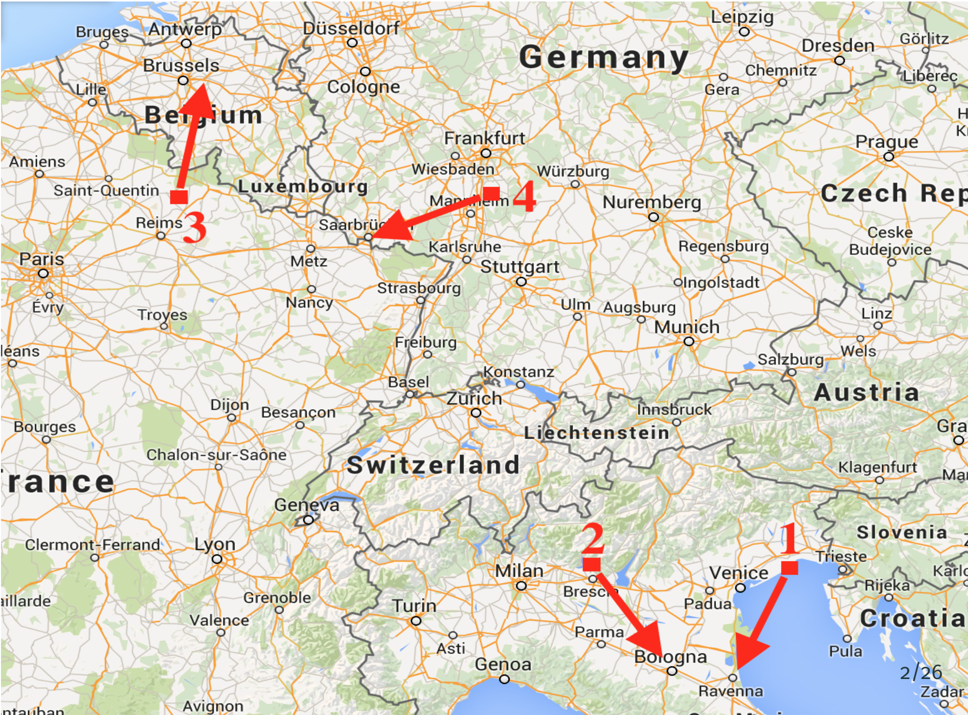
Secure Compilation

Marco Patrignani

17th October 2018

CISPA

Center for IT-Security, Privacy and Accountability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ntauban
Avignon

MAX PLANCK INSTITUTE FOR SOFTWARE SYSTEMS

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FOR CYBERSECURITY

KU LEUVEN

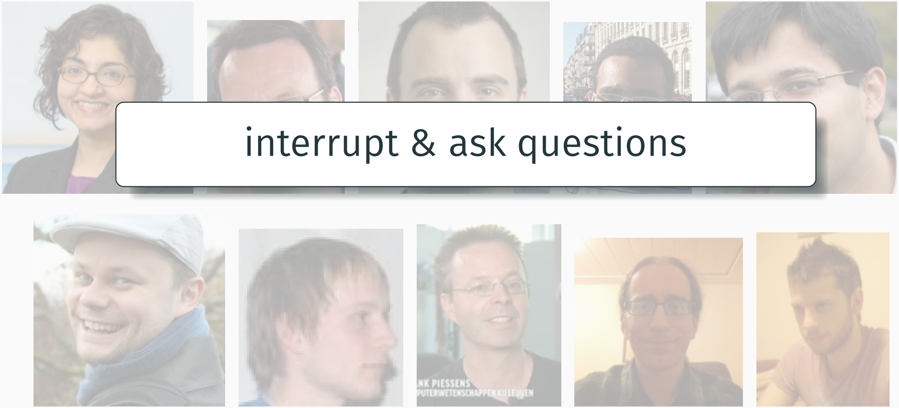
ALMA MATER STUDIORUM A.D. 1088

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Collaborators

and more whose image I couldn't find...

Collaborators



interrupt & ask questions

and more whose image I couldn't find...

Contents

- High-level picture

  (i.e., yes, you should pay attention)

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- Low-level details of a secure compiler

  (i.e., what some published work do)

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  (i.e., what some published work do)
- Formal definitions of criteria for secure compilation

  (i.e., why is a secure compiler secure)

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- High-level picture

  (i.e., yes, you should pay attention)
- Low-level details of a secure compiler

  (i.e., what some published work do)
- Formal definitions of criteria for secure compilation

  (i.e., why is a secure compiler secure)
- Advanced proof techniques for secure compilation

  (i.e., how much greek gives me a q.e.d.)

What is Secure Compilation?

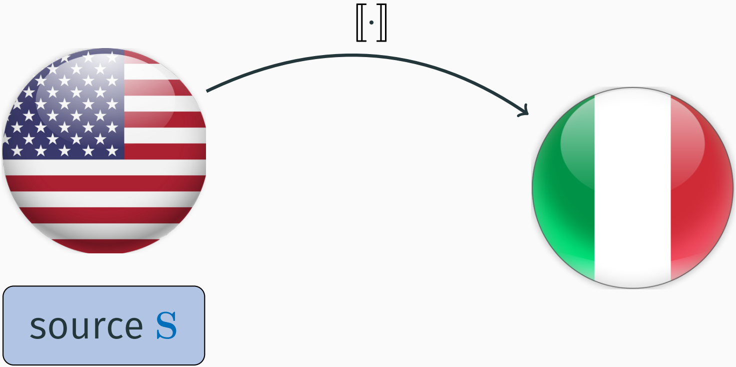
Compilation

Compilation

Compilation

source $\mathbf{S}$

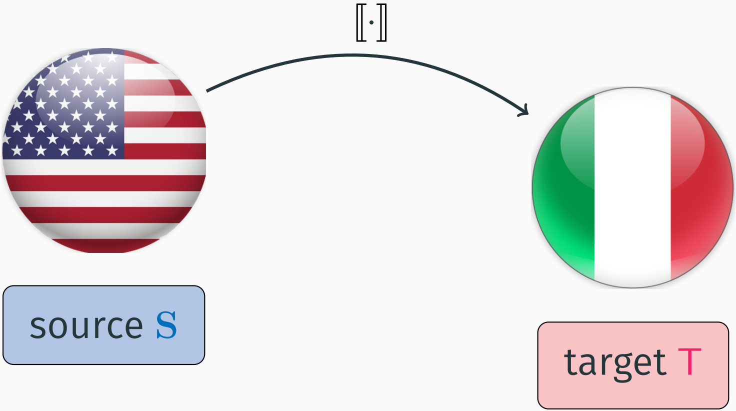
Compilation



$[\![\cdot]\!]$

source $\mathbf{S}$

Compilation

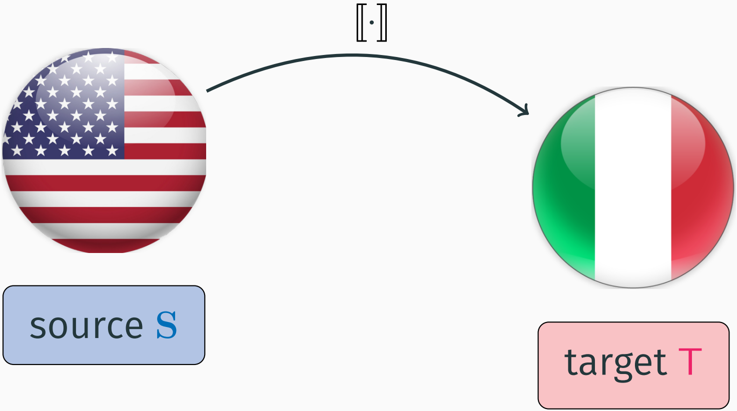


$\llbracket \cdot \rrbracket$

source S

target T

Correct Compilation



$[\![\cdot]\!]$

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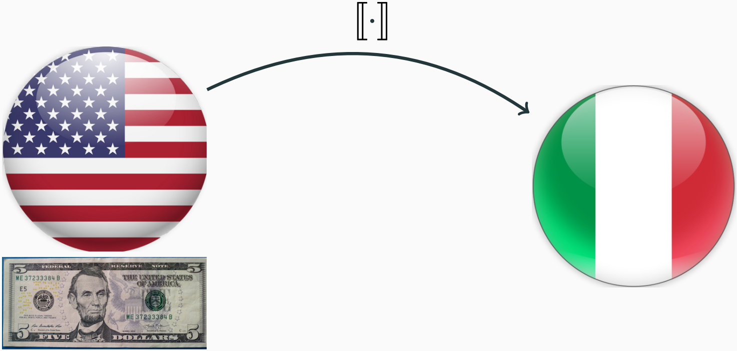
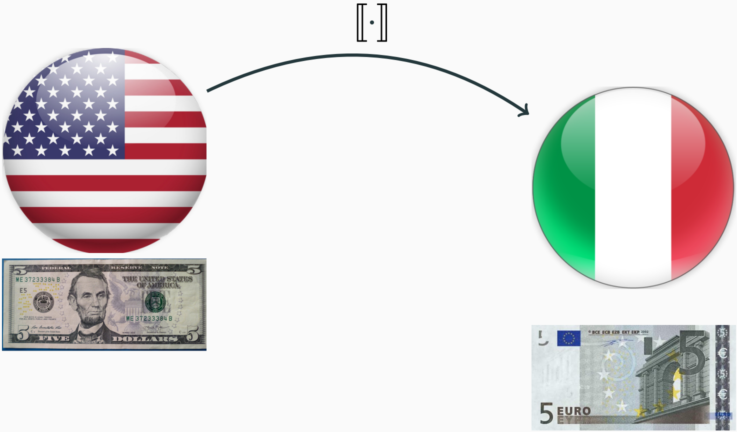
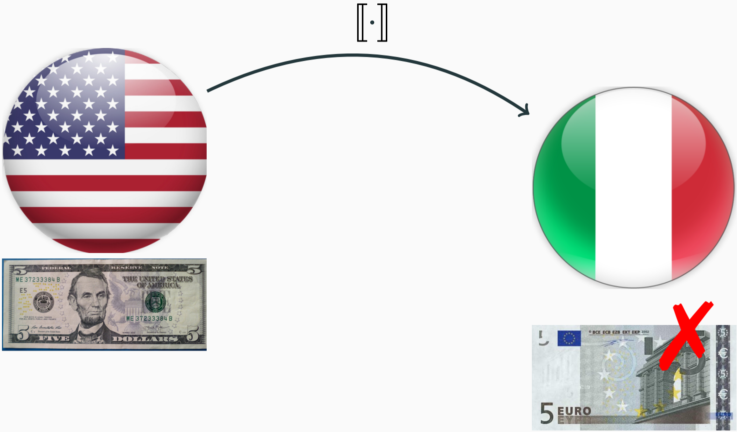
Correct Compilation



