Robustly Safe Compilation

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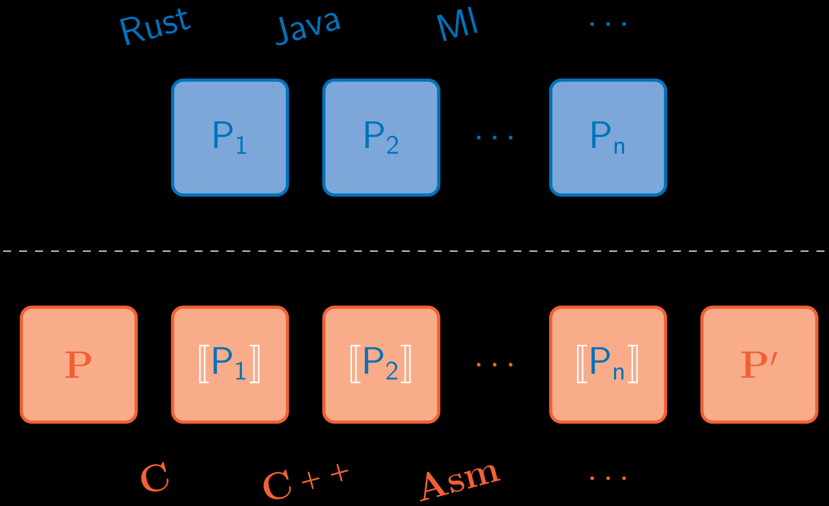
What is Secure Compilation?



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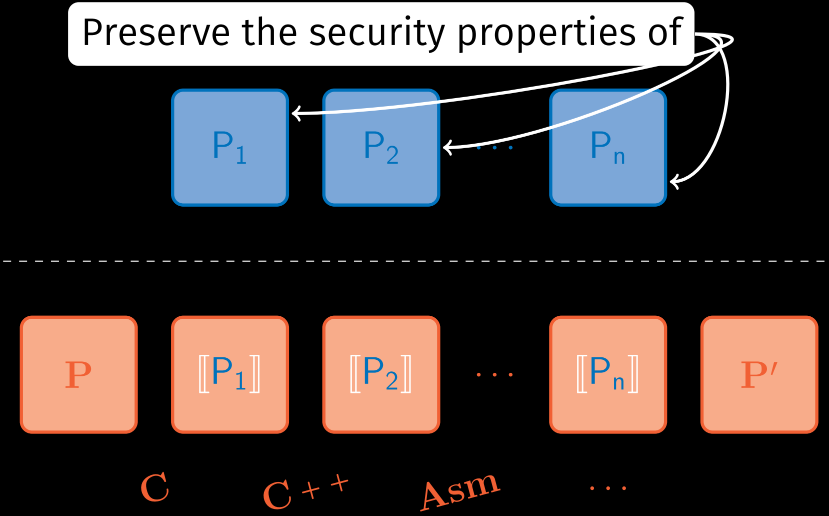

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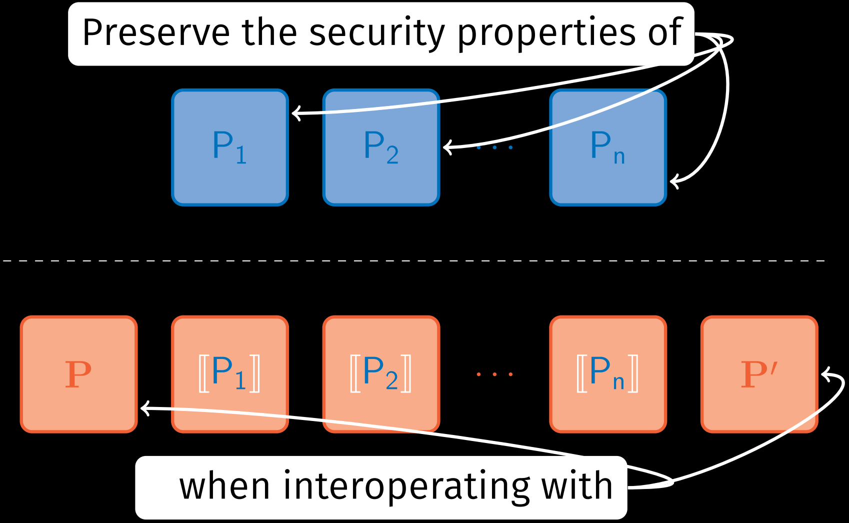

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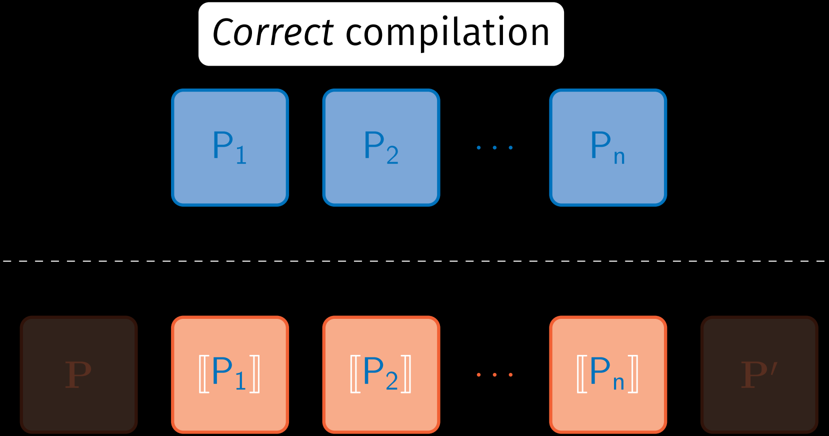

