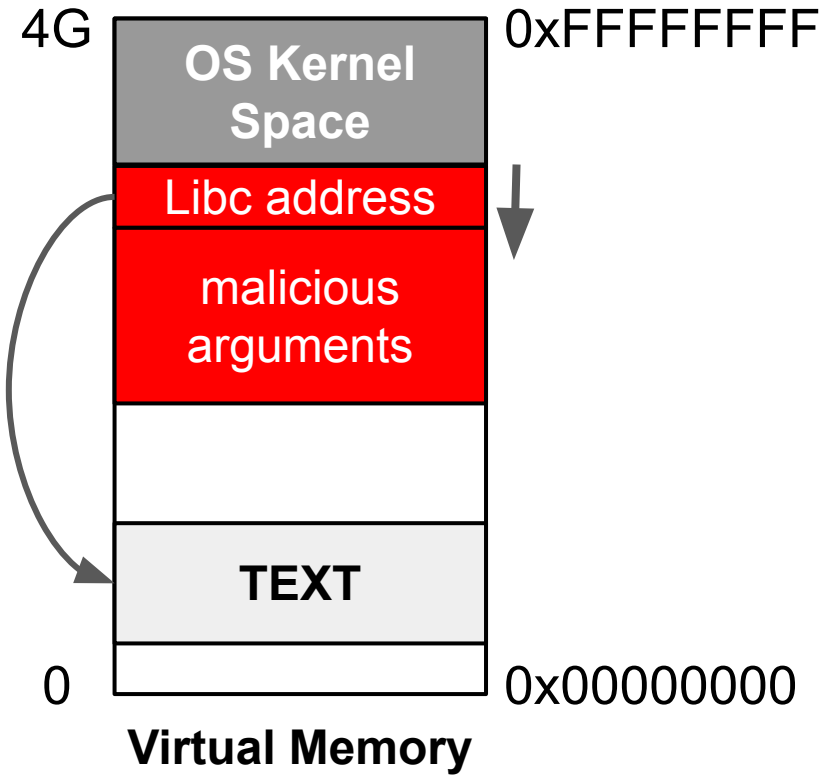
```
void main (int argc, char **argv) {
   ...
   vulnerable(argv[1]);
   ...
}
void vulnerable(char *str1){
   char str2[100];
   strcpy(str2,str1);
   return;
}
```



[4] Szekeres et. al, SoK: Eternal war in memory. **[S&P 2013]**

RETURN-TO-LIBC

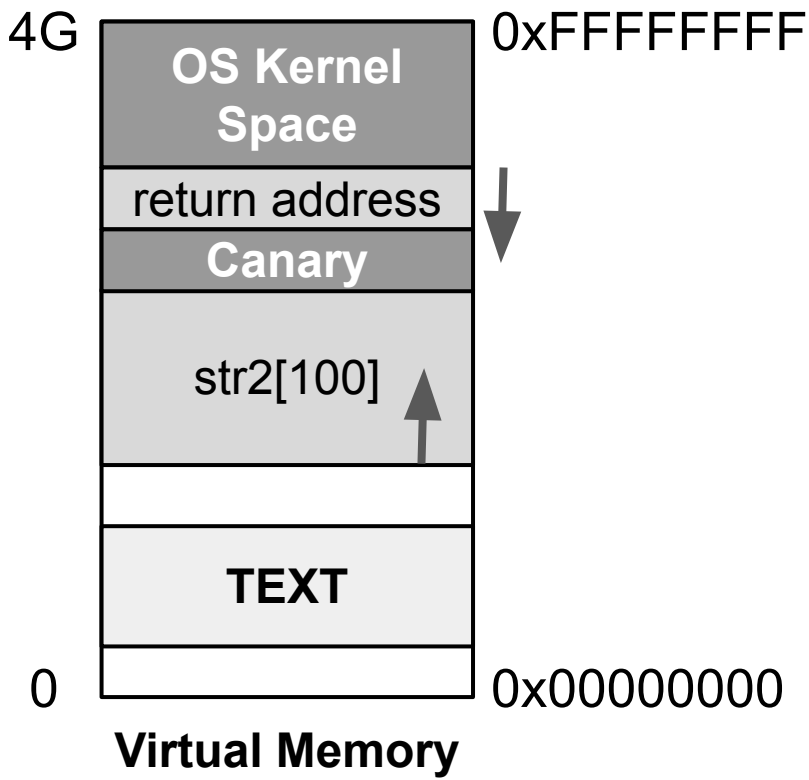
- Attack payload:
  - An address to libc function.
  - Function arguments.
- Limitations:
  - Execute whole functions.
  - Cannot target functions with ‘00’ byte in address.



[3] Van der Veen et. al., Memory errors: The past, the present, and the future. **[RAID 2012]**

STACK CANARIES

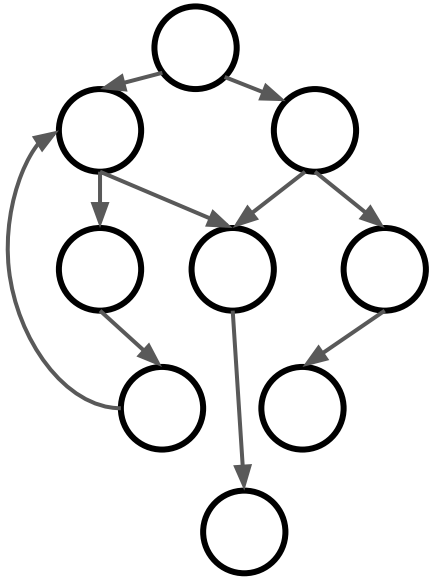
- Main Idea:
  - Insert unique variables on the stack.
  - Check their contents upon function return.
- Limitations:
  - Only detect continuous writes.
  - No read protection.



[3] Van der Veen et. al., Memory errors: The past, the present, and the future. **[RAID 2012]**

CONTROL FLOW INTEGRITY (CFI)

- Main Idea:
  - Construct a pre-defined CFG.
    - Statically with point-to analysis.
    - Dynamically with profiling.
  - Enforce it at runtime.
- Limitations:
  - Over-approximation.
  - Modularity.



CFG

[12] Burow et. al, Control-flow integrity: Precision, security, and performance. **[ACM Surveys 2017]**

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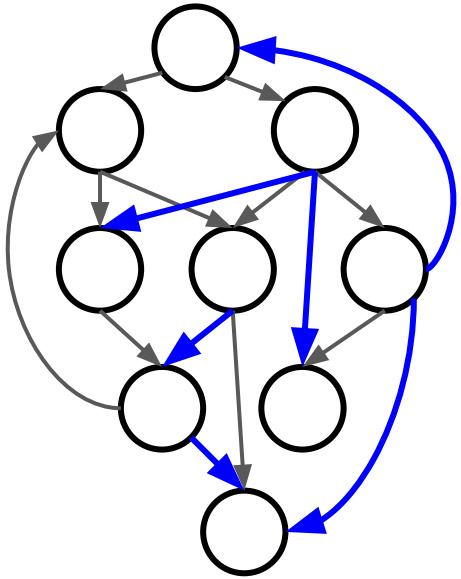

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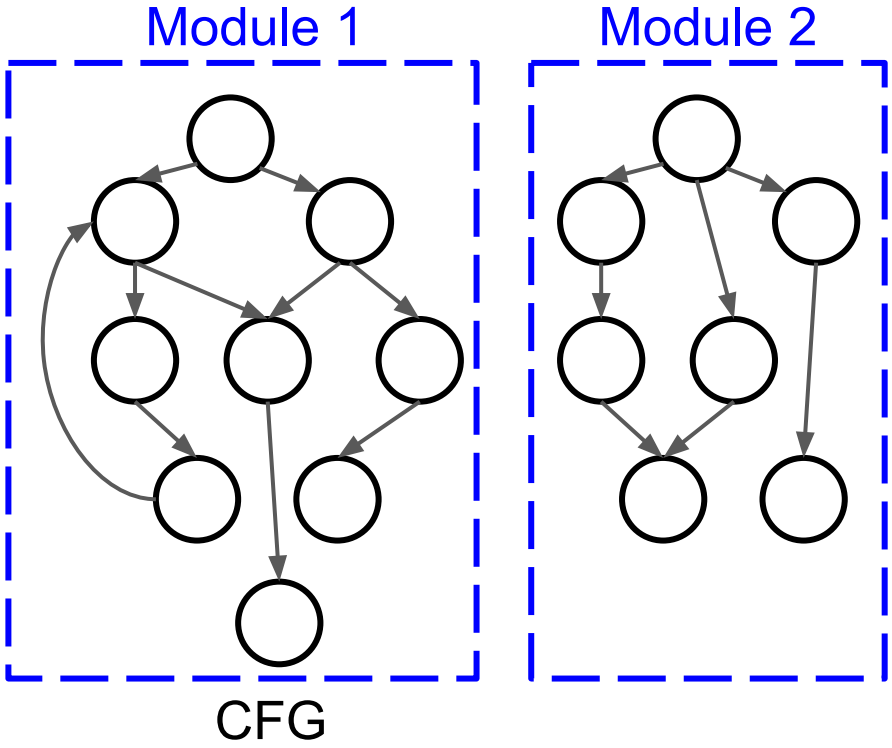

