Opaque Control-Flow Integrity

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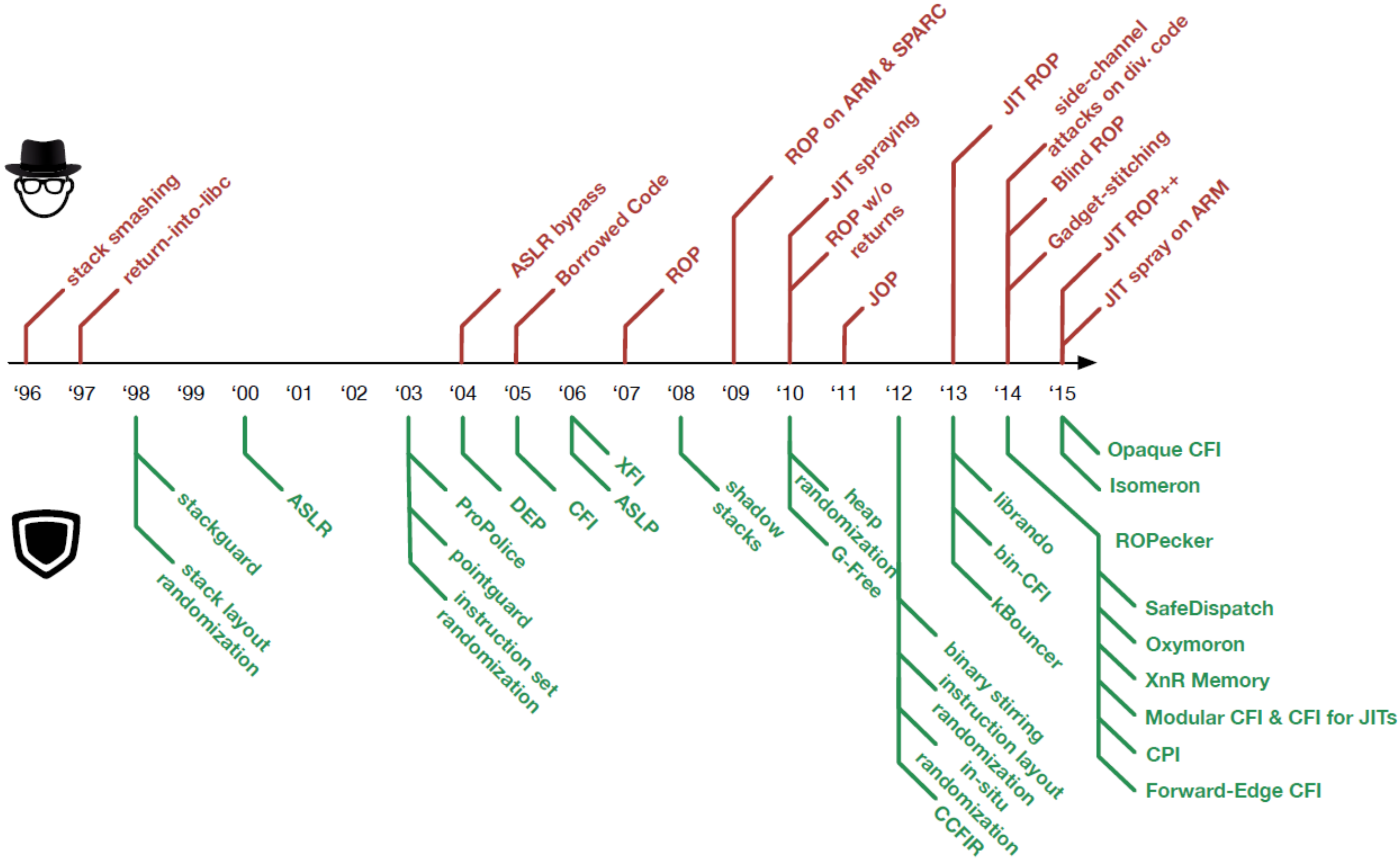
stack smashing
return-into-libc
ASLR bypass
Borrowed Code
ROP
ROP on ARM & SPARC
JIT spraying
ROP w/o returns
JOP
JIT ROP
side-channel attacks on div. code
Blind ROP
Gadget-stitching
JIT ROP++
JIT spray on ARM
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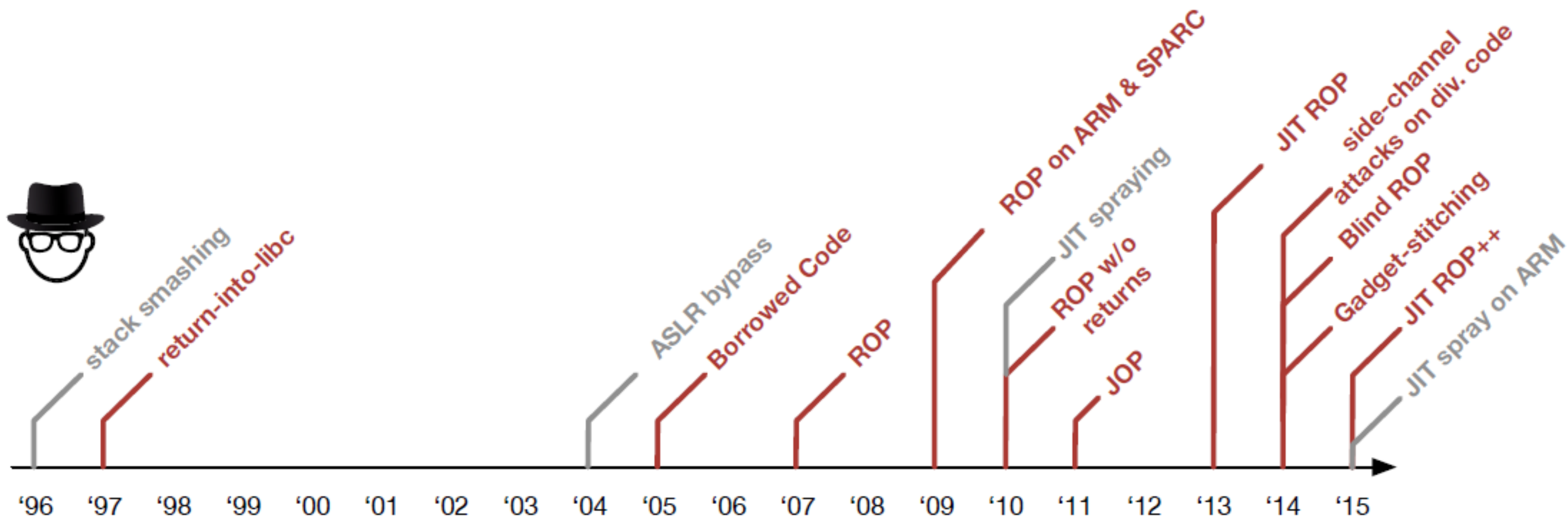
stackguard