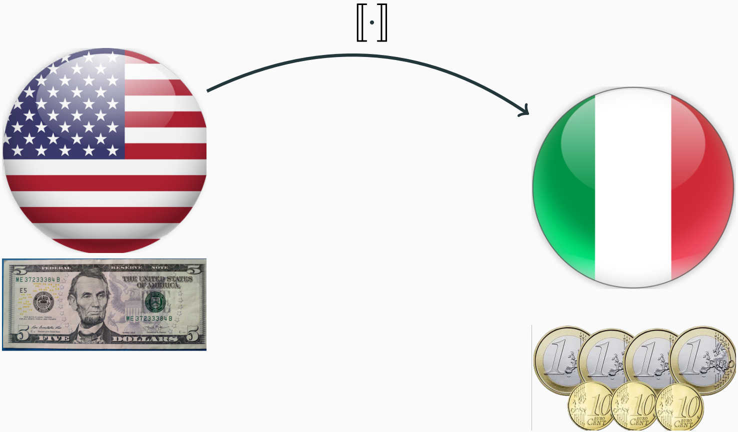
Correct Compilation



Correct Compilation

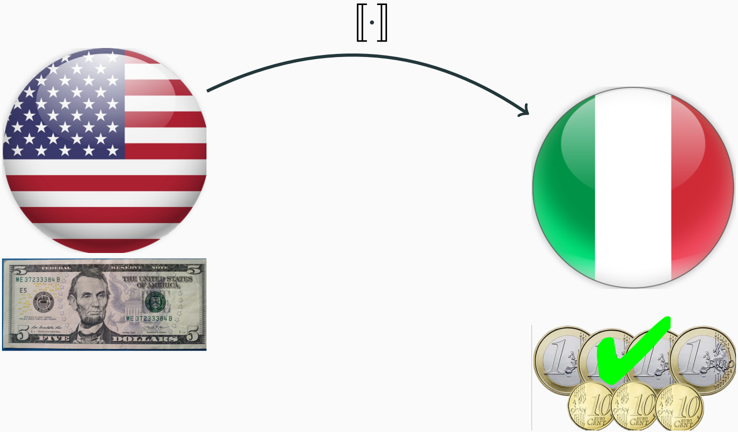


Correct Compilation

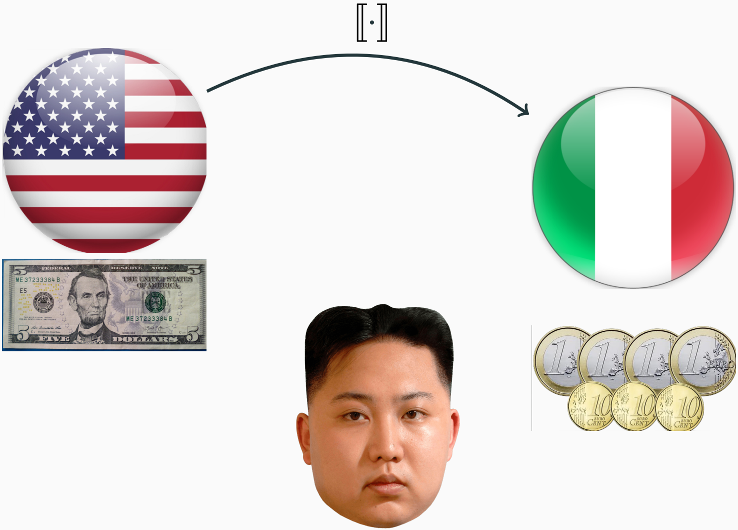


$[\![\cdot]\!]$

Correct Compilation



Secure Compilation



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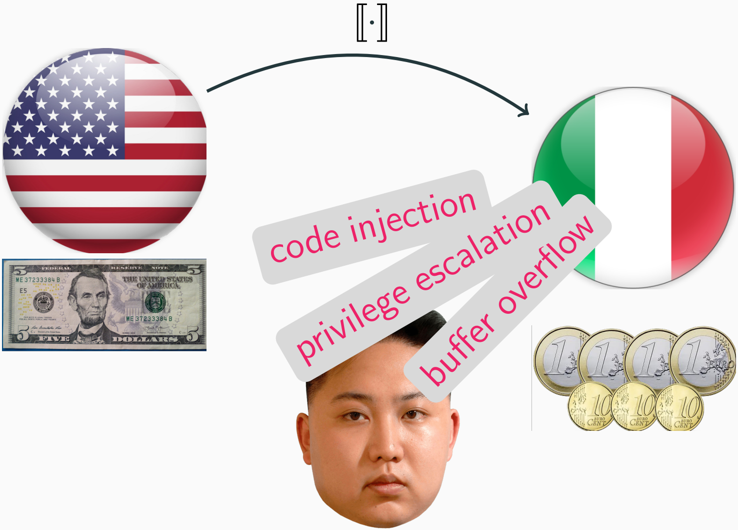


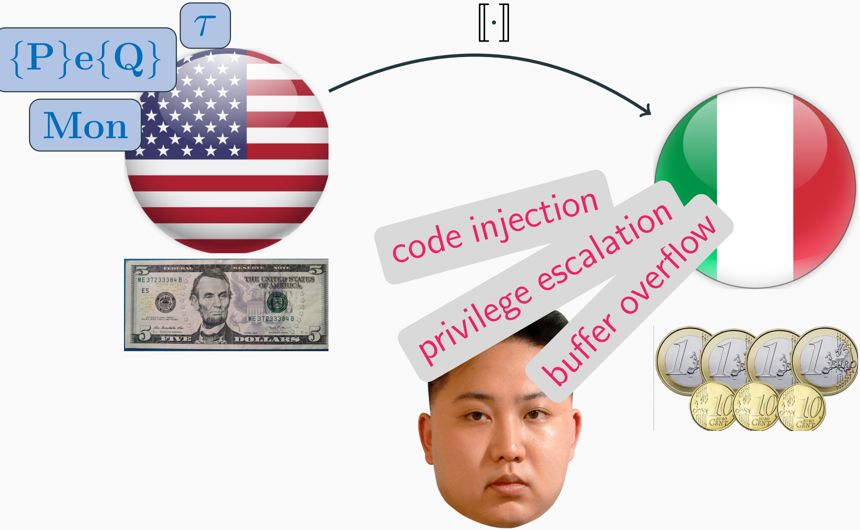
$[\![\cdot]\!]$

code injection

privilege escalation

buffer overflow

Secure Compilation



τ

$\{P\}e\{Q\}$

Mon

$[\![\cdot]\!]$

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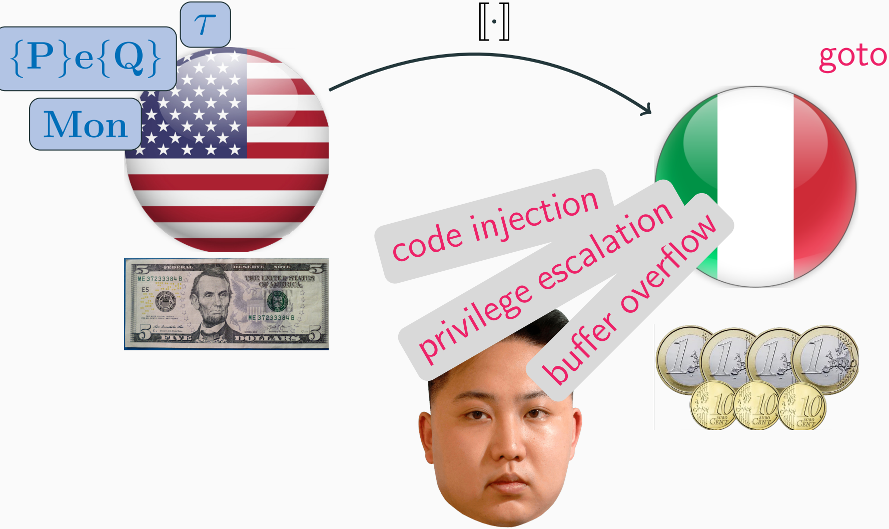
privilege escalation

buffer overflow

Secure Compilation



$\mathcal{T}$

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$[\![\cdot]\!]$

goto

code injection

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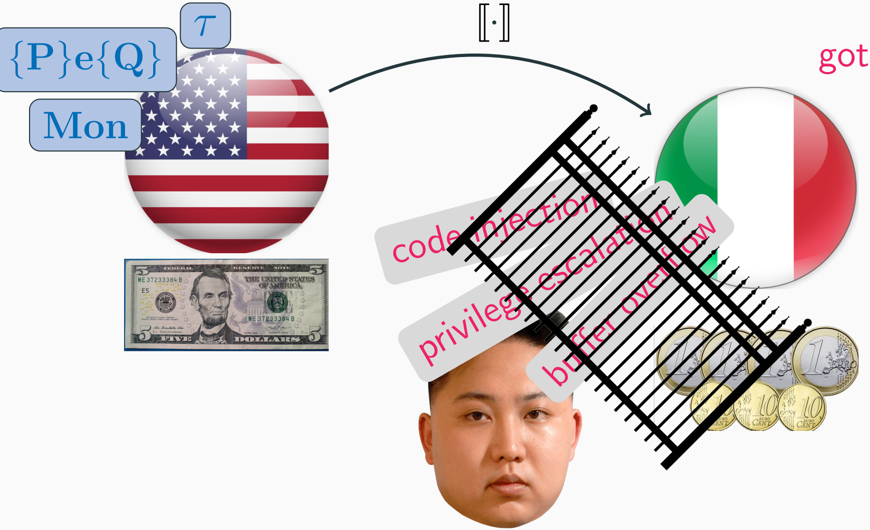
Secure Compilation



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buffer overflow

Secure Compilation

τ

{P}e{Q}

Mon

$[\![\cdot]\!]$

goto

code injectio

privilege esca

buffe

Enclaves

ASLR

Cap.Mach.

Tag.Mach.

