Robustly Safe Compilation


Marco Patrignani[1,2] Deepak Garg[3]

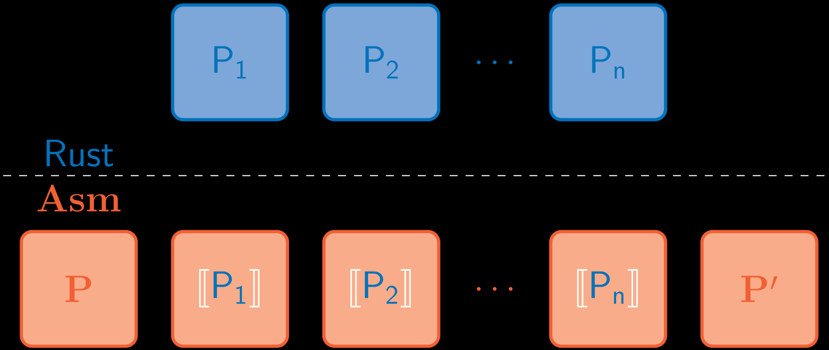

10^{th} April 2019

1 Stanford University

2 CISPA Helmholtz Center for Information Security

3 Max Planck Institute for Software Systems

What is Secure Compilation?



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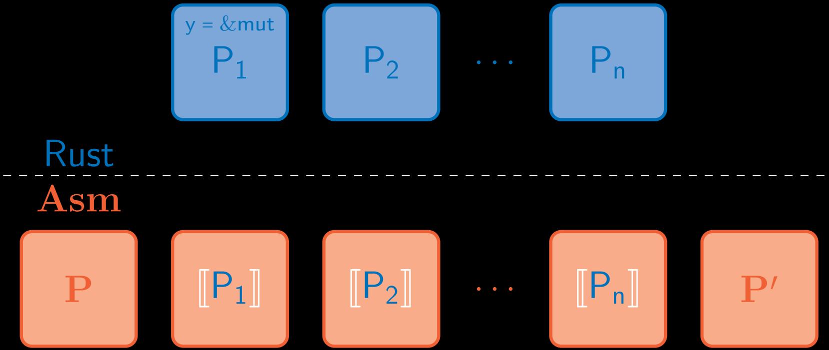

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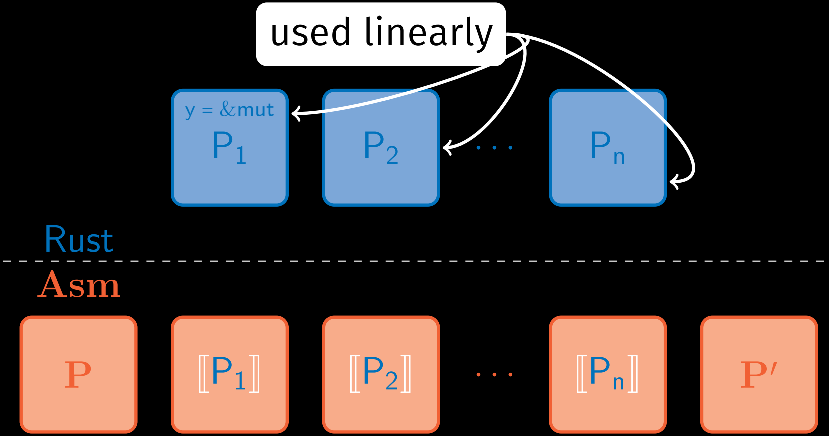

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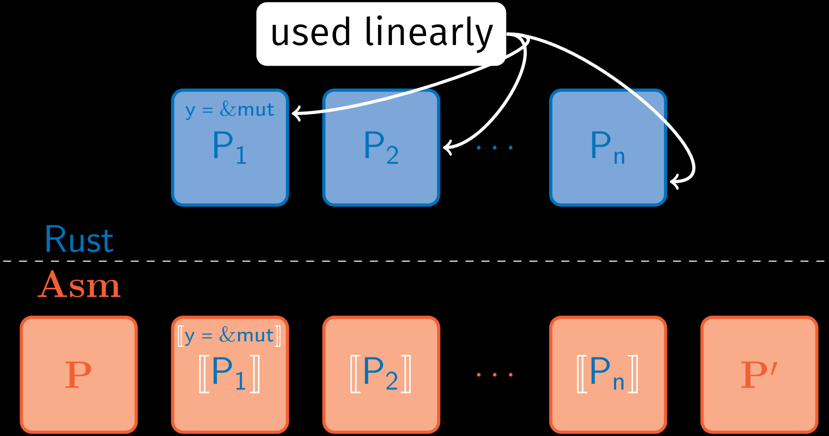

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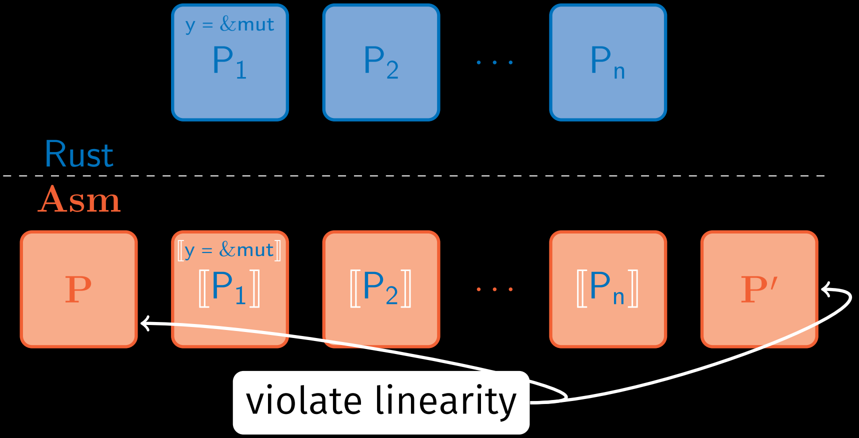

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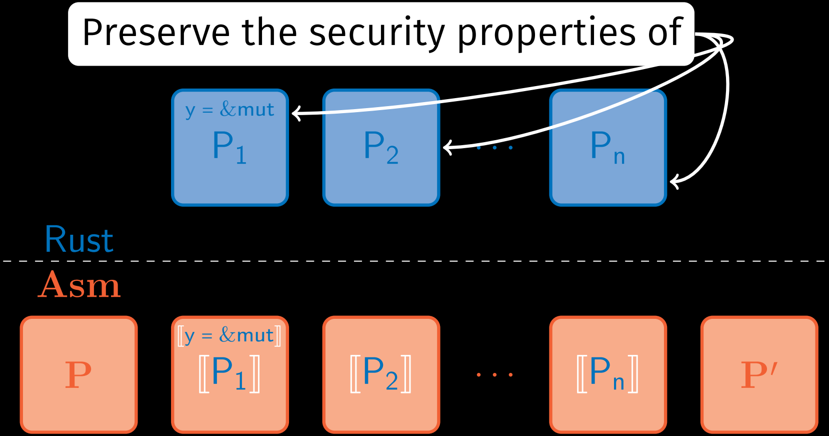

