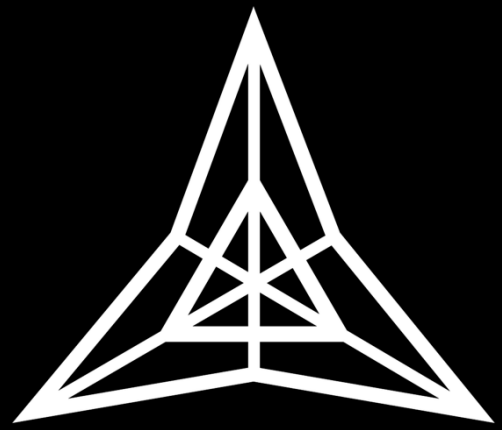
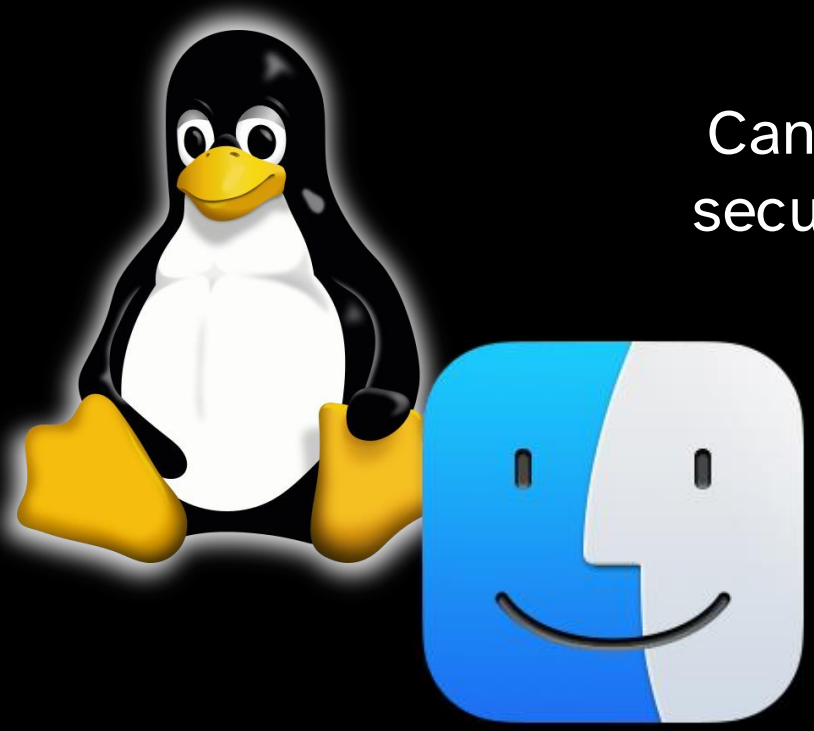