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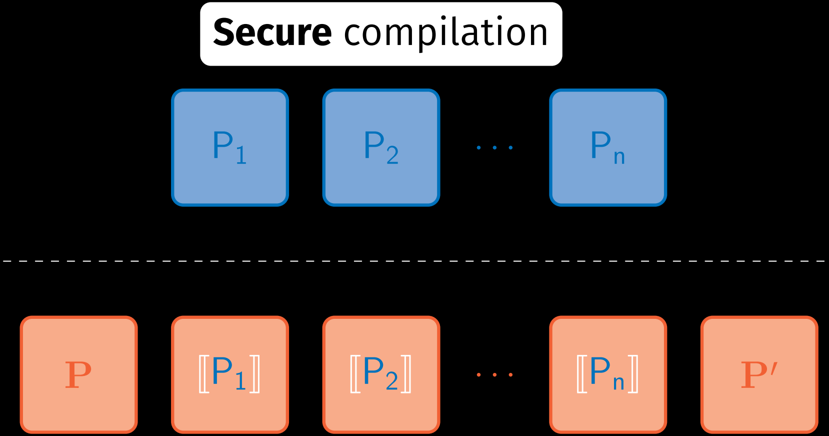
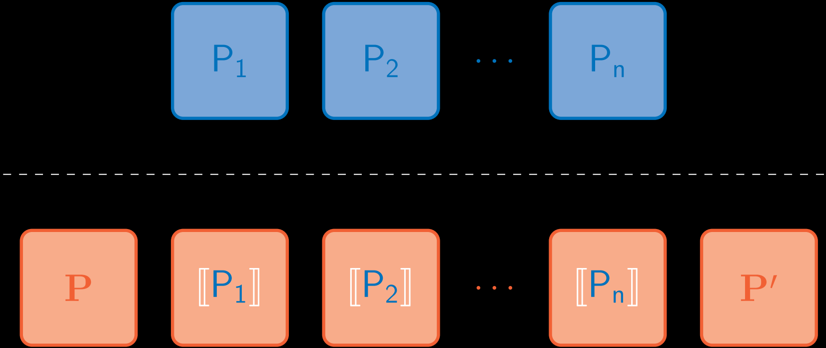


What is Secure Compilation?

Enable source-level security reasoning



Do Secure Compilers Exist?

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Yes!

Do Secure Compilers Exist?

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

But...

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

But...

secure compilers:

- : lack formal proof of their security guarantees
- **P2** : prove preservation of ad-hoc security properties
- **P3** : inefficient

complex proofs

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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- with clear security guarantees

Contributions

- RSC: a criterion fulfilling our goals

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part 1

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part 1

part 2

Talk Roadmap

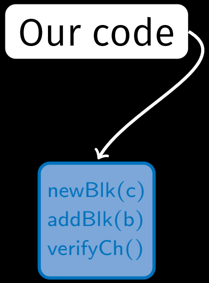
Robust Safety

Robustly Safe Compilation

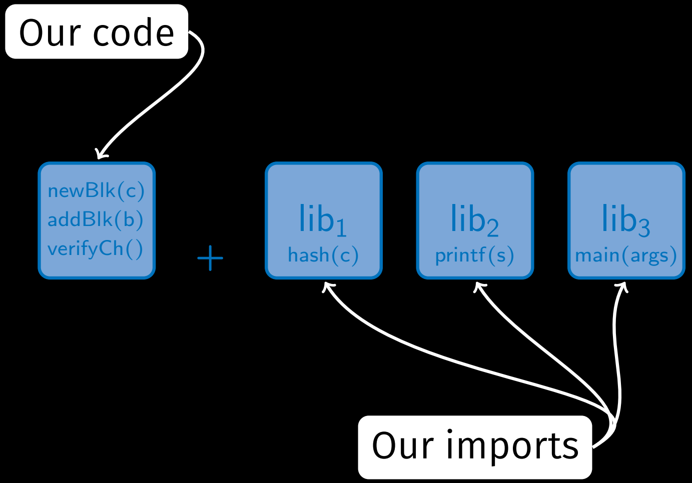
Backtranslation Proof Technique

Robust Safety

Robustness

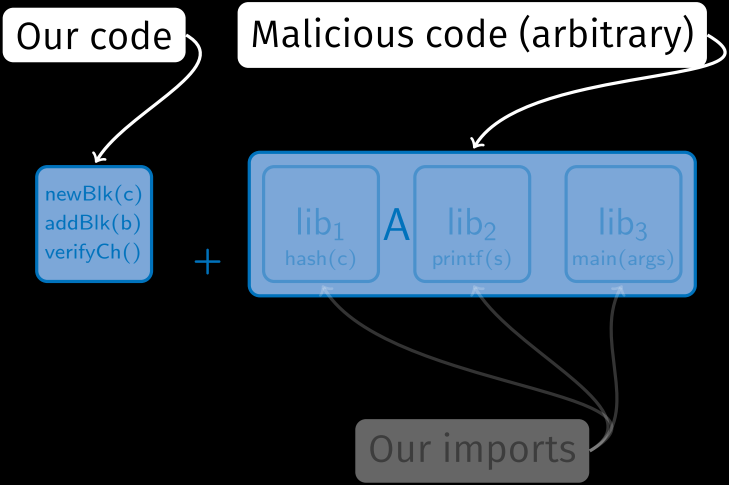


Robustness



Our code
newBlk(c)
addBlk(b)
verifyCh()
+
lib1
hash(c)
lib2
printf(s)
lib3
main(args)
Our imports

Robustness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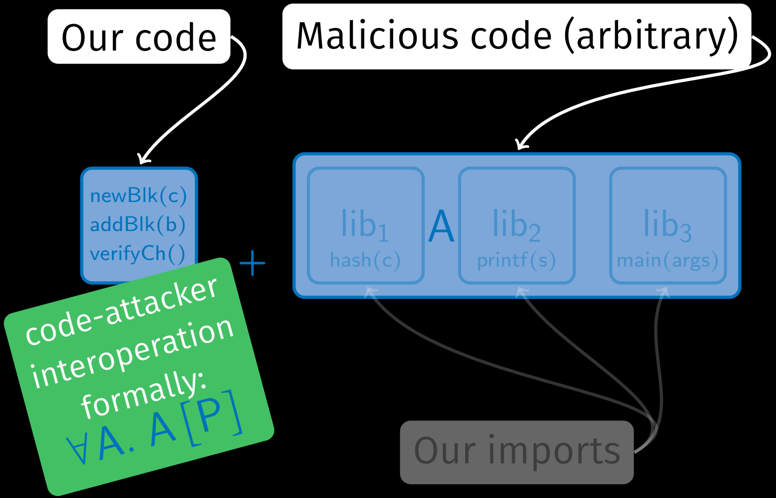

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Our imports
code-attacker
interoperation
formally:
∀A. A[P]