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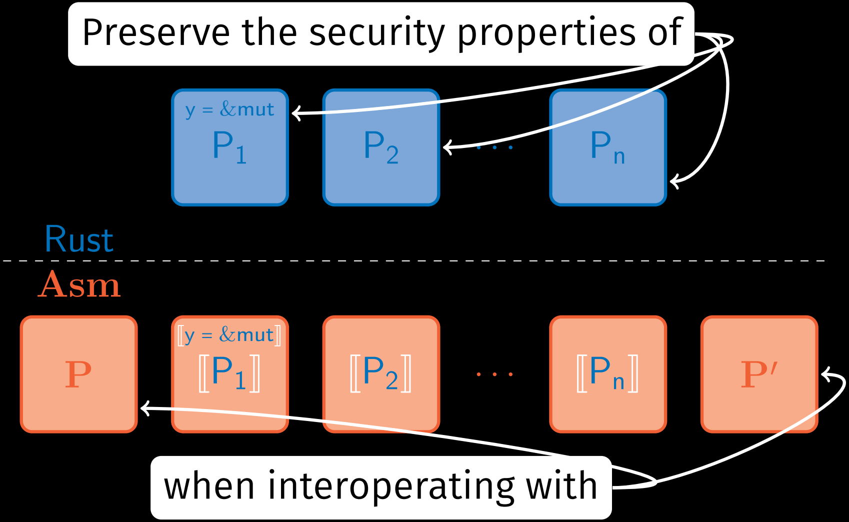

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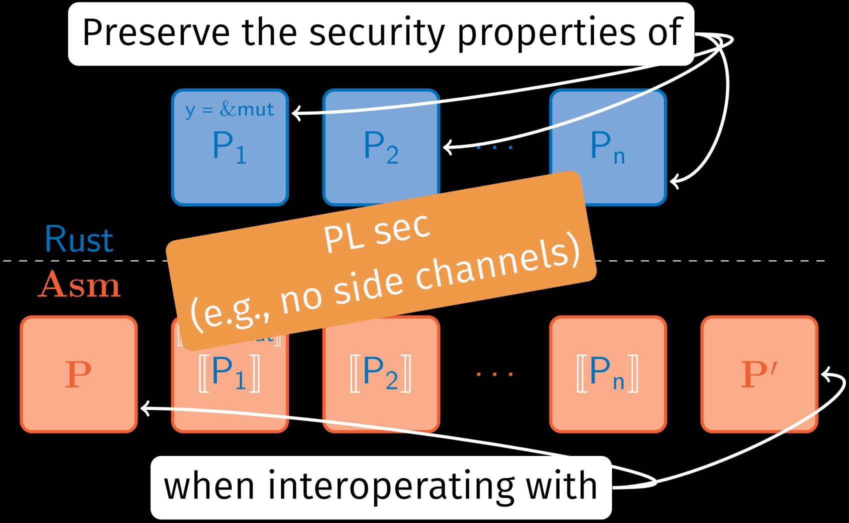

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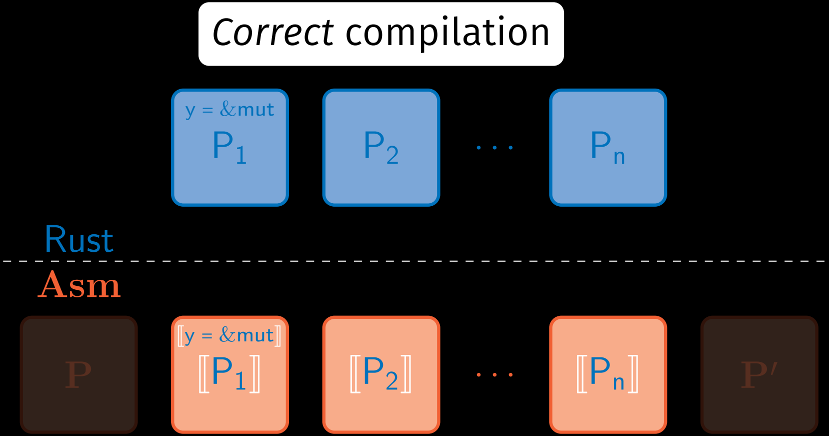

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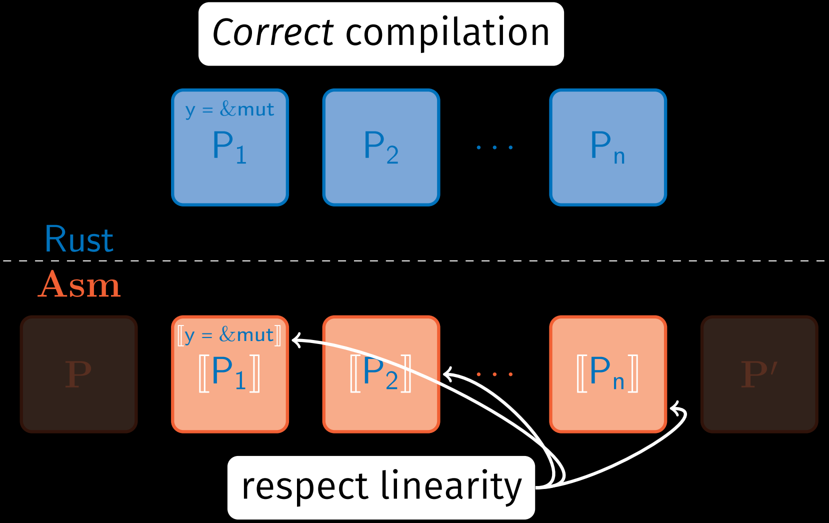