Secure Compilation

- use security architectures to protect code

Secure Compilation

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- demonstrate that $[\![\cdot]\!]$ attains security

Secure Compilation

- use security architectures to protect code SGX-like enclaves (coming up)
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more generally

- build securely, don't fix afterwards

Secure Compilation

- use security architectures to protect code SGX-like enclaves (coming up)
- demonstrate that $[\![\cdot]\!]$ attains security criteria and proof techniques (later)

more generally

- build securely, don’t fix afterwards
- understand what ‘securely’ means

Example of a Secure Compiler

- source = **Java-like language**

Example of a Secure Compiler

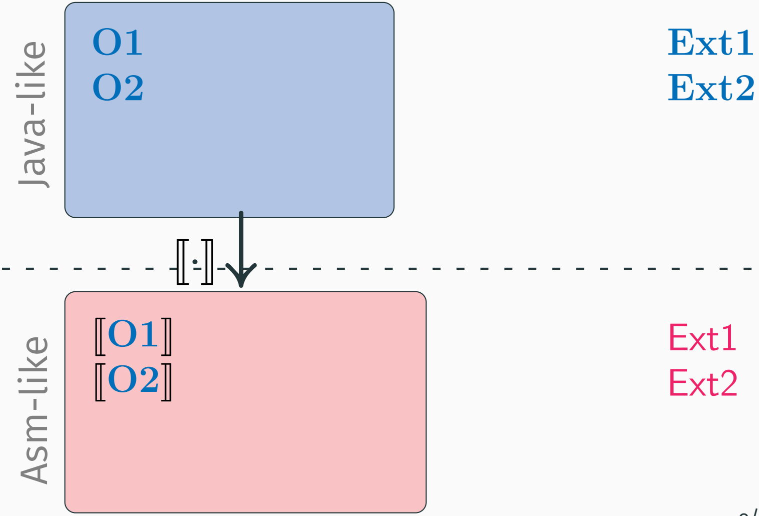
- source = **Java-like language**
- target = Assembly-like + isolation (sgx-likes)

Example of a Secure Compiler

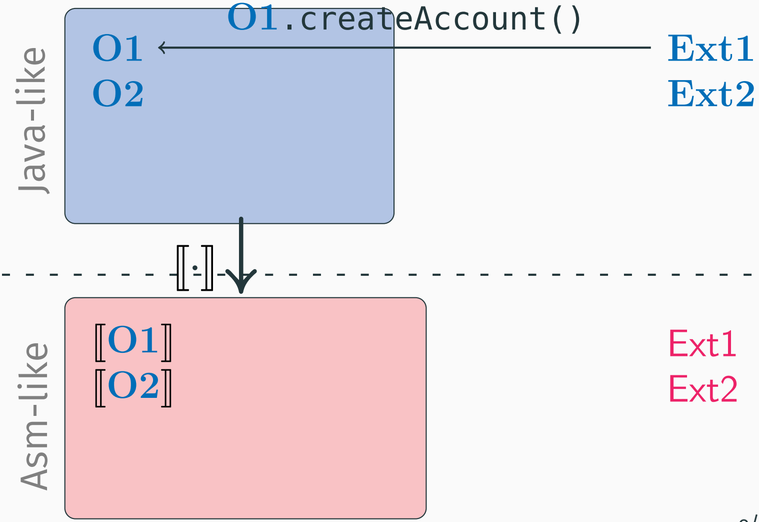
- source = **Java-like language**
- target = Assembly-like + isolation (sgx-likes)
- based on Agten *et al.*'12, Patrignani *et al.*'15'16

Warning fairly high level

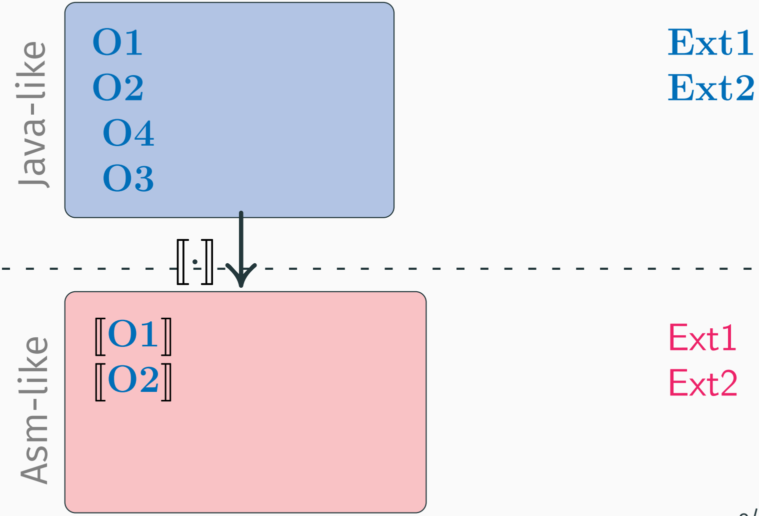
Memory Allocation Issues



Memory Allocation Issues



Memory Allocation Issues



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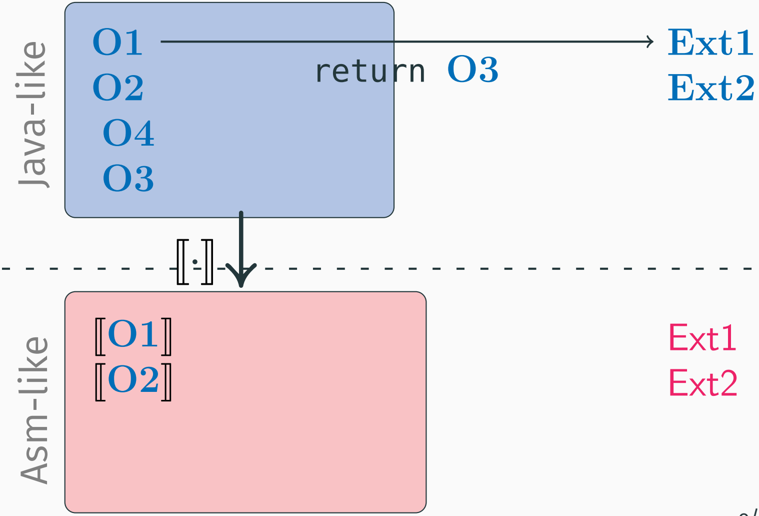

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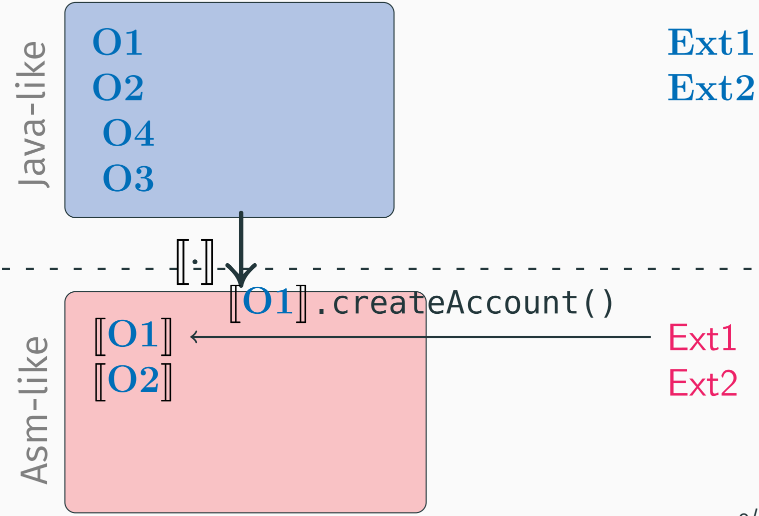


Java-like

O1

O2

O4

O3

Ext1

Ext2

$[\![\cdot]\!]$

$[\![\mathbf{O1}]\!]$`.createAccount()`

Asm-like

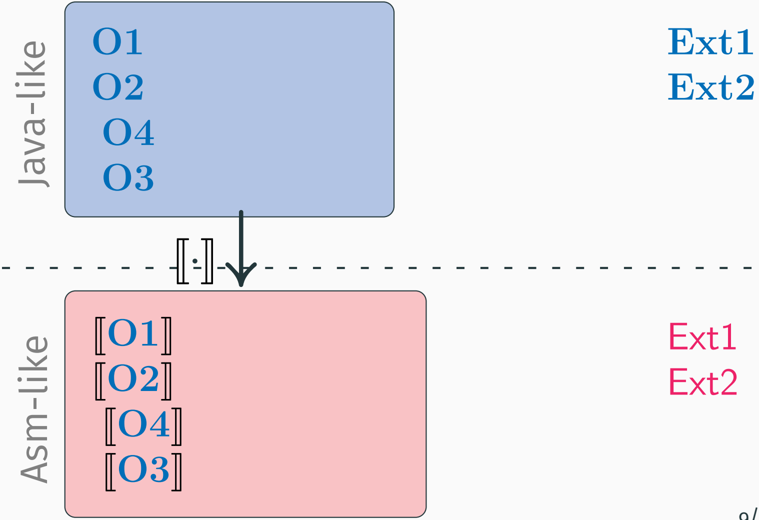
$[\![\mathbf{O1}]\!]$

$[\![\mathbf{O2}]\!]$

Ext1

Ext2

Memory Allocation Issues



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$\llbracket \cdot \rrbracket$

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Ext2

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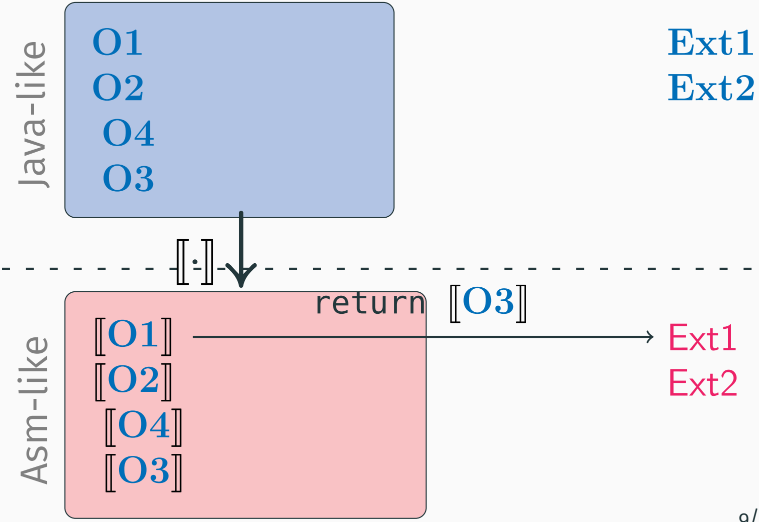

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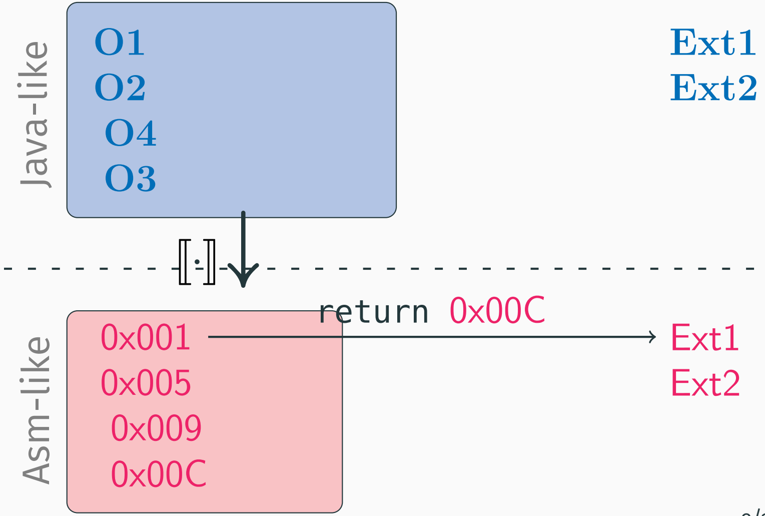