FRACTAL

An Operating System Designed for Microarchitecture Reverse Engineering

Joseph Ravichandran & Mengjia Yan
MIT CSAIL

Research Question

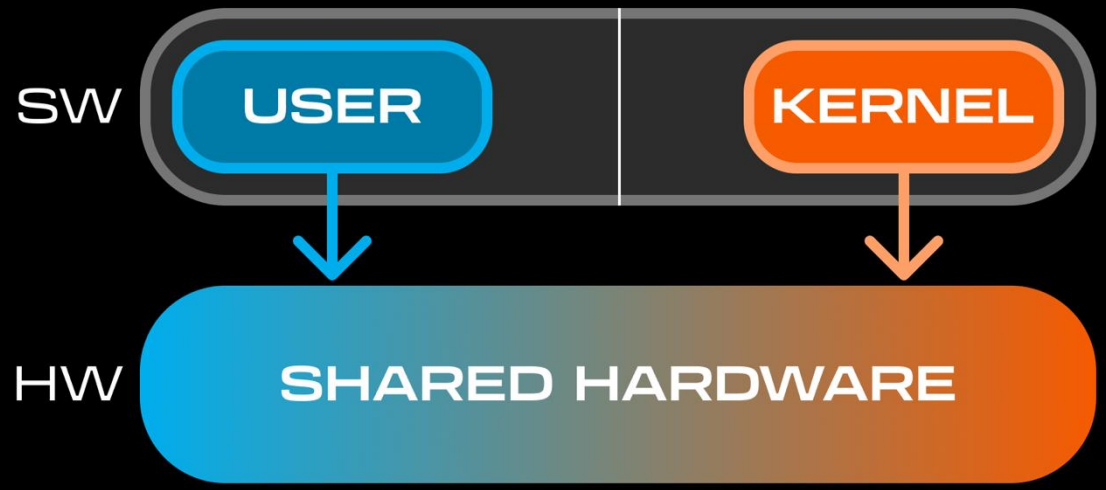


Linux/ macOS

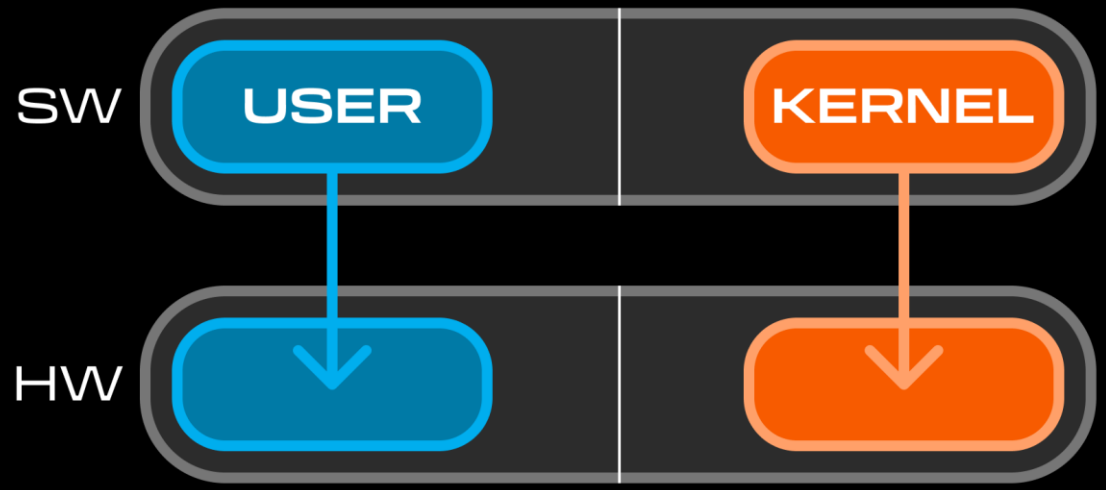
Can we improve microarchitecture security research by creating a new operating system?