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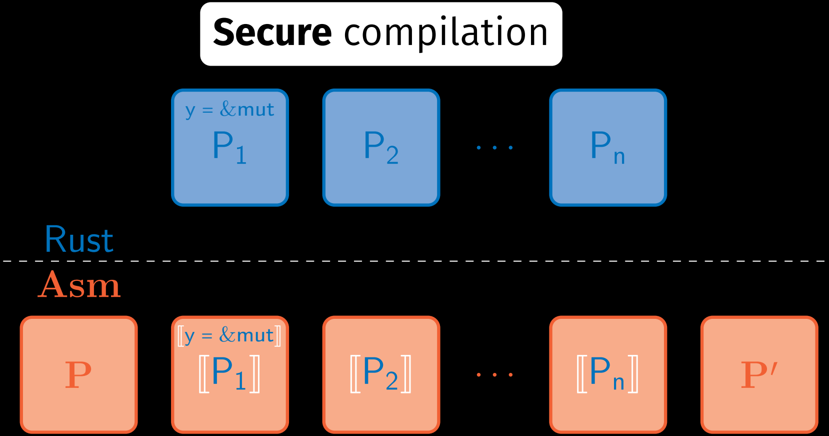

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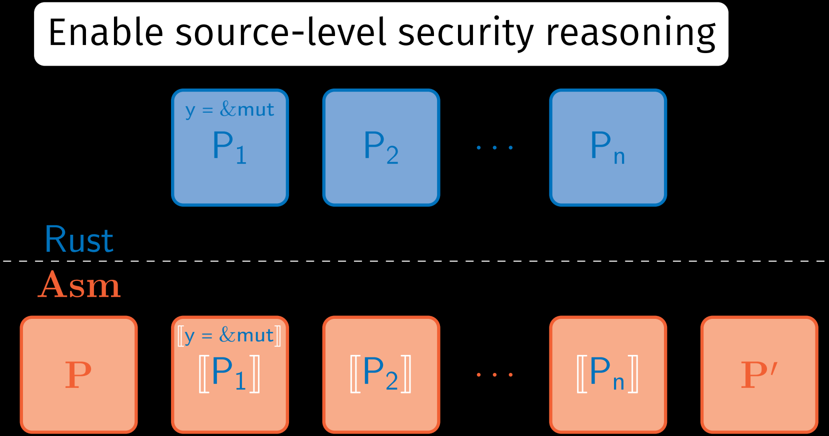

Do Secure Compilers Exist?

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Yes!

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Yes!

They rely on security mechanisms:

- enclaves
- capabilities
- types
- tagged memory
- ASLR
- CFI, SFI
- processes
- . . .

But...

Some secure compilers:

- $\mathrm{P1}$: lack formal proof of their security guarantees

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- $\mathbf{P1}$: lack formal proof of their security guarantees
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- $\mathrm{P3}$: inefficient

But...

Se secure compilers:

complex proofs

- : lack formal proof of their security guarantees
- $\mathbf{P2}$: prove preservation of ad-hoc security properties
- $\mathbf{P3}$: inefficient

unclear how to generalise

dictated by existing definitions

Goal:

Define a formal criterion for secure compilation:

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- attainable
- efficient (wrt existing ones)
- ~~easy~~ not too hard to prove

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Talk Roadmap

Robust Safety

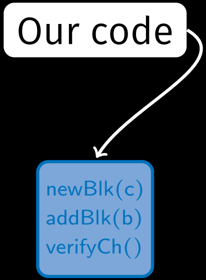
Robustly Safe Compilation

Backtranslation Proof Technique

Robust Safety

- Robustness
- Behaviour
- Safety

Robustness



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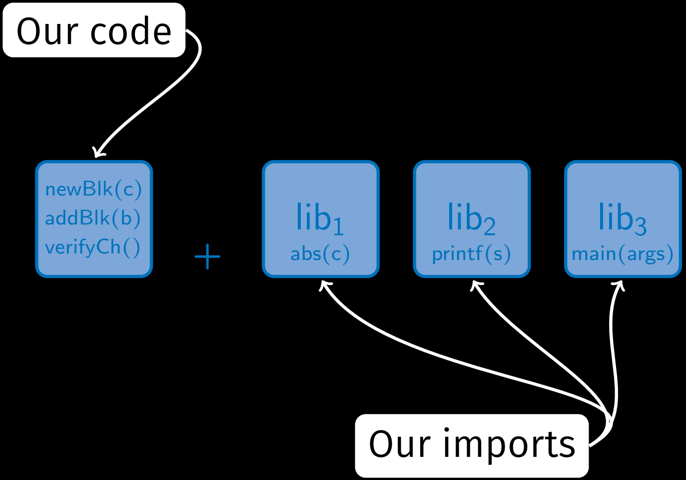
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Our imports

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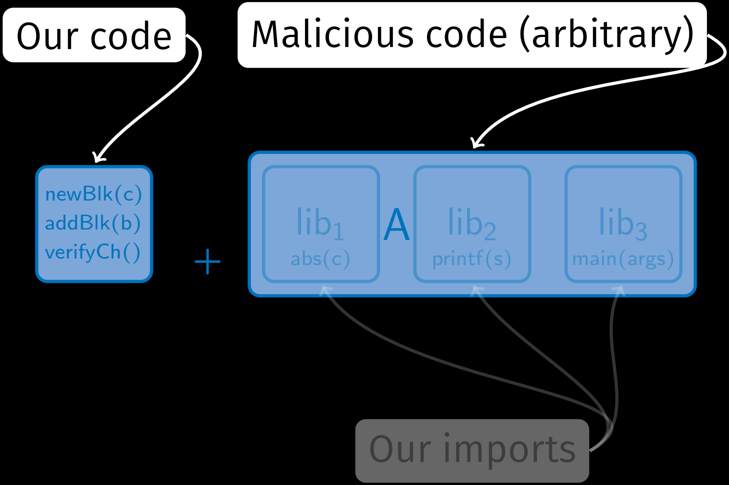
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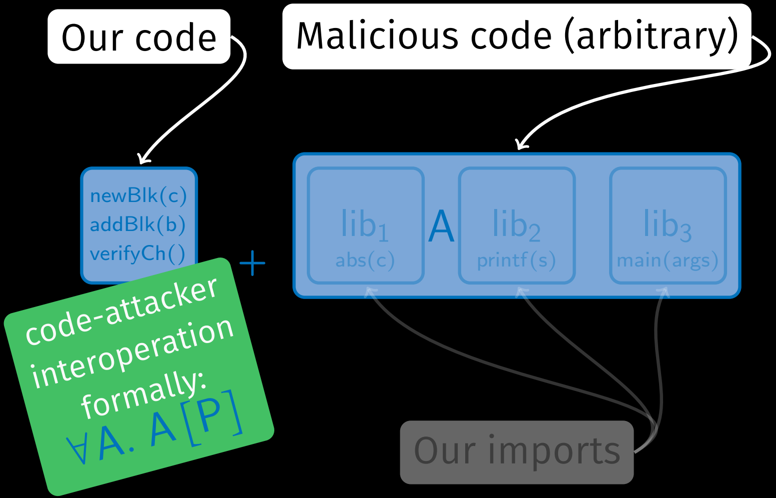
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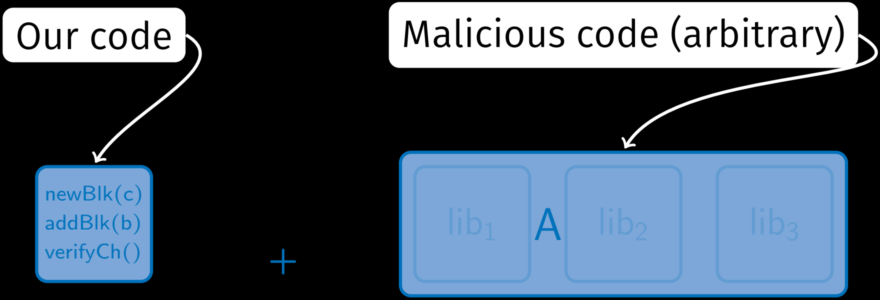
Our imports
code-attacker
interoperation
formally:
∀A. A[P]