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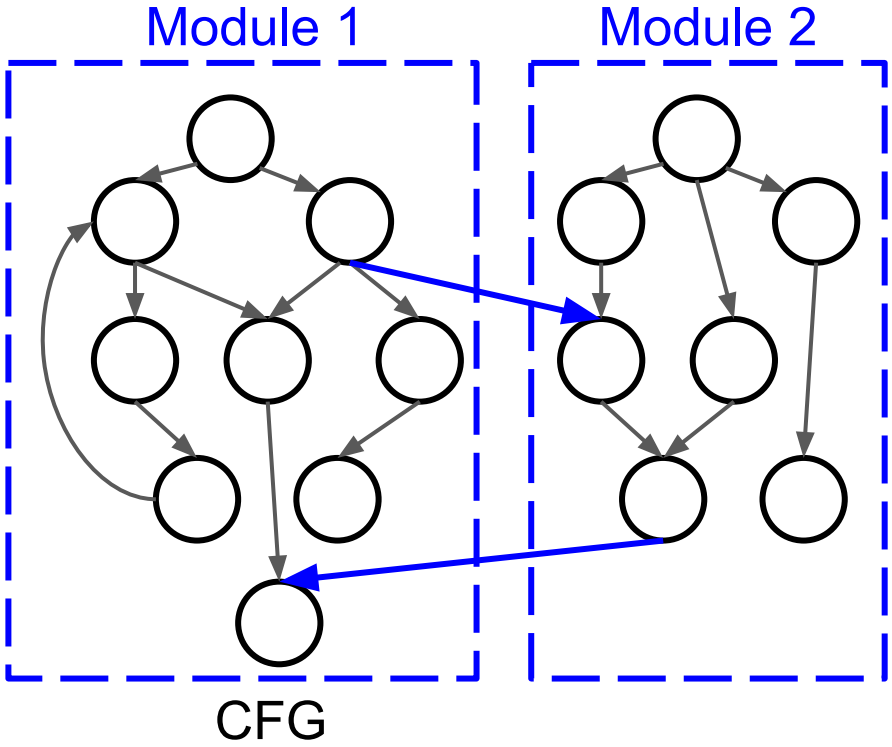
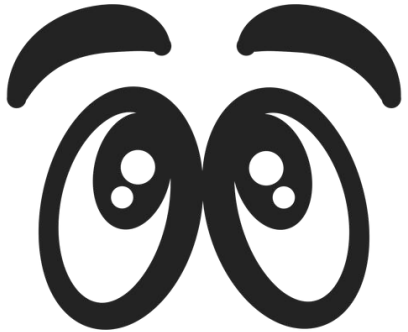


[12] Burow et. al, Control-flow integrity: Precision, security, and performance. **[ACM Surveys 2017]**

Counterfeit Object Oriented Programming

[9] Schuster et. al, Counterfeit object-oriented programming. **[S&P 2015]**

What are C++ Virtual Pointers?



C++ CONCEPTS: OBJECT-ORIENTED

```
class A {
  public:
    int x;
    char *y;

    void foo();
    void bar();
}
```

C++ CONCEPTS: OBJECT-ORIENTED

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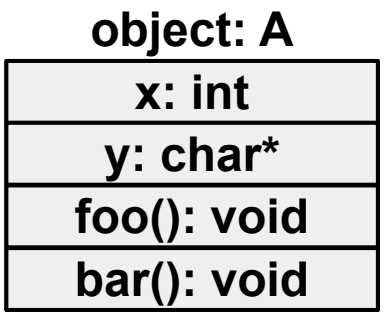


C++ CONCEPTS: INHERITANCE

```
class A {
  public:
    int x;
    char *y;

    void foo();
    void bar();
}
```

object: A

x: int
y: char*
foo(): void
bar(): void

```
class B : public A {
  public:
    int z;

}
```

object: B

z: int
x: int
y: char*
foo(): void
bar(): void

C++ CONCEPTS: POLYMORPHISM

```
class A {
  public:
    int x;
    char *y;

    void foo();
    virtual void bar();
}
```

```
class B : public A {
  public:
    int z;

    void bar();
}
```

object: A

x: int
y: char*
foo(): void
bar(): void

C++ CONCEPTS: COMPILER

```
class A {
  public:
    int x;
    char *y;

    void foo();
    virtual void bar();
}
```

```
class B : public A {
  public:
    int z;

    void bar();
}
```

B::vTable

...
...
& B::bar

object: A

x: int
y: char*
foo(): void
bar(): void

C++ CONCEPTS: COMPILER

```
class A {
  public:
    int x;
    char *y;

    void foo();
    virtual void bar();
}
```

object: A

x: int
y: char*
foo(): void
bar(): void

```
class B : public A {
  public:
    int z;

    void bar();
}
```