Fractal

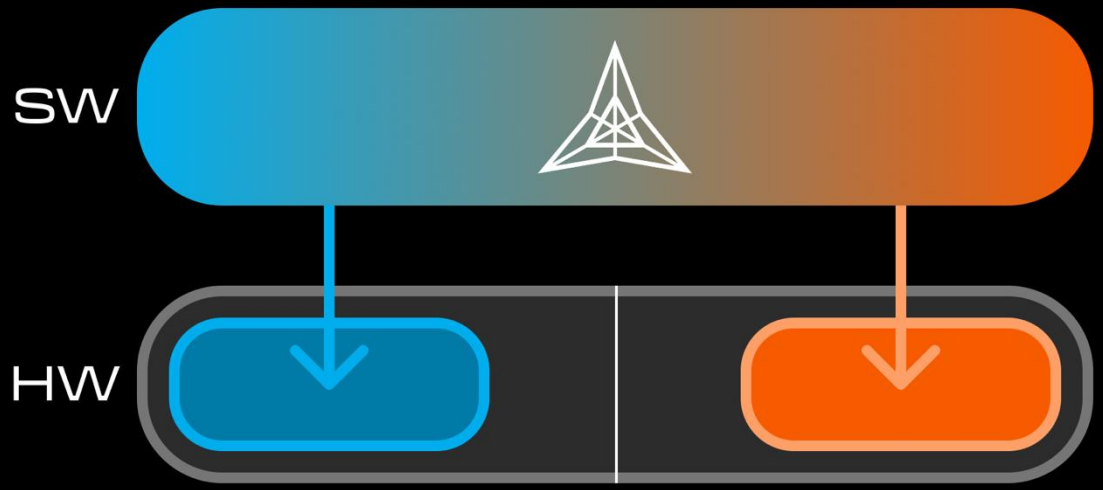
ISA separates user & kernel code



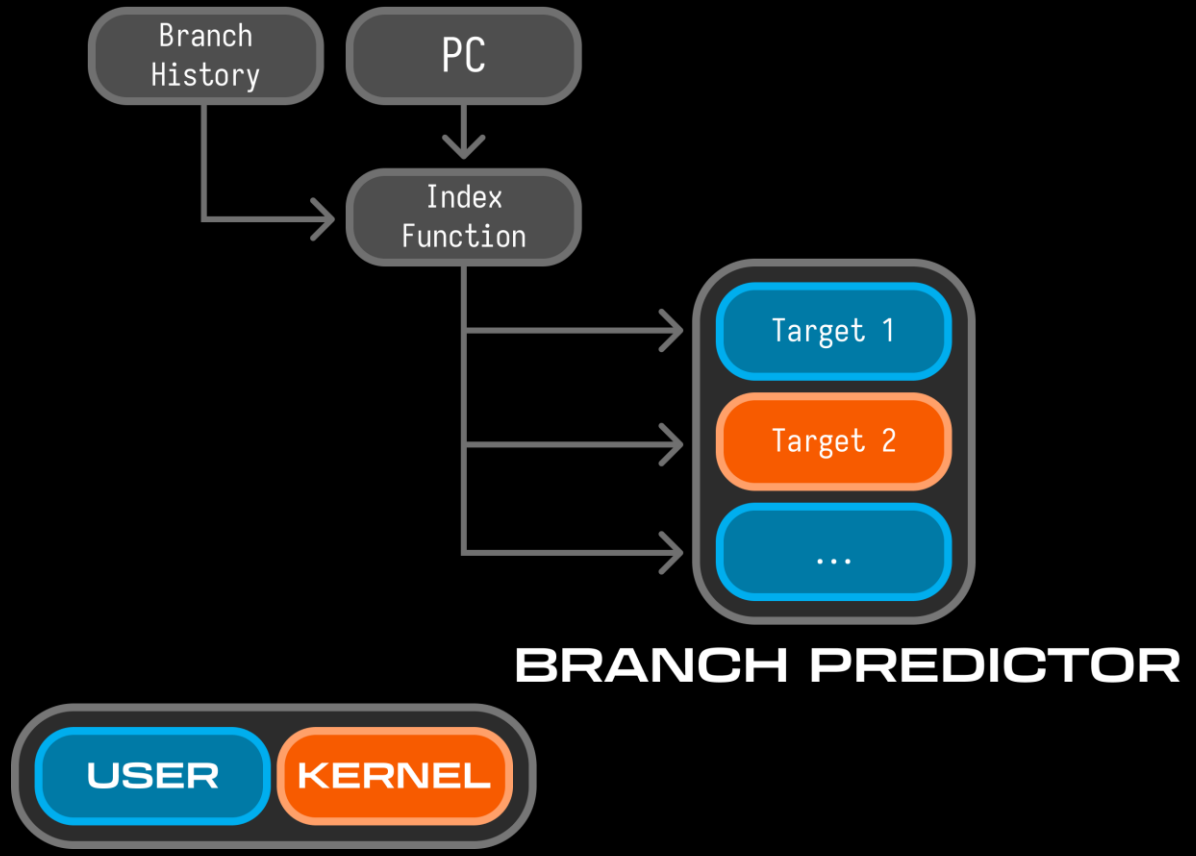
Recent defenses separate hardware



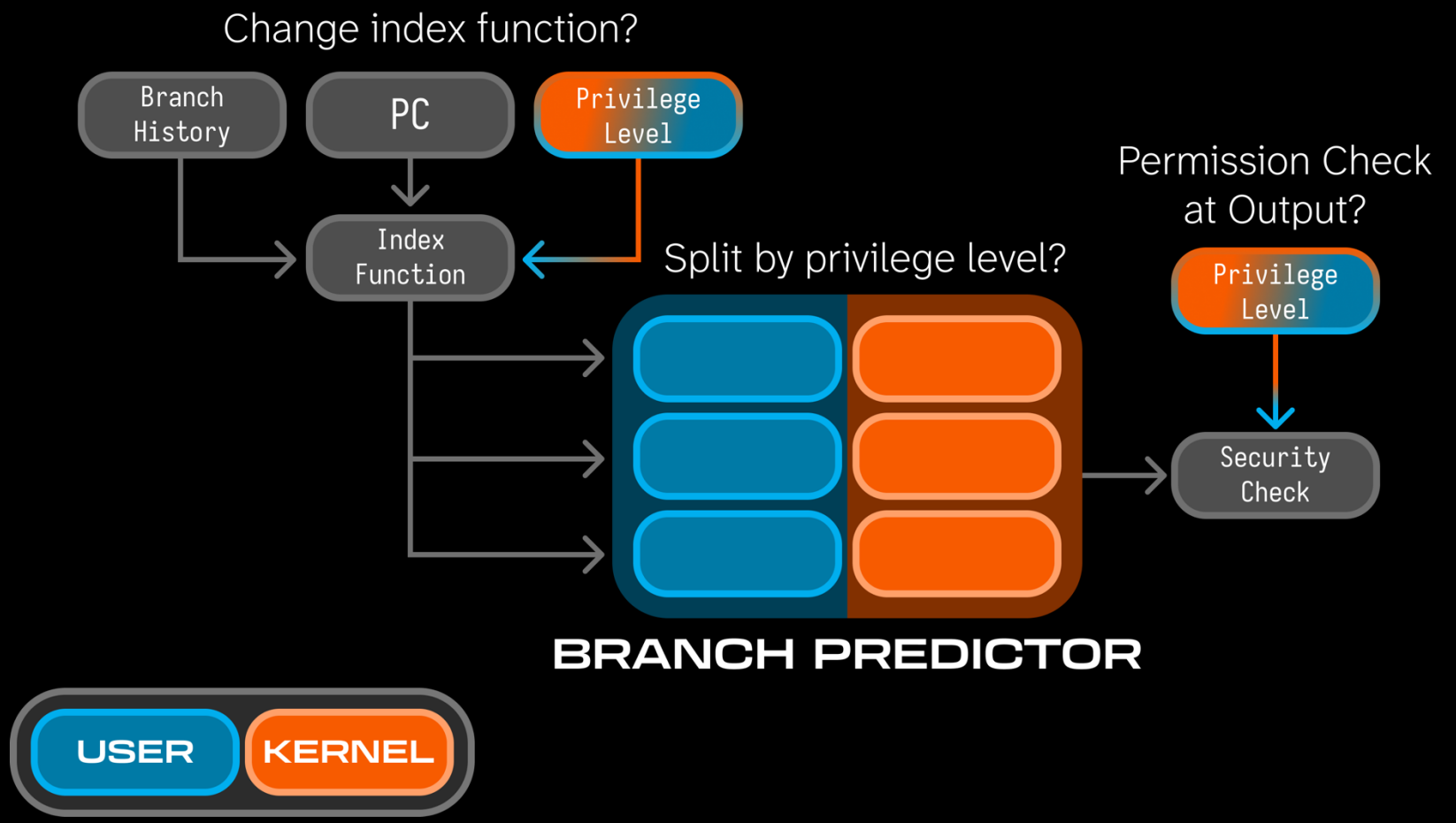
Fractal blends software modes to better understand hardware



Shared entries can lead to security issues!