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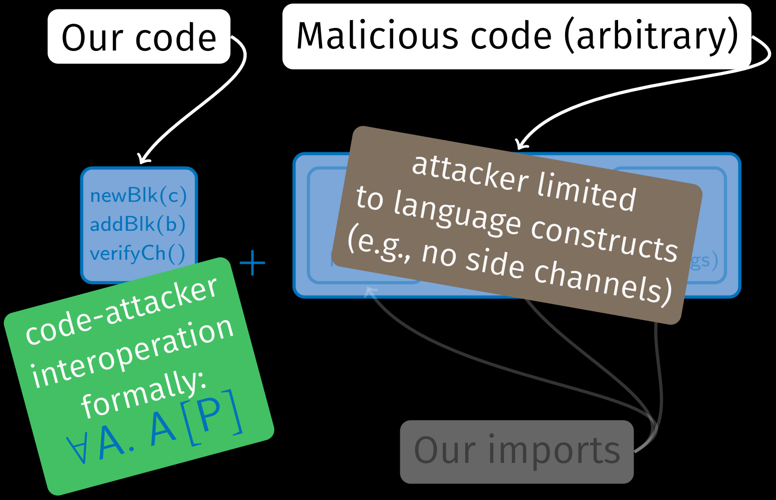
Our code
Malicious code (arbitrary)
newBlk(c)
addBlk(b)
verifyCh()
+
attacker limited to language constructs (e.g., no side channels)
code-attacker interoperation formally:
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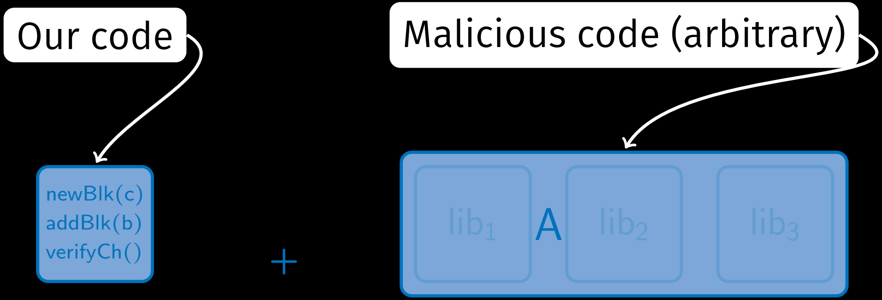
Our imports

Program Behaviour



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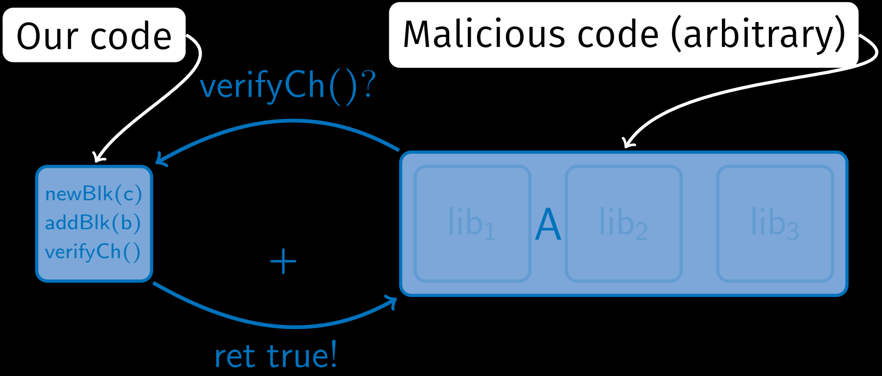

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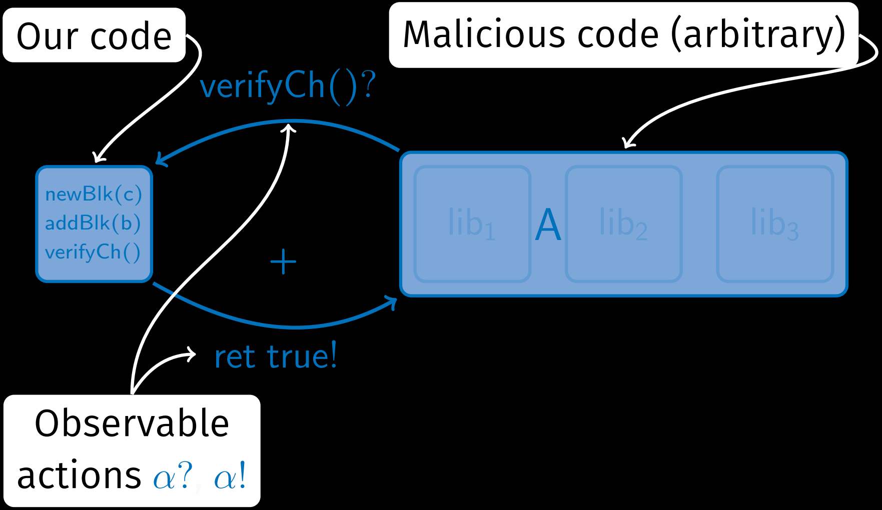

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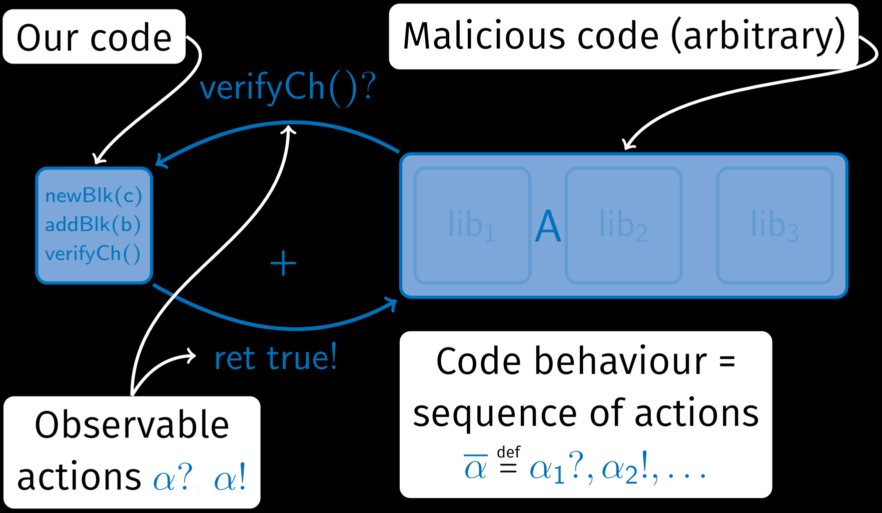