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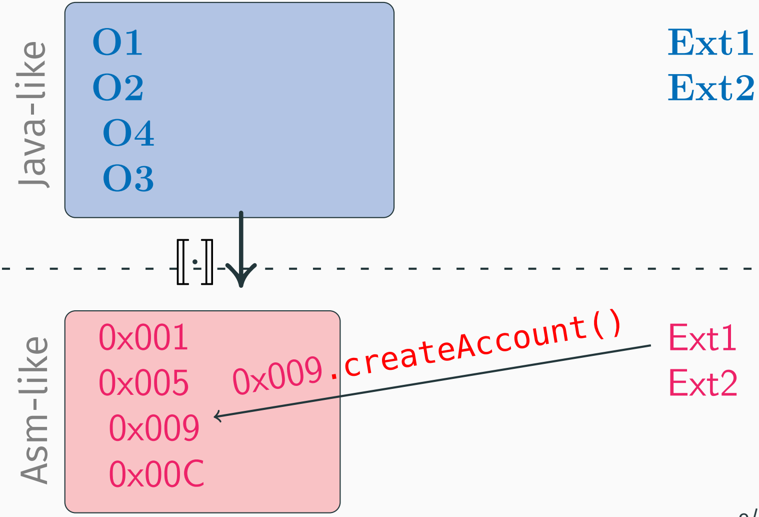

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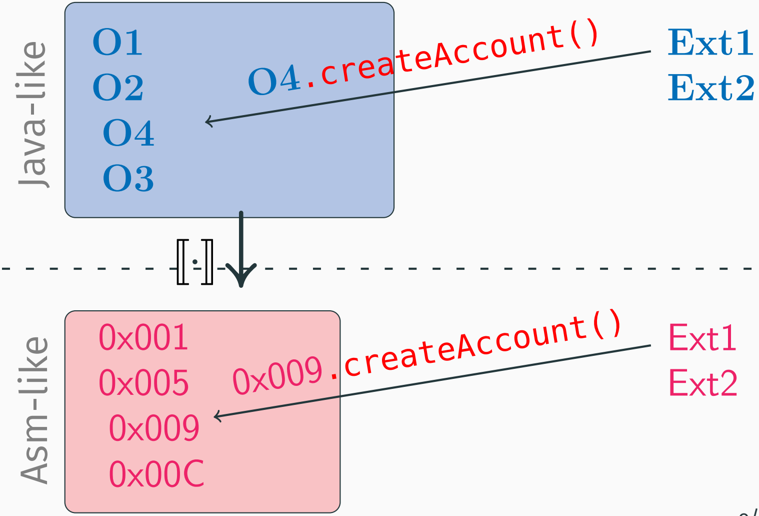

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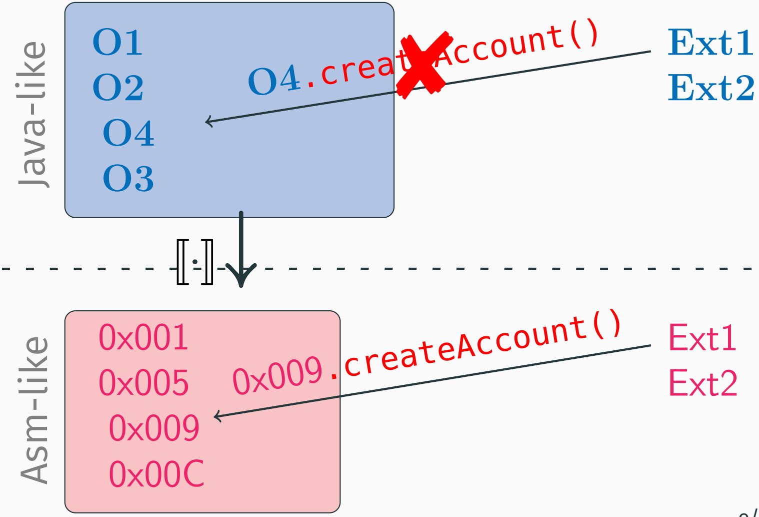
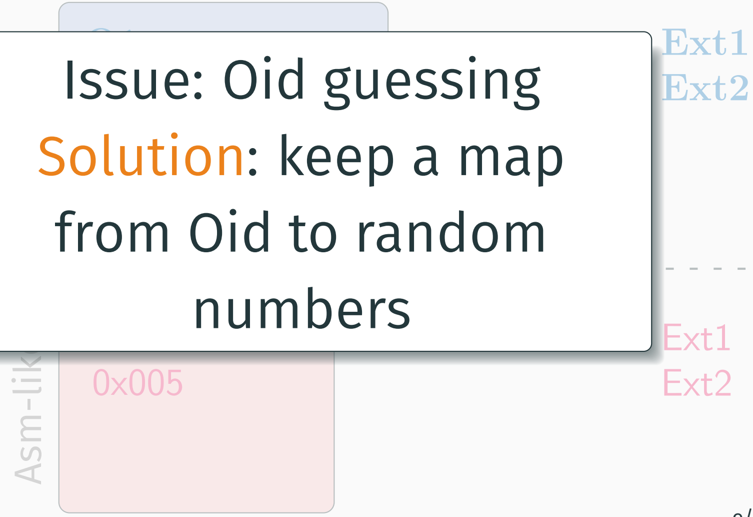


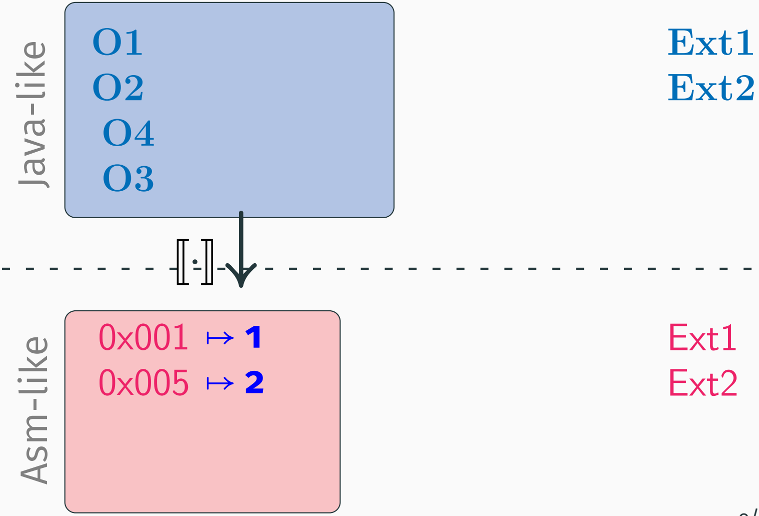
Memory Allocation Issues

Issue: Oid guessing

Solution: keep a map from Oid to random numbers



Memory Allocation Issues



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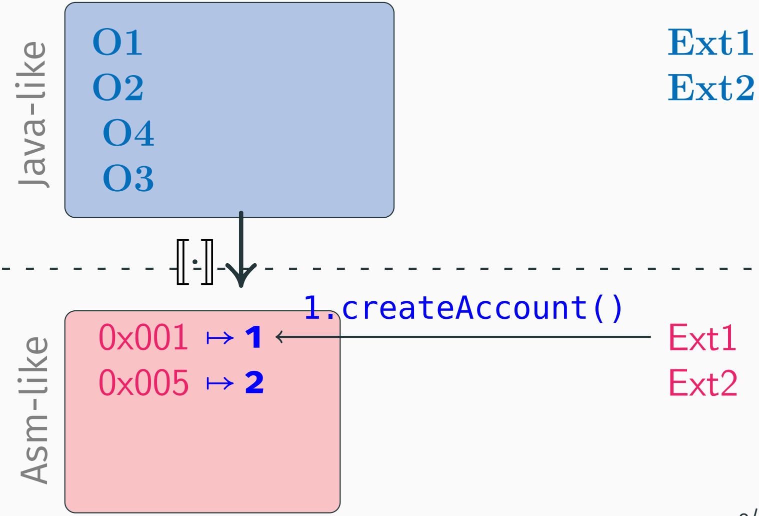

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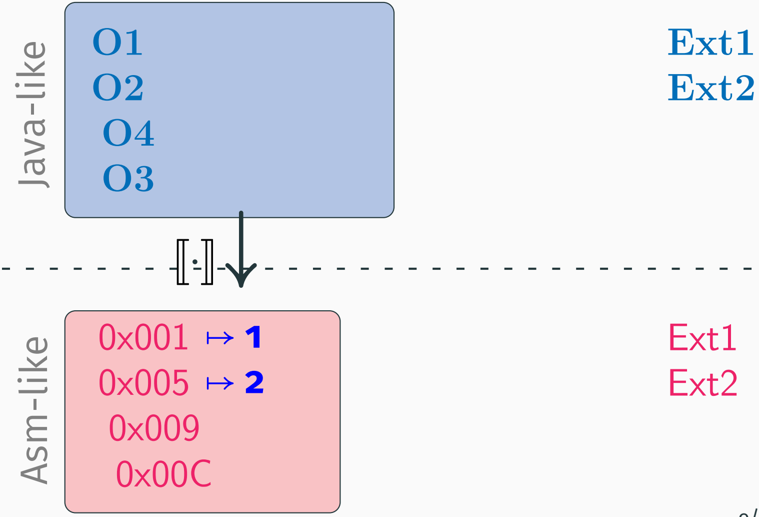