Multiple Possible Designs: We want to reverse engineer



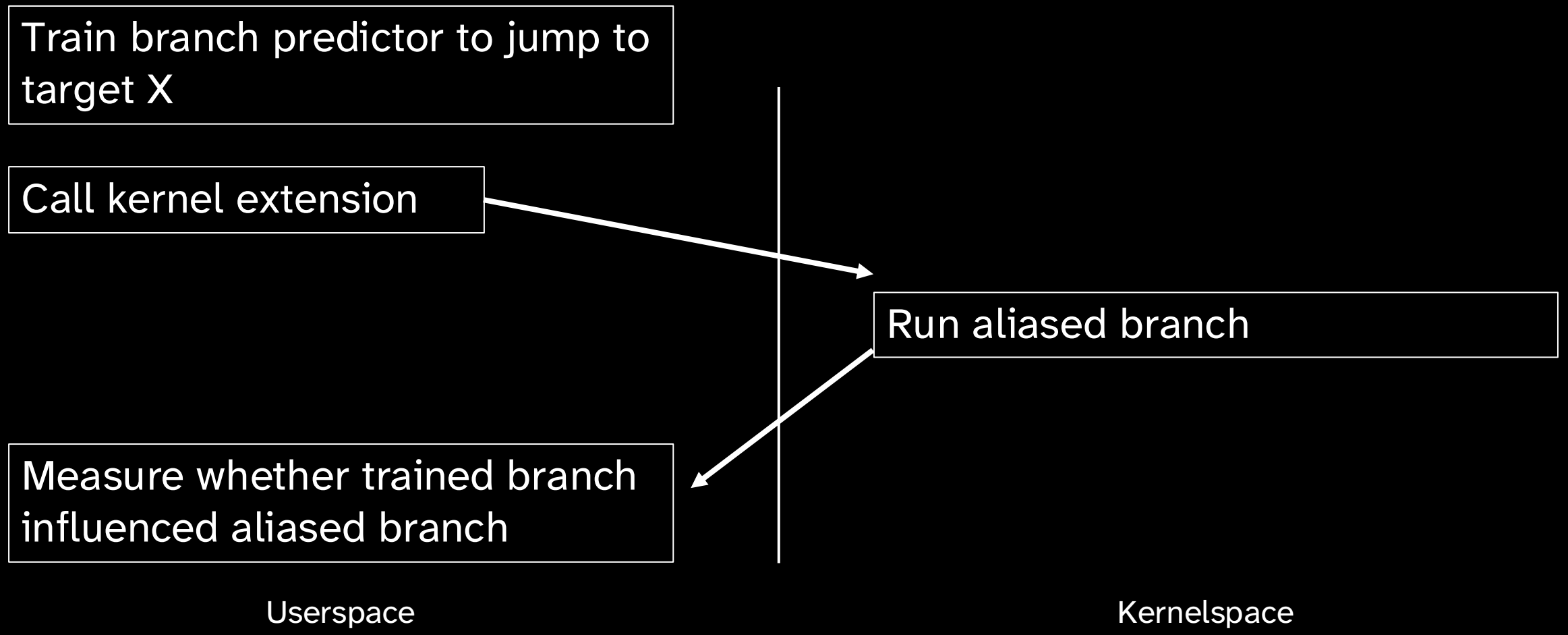
Approach: Build attacks to study defenses