stack layout randomization
ASLR
ProPolice
pointguard
instruction set randomization
DEP
CFI
XFI
ASLP
shadow stacks
heap randomization
G-Free
binary stirring
instruction layout randomization
in-situ randomization
CCFIR
librando
bin-CFI
kBouncer
ROPecker
SafeDispatch
Oxymoron
XnR Memory
Modular CFI & CFI for JITs
CPI
Forward-Edge CFI
Opaque CFI
Isomeron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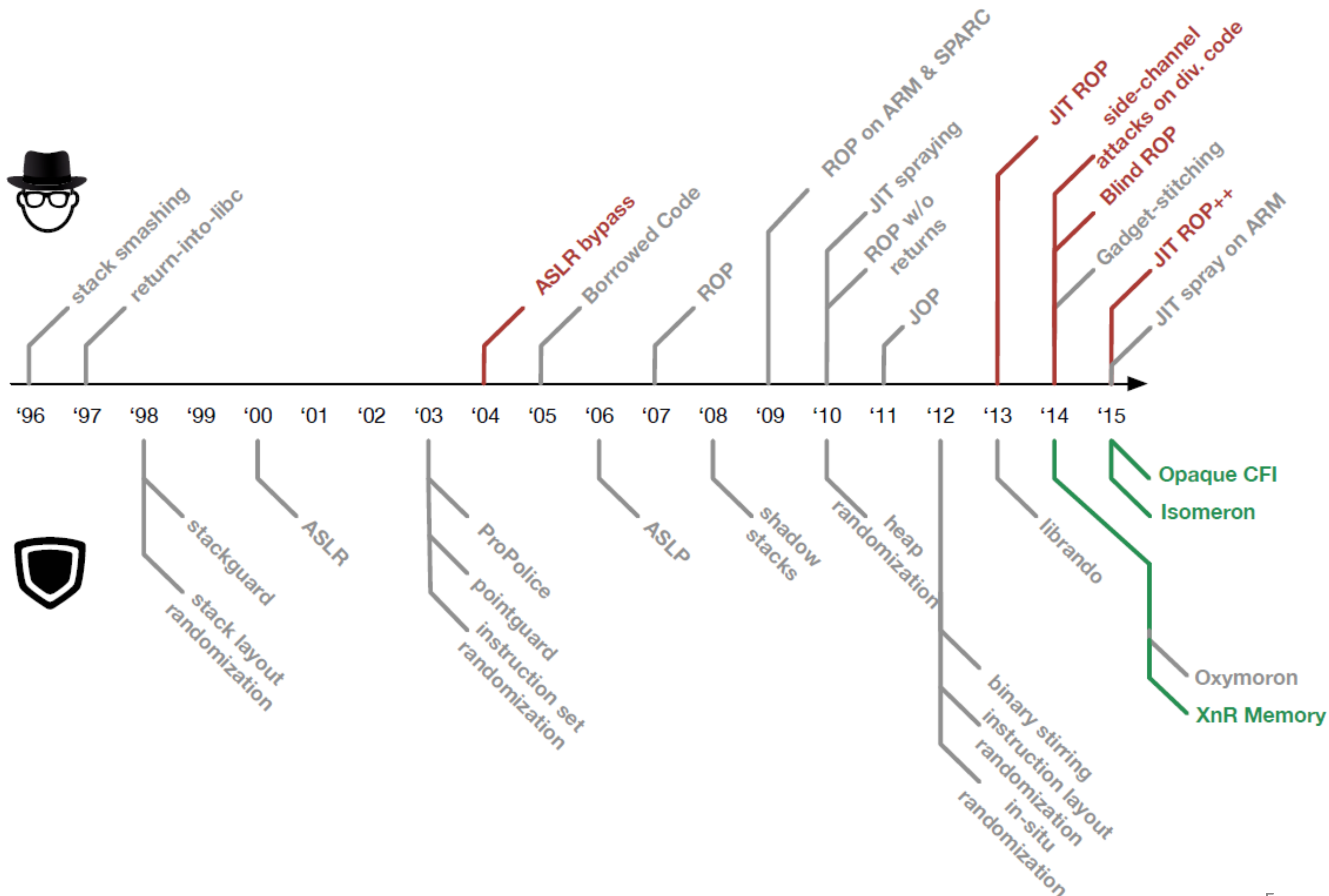
Code Reuse Attacks