object: B

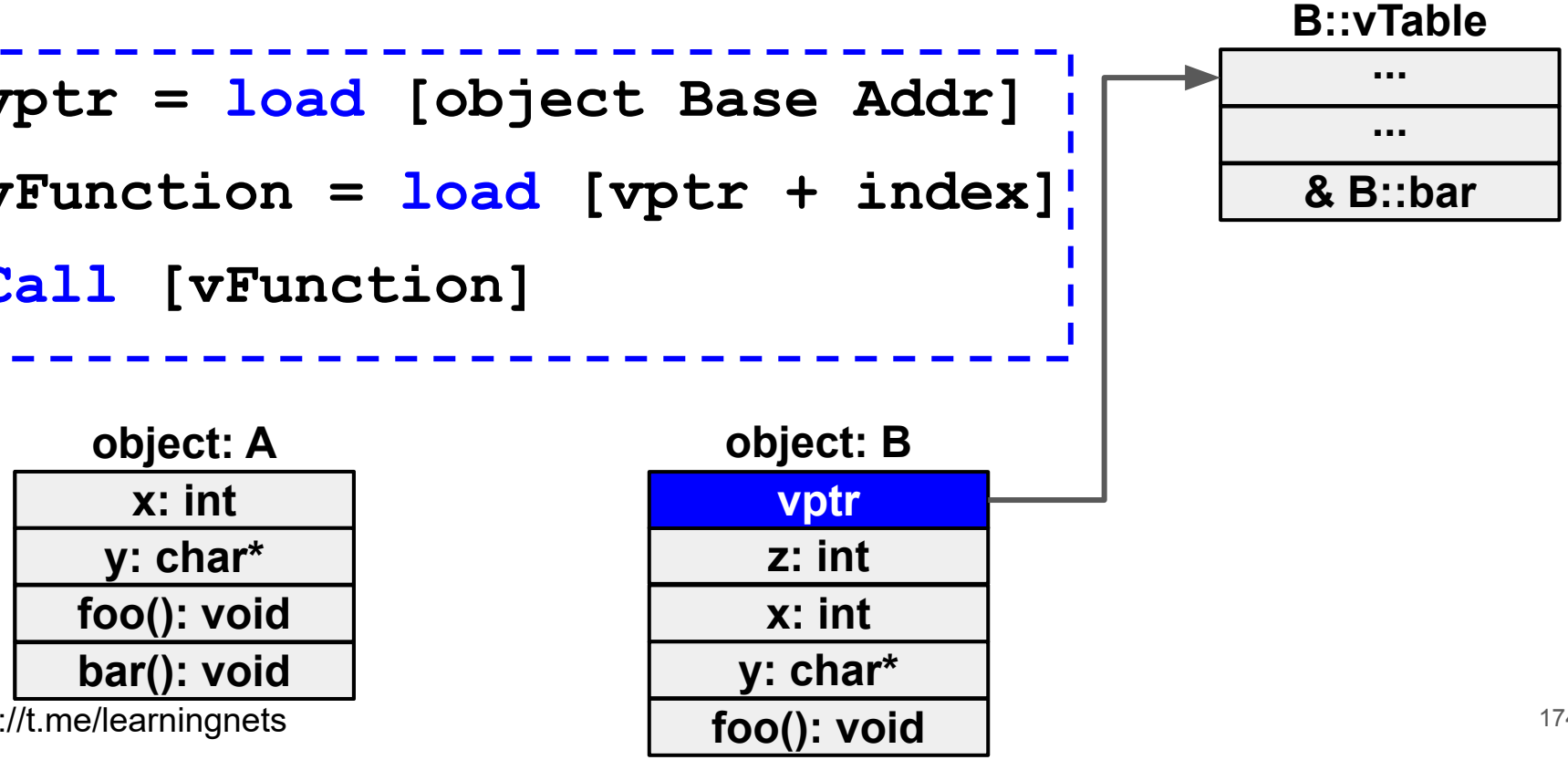
vptr
z: int
x: int
y: char*
foo(): void

B::vTable

...
...
& B::bar

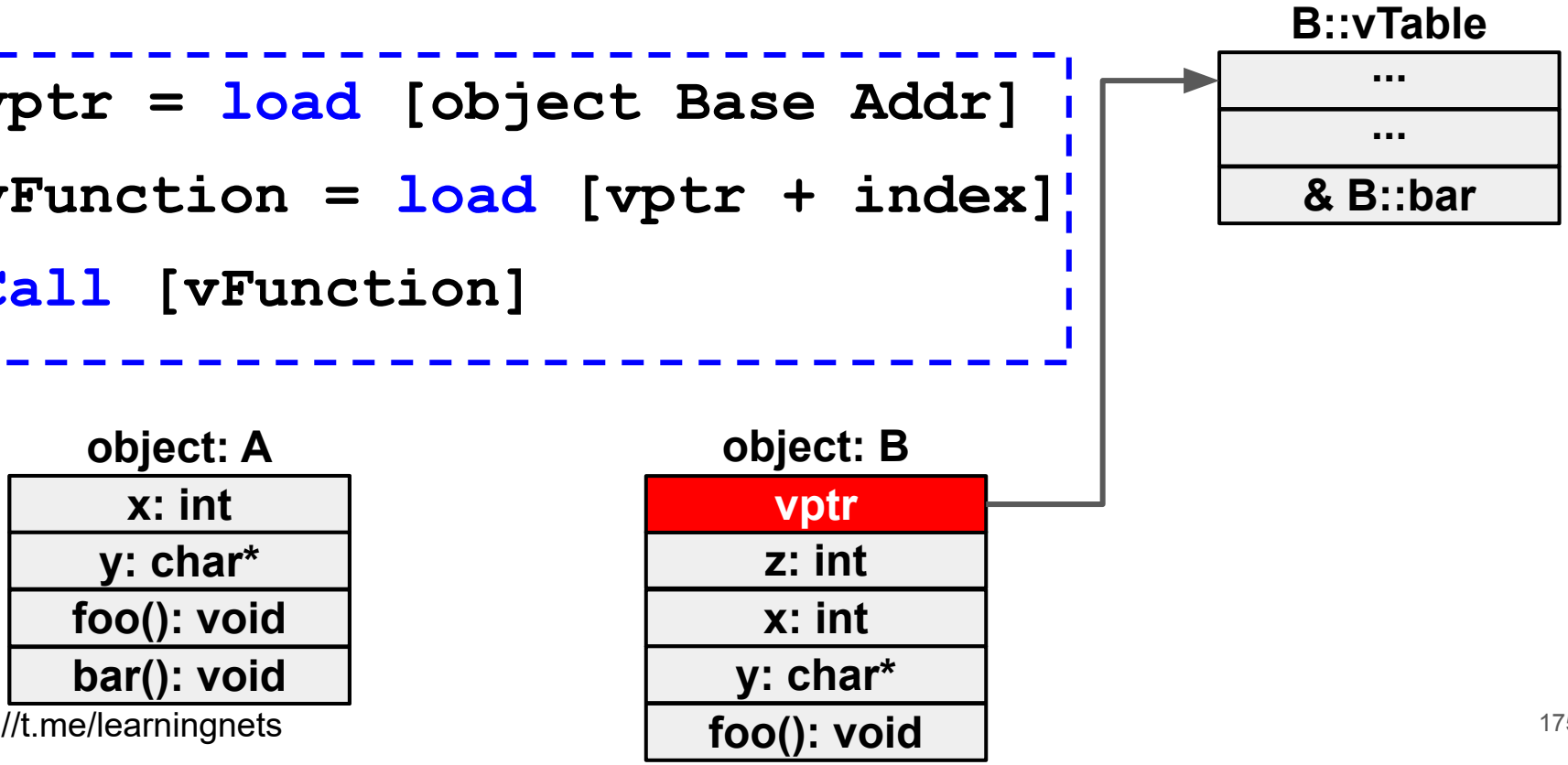
C++ CONCEPTS: COMPILER

```
vptr = load [object Base Addr]
vFunction = load [vptr + index]
Call [vFunction]
```



COUNTERFEIT OBJECT ORIENTED PROGRAMMING (COOP)

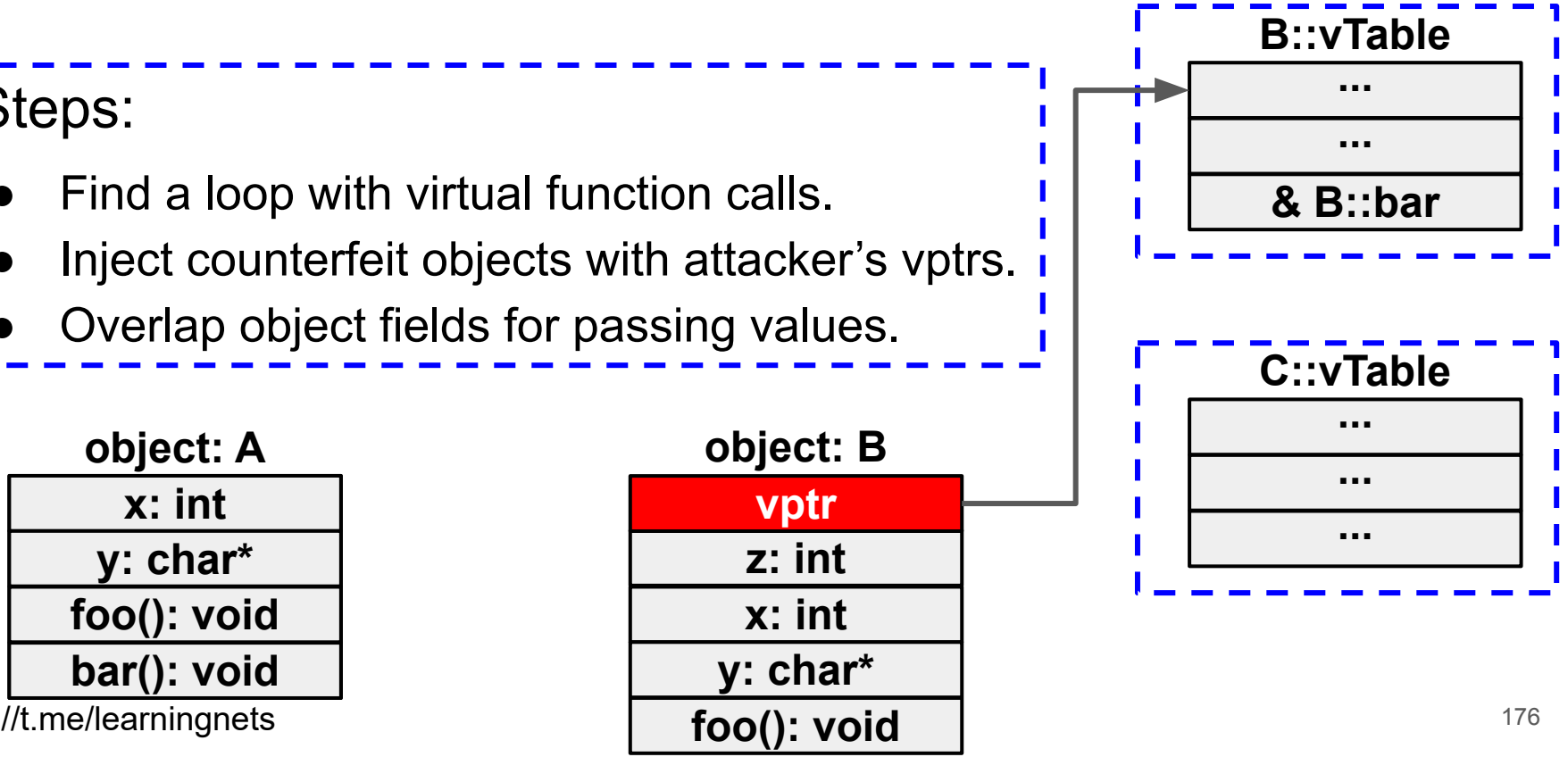
```
vptr = load [object Base Addr]
vFunction = load [vptr + index]
Call [vFunction]
```



COUNTERFEIT OBJECT ORIENTED PROGRAMMING (COOP)

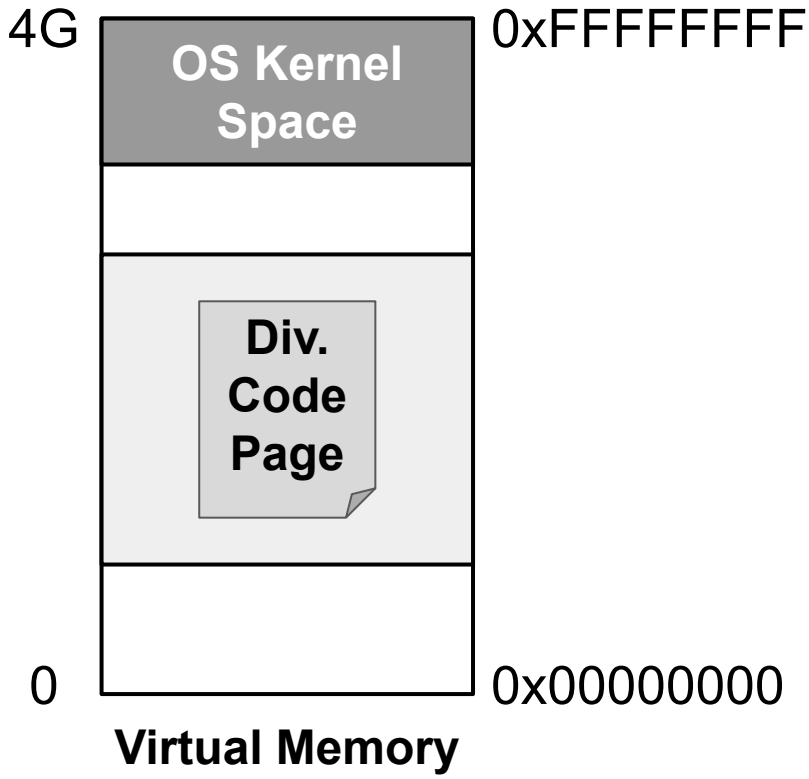
Steps:

- Find a loop with virtual function calls.
- Inject counterfeit objects with attacker's vptrs.
- Overlap object fields for passing values.