Program Behaviour



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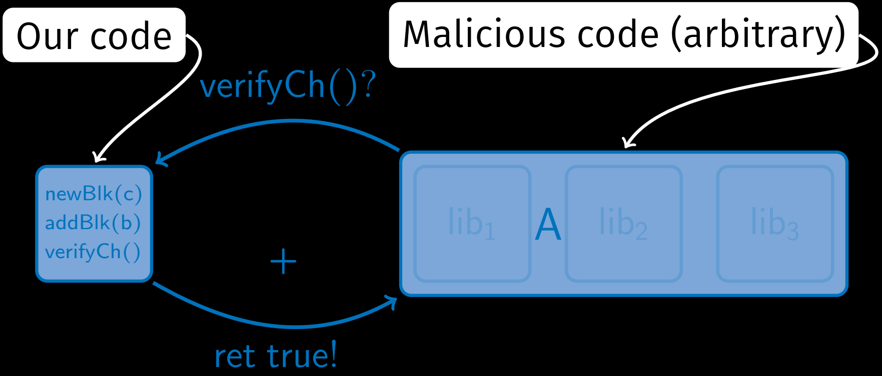

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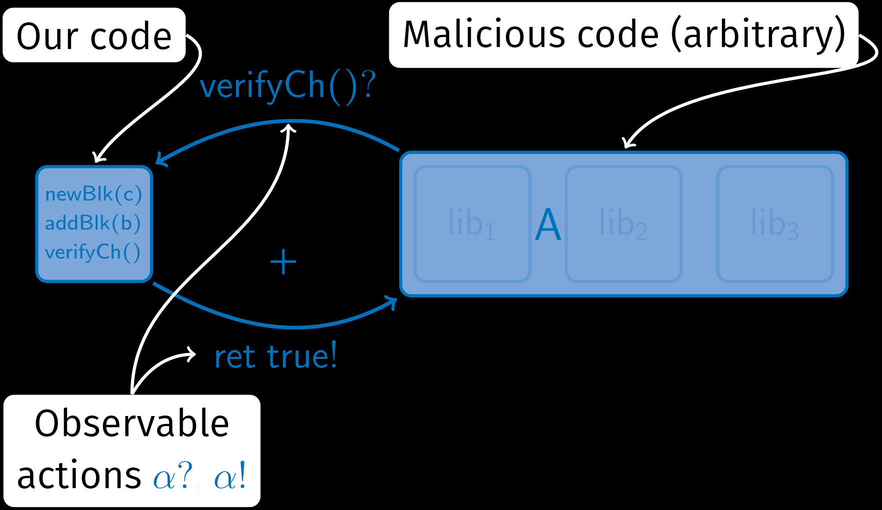

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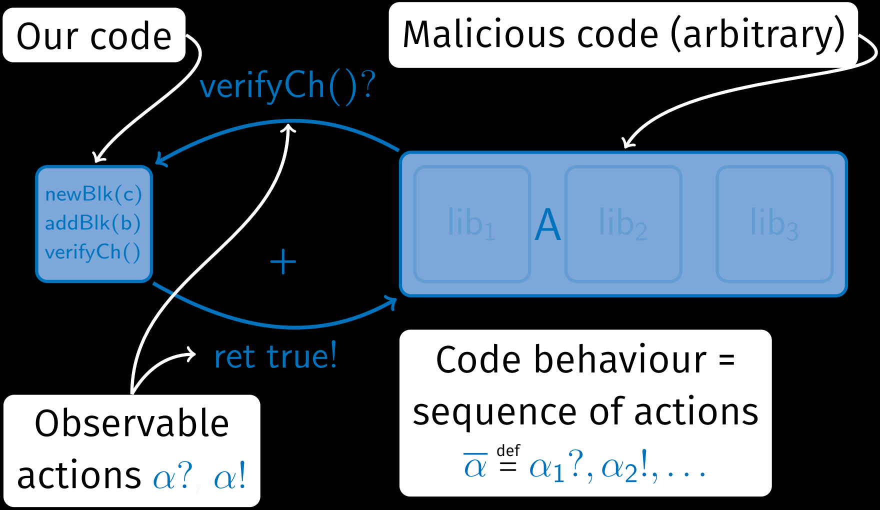

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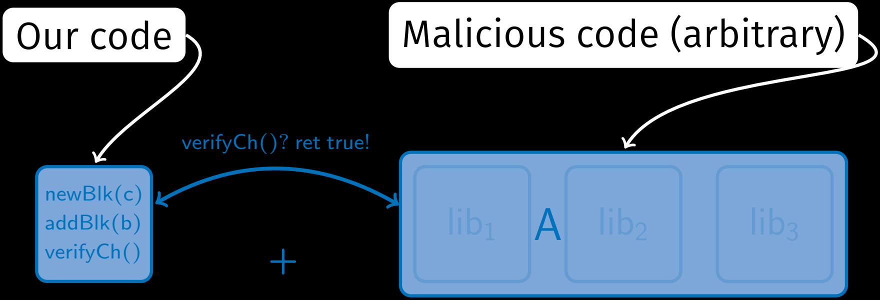