- Needs
  - Location of code
  - Hijack control-flow
- Defensive options
  - Randomization
  - Control Flow Integrity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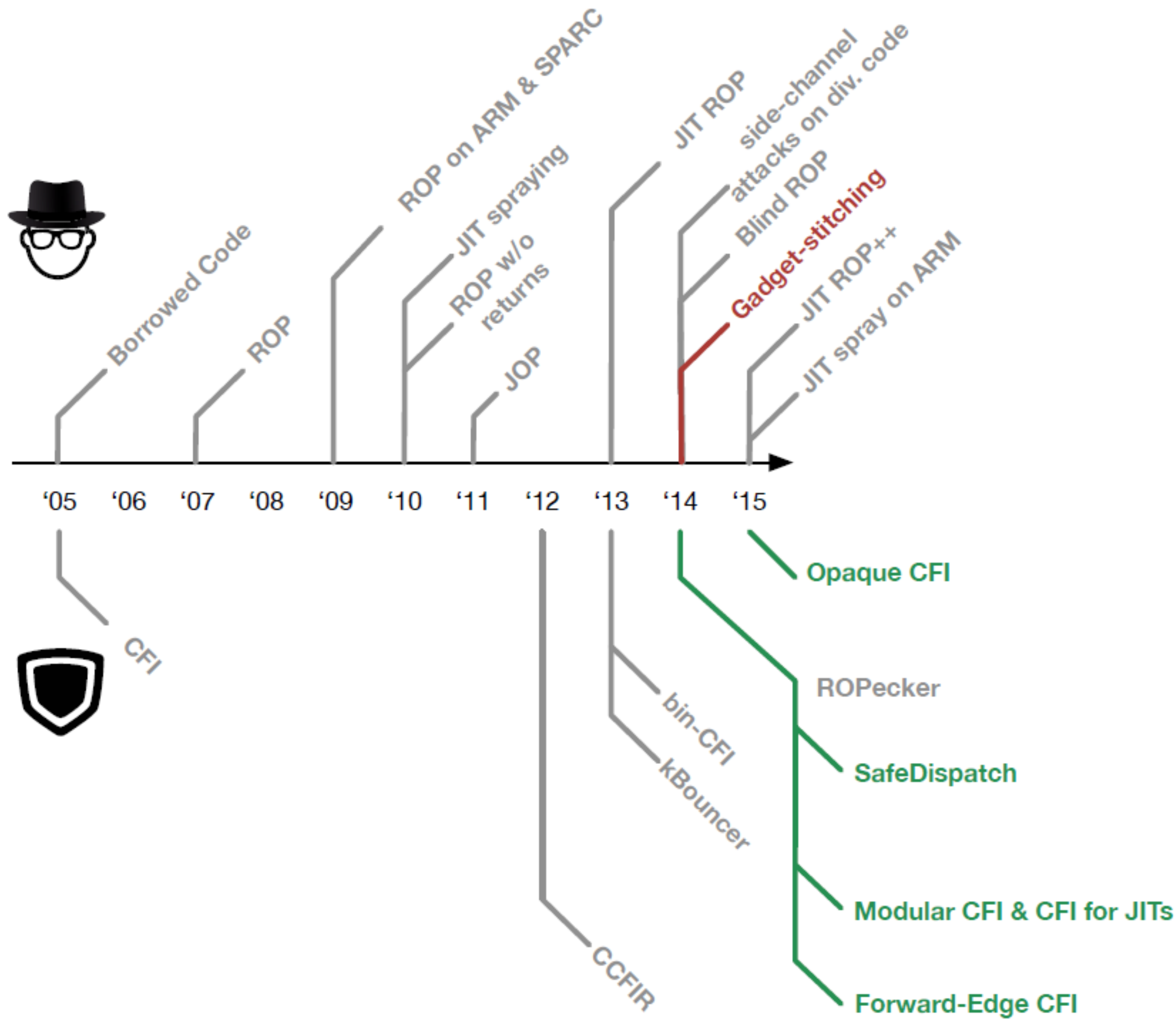
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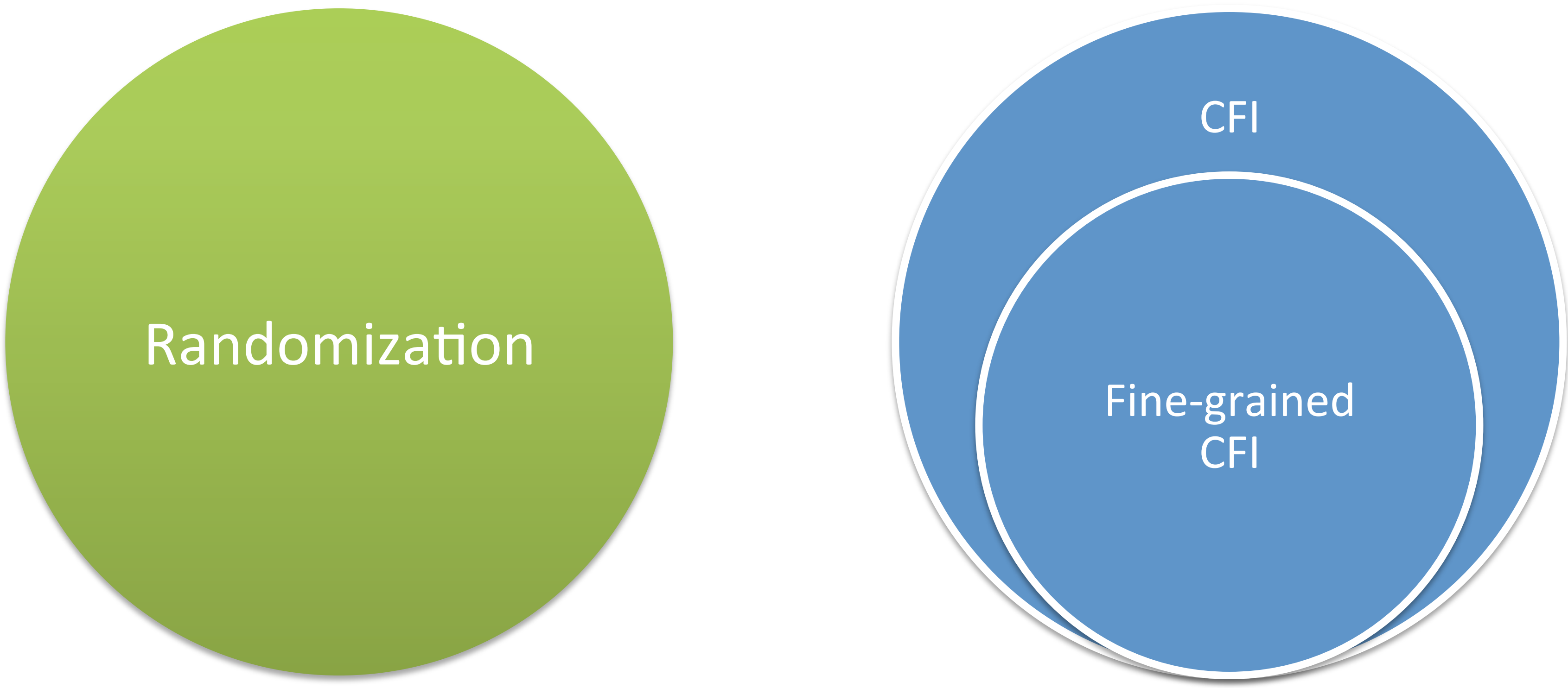
Where does that leave us?