JUST-IN-TIME ROP

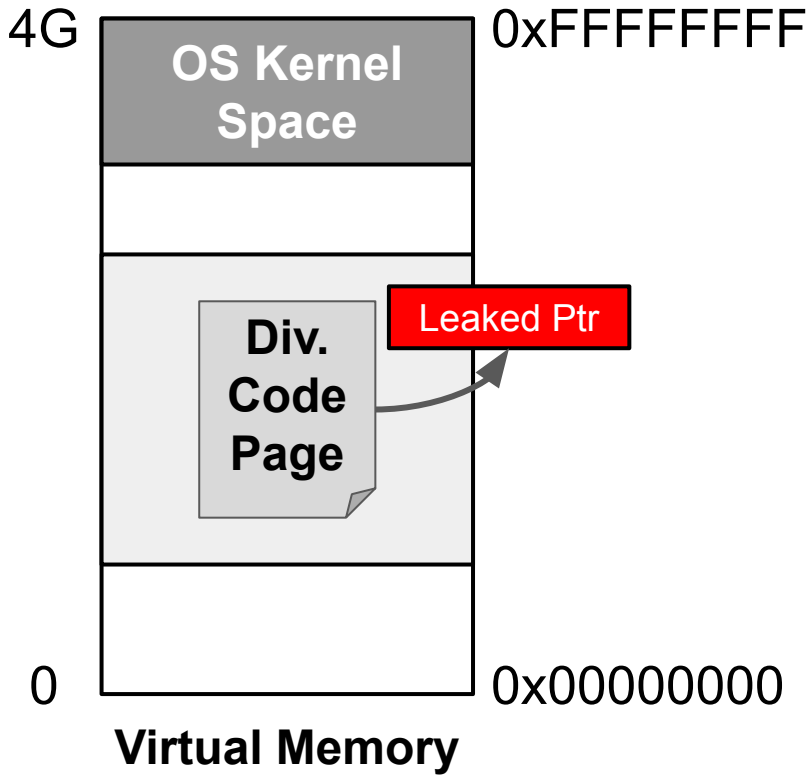
- Main Idea:
  - Repeatedly abuse a memory disclosure.



[8] Snow et. al,Just-in-time code reuse: On the effectiveness of fine-grained ASLR. **[S&P 2013]**

JUST-IN-TIME ROP

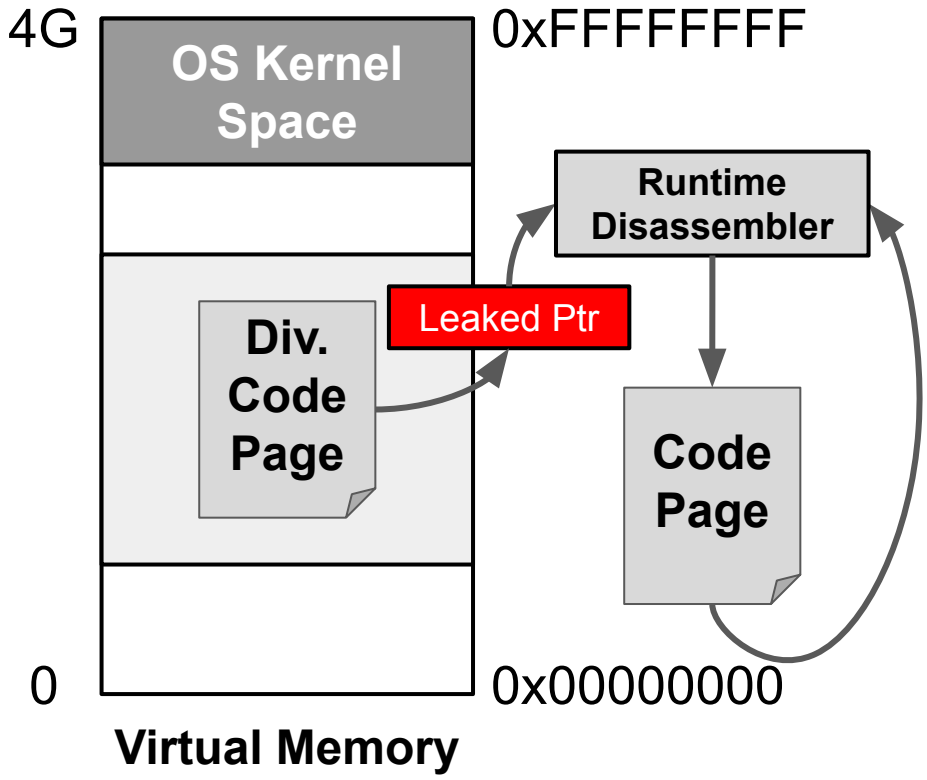
- Main Idea:
  - Repeatedly abuse a memory disclosure.
- Attack Steps:
  - **Leak one code pointer.**



[8] Snow et. al,Just-in-time code reuse: On the effectiveness of fine-grained ASLR. **[S&P 2013]**

JUST-IN-TIME ROP

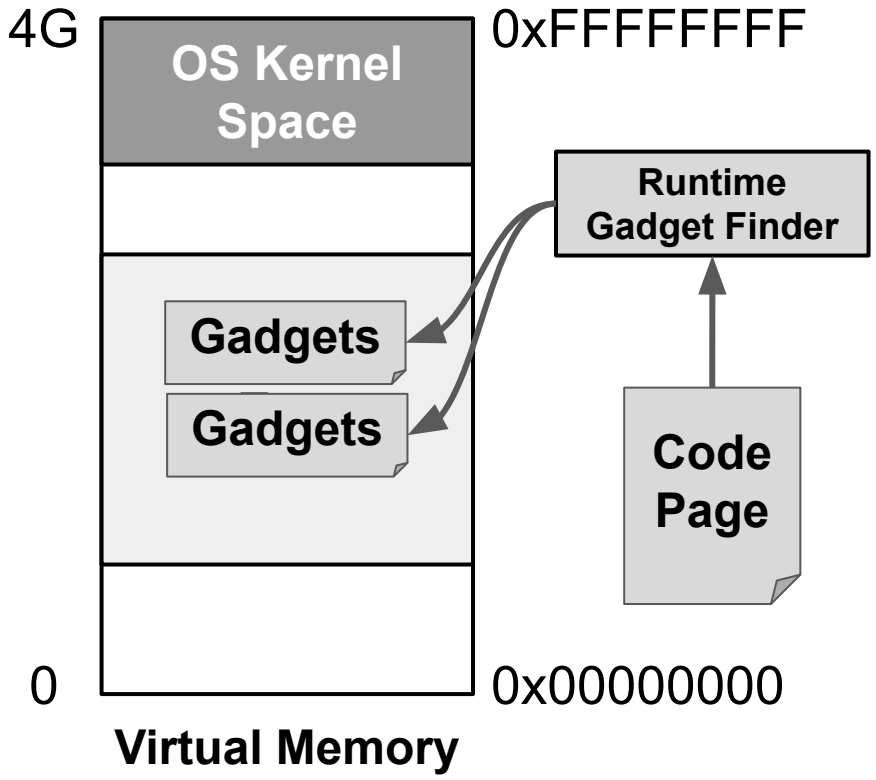
- Main Idea:
  - Repeatedly abuse a memory disclosure.
- Attack Steps:
  - Leak one code pointer.
  - **Scan code pages on the fly.**



[8] Snow et. al,Just-in-time code reuse: On the effectiveness of fine-grained ASLR. **[S&P 2013]**

JUST-IN-TIME ROP

- Main Idea:
  - Repeatedly abuse a memory disclosure.
- Attack Steps:
  - Leak one code pointer.
  - Scan code pages on the fly.
  - **Pinpoint useful gadgets**.