Code behaviour = sequence of actions

$$\overline{\alpha} \stackrel{\text{def}}{=} \alpha_1?, \alpha_2!, \ldots$$

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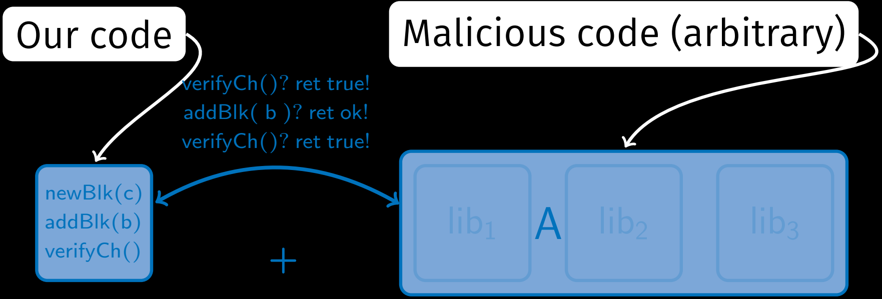

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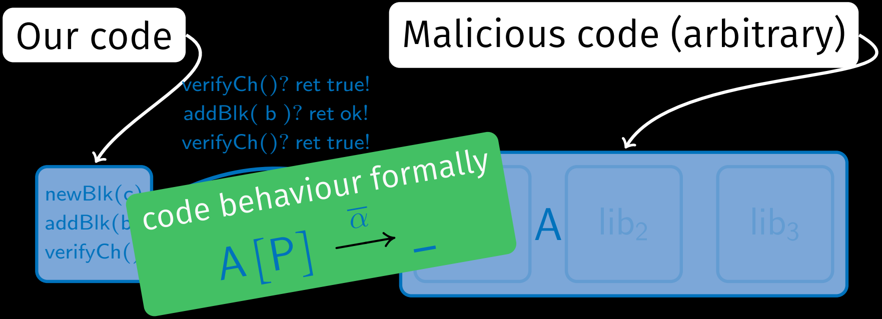

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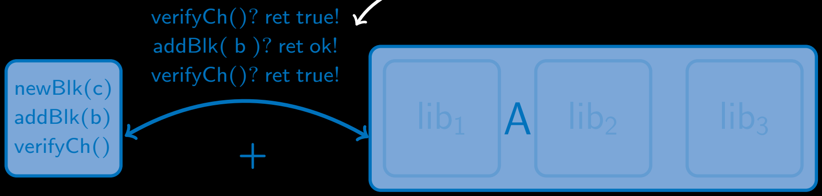
Safety Properties

no bad thing happens (finitely)



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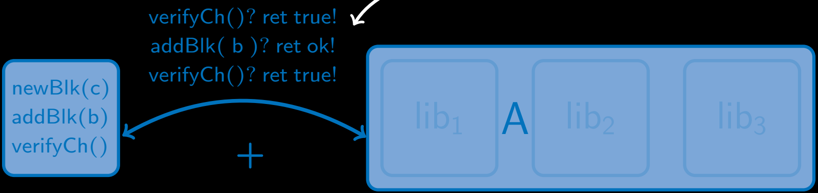

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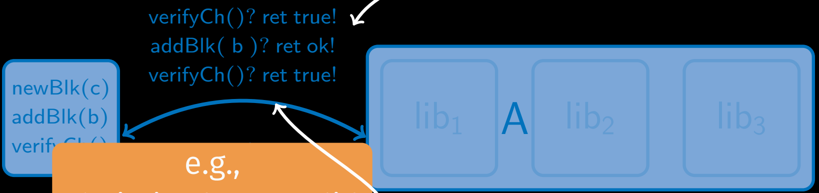

e.g.,
chain is always valid
NO: addBlk(b)? ret ok!
verifyCh()? ret false!

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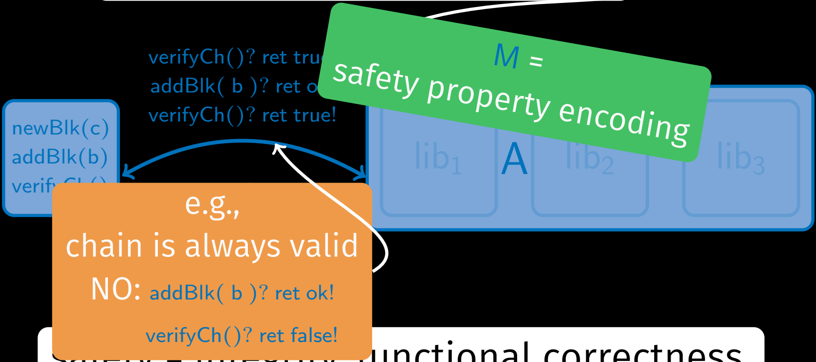

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- for a safety property (M)
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- our program behaves in a way (if $\mathsf{A}\left[\mathsf{P}\right] \xrightarrow{\overline{\alpha}}$)
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robust safety formally
$\mathsf{M} \vdash \mathsf{P}$

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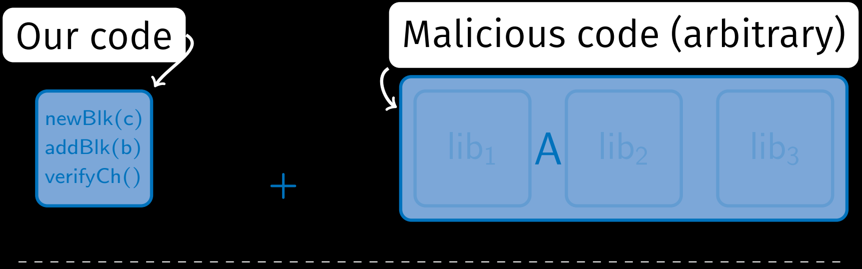
Robust Safety Across Compilation



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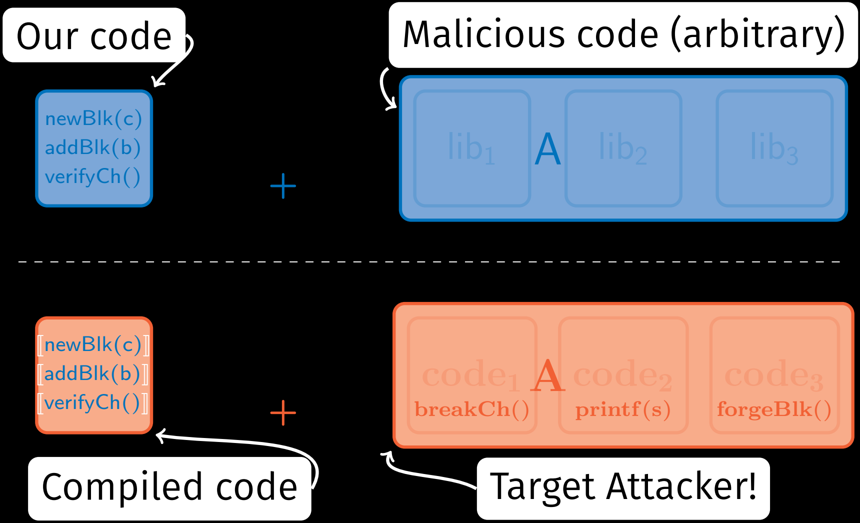