1. Create a simple single-domain attack

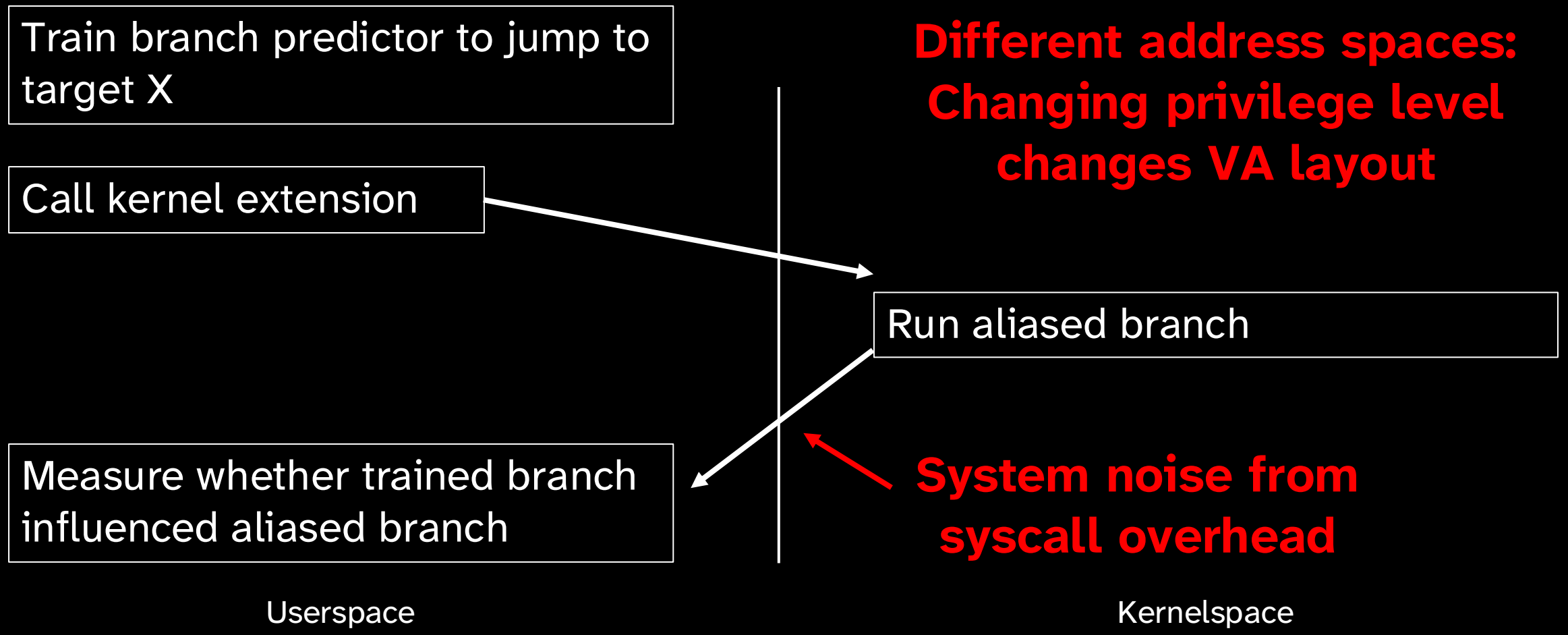
2. Vary the privilege level

3. Learn how hardware prevents our attack across domains

Attacking the indirect branch predictor

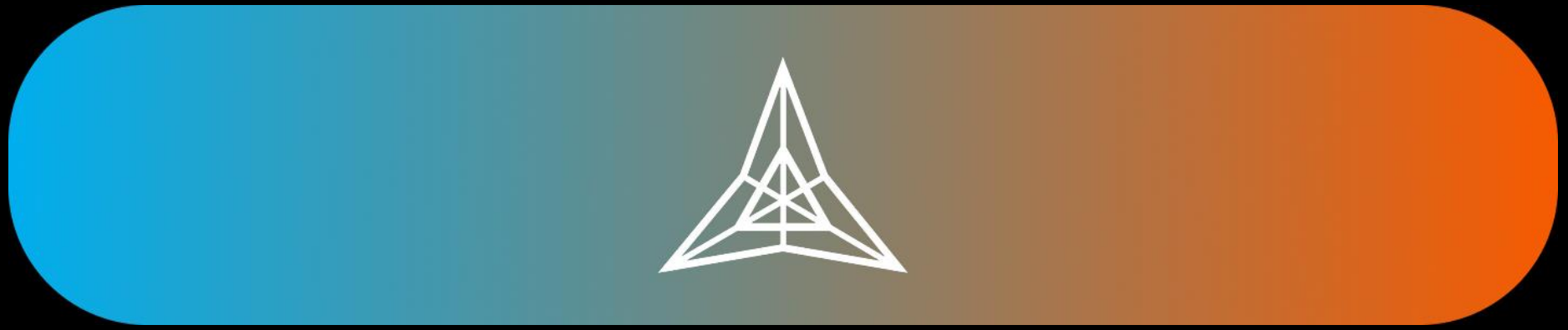


Attacking the indirect branch predictor

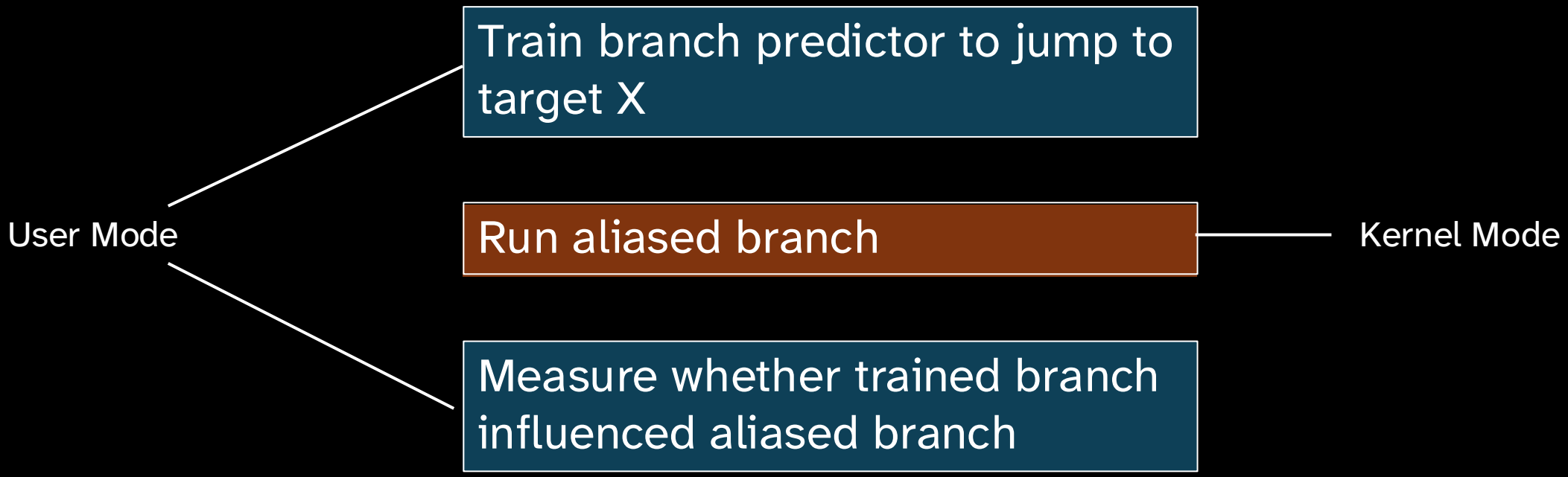


Solution