Java-like

O1
O2
O4
O3

Ext1
Ext2

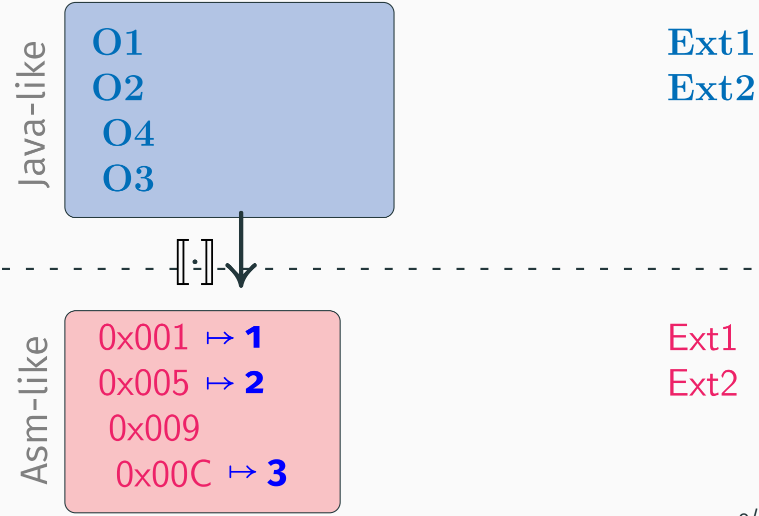
$[\![\cdot]\!]$

Asm-like

0x001 $\mapsto$ **1**
0x005 $\mapsto$ **2**
0x009
0x00C

Ext1
Ext2

Memory Allocation Issues



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$[\![\cdot]\!]$

Asm-like

0x001 $\mapsto$ **1**

0x005 $\mapsto$ **2**

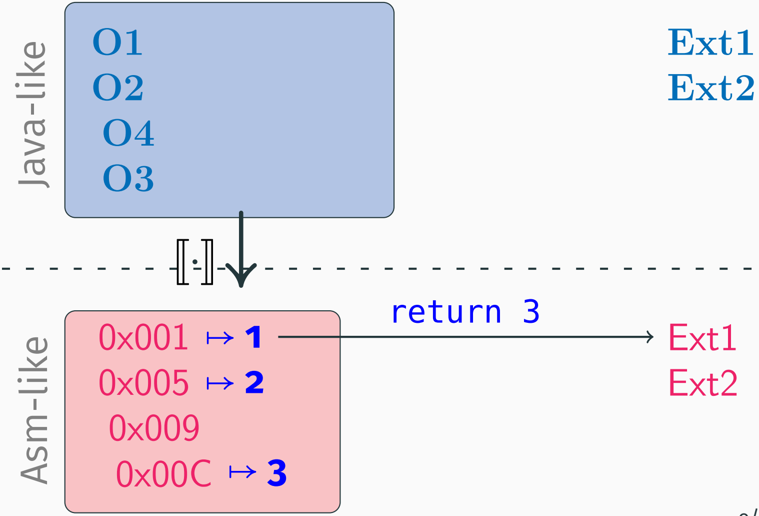
0x009

0x00C $\mapsto$ **3**

Ext1

Ext2

Memory Allocation Issues



Java-like

O1

O2

O4

O3

Ext1

Ext2

⟦·⟧

Asm-like

0x001 $\mapsto$ **1**

0x005 $\mapsto$ **2**

0x009

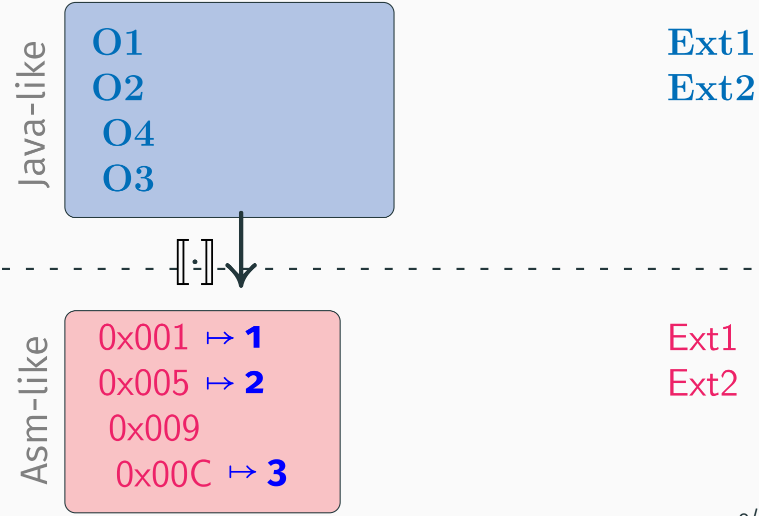
0x00C $\mapsto$ **3**

`return 3`

Ext1

Ext2

Memory Allocation Issues



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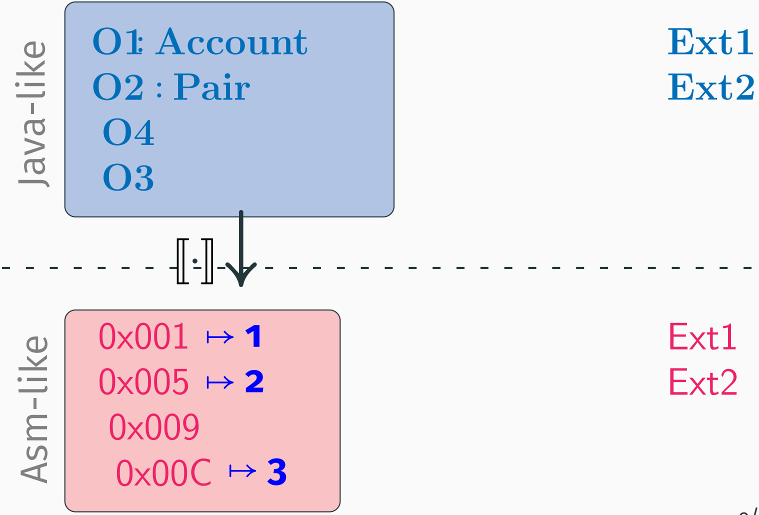
Ext1

Ext2

Memory Allocation Issues



Java-like

O1 : Account

O2 : Pair

O4

O3

Ext1

Ext2

$[\![\cdot]\!]$

Asm-like

0x001 ↦ **1**

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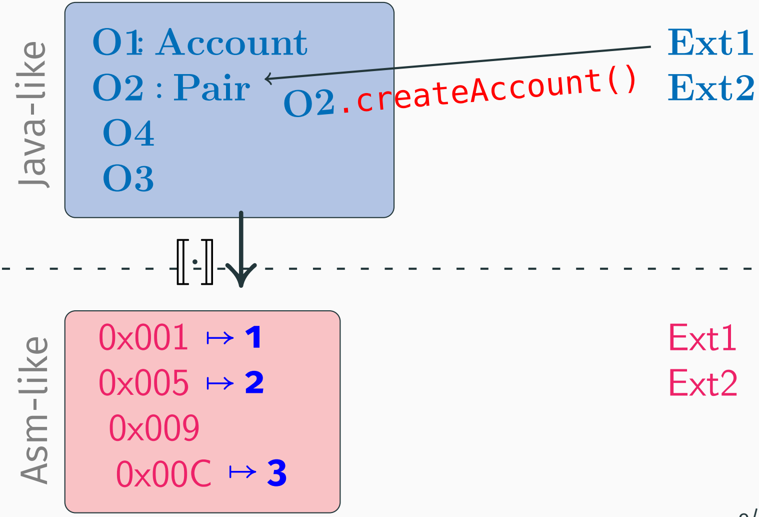
0x009

0x00C ↦ **3**

Ext1

Ext2

Memory Allocation Issues



Java-like

O1: Account

O2 : Pair

O4

O3

O2.`createAccount()`

Ext1

Ext2

$[\![\cdot]\!]$

Asm-like

0x001 $\mapsto$ **1**

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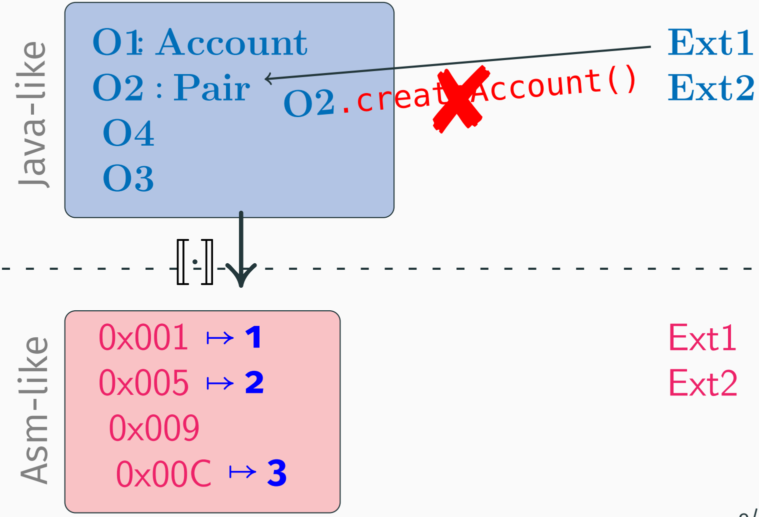
0x009

0x00C $\mapsto$ **3**

Ext1

Ext2

Memory Allocation Issues



Java-like

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O4

O3

O2.creat✘Account()

Ext1

Ext2

$\llbracket \cdot \rrbracket$

Asm-like

0x001 ↦ **1**

0x005 ↦ **2**

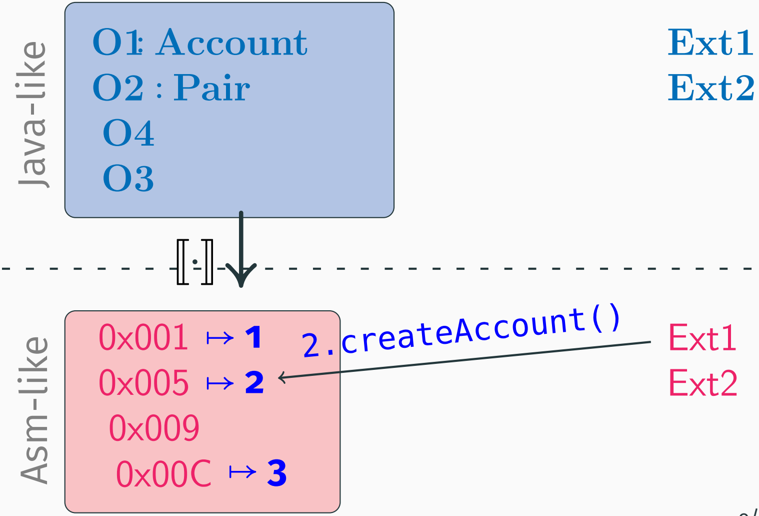
0x009

0x00C ↦ **3**

Ext1

Ext2

Memory Allocation Issues



Java-like

O1: Account

O2 : Pair

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O3

Ext1

Ext2

$[\![\cdot]\!]$

Asm-like

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0x009

0x00C $\mapsto$ **3**

2.createAccount()