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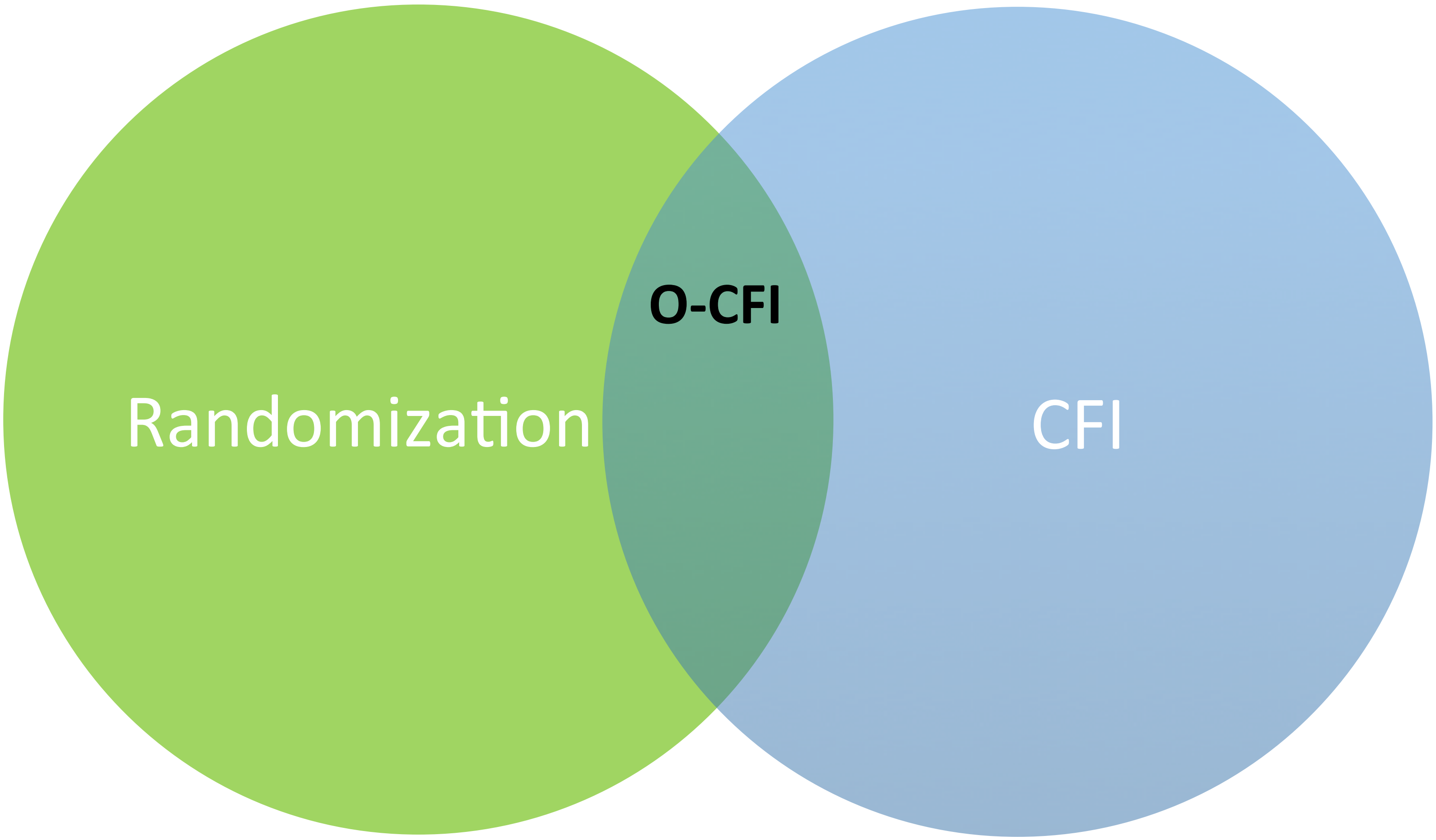
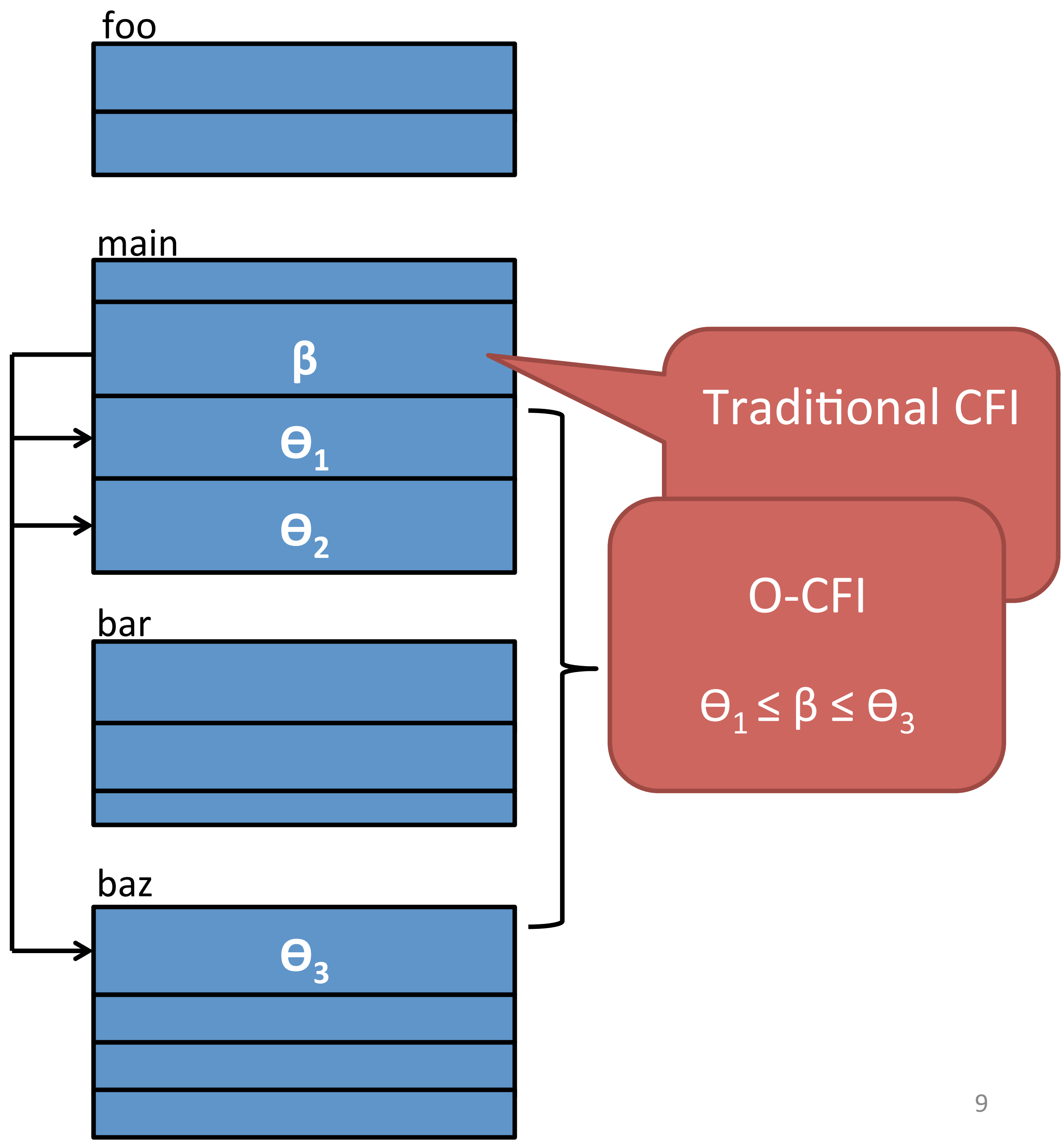