[8] Snow et. al,Just-in-time code reuse: On the effectiveness of fine-grained ASLR. **[S&P 2013]**

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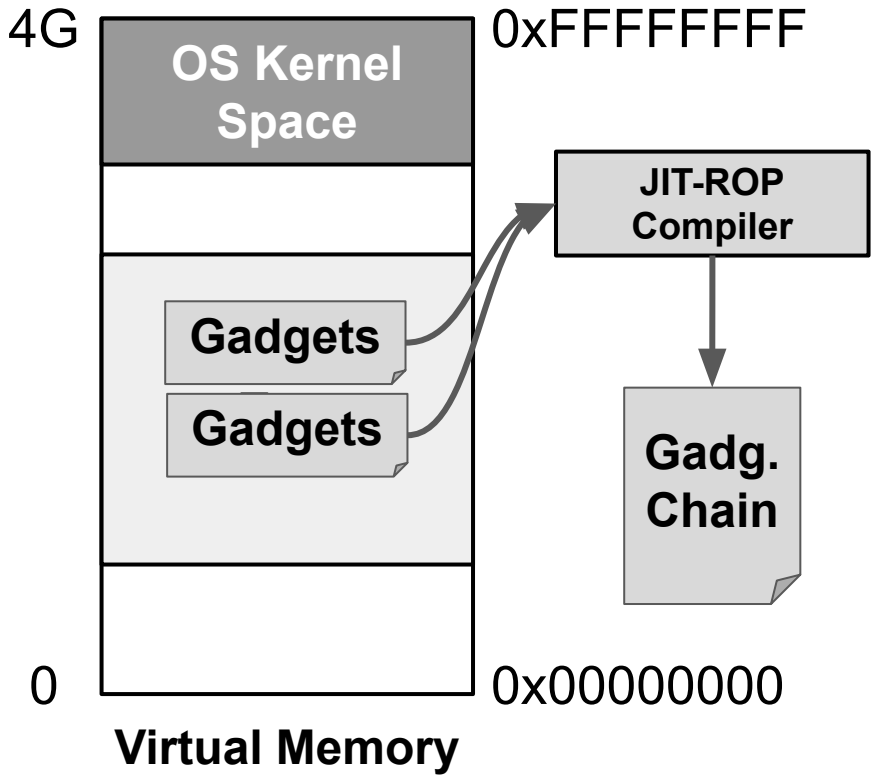
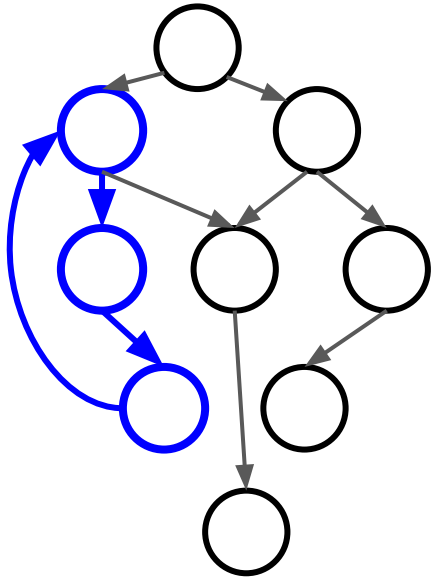
  - Pinpoint useful gadgets.
  - **JIT-compile an ROP gadget chain.**



[8] Snow et. al,Just-in-time code reuse: On the effectiveness of fine-grained ASLR. **[S&P 2013]**

😈 DATA ORIENTED PROGRAMMING (DOP)

- Attack Steps:
  - Trigger a memory safety vulnerability.
  - Manipulate non control data.
  - Use the corrupted data.
- Goal:
  - Never change program CFG.

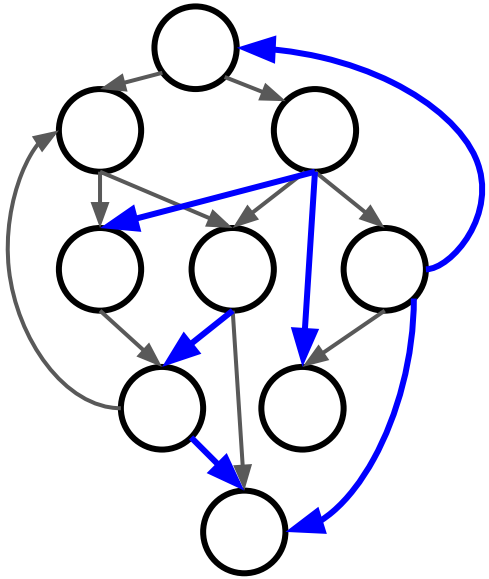


CFG

[10] Cheng et. al., Exploitation techniques and defenses for data-oriented attacks. **[SecDev 2019]**

DATA FLOW INTEGRITY

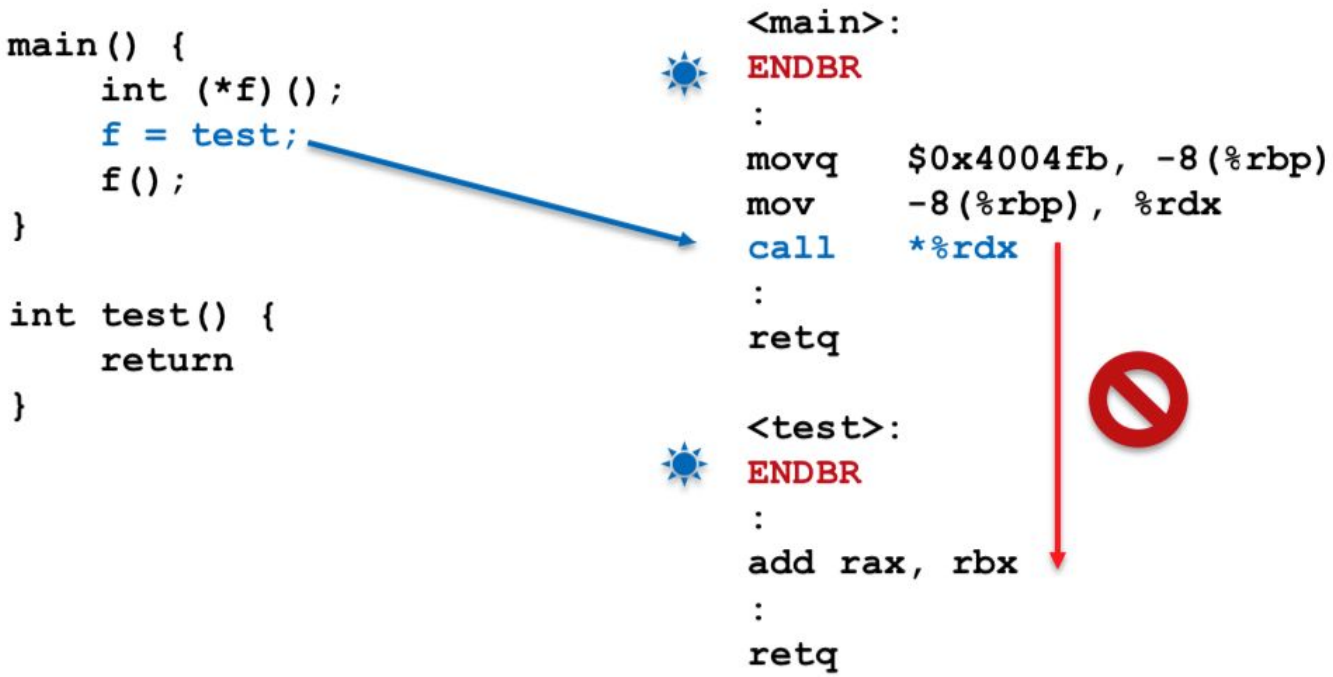
- Main Idea:
  - Construct a compile-time DFG.
    - Load inst. → {IDs of store insts.} with point-to analysis.
  - Enforce it at runtime.
    - Tag every memory word with 2-byte shadow.
    - Write the ID to the Tag upon store.
    - Compare ID vs. set upon load.
- Limitations:
  - Over-approximation.