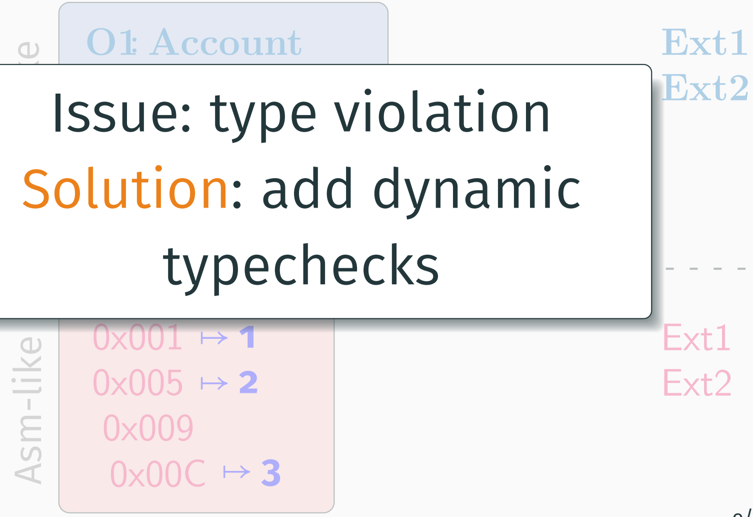
Ext1

Ext2

Memory Allocation Issues

Issue: type violation

Solution: add dynamic typechecks



O1: Account

Ext1

Ext2

Asm-like

0x001 ↦ 1

0x005 ↦ 2

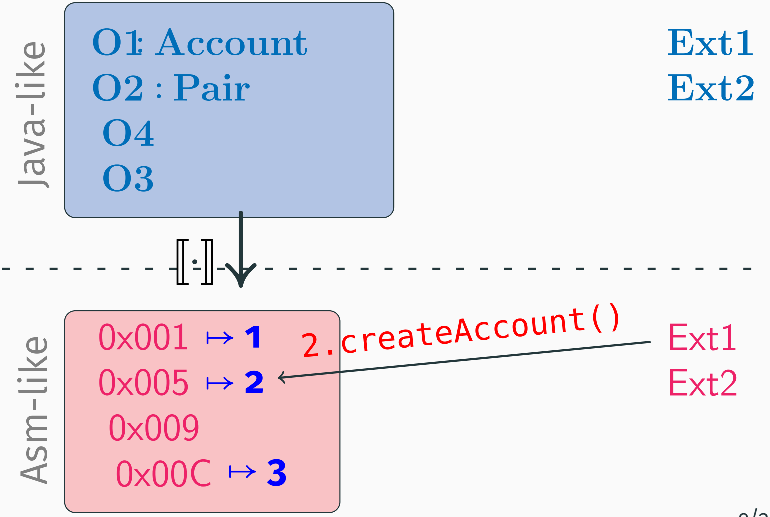
0x009

0x00C ↦ 3

Ext1

Ext2

Memory Allocation Issues



Java-like

O1: Account

O2 : Pair

O4

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Ext1

Ext2

$[\![\cdot]\!]$

Asm-like

0x001 $\mapsto$ **1**

0x005 $\mapsto$ **2**

0x009

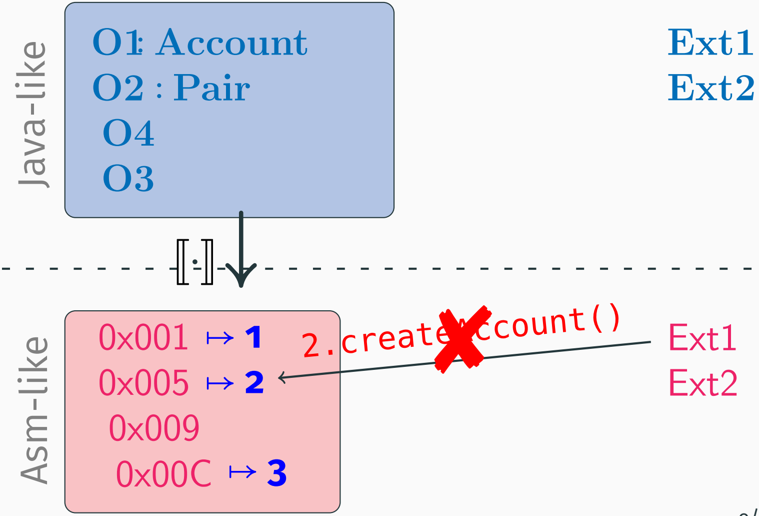
0x00C $\mapsto$ **3**

`2.createAccount()`

Ext1

Ext2

Memory Allocation Issues



Java-like

O1: Account

O2 : Pair

O4

O3

Ext1

Ext2

$⟦\cdot⟧$

Asm-like

0x001 ↦ **1**

0x005 ↦ **2**

0x009

0x00C ↦ **3**

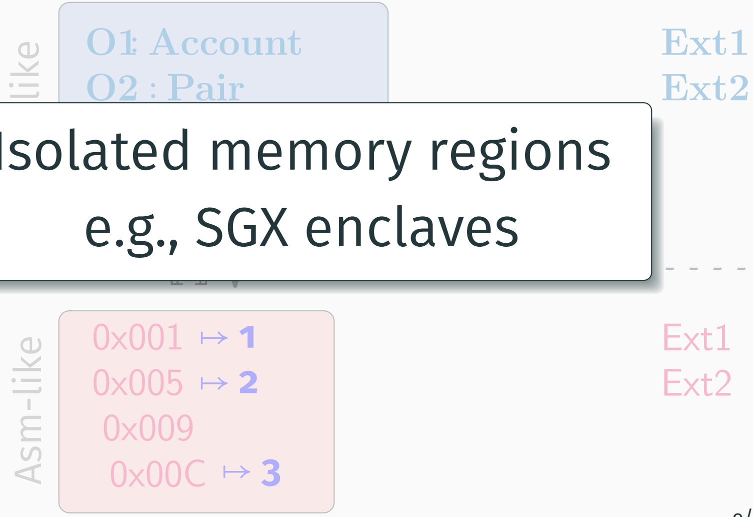
`2.createAccount()`

Ext1

Ext2

Memory Allocation Issues

Isolated memory regions
e.g., SGX enclaves



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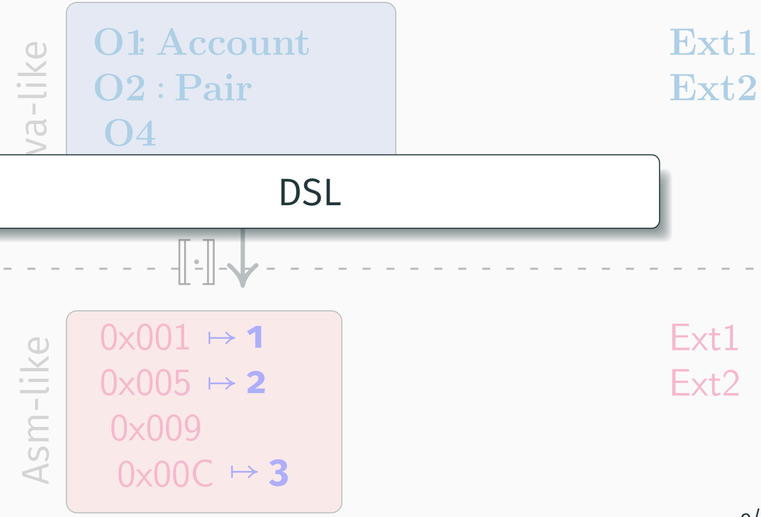


va-like

O1: Account

O2 : Pair

O4

Ext1

Ext2

DSL

$[\![\cdot]\!]$

Asm-like

0x001 ↦ **1**

0x005 ↦ **2**

0x009

0x00C ↦ **3**

Ext1

Ext2

Memory Allocation Issues

- design
- implement
- fund a startup in the Bay Area
-

Ext1
Ext2

Ext1
Ext2

Asm-

0x009
0x00C ↦ **3**

Concerns

1. Is this actually secure?

Concerns

1. Is this actually secure?
2. How efficient is this?

Concerns

1. Is this actually secure?
2. How efficient is this?

1. Yes!

Concerns

1. Is this actually secure?
2. How efficient is this?

1. Yes! So prove it!

Concerns

1. Is this actually secure?
2. How efficient is this?

1. Yes! So prove it!
2. Not bad, but we can aim for better.

Concerns

We need criteria for secure compilation, they:

- tell us what to prove about the compiler (e.g., compiler correctness, or type soundness criteria)

Concerns

1

2

1

2

We need criteria for secure compilation, they:

- tell us what to prove about the compiler (e.g., compiler correctness, or type soundness criteria)
- impact efficiency

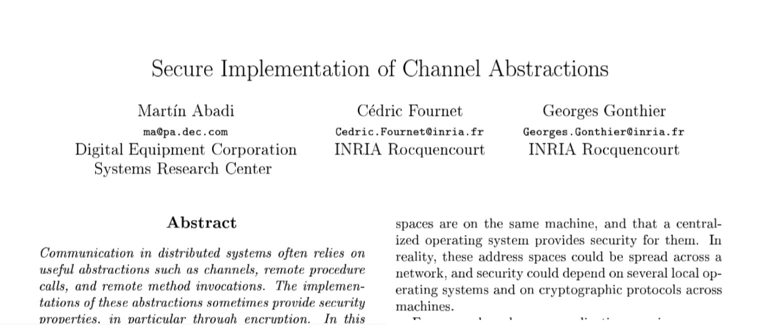
Concerns

We need criteria for secure compilation, they:

- tell us what to prove about the compiler (e.g., compiler correctness, or type soundness criteria)
- impact efficiency
- define security guarantees (what security properties they preserve)

Secure Compilation Criteria

The Origins of the Secure Compiler



Secure Implementation of Channel Abstractions

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Digital Equipment Corporation
Systems Research Center

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INRIA Rocquencourt

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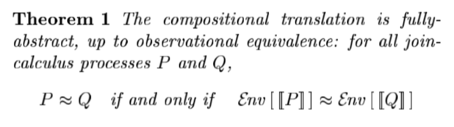
Abstract

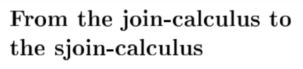
Communication in distributed systems often relies on useful abstractions such as channels, remote procedure calls, and remote method invocations. The implementations of these abstractions sometimes provide security properties, in particular through encryption. In this

spaces are on the same machine, and that a centralized operating system provides security for them. In reality, these address spaces could be spread across a network, and security could depend on several local operating systems and on cryptographic protocols across machines.



Theorem 1 *The compositional translation is fully-abstract, up to observational equivalence: for all join-calculus processes P and Q,*

$$P \approx Q \quad \textit{if and only if} \quad \mathcal{E}nv\,[\,[\![P]\!]\,] \approx \mathcal{E}nv\,[\,[\![Q]\!]\,]$$



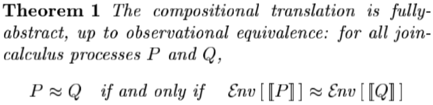
From the join-calculus to the sjoin-calculus

The Origins of the Secure Compiler

they needed a definition that their implementation of **secure channels** via cryptography was secure

The Origins of the Secure Compiler

Fully Abstract Compilation (FAC)



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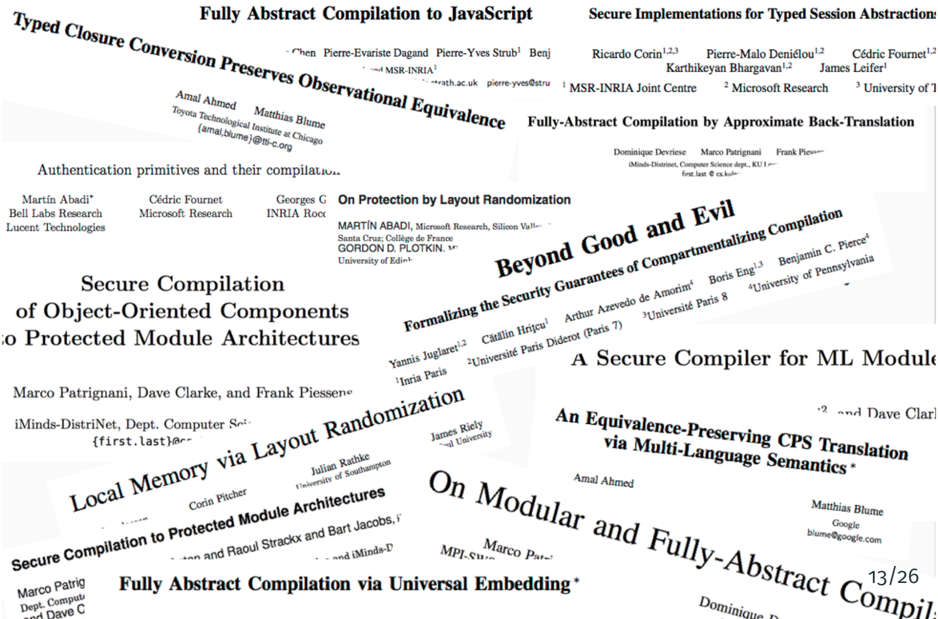
Fully Abstract Compilation Influence