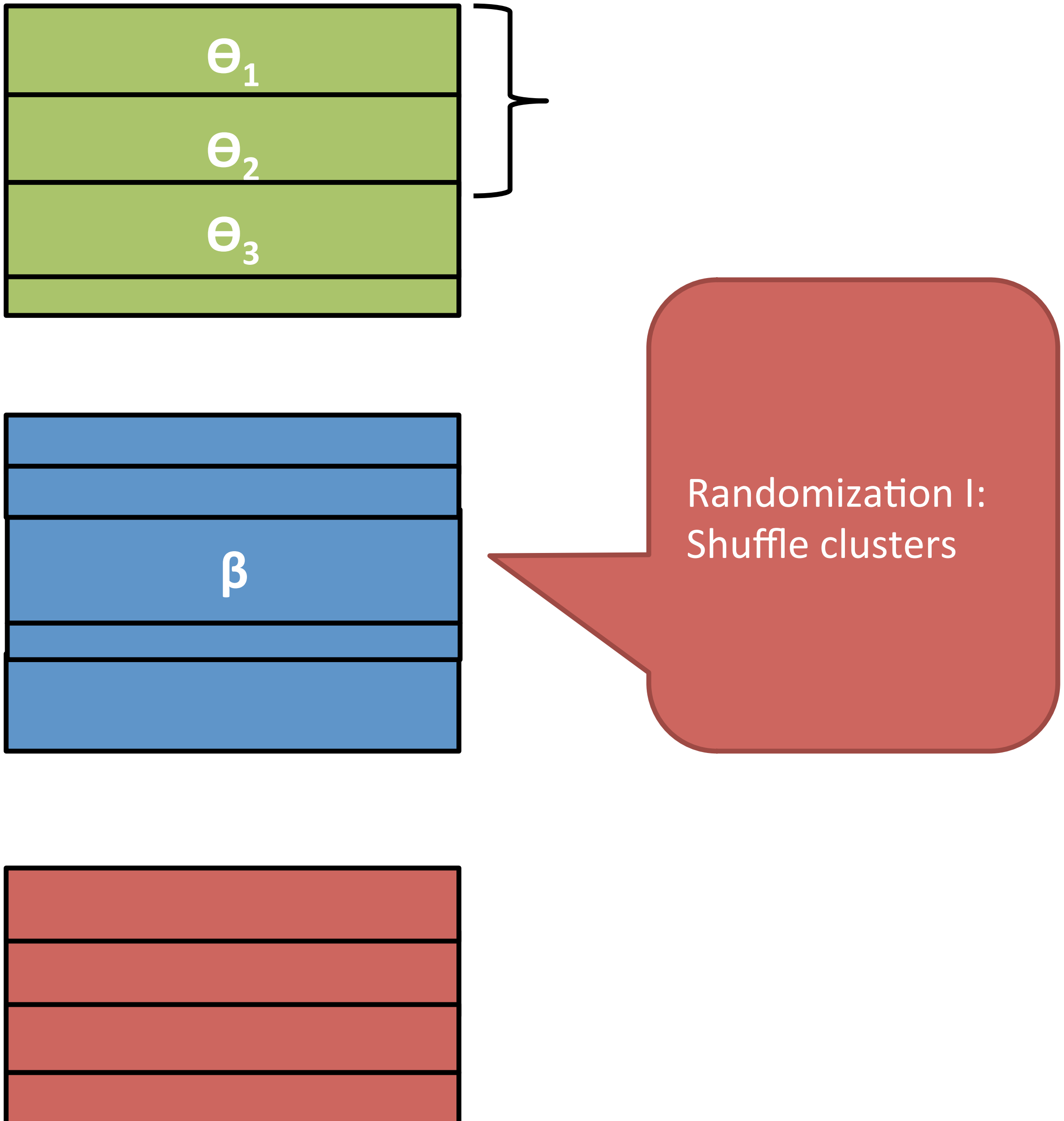
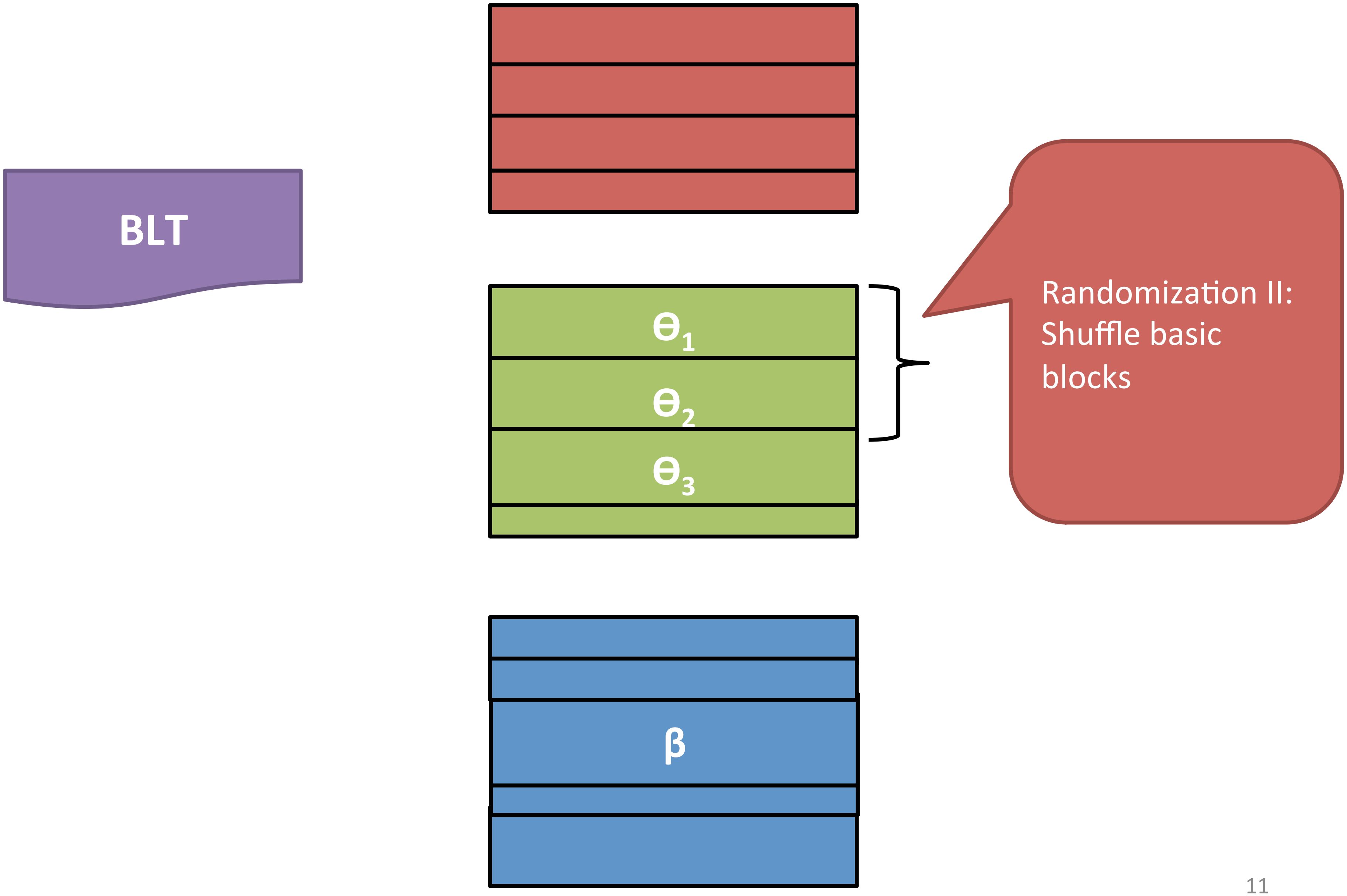