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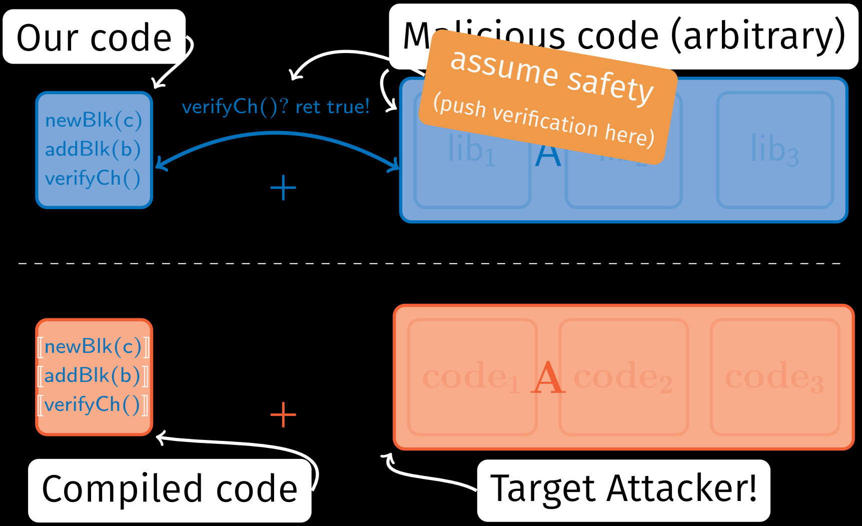

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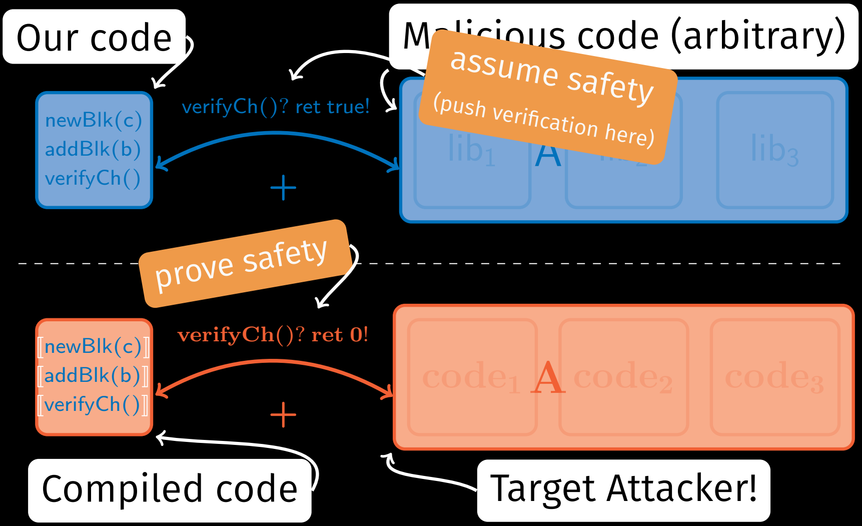

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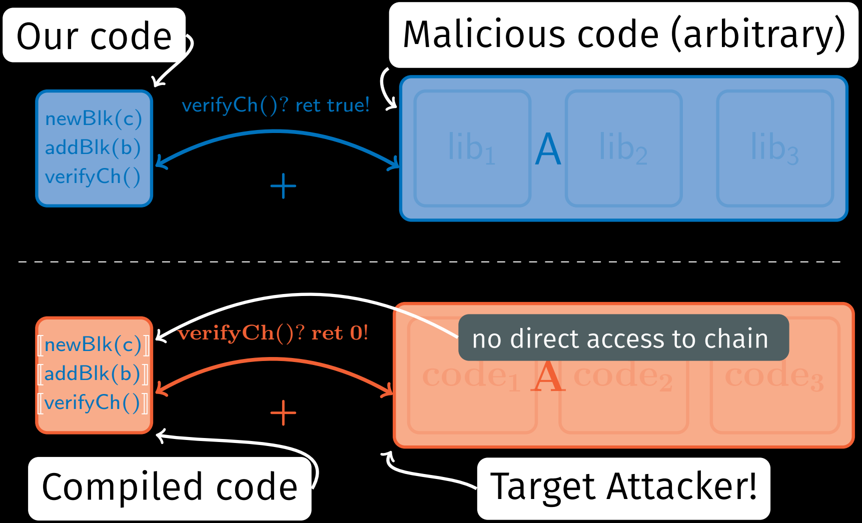

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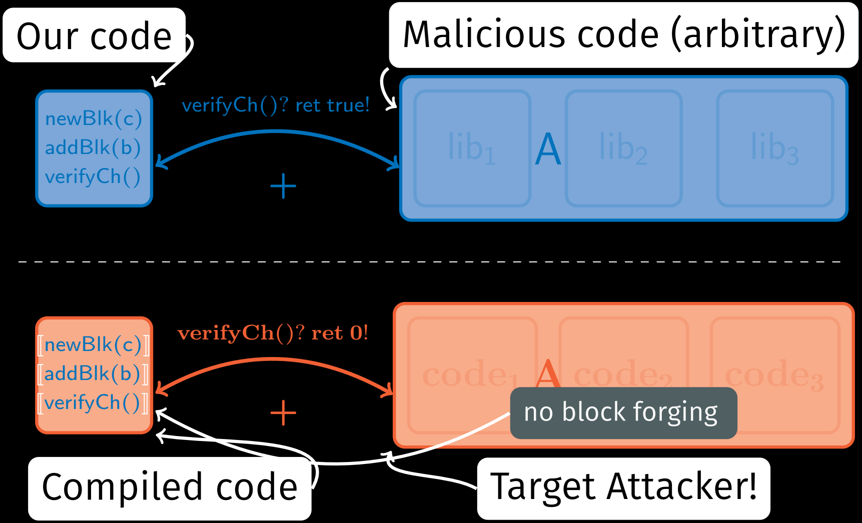