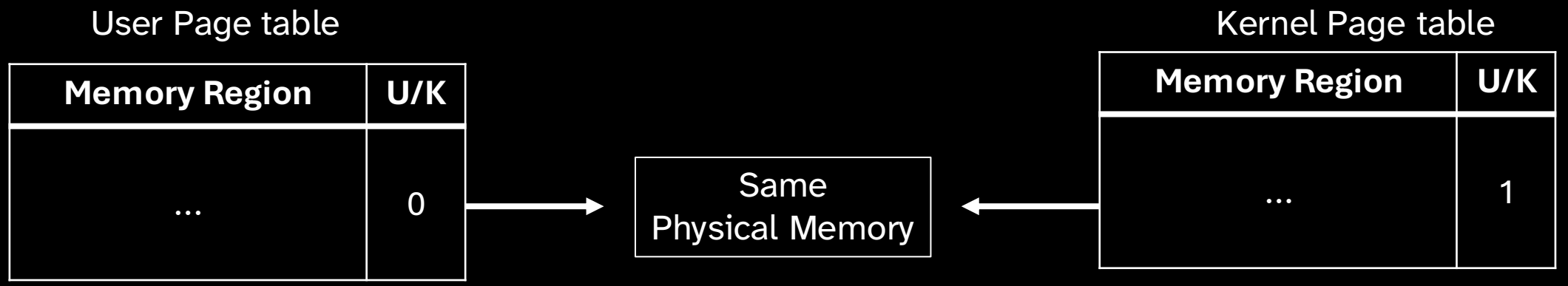
Make user and kernel share an address space & code



Fractal lets you change the privilege level of specific parts of your program



How do we change a running program's privilege level?



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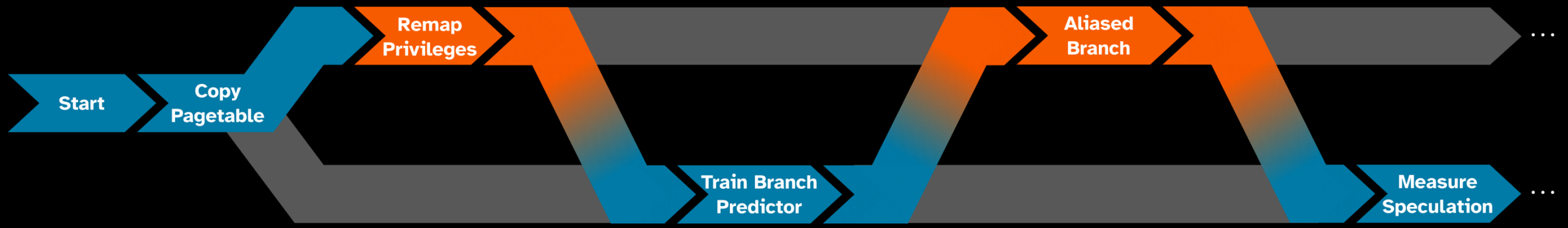
The Full Picture