DFG

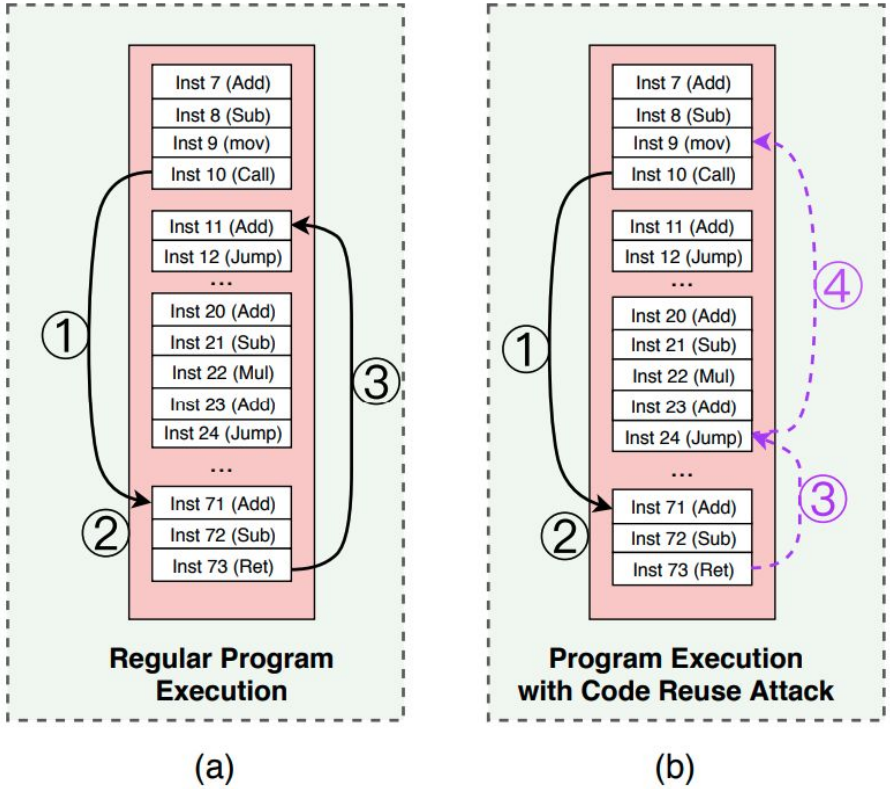
[13] Castro et. al., Securing software by enforcing data-flow integrity. **[OSDI 2006]**

INTEL CONTROL FLOW ENF. TECH. (CET)



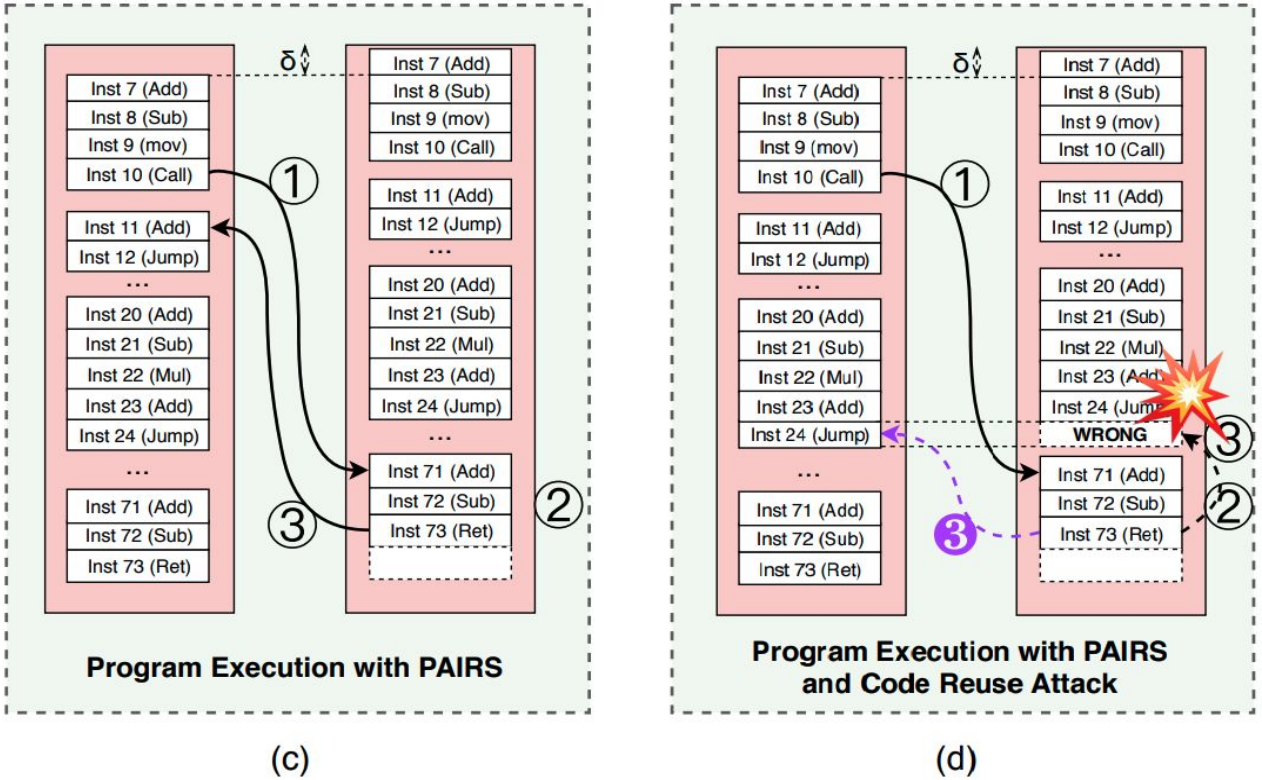
Source:
https://t.me/learningnets
https://www.linuxplumbersconf.org/event/2/contributions/147/attachments/72/83/CET-LPC-2018.pdf

PAIRS vs. CODE REUSE ATTACKS



[2] Mohamed et. al, PAIRS: Control flow protection using phantom addressed instructions. **[arXiv 2019]**

PAIRS vs. CODE REUSE ATTACKS

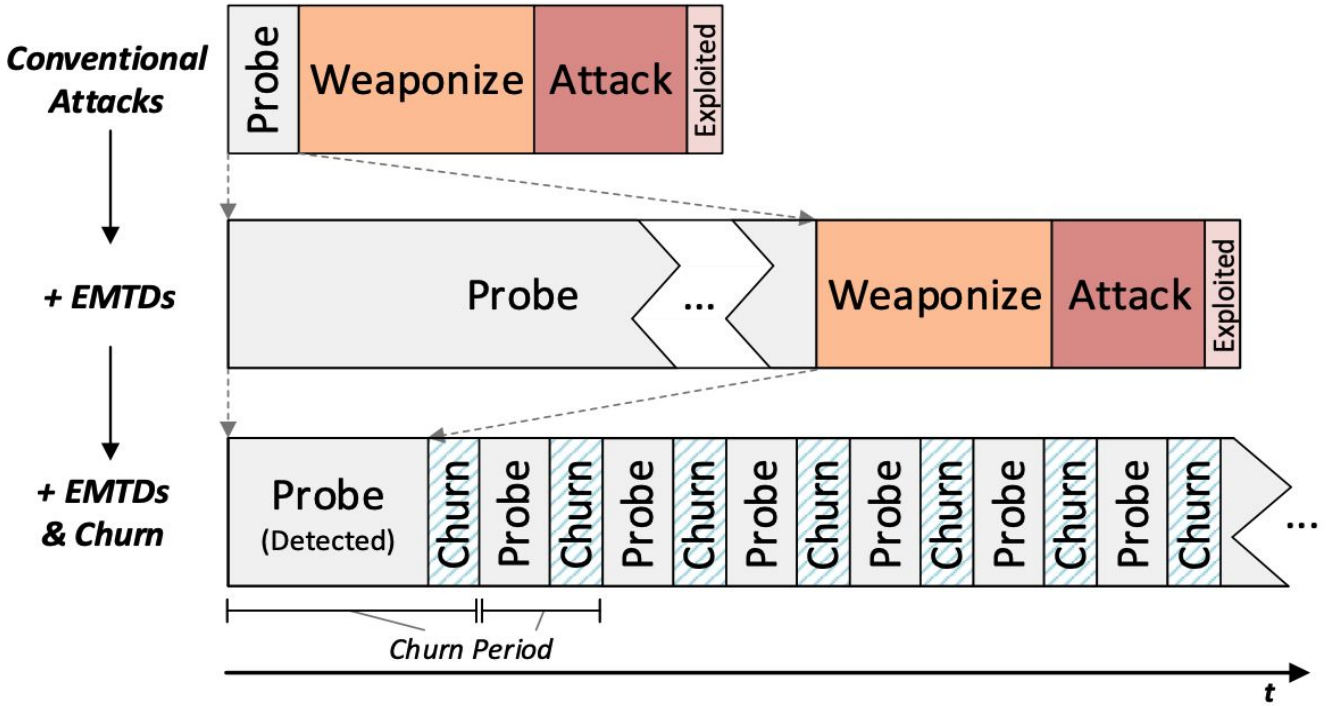


[2] Mohamed et. al, PAIRS: Control flow protection using phantom addressed instructions. **[arXiv 2019]**

DATA SPACE RANDOMIZATION

- Main Idea:
  - Randomize the representation of data stored in memory.
- Approaches:
  - Use encryption with a unique key per variable.
    - DSR.
  - Statically randomize structs layout in a program.
    - GCC struct randomization.
  - Dynamically randomize objects layout in memory.
    - SALADS, SmokeStack, and POLAR.

