Exorcising Spectres with Secure Compilers

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Contributions & Outline

1. Formal framework for assessing security of Spectre v1 compiler countermeasures

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2. Proofs of security and insecurity of existing Spectre v1 compiler countermeasures

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Speculative Semantics & SNI

$\mathbf{void\ f\ (int\ x)} \mapsto \mathbf{if(x < A.size)\ \{y = B[A[x]]\}}$

run 1: A.size = 16, A[128] = 3

call f 128

Speculative Semantics & SNI

void f (int x) ↦ if(x < A.size) {y = B[A[x]]}

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if (128 < 16) { y = B[A[128]] }

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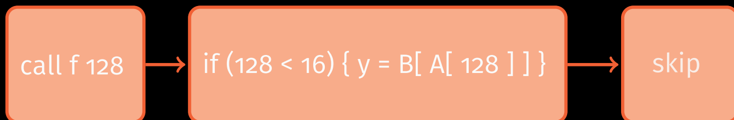

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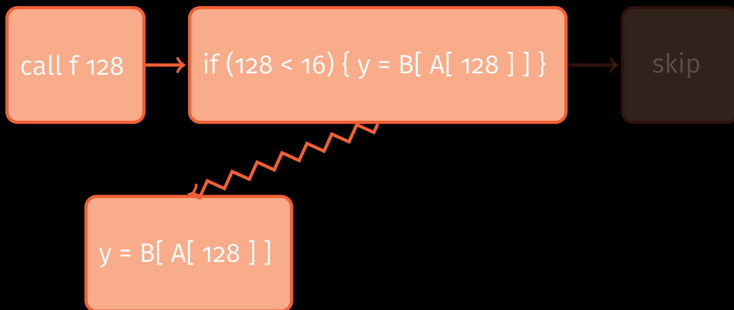

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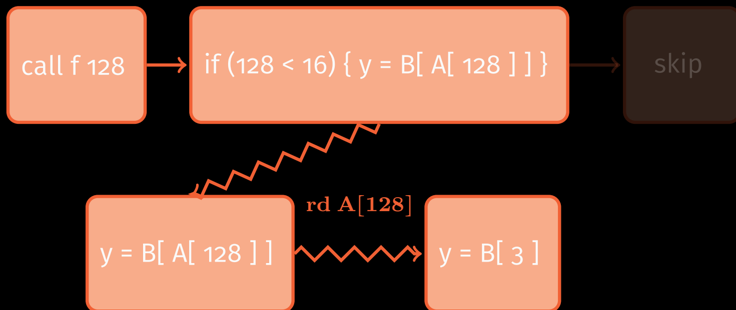

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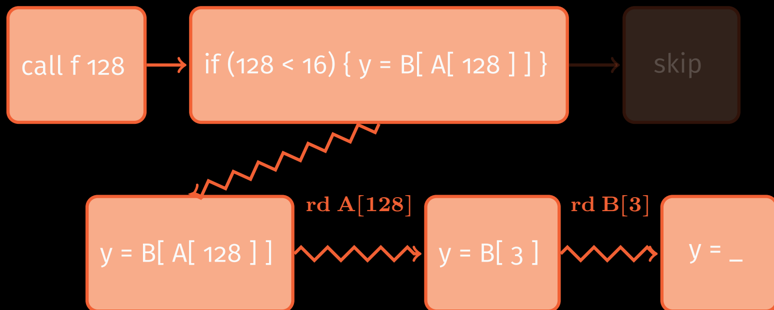

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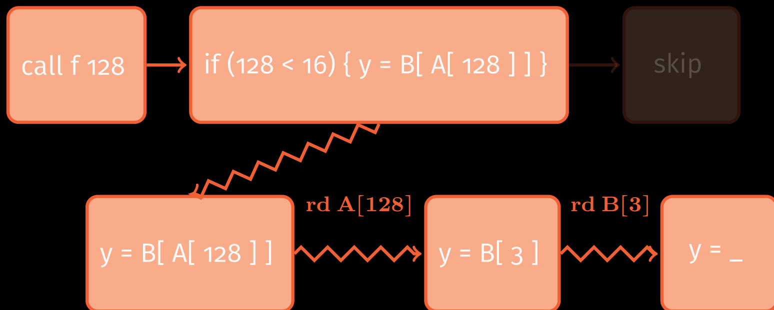