Vary Just the Privilege Level

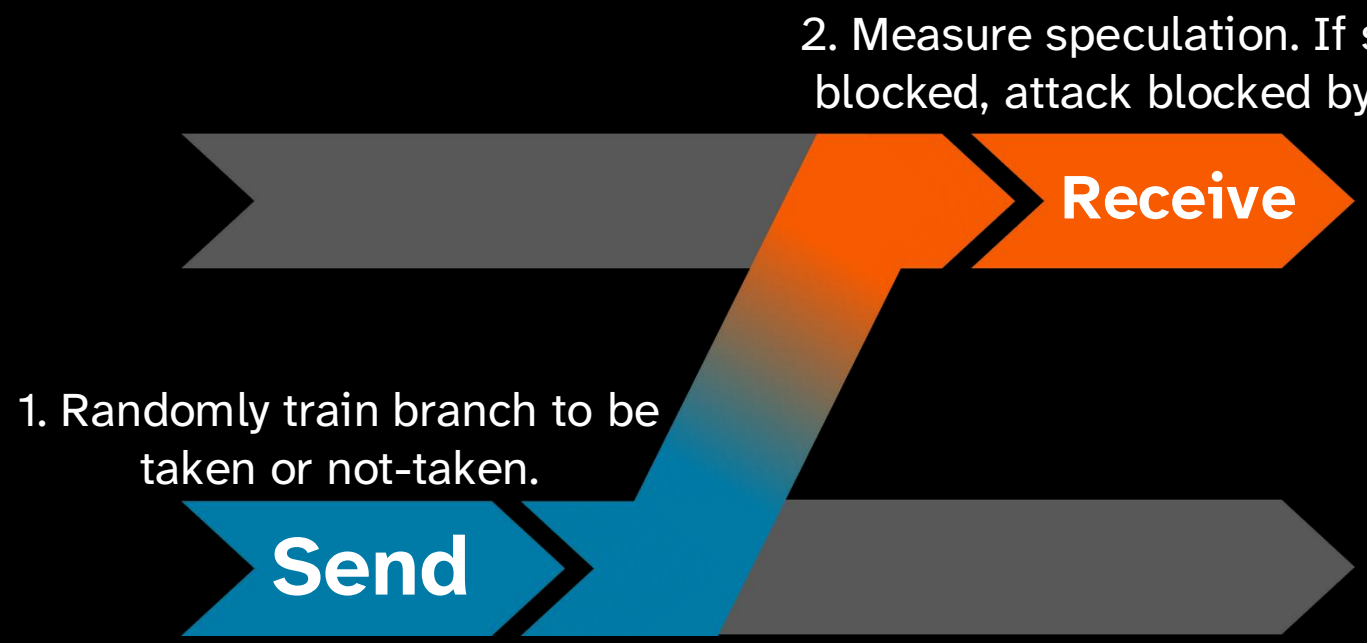
User → Kernel

Kernel → User

User → User

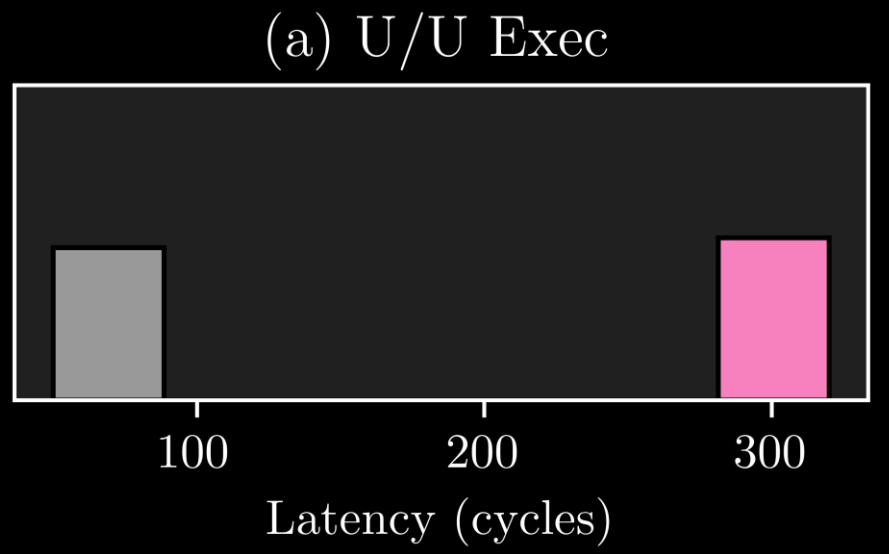
Kernel → Kernel

Sender & Receiver



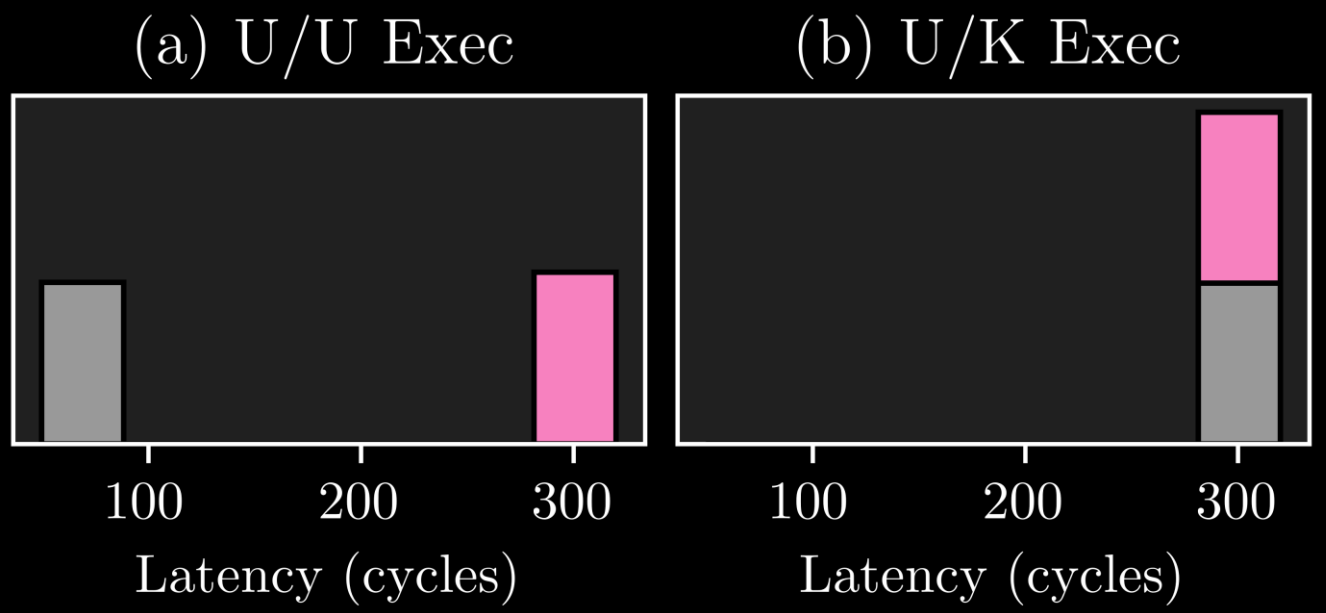
Evaluation on Apple M1

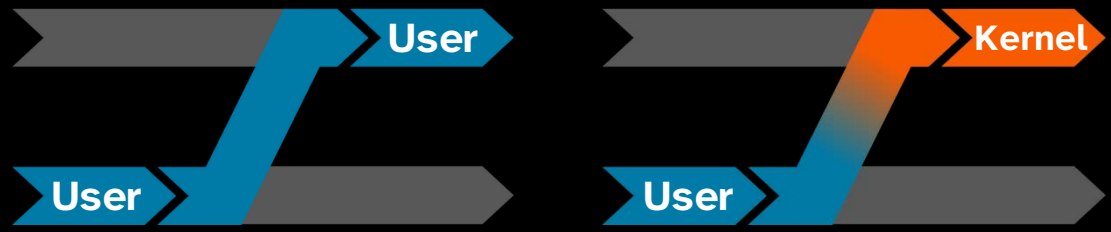
When running same-privilege receiver, hardware uses branch targets trained by sender