MOVING TARGET DEFENSE (MORPHEUS)



Gallagher et. al., Morpheus: A Vulnerability-Tolerant Secure Architecture Based on Ensembles of Moving Target Defenses with Churn. **[ASPLOS 2019]**

CALIFORMS: INSERTION POLICIES

```
struct A_opportunistic
{
  char c;
  char tripwire[3];
  int i;
  char buf[64];
  void (*fp)();
}
```

(1) Opportunistic

```
struct A_full {
  char tripwire[2];
  char c;
  char tripwire[1];
  int i;
  char tripwire[3];
  char buf[64];
  char tripwire[2];
  void (*fp)();
  char tripwire[1];
}
```

(2) Full

```
struct A_intelligent {
  char c;
  int i;
  char tripwire[3];
  char buf[64];
  char tripwire[2];
  void (*fp)();
  char tripwire[3];
}
```

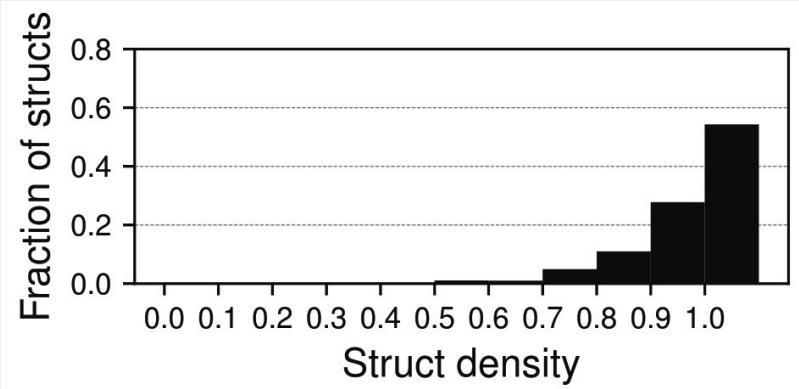
(3) Intelligent

Tripwire Insertion Policies

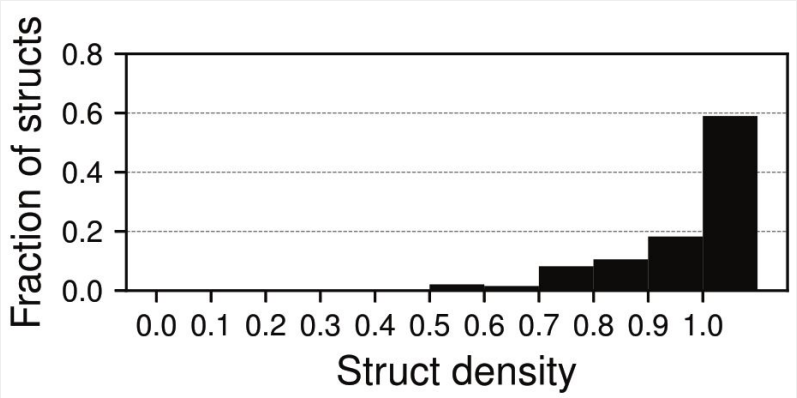
[1] Sasaki et. al., Practical byte-granular memory blacklisting using Califorms. **[MICRO 2019]**

CALIFORMS: DEAD BYTES

Normally Occurring Dead Bytes



SPEC CPU2006 C and C++ Benchmarks

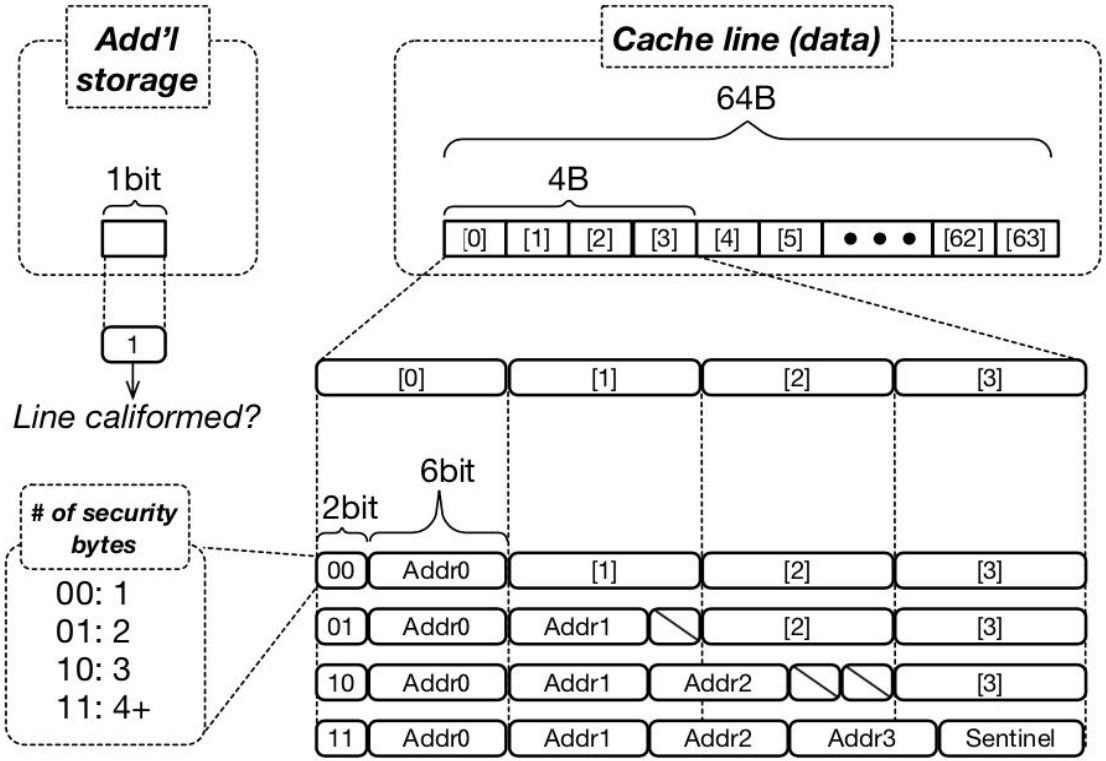


V8 JavaScript Engine

Struct density = $\sum_{i}^{\#fields}(sizeof(field_i))/sizeof(struct)$

[1] Sasaki et. al., Practical byte-granular memory blacklisting using Califorms. **[MICRO 2019]**

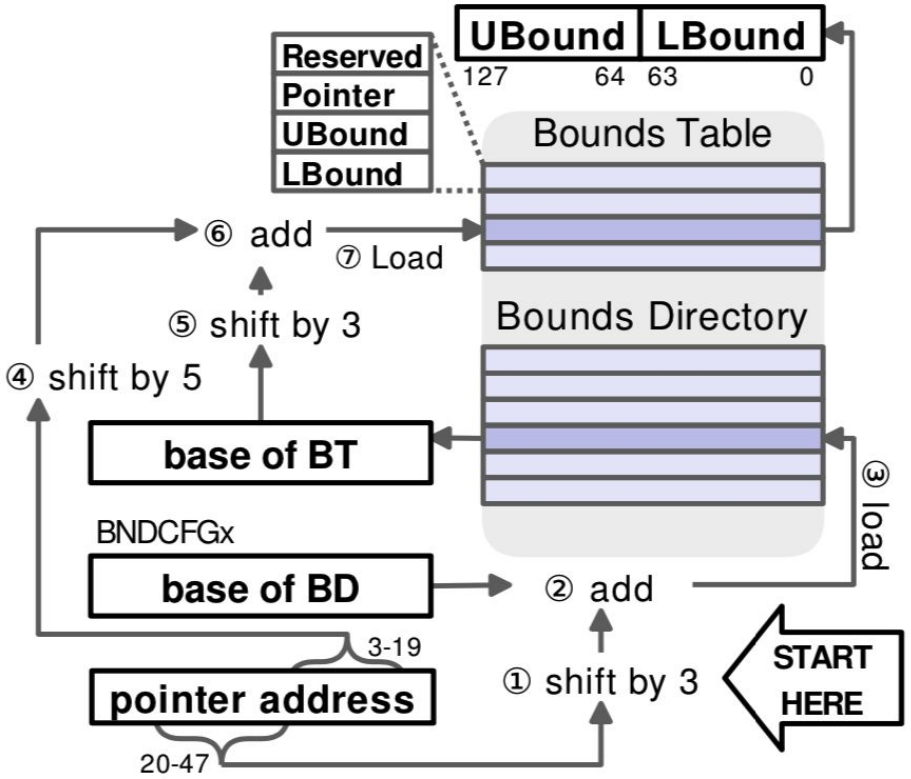
CALIFORMS: CACHELINE FORMAT



[1] Sasaki et. al., Practical byte-granular memory blacklisting using Califorms. **[MICRO 2019]**