Typed Closure Conversion Preserves Observational Equivalence

Amal Ahmed Matthias Blume
Toyota Technological Institute at Chicago
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Fully Abstract Compilation to JavaScript

Chen Pierre-Evariste Dagand Pierre-Yves Strub[1] Benj
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Secure Implementations for Typed Session Abstractions

Ricardo Corin[1,2,3] Pierre-Malo Deniélou[1,2] Cédric Fournet[1,2]
Karthikeyan Bhargavan[1,2] James Leifer[1]
[1] MSR-INRIA Joint Centre [2] Microsoft Research [3] University of T

Fully-Abstract Compilation by Approximate Back-Translation

Dominique Devriese Marco Patrignani Frank Piess
iMinds-Distrinet, Computer Science dept., KU L
first.last @ cs.kule

Authentication primitives and their compilation

Martín Abadi* Cédric Fournet Georges G
Bell Labs Research Microsoft Research INRIA Rocq
Lucent Technologies

On Protection by Layout Randomization

MARTÍN ABADI, Microsoft Research, Silicon Vall
Santa Cruz; Collège de France
GORDON D. PLOTKIN, M
University of Edin

Beyond Good and Evil

Formalizing the Security Guarantees of Compartmentalizing Compilation

Yannis Juglaret[1,2] Cătălin Hriţcu[1] Arthur Azevedo de Amorim[4] Boris Eng[1,3] Benjamin C. Pierce[4]
[1]Inria Paris [2]Université Paris Diderot (Paris 7) [3]Université Paris 8 [4]University of Pennsylvania

Secure Compilation
of Object-Oriented Components
to Protected Module Architectures

Marco Patrignani, Dave Clarke, and Frank Piessens
iMinds-DistriNet, Dept. Computer Sci
{first.last}@c

A Secure Compiler for ML Module

2 and Dave Clar

Local Memory via Layout Randomization

Corin Pitcher Julian Rathke James Riely
University of Southampton ul University

Secure Compilation to Protected Module Architectures

n and Raoul Strackx and Bart Jacobs,
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An Equivalence-Preserving CPS Translation via Multi-Language Semantics *

Amal Ahmed Matthias Blume
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On Modular and Fully-Abstract Compil

Marco Patr
MPI-SWS

Dominique D

Fully Abstract Compilation via Universal Embedding *

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Fully Abstract Compilation via Universal Embedding *

Dominique D

How

does Fully Abstract Compilation entail

security?

FAC and Security

FAC ensures that a target-level attacker has the same power of a source-level one

Compiler Full Abstraction

$$\begin{array}{ll} \mathbf{x} = \mathbf{1}; & \mathbf{x} = \mathbf{0}; \\ \mathbf{x}{+}{+}; & \mathbf{x}{+}{=}\ \mathbf{2}; \\ \mathbf{x} & \mathbf{x} \end{array}$$

Compiler Full Abstraction

$$\begin{array}{l} \mathbf{x} = \mathbf{1}; \\ \mathbf{x}\ ++; \\ \mathbf{x} \end{array} \quad = \quad \begin{array}{l} \mathbf{x} = \mathbf{0}; \\ \mathbf{x} += \mathbf{2}; \\ \mathbf{x} \end{array}$$

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$$\Updownarrow$$

$$\begin{array}{ll} \mathsf{loadi}\ \mathsf{r}_0\ 1 & \mathsf{loadi}\ \mathsf{r}_0\ 0 \\ \mathsf{inc}\ \mathsf{r}_0 & \mathsf{addi}\ \mathsf{r}_0\ 2 \\ \mathsf{ret}\ \mathsf{r}_0 & \mathsf{ret}\ \mathsf{r}_0 \end{array}$$

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Compiler Full Abstraction

$x = 1;$ $\qquad\qquad$ $x = 0;$

$x++;$ $\qquad = \qquad$ $x += 2;$

and have different powers!

inc r_0 $\qquad = \qquad$ addi r_0 2

ret r_0 $\qquad\qquad$ ret r_0

Why is FAC Secure?

- is an attacker linking or injecting target code

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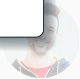
- the co-implied equalities reduce to 

- FAC protects against target attacks

Why is FAC Secure?

1. confidentiality
2. integrity
3. invariant definition
4. memory allocation
5. well-bracketed control flow

Survey by Patrignani *et al.*'19, based on Agten *et al.*'12, Abadi and Plotkin '10, Jagadeesan *et al.*'11, Patrignani *et al.*'15'16

Why is

confidentiality:

$$\mathbf{P1} = \mathbf{P2} \iff [\![\mathbf{P1}]\!] = [\![\mathbf{P2}]\!]$$

- $\mathbf{P1}$ and $\mathbf{P2}$ have different secrets
- but they are equivalent

1. c
2. i
3. i
4. r
5. w

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- but they are equivalent
- so the secret does not leak

Survey by Patrignani *et al.*'19, based on Agten *et al.*'12, Abadi and Plotkin '10, Jagadeesan *et al.*'11, Patrignani *et al.*'15'16

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Why is FAC Secure?

1. confidentiality
2. integrity
3. i
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- FAC preserves these properties

If the source has it.

Survey by Patrignani *et al.*’19, based on Agten *et al.*’12, Abadi and Plotkin ’10, Jagadeesan *et al.*’11, Patrignani *et al.*’15’16

Not All That Glitters is Gold

- No support for separate compilation

  [Patrignani *et al.*'16, Juglaret *et al.*'16]

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Not All That Glitters is Gold

- No support for separate compilation [Patrignani *et al.*'16, Juglaret *et al.*'16]
- No support for undefined behaviour [Juglaret *et al.*'16]
- Costly to enforce [Patrignani and Garg '19]
- Preserves hypersafety under certain conditions [Patrignani and Garg '17]

Alternatives

- FAC is not precise about security

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preserve classes of security (hyper)properties

Preserving Safety Patrignani and Garg ’19, Abate *et al.*’18

- we have a **source program** with a safety property

Preserving Safety Patrignani and Garg ’19, Abate *et al.*’18

- we have a **source program** with a safety property against any **source attacker**

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- we want its compiled counterpart to have the same safety property

Preserving Safety Patrignani and Garg ’19, Abate *et al.*’18

- we have a **source program** with a safety property against any **source attacker**
- safety = integrity / weak secrecy / correctness
- we want its compiled counterpart to have the same safety property against any target attacker

Preserving Safety Patrignani and Garg '19, Abate *et al.*'18

- property (π) = set of traces $\{t_1, t_2, \cdots\}$
- traces (t) = infinite sequences of observables
- prefixes (m) = finite sequences of observables
- $P \rightsquigarrow t$ = program P generates trace t

Preserving Safety Patrignani and Garg '19, Abate *et al.*'18

$$
\begin{aligned}
RSC: \quad & \forall \pi, \pi \in \mathit{Safety}.\ \pi \approx \pi.\ \forall \mathbf{P}. \\
& (\forall \mathbb{C}_{\mathbf{S}}, \mathbf{t}.\ \mathbb{C}_{\mathbf{S}}\left[\mathbf{P}\right] \rightsquigarrow \mathbf{t} \Rightarrow \mathbf{t} \in \pi) \\
& \ \Rightarrow (\forall \mathbb{C}_{\mathsf{T}}, \mathsf{t}.\ \mathbb{C}_{\mathsf{T}}\left[[\![\mathbf{P}]\!]\right] \rightsquigarrow \mathsf{t} \Rightarrow \mathsf{t} \in \pi)
\end{aligned}
$$

Preserving Safety Patrignani and Garg '19, Abate *et al.*'18

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\mathit{PF}\text{-}\mathit{RSC}: \quad & \forall \mathbf{P}.\ \forall \mathbb{C}_{\mathsf{T}}.\ \forall \mathbf{m}, \mathsf{m}.\ \mathbf{m} \approx \mathsf{m}. \\
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Preserving Safety Patrignani and Garg '19, Abate *et al.*'18

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$$\Updownarrow$$

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Not All That Glitters is Gold #2

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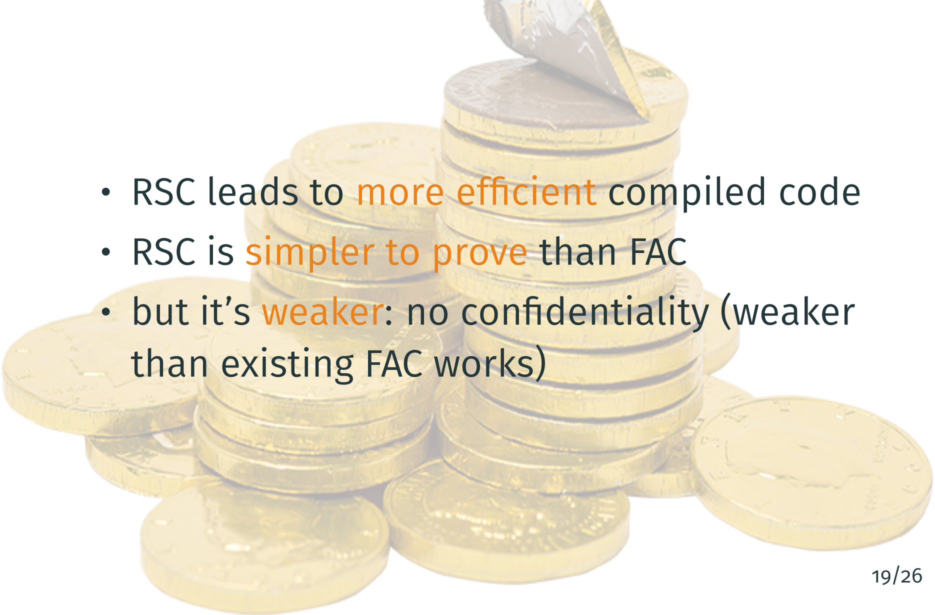
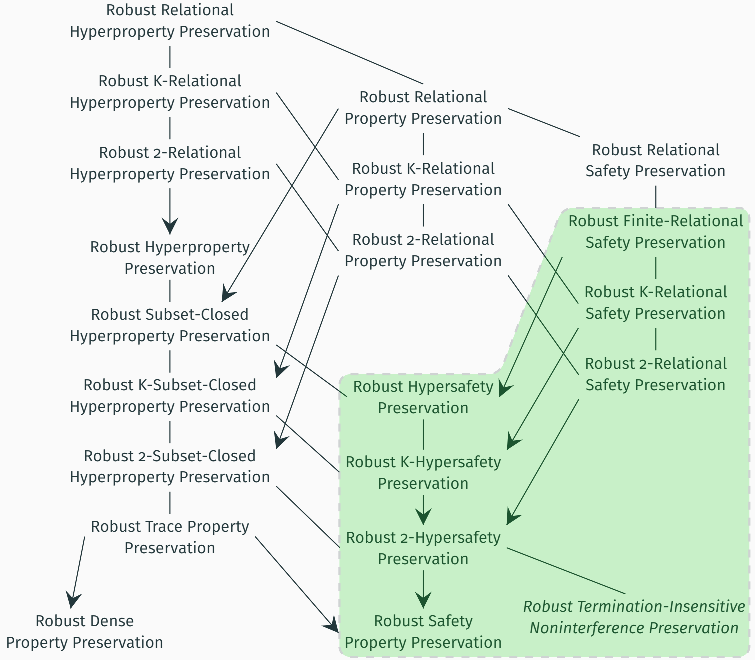
Not All That Glitters is Gold #2