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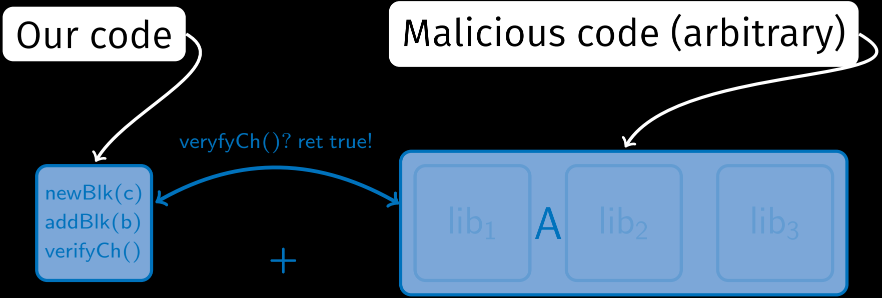

Code behaviour = sequence of actions

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

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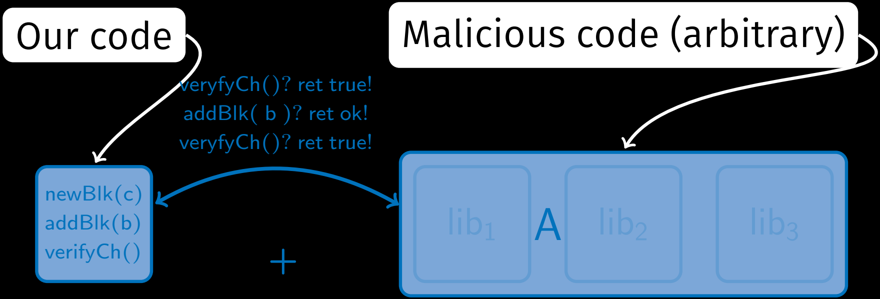

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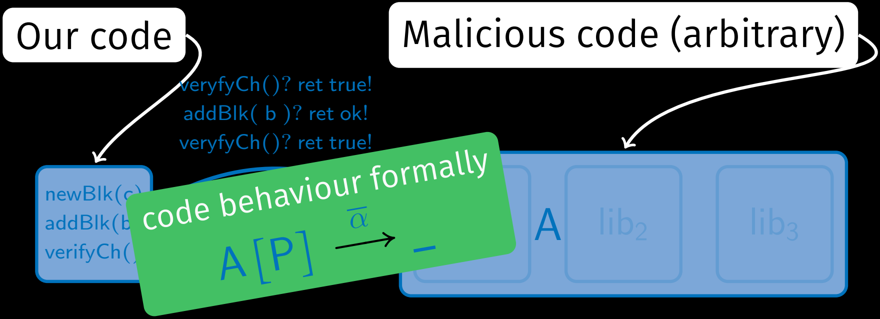

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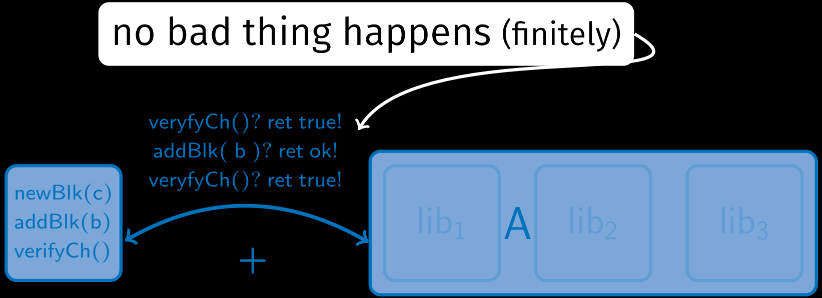
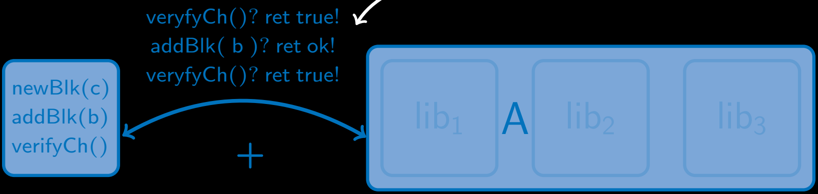
Safety Properties



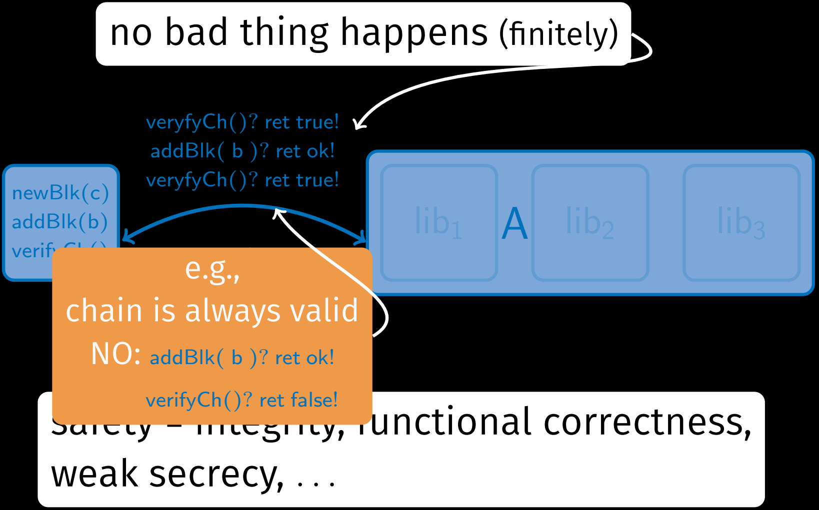
Safety Properties

no bad thing happens (finitely)



safety = integrity, functional correctness, weak secrecy, ...