INTEL MPX

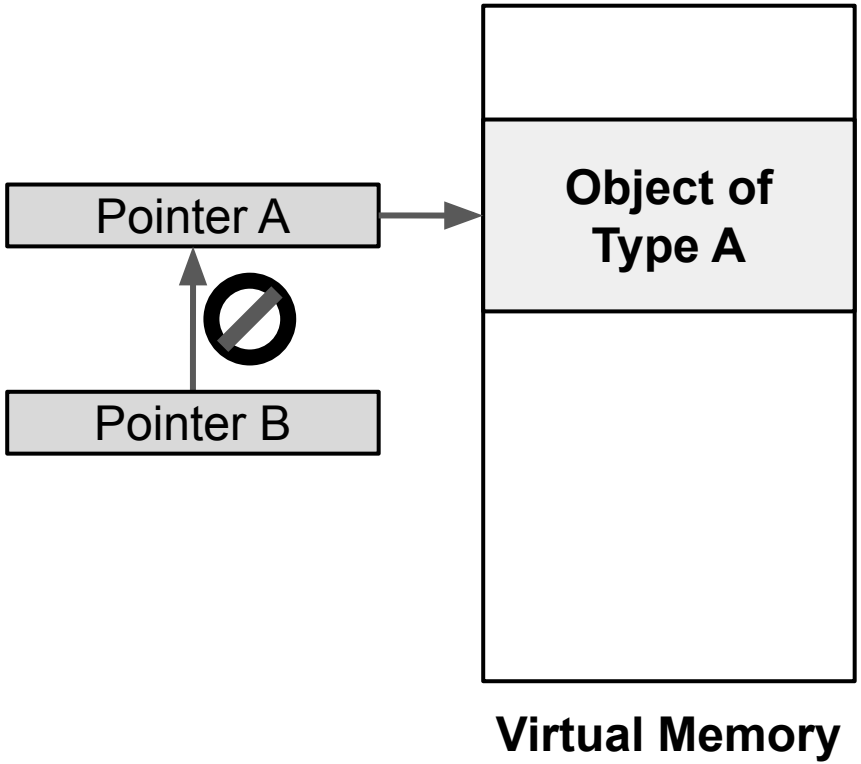
- Main Limitations:
  - High overheads (up to 4x).
  - Lack of multithreading.
  - Incorrect handling of several common C idioms.
  - Poor Interaction with other ISA extensions (like SGX).



[29] Oleksenko et. al., Intel MPX explained **[ACM Surveys 2018]**

TYPE SAFETY

- Main Idea:
  - Add runtime checks to detect incompatible type casting.



[5] Song et. al., SoK: Sanitizing for security. **[S&P 2019]**

TYPE SAFETY

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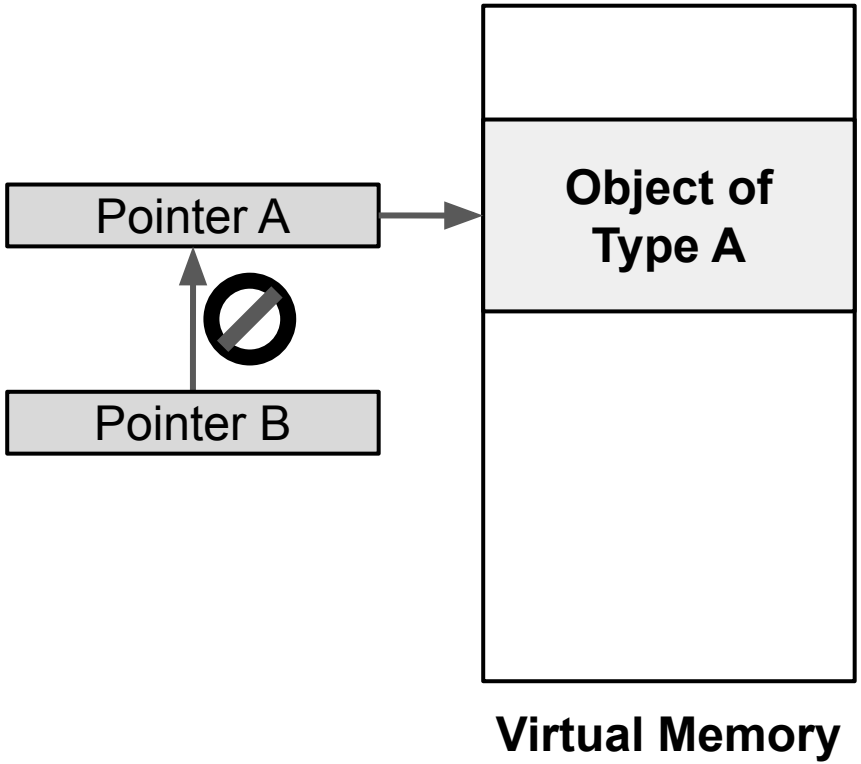
    - RTTI-based verification.



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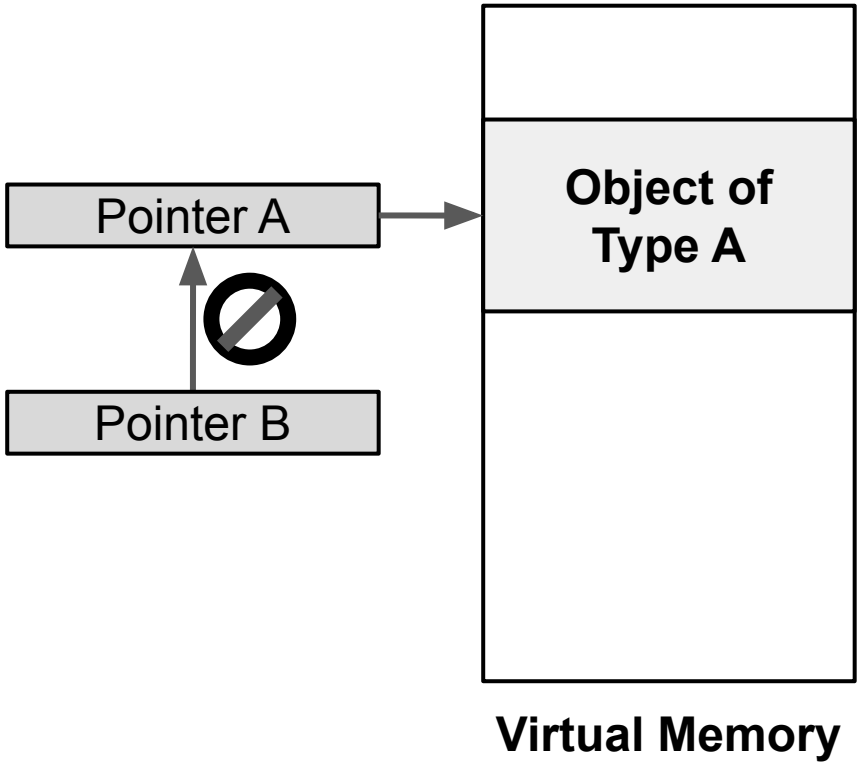
    - Custom metadata.



[5] Song et. al., SoK: Sanitizing for security. **[S&P 2019]**

TYPE SAFETY

- Main Idea:
  - Add runtime checks to detect incompatible type casting.
- Examples:
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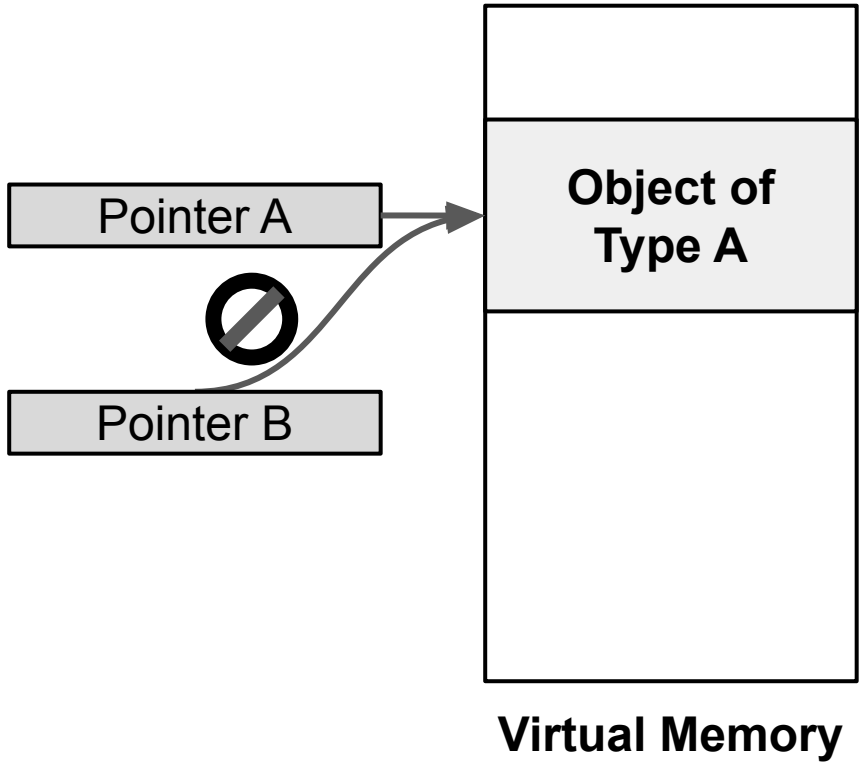
    - RTTI-based verification.
  - CaVer, TypeSan, and HexType
    - Custom metadata.
  - Clang TySan and EffetiveSan
    - Check pointer dereference.



[5] Song et. al., SoK: Sanitizing for security. **[S&P 2019]**

End of Supplementary Slides