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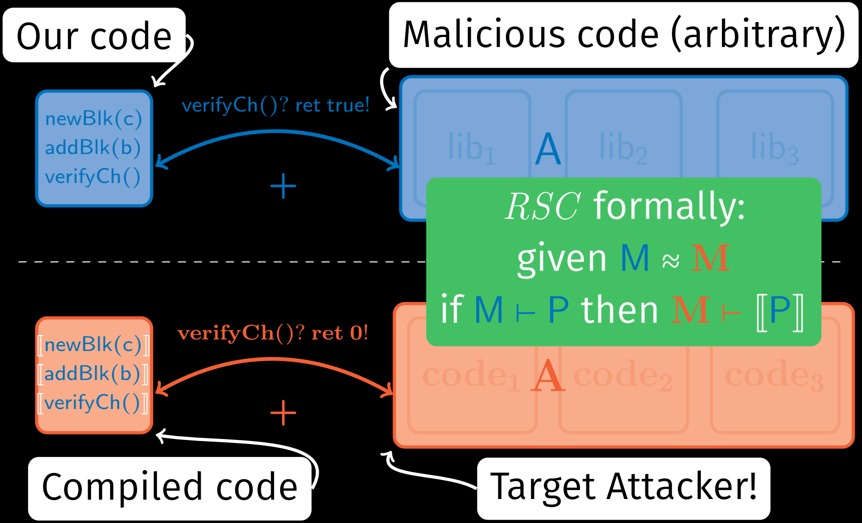

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$PF\text{-}RSC$: equivalent definition easier to prove than RSC

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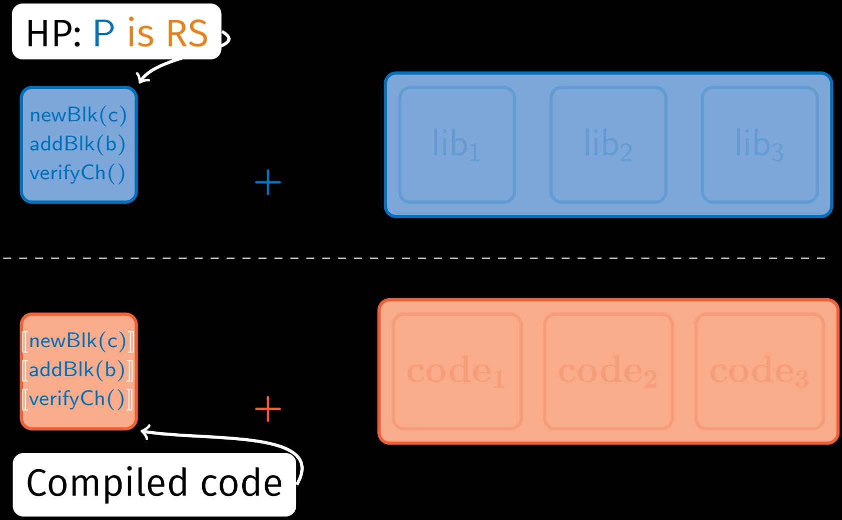
PF-RSC: equivalent definition easier to prove than RSC

(equivalence to be proven, generally true)

Backtranslation Proof Technique

Backtranslation: Build A From A or $\overline{\alpha}$



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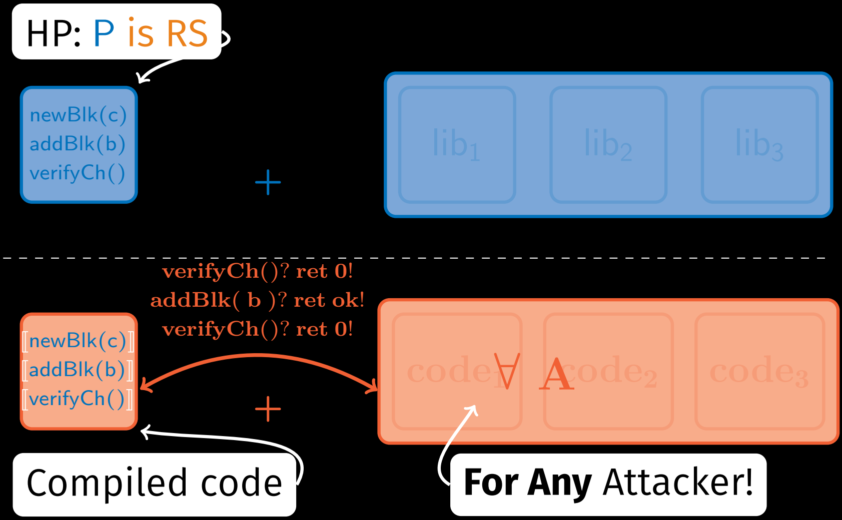

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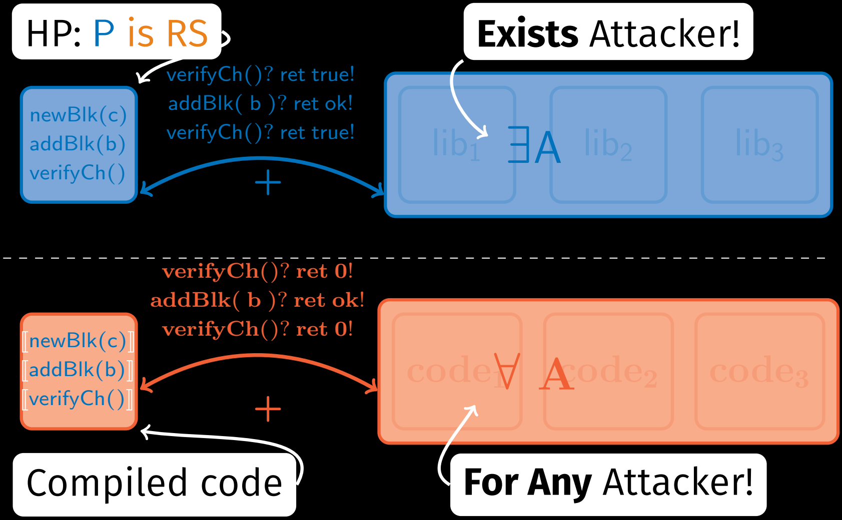

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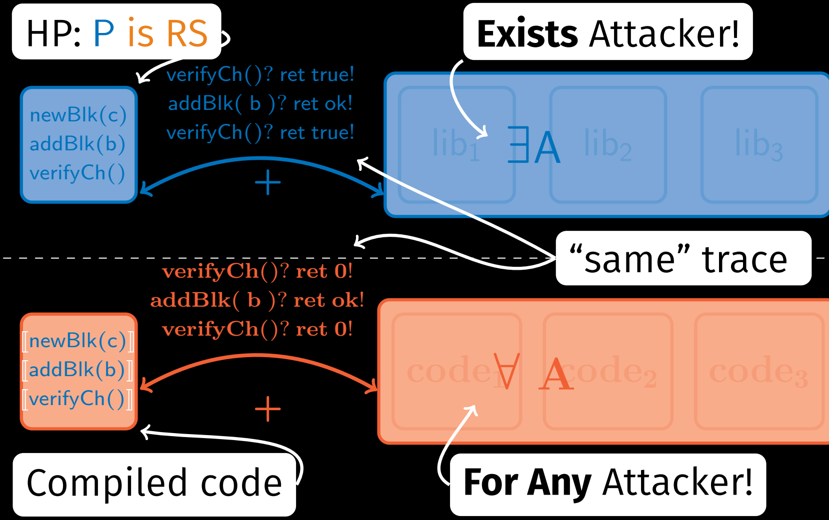