Safety Properties



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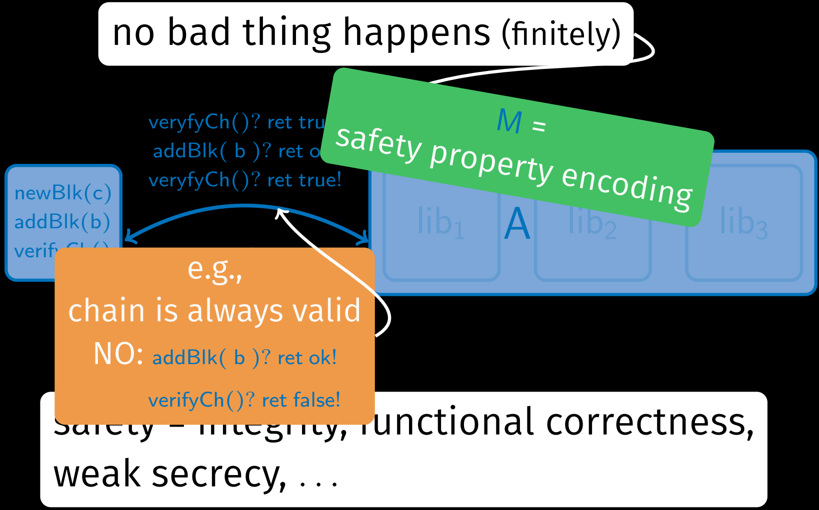

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- for a safety property (M)
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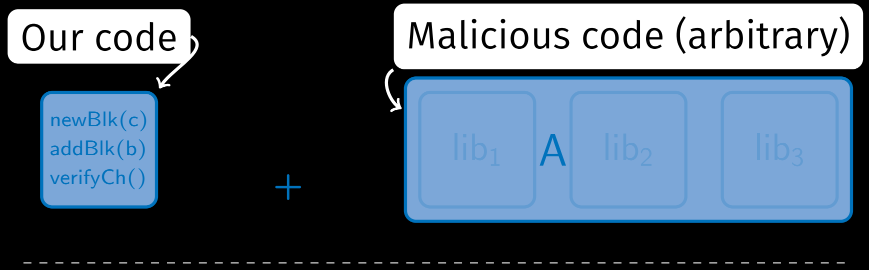
robust safety formally
$M \vdash P$

Robustly Safe Compilation

Robust Safety Across Compilation



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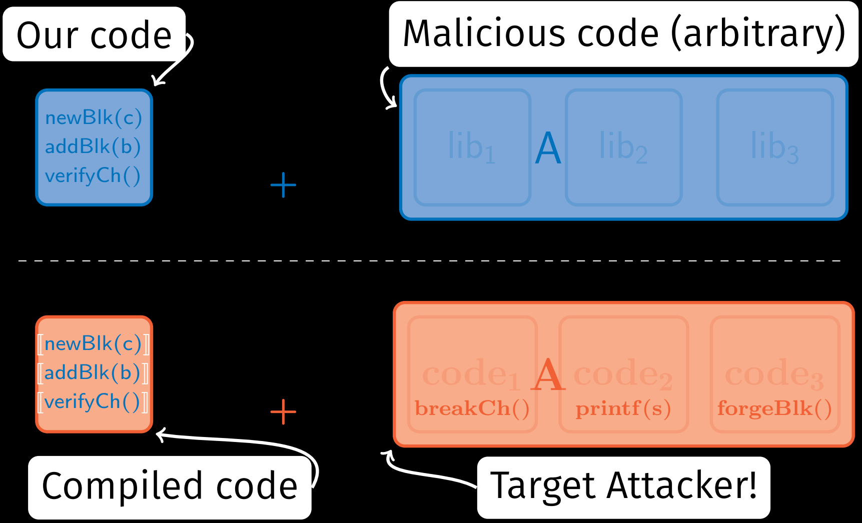

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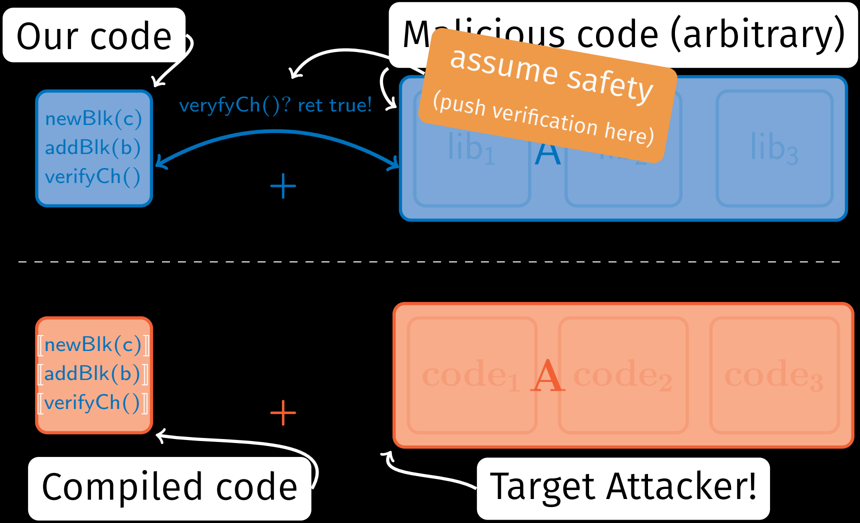

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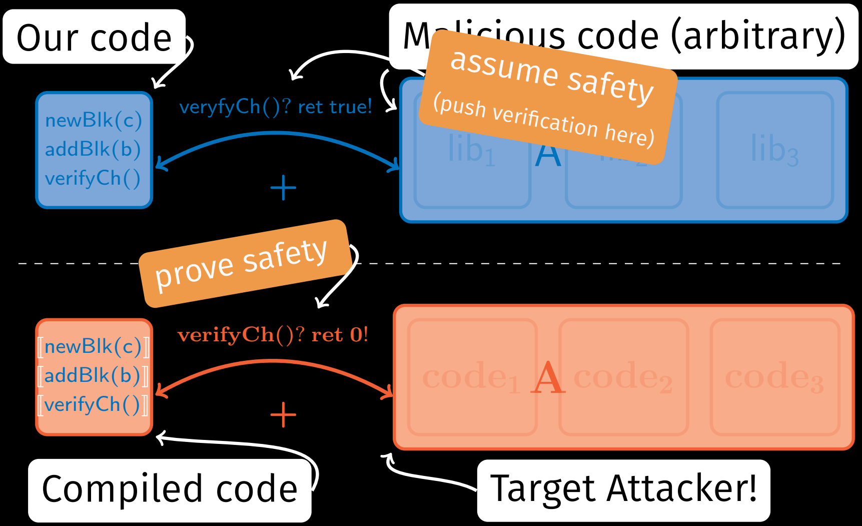