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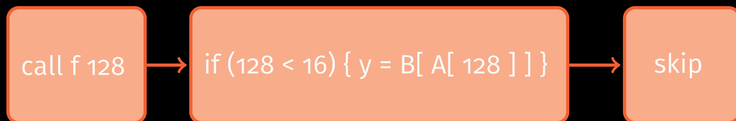

trace 1: $\mathbf{rd\ A[128]}$ $\mathbf{rd\ B[3]}$

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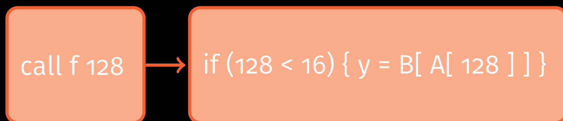
$\mathbf{void\ f\ (int\ x)} \mapsto \mathbf{if(x < A.size)\ \{y = B[A[x]]\}}$

run 1: A.size = 16, A[128] = 3

run 2: A[128] = 7 different H values



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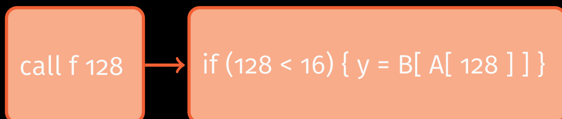

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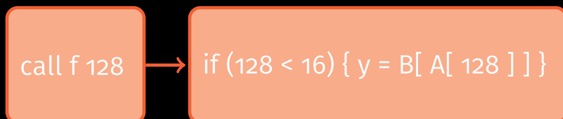

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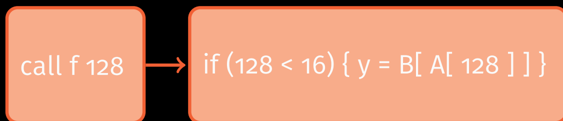

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trace 2: $\mathbf{rd\ A[128]}$ $\mathbf{rd\ B[7]}$ $\Rightarrow$ SNI violation

Speculative Semantics & SNI

A program is SNI ($\vdash \mathbf{P} : \mathbf{SNI}$) if, given two runs from low-equivalent states:

- assuming the non-speculative traces are low-equivalent
- then the speculative traces are also low-equivalent

call f

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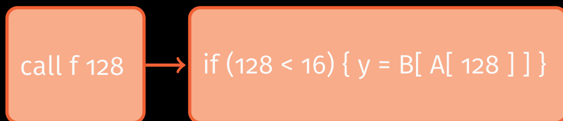

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Problems Problems Problems ...

Problem: Proving compiler preserves SNI is hard

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Solution: overapproximate SNI with a novel property: speculative safety (SS)

Speculative Safety (SS): Taint Tracking

$\mathbf{void\ f\ (int\ x)} \mapsto \mathbf{if(x < A.size)\ \{y = B[A[x]]\}}$

only 1 run needed: A.size=16, A[128]=3

integrity lattice: $S \subset U \quad S \sqcap U = S \quad U$ does not flow to S

call f 128

pc : S

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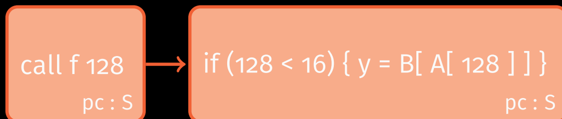

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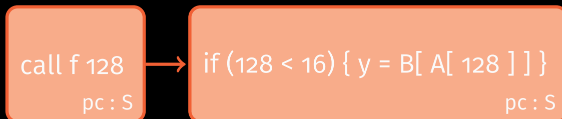

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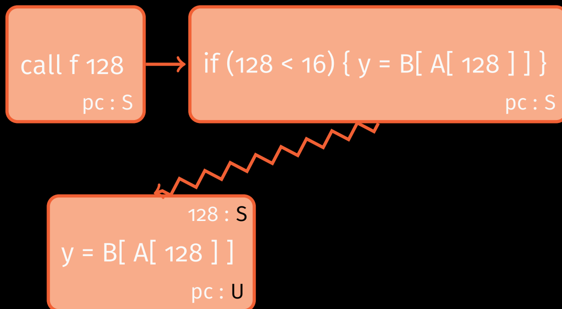

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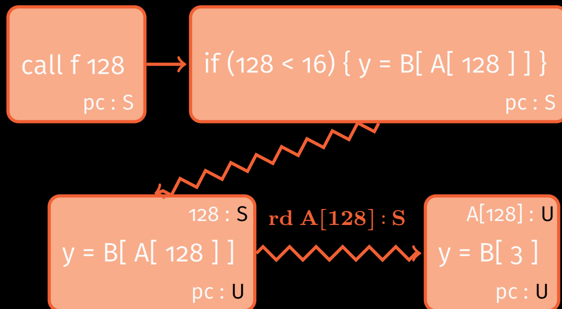