Evaluation on Apple M1

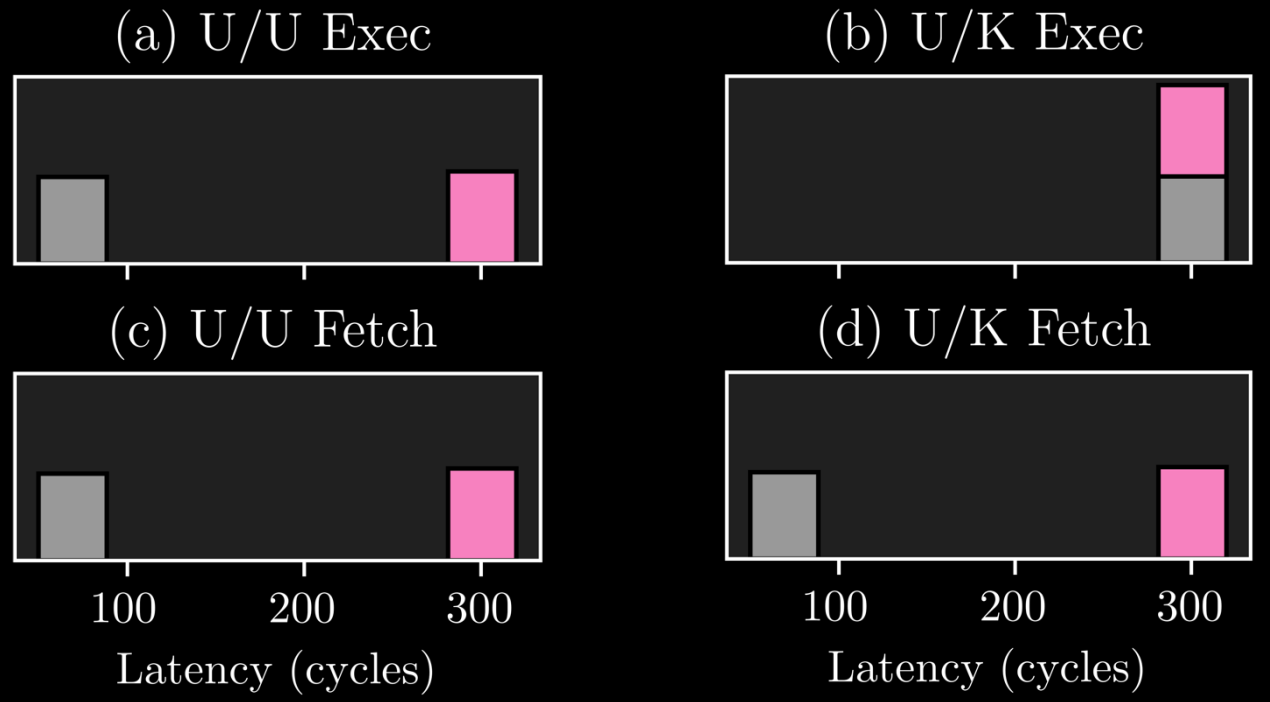
When receiver is moved to kernel mode, hardware stops using target for predictions!





Evaluation on Apple M1

Surprisingly, hardware still ***fetches*** trained targets no matter the privilege mode!



Surprising!

Evaluation on Apple M1

- CBP has no protection
- Cross-ASID acts like cross-privilege on IBP

	Same Domain Fetch	**Same Domain Exec**	**X-Priv Fetch**	**X-Priv Exec**	**X-ASID Fetch**	**X-ASID Exec**
CBP	✅	✅	✅	✅	✅	✅
IBP	✅	✅	✅	❌	✅	❌

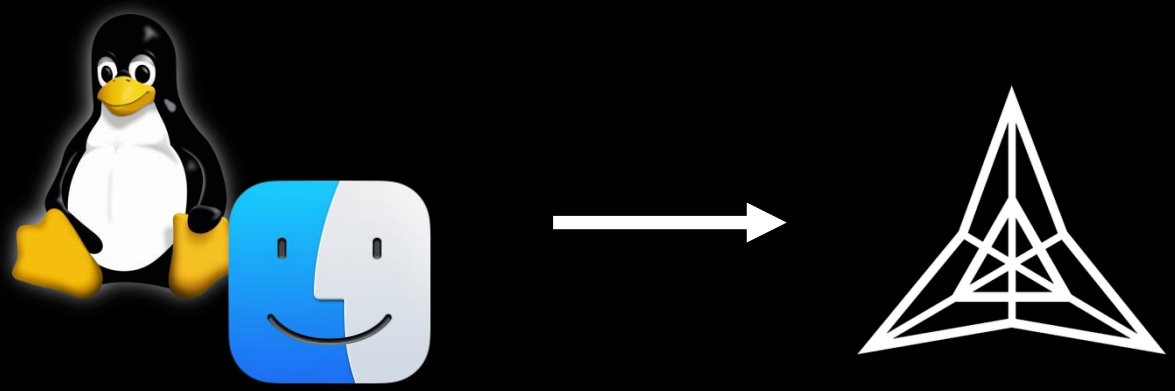
✅ = Attack Succeeds
❌ = Attack Blocked by Hardware

Evaluation on Apple M1

- Phantom speculation: replace receiver branch with NOP, check whether it gets speculatively decoded as a branch
- Phantom fetches exist, but Phantom speculative execution blocked

	Same Domain Fetch	**Same Domain Exec**	**X-Priv Fetch**	**X-Priv Exec**	**X-ASID Fetch**	**X-ASID Exec**
CBP	✅	❌	✅	❌	✅	❌
IBP	✅	❌	✅	❌	✅	❌

✅ = Attack Succeeds
❌ = Attack Blocked by Hardware



https://fractal-os.com

By creating new system software, microarchitecture reverse engineering workflows can be improved.

More in the paper:
CPU stack aliasing, syscall returns, shared C library, shadow memory maps, memory management approaches, and more!

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