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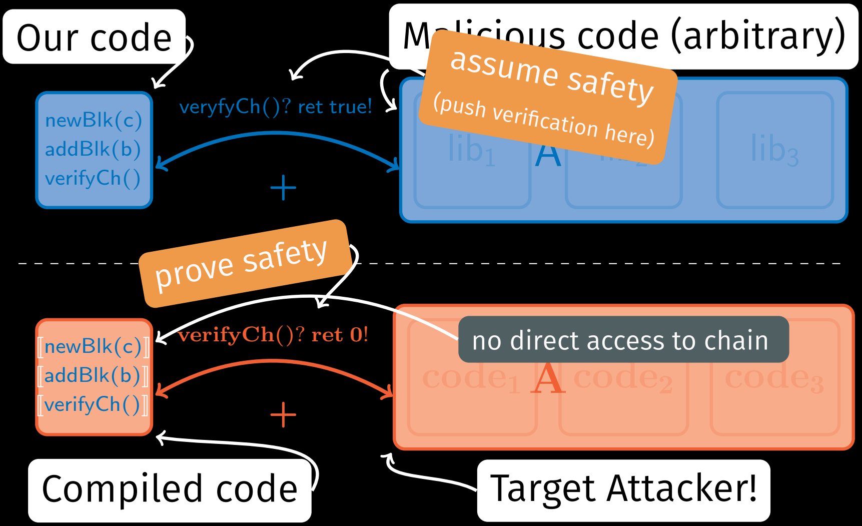

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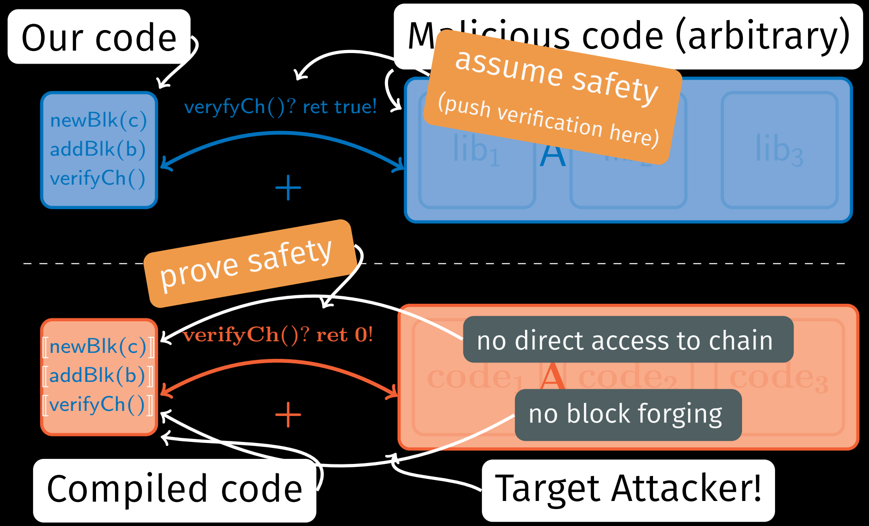

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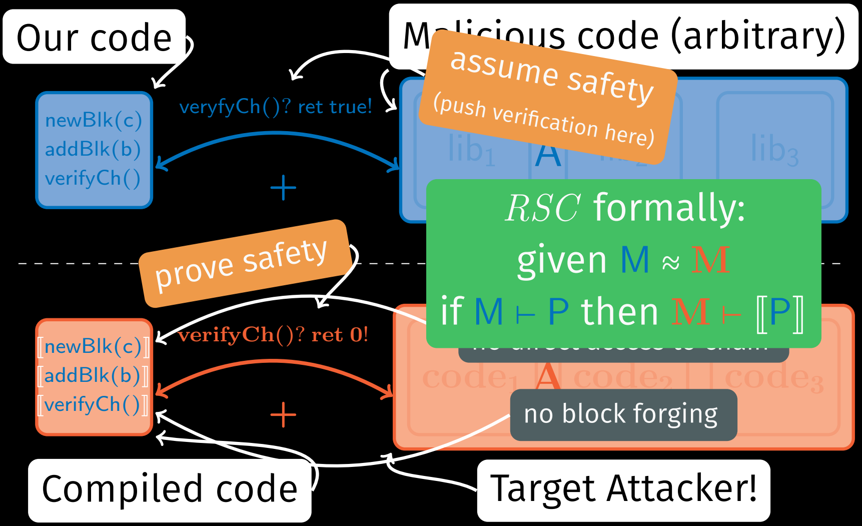

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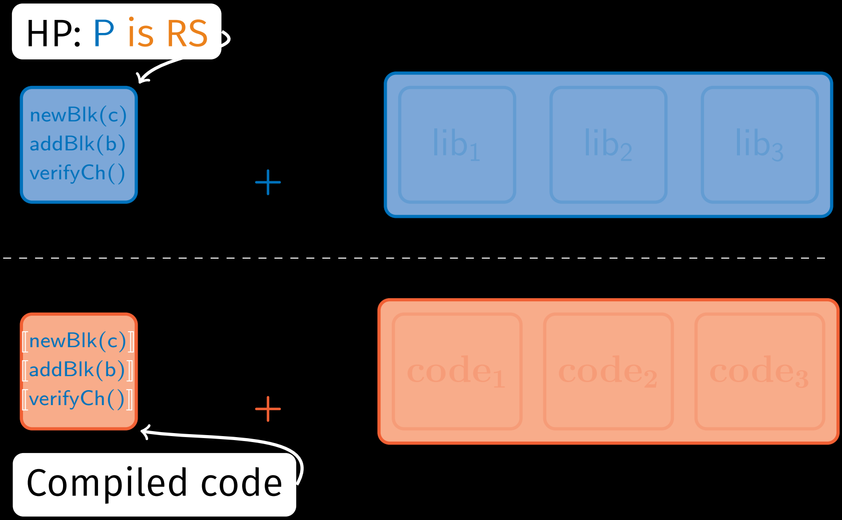
(equivalence to be proven, generally true)