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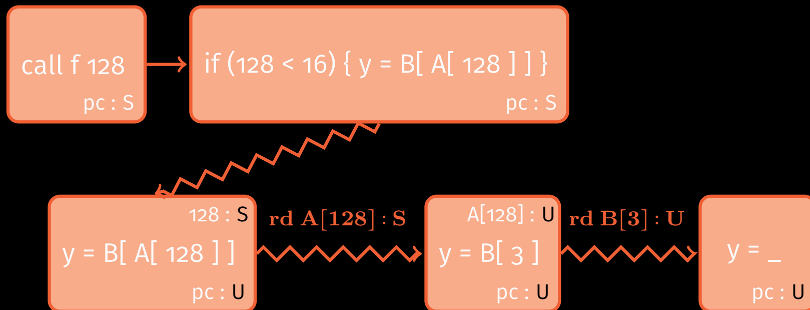

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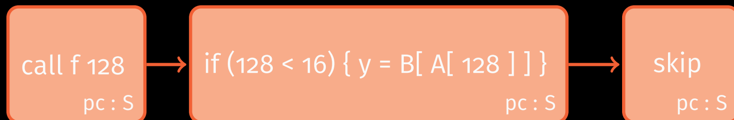

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A program is SS ($\vdash \mathbf{P} : \mathbf{SS}$) if its traces do not contain $\mathbf{U}$ actions

call f 128
pc : S

if (128 < 16) { y = B[A[128]] }
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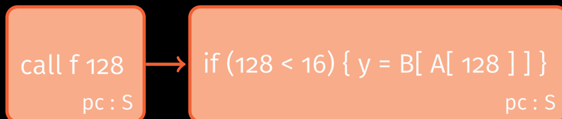

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- in the $\mathbf{target}$: $\forall \mathbf{P} \vdash \mathbf{P} : \mathbf{SS} \Rightarrow \mathbf{P} : \mathbf{SNI}$

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- in the **target**: $\forall \mathbf{P} \vdash \mathbf{P} : \mathbf{SS} \Rightarrow \mathbf{P} : \mathbf{SNI}$
- in the source: $\forall \mathsf{P} \vdash \mathsf{P} : \mathsf{SS} \iff \mathsf{P} : \mathsf{SNI}$
  (recall, no speculative execution in source)

SS-Preserving Compiler: RSSC & RSSP

$$[\![\cdot]\!] : \mathsf{RSSP} \overset{\text{def}}{=} \text{ if } \forall \mathsf{A}.\mathsf{A}\,[\mathsf{P}] : SS \text{ then } \forall \mathbf{A}.\mathbf{A}\,[[\![\mathsf{P}]\!]] : SS$$

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$\approx$= same traces, plus $\mathbf{S}$ actions in $\mathbf{m}$

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- $\forall$ attackers: explicit attacker model

  robustness

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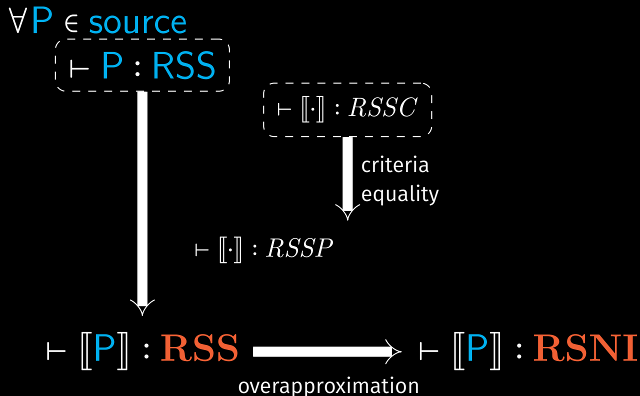
- $\forall$ attackers: explicit attacker model
  robustness
- Proof: RSSC & RSSP are equivalent
  RSSC : clear security guarantees
  RSSP : simpler proofs