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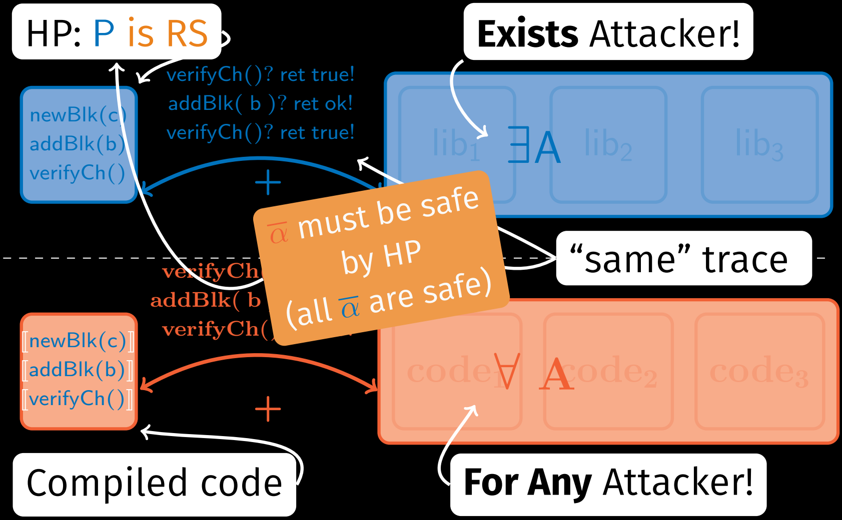

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- then $\overline{\alpha}$ is not bad
  because $\overline{\alpha}$ does not violate safety
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PF-RSC formally:
if $\forall \mathbf{A}.\mathbf{A}\left[[\![\mathsf{P}]\!]\right] \xrightarrow{\overline{\alpha}}$
then $\exists \mathsf{A}.\mathsf{A}\left[\mathsf{P}\right] \xrightarrow{\overline{\alpha}}$ and $\overline{\alpha} \approx \overline{\alpha}$

RSC and PF-RSC

RSC: given $\mathsf{M} \approx \mathbf{M}$
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$\Longleftrightarrow$

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- $\iff$ must be proven (when needed)
- proof is (generally) trivial
- sanity-check for cross-language safety encoding ($\mathsf{M} \approx \mathbf{M}$)

Take Home Message

What to make of this result?

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- encode safety properties in the systems

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What to make of this result?

- encode safety properties in the systems
- ensure the desired property follows from the encoding
- use our proof techniques to prove safety is preserved

What Else?

The paper (or the techreport) contains more:

- one RSC $[\![\cdot]\!]^{\mathsf{L}^{\mathsf{U}}}_{\mathbf{L}^{\mathbf{P}}}$ from untyped while to **capabilities**
- one RSC $[\![\cdot]\!]^{\mathsf{L}^{\tau}}_{\mathbf{L}^{\pi}}$ from typed, concurrent while to **capabilities**
- one RSC $[\![\cdot]\!]^{\mathsf{L}^{\tau}}_{L^{I}}$ from typed, concurrent while to *enclaves*
- a backtranslation-based RSC proof (for $[\![\cdot]\!]^{\mathsf{L}^{\mathsf{U}}}_{\mathbf{L}^{\mathbf{P}}}$)
- two simulation-based RSC proofs (for $[\![\cdot]\!]^{\mathsf{L}^{\tau}}_{\mathbf{L}^{\pi}}$ and $[\![\cdot]\!]^{\mathsf{L}^{\tau}}_{L^{I}}$)
- a FAC $[\![\boxed{\cdot}]\!]^{\mathsf{L}^{\mathsf{U}}}_{\mathbf{L}^{\mathbf{P}}}$ from untyped while to **capabilities**
- a backtranslation-based FAC proof sketch (for $[\![\boxed{\cdot}]\!]^{\mathsf{L}^{\mathsf{U}}}_{\mathbf{L}^{\mathbf{P}}}$)
- a comparison of efficiency and proof complexity between $[\![\cdot]\!]^{\mathsf{L}^{\mathsf{U}}}_{\mathbf{L}^{\mathbf{P}}}$ and $[\![\boxed{\cdot}]\!]^{\mathsf{L}^{\mathsf{U}}}_{\mathbf{L}^{\mathbf{P}}}$

Questions?

Backtranslation Example

(1) $\texttt{call f 0}\ (\overbrace{\mathbf{1} \mapsto \mathbf{4} : \bot}, \overbrace{\mathbf{2} \mapsto \mathbf{3} : \bot})?$

(2) $\texttt{ret}\ (\mathbf{1} \mapsto \mathbf{4} : \bot, \mathbf{2} \mapsto \langle \mathbf{3}, \mathbf{k} \rangle : \bot, \overbrace{\mathbf{3} \mapsto \mathbf{11} : \mathbf{k}})!$

(3) $\texttt{call f 2}\ (\underbrace{\mathbf{1} \mapsto \mathbf{55} : \bot}, \mathbf{2} \mapsto \langle \mathbf{3}, \mathbf{k} \rangle : \bot, \underbrace{\mathbf{3} \mapsto \mathbf{15} : \mathbf{k}})?$

main(z) $\mapsto$

let x = new 4 in L :: $\langle$x, 1$\rangle$; (1)
let x = new 3 in L :: $\langle$x, 2$\rangle$;
call f 0;

let x =!L(2) in L :: $\langle$x, 3$\rangle$; (2)

let x = new L(1) in x := 55; (3)
let x = new L(3) in x := 15;
call f 2;

Simulation-Based Proof

Set up cross-language relation $\approx_\beta$ that:

- knows trusted locations: $\tau \nvdash \circ$.
- splits heaps (source and **target**) into trusted and untrusted;
- constitutes trusted heap by trusted locations ($\tau \nvdash \circ$);
- relates trusted **heap** to trusted heap
- protects every trusted **location** by a capability;
- capability protecting a trusted **location** is not in attacker code, nor in the untrusted heap