Backtranslation Proof Technique

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



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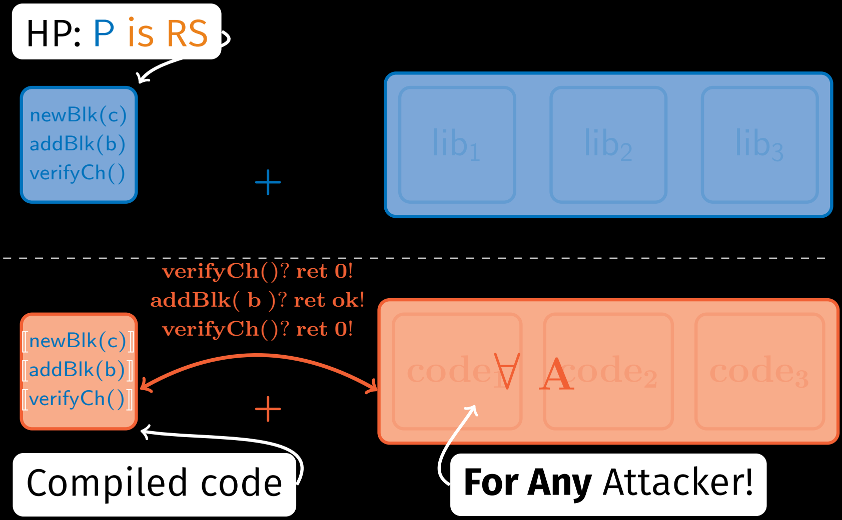

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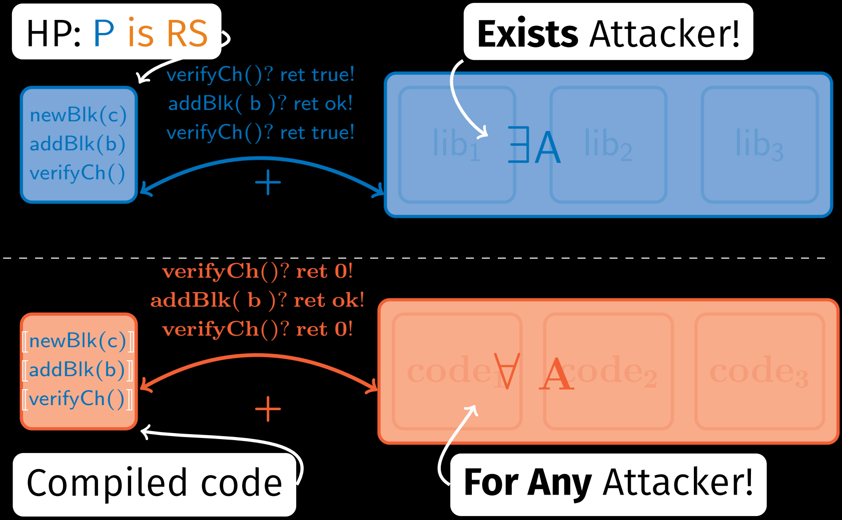

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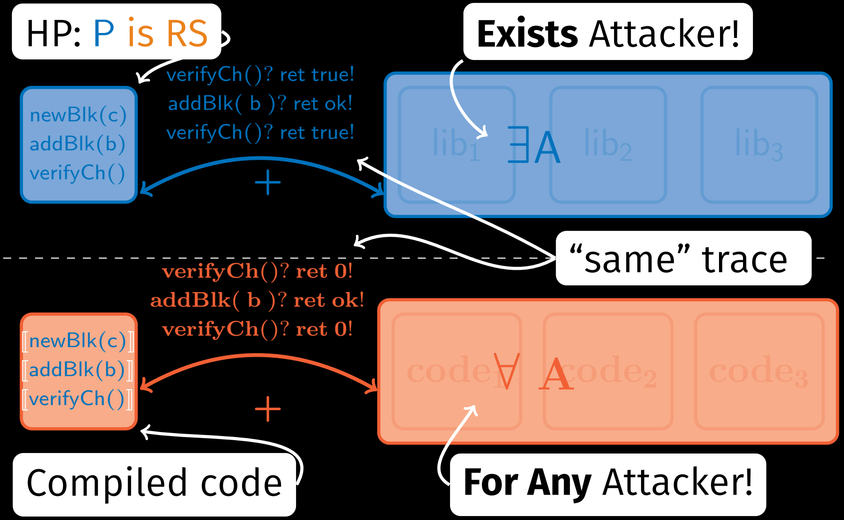

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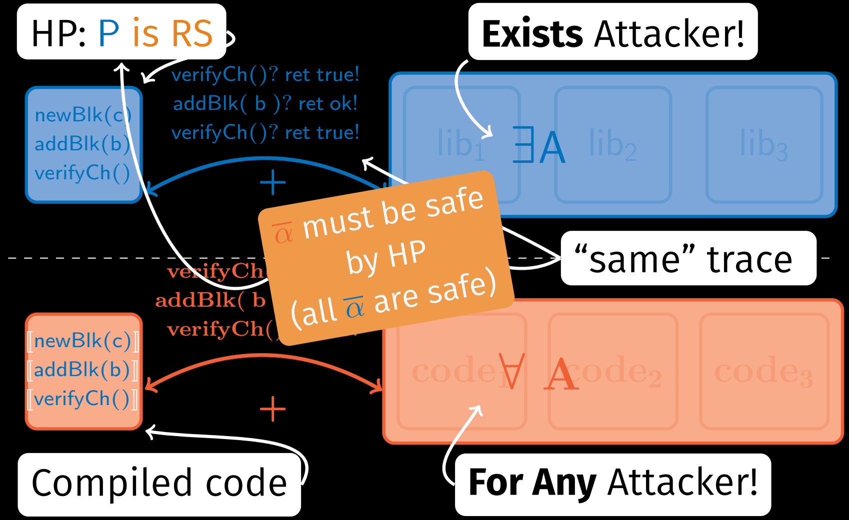

Safety as a Dual and PF-RSC

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PF-RSC formally:
if $\forall \mathbf{A}. \mathbf{A}\,[\llbracket P \rrbracket] \xrightarrow{\overline{\alpha}}$
then $\exists A.A\,[P] \xrightarrow{\overline{\alpha}}$ and $\overline{\alpha} \approx \overline{\alpha}$

RSC and PF-RSC

RSC: given $\mathsf{M} \approx \mathbf{M}$
if $\mathsf{M} \vdash \mathsf{P}$ then $\mathbf{M} \vdash [\![\mathsf{P}]\!]$

$\Longleftrightarrow$

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- $\Longleftrightarrow$ must be proven (when needed)

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$\iff$

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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 your systems

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- ensure your desired property follows from the encoding

Take Home Message

What to make of this result?