Secure Compilation Framework for Spectre



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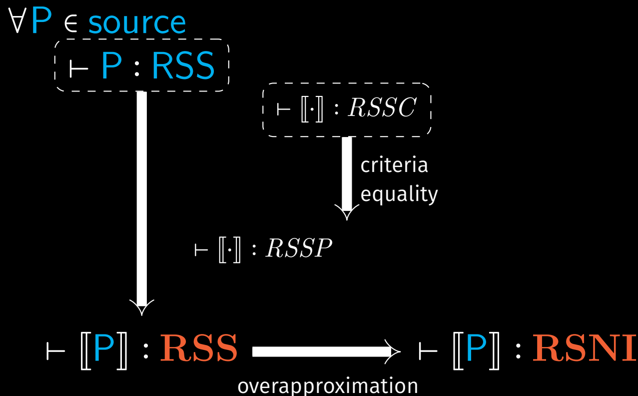

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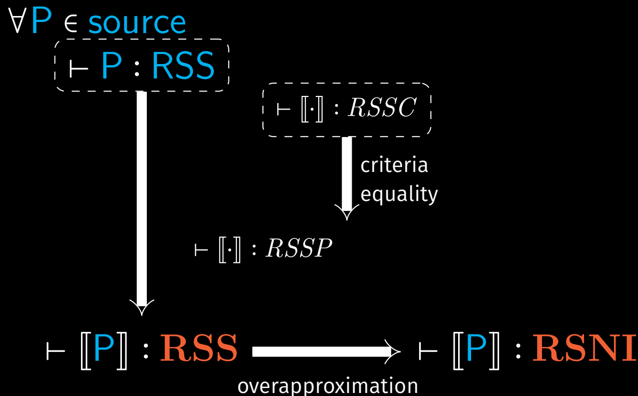

- dashed premises are already discharged
- to show security: simply prove $RSSP$

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- 2 notions of SS and SNI (thus 2 targets):
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```
void get (int y)
  if (y < size) then
    temp = B[A[y]*512]
```

Violates + and -