foo
main
β
Θ1
Θ2
bar
baz
Θ3
Traditional CFI
O-CFI
Θ1 ≤ β ≤ Θ3


θ1
θ2
θ3
β
Randomization I:
Shuffle clusters


BLT
θ1
θ2
θ3
β
Randomization II: Shuffle basic blocks

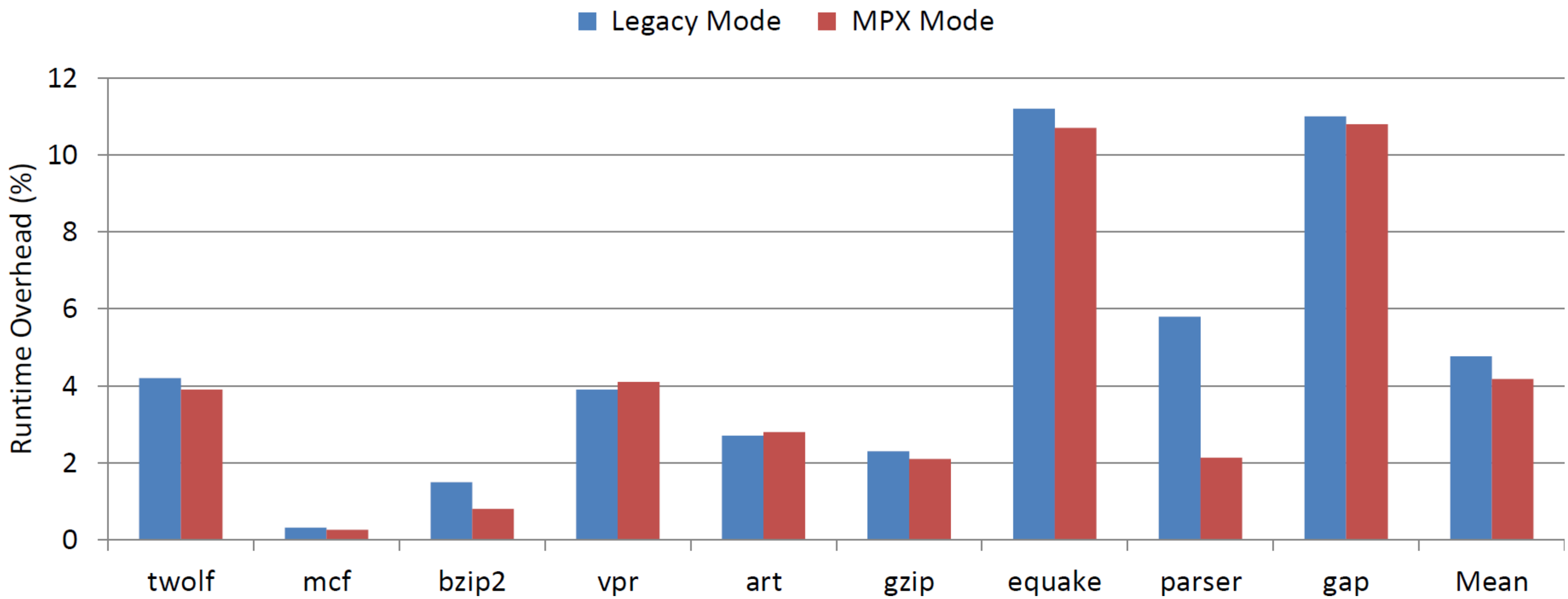
Accelerated Bounds Checks

- MPX mode on supported chipsets

Syntax	Description
`bndmov bnd, m64`	Move upper and lower bound from `m64` to bound register `bnd`.
`bndcl bnd, r/m32`	Generate a #BR if `r/m32` is less than the lower bound in `bnd`.
`bndcu bnd, r/m32`	Generate a #BR is `r/m32` is higher than the upper bound in `bnd`.

- Legacy mode as fallback

Performance



Legacy mode overhead 4.7%

MPX mode overhead ≈ 4.2%

Security

- When the CFI policy is opaque

Gadget Chain Size	Chance(%)
2	2.0
3	0.8
4	0.01
5	-

Security

- When the CFI policy is not opaque
  - Expressed as CSP
  - Attempted constructing `VirtualAlloc` payload
  - Across Mona/custom tool, no payload found

Conclusion

- Coarse-grained CFI with randomization
  - Advantages of both
- Effective against state-of-the-art exploits
  - JIT-ROP, BROP, Gadget stitching
- Efficient
  - 4.7% overhead in legacy mode

Thank you

Extra Resources

Optimizing Guards

- Actual guard implementation
  - PittSFIeld inspired guards
  - Want minimal chunk size
  - Comparison instructions rather large (~ 7 bytes)
- How efficient can we be?

Optimizing Guards

Description	Original Code	Rewritten Code (MPX-mode)	Rewritten Code (Legacy-mode)
Indirect Branches	call/jmp r/[m]	1: mov [esp-4], eax 2: mov eax, r/[m] 3: cmp byte ptr [eax], 0xF4 4: cmovz eax, [eax+1] — chunk boundary — 5: bndmov bnd1, gs:[branch_id] 6: bndcu bnd1, eax 7: jmp 9 — chunk boundary — 8: xor eax, eax 9: and al, align_mask 10: bndcl bnd1, eax 11: xchg eax, [esp-4] 12: call/jmp [esp-4]	1: push ecx 2: push eax 3: mov eax, r/[m] 4: cmp byte ptr [eax], 0xF4 5: cmovz eax, [eax+1] — chunk boundary — 6: mov ecx, branch_id 7: cmp eax, gs:[ecx] 8: jb 10 9: cmp gs:[ecx+4], eax boundary —— 10: jbe abort — chunk 11: and al, align_mask 12: xchg eax, [esp] 13: pop ecx 14: pop ecx 15: call/jmp [esp-8]
Returns	ret ⟨n⟩	— chunk boundary — 1: xchg eax, [esp] 2: and al, align_mask 3: bndmov bnd1, gs:[branch_id] 4: jmp 6 — chunk boundary — 5: xor eax, eax 6: bndcu bnd1, eax 7: bndcl bnd1, eax 8: xchg eax, [esp] 9: ret ⟨n⟩	— chunk boundary — 1: xchg eax, [esp] 2: cmp eax, gs:[branch_id] 3: jb 9 boundary —— 4: and al, align_mask —— chunk 5: cmp eax, gs:[branch_id + 4] 6: jae 9 7: xchg eax, [esp] 8: ret ⟨n⟩ — chunk boundary — 9: jmp abort

Coarse Grained Insecurity

		CFI [1]	bin-CFI [50]	CCFIR [49]	kBouncer [33]	ROPecker [7]	ROPGuard [16]	EMET [30]
DeMott [12]	Feb 2014							☹
Göktaş et al. [18]	May 2014	☹	☹	☹				
Davi et al. [11]	Aug 2014		☹		☹	☹	☹	☹
Göktaş et al. [19]	Aug 2014				☹	☹		
Carlini and Wagner [6]	Aug 2014				☹	☹		