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

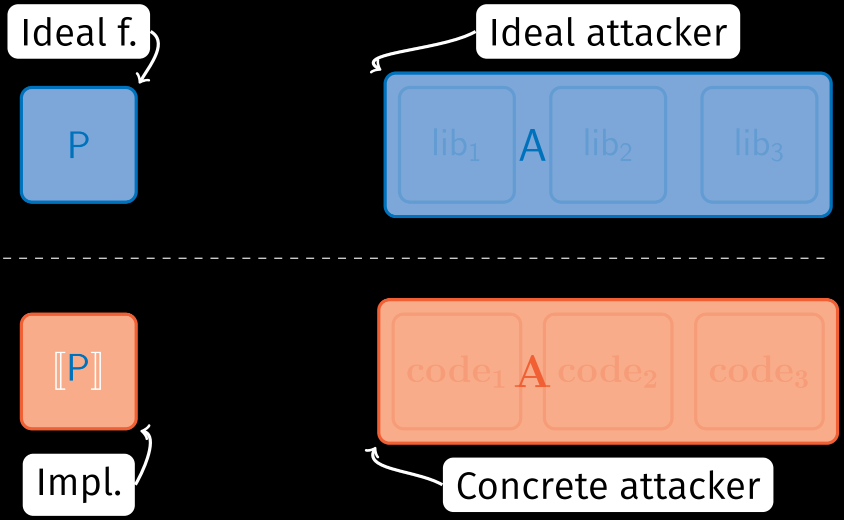
What Else?

The paper (or the techreport) contains more:

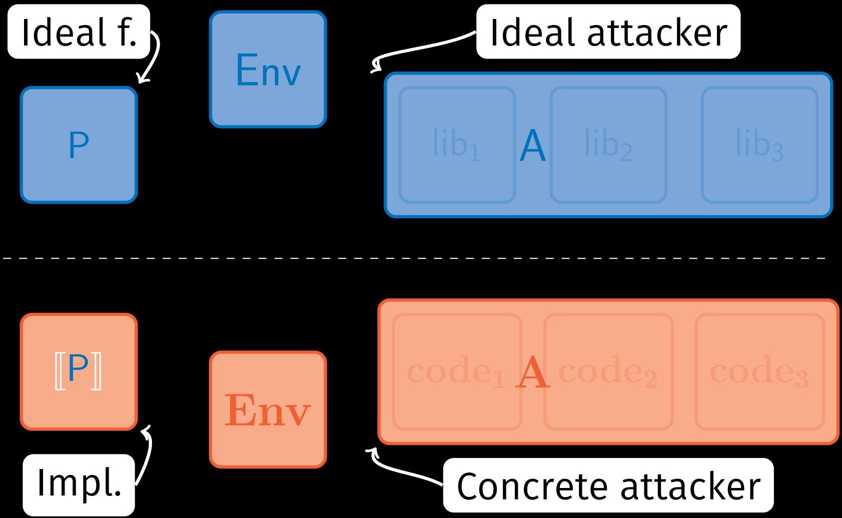
- one RSC $[\![\cdot]\!]^{\mathsf{L}^{\mathsf{U}}}_{\mathbf{L}^{\mathbf{P}}}$ from untyped while to **capabilities**
- one RSC $[\![\cdot]\!]^{\mathsf{L}^{\tau}}_{\mathbf{L}^{\pi}}$ from typed, concurrent while to **capabilities**
- one RSC $[\![\cdot]\!]^{\mathsf{L}^{\tau}}_{L^{I}}$ from typed, concurrent 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?

RSC and UC

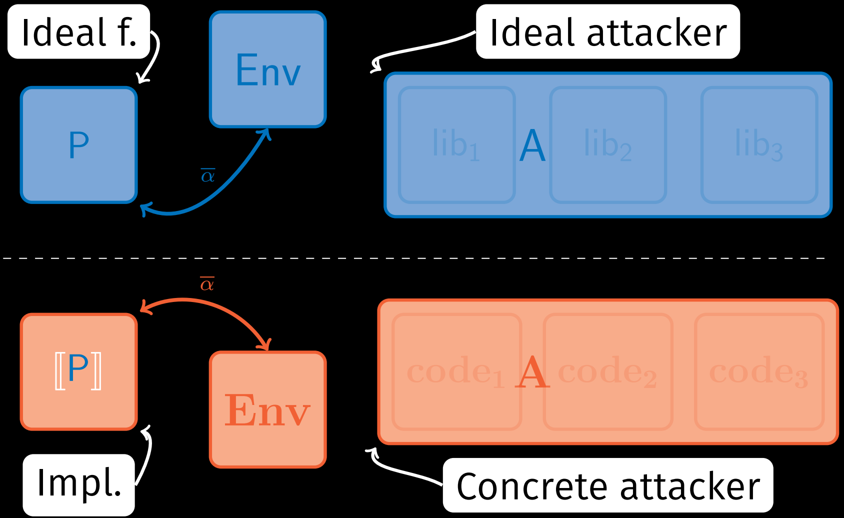

Ideal f.
P
Ideal attacker
lib1
A
lib2
lib3
⟦P⟧
Impl.
code1
A
code2
code3
Concrete attacker

RSC and UC



Ideal f.
Env
Ideal attacker
P
lib₁
A
lib₂
lib₃
⟦P⟧
Env
code₁
A
code₂
code₃
Impl.
Concrete attacker

RSC and UC



Ideal f.
Env
Ideal attacker
P
lib$_1$
A
lib$_2$
lib$_3$
$\overline{\alpha}$
$\overline{\alpha}$
⟦P⟧
Env
code$_1$
A
code$_2$
code$_3$
Impl.
Concrete attacker

Backtranslation Example

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

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

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

$\mathsf{main}(z) \mapsto$

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

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

(3)
$\mathsf{let}\ x = \mathsf{new}\ L(1)\ \mathsf{in}\ x := 55;$
$\mathsf{let}\ x = \mathsf{new}\ L(3)\ \mathsf{in}\ x := 15;$
$\mathsf{call}\ f\ 2;$

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