```
void get (int y)
  x = A[y];
  if (y < size) then
    temp = B[x];
```

Violates +, Satisfies -

RSSC for `lfence`

$\mathsf{void\ f(int\ x) \mapsto if(x < A.size)\{y = B[A[x]]\}}$ // A.size=16, A[128]=3

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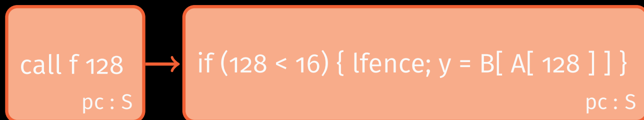

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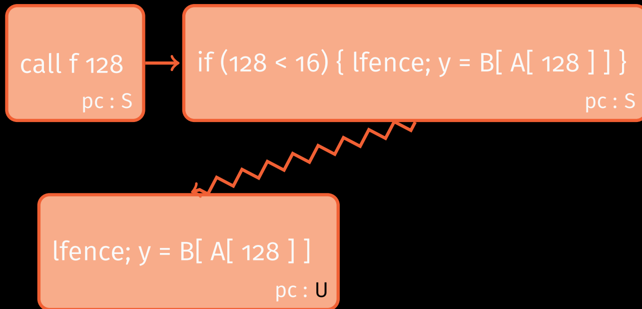

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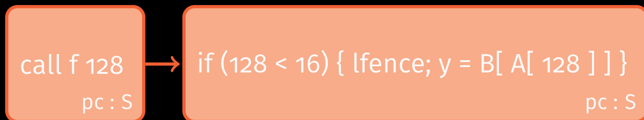

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RSSC for SLH

$\text{void f(int x)} \mapsto \text{if}(x < \text{A.size})\{y = \text{B}[\text{A}[x]]\}$ // A.size=16, A[128]=3

$[\![\cdot]\!] = \textbf{void f(int x)} \mapsto \textbf{if}(\mathbf{x} < \mathbf{A.size})\{\mathbf{y} = \mathbf{B}[\mathbf{mask}(\mathbf{A}[\mathbf{x}])]\}$

call f 128

pc : S

RSSC **for** SLH

$\texttt{void f(int x)} \mapsto \texttt{if(x < A.size)\{y = B[A[x]]\}}$ // A.size=16, A[128]=3

$[\![\cdot]\!] = \mathbf{void\ f(int\ x)} \mapsto \mathbf{if(x < A.size)\{y = B[mask(A[x])]\}}$

call f 128
pc : S

if (128 < 16) { y = B[mask(A[128])] }
pc : S

RSSC **for** SLH

void f(int x) ↦ if(x < A.size){y = B[A[x]]}   // A.size=16, A[128]=3

$\llbracket\cdot\rrbracket$ = **void f(int x) ↦ if(x < A.size){y = B[mask(A[x])]}**

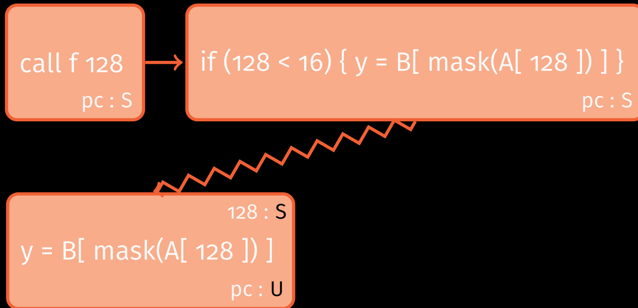
call f 128
pc : S

if (128 < 16) { y = B[mask(A[128])] }
pc : S

RSSC **for** SLH

void f(int x) ↦ if(x < A.size){y = B[A[x]]}   // A.size=16, A[128]=3

⟦·⟧ = **void f(int x) ↦ if(x < A.size){y = B[mask(A[x])]}**



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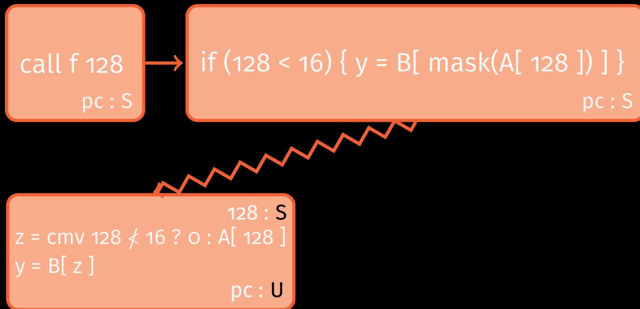

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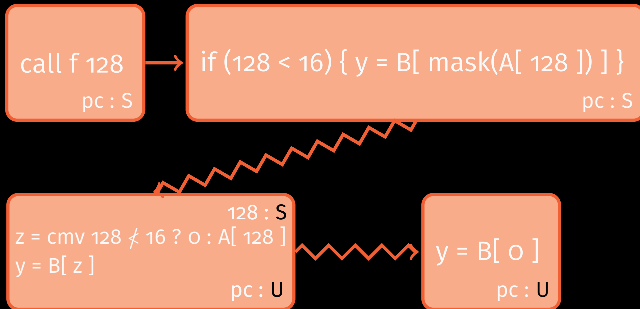

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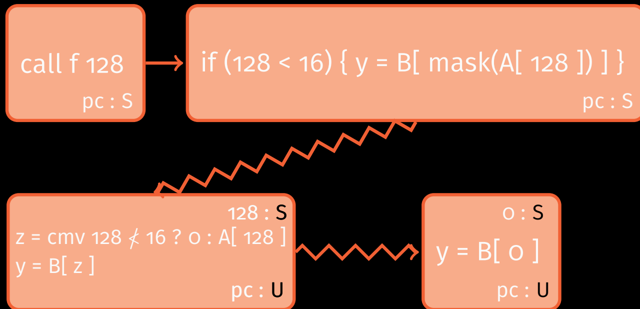

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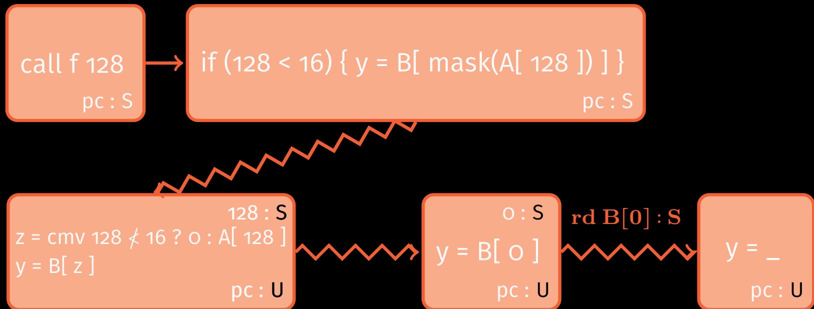

RSSC for SLH

SLH preserves SS- (and thus SNI-) but not SS+ (and thus not SNI+)

Framework benefits: fine-grained analysis of countermeasures security

Insecurity Results

- MSVC is Insecure
- Non-interprocedural SLH is insecure

Both omit speculation barriers

Proofs Insight