- RSC leads to more efficient compiled code
- RSC is simpler to prove than FAC
- but it’s weaker: no confidentiality (weaker than existing FAC works)


Robust Relational Hyperproperty Preservation
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Robust 2-Relational Hyperproperty Preservation
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Robust 2-Subset-Closed Hyperproperty Preservation
Robust Trace Property Preservation
Robust Dense Property Preservation
Robust Relational Property Preservation
Robust K-Relational Property Preservation
Robust 2-Relational Property Preservation
Robust Relational Safety Preservation
Robust Finite-Relational Safety Preservation
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Robust K-Hypersafety Preservation
Robust 2-Hypersafety Preservation
Robust Safety Property Preservation
Robust Termination-Insensitive Noninterference Preservation

Abate *et al.*'19

Proof Techniques for Secure Compilation

Proving FAC

$$\mathbf{P1} \;\simeq_{ctx}\; \mathbf{P2}$$

$$\Updownarrow$$

$$[\![\mathbf{P1}]\!] \simeq_{ctx} [\![\mathbf{P2}]\!]$$

Proving FAC

$$\mathbf{P1} \quad \simeq_{ctx} \quad \mathbf{P2}$$

$$\Uparrow$$

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Proving FAC

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$$\Downarrow$$

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Proving FAC

$$\mathbf{P1} \ \simeq_{ctx} \ \mathbf{P2}$$

$$\Downarrow$$

$$\forall \mathbb{C}. \mathbb{C}[\llbracket \mathbf{P1} \rrbracket] \Downarrow \iff \mathbb{C}[\llbracket \mathbf{P2} \rrbracket] \Downarrow$$

Proving FAC (History)

$$\mathbf{P1} \;\simeq_{ctx}\; \mathbf{P2}$$

$$\Downarrow$$

$$[\![\mathbf{P1}]\!] \;\overset{\top}{=}\; [\![\mathbf{P2}]\!]$$

Proving FAC (History)

$$\mathbf{P1} \simeq_{ctx} \mathbf{P2}$$

Jagadeesan *et al.*’11,
Agten *et al.*’12,
Patrignani *et al.*’15’16,
Juglaret *et al.*’16

$$\llbracket \mathbf{P1} \rrbracket \simeq \llbracket \mathbf{P2} \rrbracket$$

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$$\mathbf{P1} \quad \simeq_{ctx} \quad \mathbf{P2}$$

$$\Downarrow$$

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Abadi *et al.*'00'01'02'

Bugliesi *et al.*'07

Adao *et al.*'06

Fournet *et al.*'13

$$[\![\mathbf{P1}]\!] \approx [\![\mathbf{P2}]\!]$$

Proving FAC (History)

$$\mathbf{P1} \simeq_{ctx} \mathbf{P2}$$

$$\Downarrow$$

$$[\![\mathbf{P1}]\!] \sim_{\mathsf{n}} [\![\mathbf{P2}]\!]$$

Proving FAC (History)

$$\mathbf{P1} \quad \simeq_{ctx} \quad \mathbf{P2}$$

Ahmed *et al.*'8'11'14'15'16'17,
Devriese *et al.*'16'17

$$[\![\mathbf{P1}]\!] \quad \sim_{\mathsf{n}} \quad [\![\mathbf{P2}]\!]$$

Proving FAC with Logical Relations

$$\begin{tikzcd}
\mathbf{P1} \simeq_{ctx} \mathbf{P2} \arrow[d, Rightarrow, "\text{approx. compiler security}"] \\
[\![\mathbf{P1}]\!] \overset{?}{\simeq}_{ctx} [\![\mathbf{P2}]\!]
\end{tikzcd}$$

Proving FAC with Logical Relations

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approx. compiler security

$$\mathbb{C}\Big[\llbracket\mathbf{P1}\rrbracket\Big]\Downarrow_{\mathsf{n}} \quad \overset{?}{\Rightarrow} \quad \mathbb{C}\Big[\llbracket\mathbf{P2}\rrbracket\Big]\Downarrow_{\_}$$

$$\llbracket\mathbf{P1}\rrbracket \overset{?}{\simeq}_{ctx} \llbracket\mathbf{P2}\rrbracket$$

Proving FAC with Logical Relations

$$\mathbf{P1} \simeq_{ctx} \mathbf{P2}$$

$\langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathbf{n}} \sim_n \mathbb{C}$

$\mathbf{P1} \sim_{\_} [\![\mathbf{P1}]\!]$

$\Uparrow$ (1)

$$\mathbb{C}\left[[\![\mathbf{P1}]\!] \right]\Downarrow_{\mathsf{n}} \overset{?}{\Rightarrow} \mathbb{C}\left[[\![\mathbf{P2}]\!] \right]\Downarrow_{\_}$$

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$\Downarrow$ approx. compiler security

Proving FAC with Logical Relations

$$\mathbf{P1} \simeq_{ctx} \mathbf{P2}$$

$$\langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathbf{n}}\left[\mathbf{P1}\right] \Downarrow_{\_}$$

$$\langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathbf{n}} \sim_{n} \mathbb{C}$$

$$\mathbf{P1} \sim_{\_} [\![\mathbf{P1}]\!]$$

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 & \langle\langle\mathbb{C}\rangle\rangle_{\mathbf{n}}\left[\mathbf{P1}\right]\Downarrow_{\_} \arrow[r, Rightarrow, "(2)"'] & \langle\langle\mathbb{C}\rangle\rangle_{\mathbf{n}}\left[\mathbf{P2}\right]\Downarrow_{\_} & {} \arrow[dd, Rightarrow, "\text{approx. compiler security}"] \\
 \begin{array}{l} \langle\langle\mathbb{C}\rangle\rangle_{\mathbf{n}} \sim_{n} \mathbb{C} \\ \mathbf{P1} \sim_{\_} \llbracket\mathbf{P1}\rrbracket \end{array} & & & \\
 & \mathbb{C}\left[\llbracket\mathbf{P1}\rrbracket\right]\Downarrow_{\mathsf{n}} \arrow[uu, Rightarrow, "(1)"'] \arrow[r, Rightarrow, "?"] & \mathbb{C}\left[\llbracket\mathbf{P2}\rrbracket\right]\Downarrow_{\_} & {} \\
 & \llbracket\mathbf{P1}\rrbracket \overset{?}{\simeq}_{ctx} \llbracket\mathbf{P2}\rrbracket & &
\end{tikzcd}$$

Proving FAC with Logical Relations

$$\begin{tikzcd}
\mathbf{P1} \simeq_{ctx} \mathbf{P2} & & {} \arrow[ddd, Rightarrow, "\text{approx. compiler security}"] \\
\langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathbf{n}}[\mathbf{P1}]\Downarrow_{\_} \arrow[r, Rightarrow, "(2)"'] & \langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathbf{n}}[\mathbf{P2}]\Downarrow_{\_} \arrow[d, Rightarrow, bend left, "(3)"'] & \\
\mathbb{C}\left[[\![\mathbf{P1}]\!]\right]\Downarrow_{\mathsf{n}} \arrow[u, Rightarrow, bend left, "(1)"] \arrow[r, Rightarrow, "?"] & \mathbb{C}\left[[\![\mathbf{P2}]\!]\right]\Downarrow_{\_} & \\
[\![\mathbf{P1}]\!] \overset{?}{\simeq}_{ctx} [\![\mathbf{P2}]\!] & & {}
\end{tikzcd}$$

$$\langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathbf{n}} \sim_n \mathbb{C}$$
$$\mathbf{P1} \sim_{\_} [\![\mathbf{P1}]\!]$$

$$\langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathbf{n}} \sim_{\_} \mathbb{C}$$
$$\mathbf{P2} \sim_{\_} [\![\mathbf{P2}]\!]$$

Proving FAC with Logical Relations

$\mathbf{P1} \simeq_{ctx} \mathbf{P2}$

$\langle\!\langle \mathbb{C} \rangle\!\rangle \; [\![\mathbf{P1}]\!]\Downarrow$ $\quad\langle\!\langle \mathbb{C} \rangle\!\rangle \; [\![\mathbf{P2}]\!]\Downarrow\_$

$\mathbf{P1} \sim [\![\mathbf{P1}]\!]$ is obtained with standard techniques

Benton *et al.*’09’10

Hur *et al.*’11

Neis *et al.*’15

$\langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathbf{n}} \sim_n$ $\quad\sim\_ \; \mathbb{C}$

$\mathbf{P1} \sim\_ \; [\![\mathbf{P}$ $\quad[\![\mathbf{P2}]\!]$

$\mathbb{C}\left[[\![\mathbf{P1}]\!] \right] \Downarrow_{\mathsf{n}} \quad \overset{?}{\Rightarrow} \quad \mathbb{C}\left[[\![\mathbf{P2}]\!] \right] \Downarrow\_$

$[\![\mathbf{P1}]\!] \overset{?}{\simeq}_{ctx} [\![\mathbf{P2}]\!]$

approx. compiler security

Proving FAC with Logical Relations

$\langle\langle \mathbb{C} \rangle\rangle_{\mathbf{n}} \sim \mathbb{C}$ requires

- back-translation of terms
- reasoning at the type of back-translated terms

$$[\![\mathbf{P1}]\!] \overset{?}{\simeq}_{ctx} [\![\mathbf{P2}]\!]$$

approx. compiler security

Proving FAC with Logical Relations

$\langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathbf{n}} \sim \mathbb{C}$ requires

- back-translation of terms
- reasoning at the type of back-translated terms
- needed for all kinds of back-translation

$$[\![\mathbf{P1}]\!] \overset{?}{\simeq}_{ctx} [\![\mathbf{P2}]\!]$$

approx. compiler security

Proving FAC with Logical Relations

$\langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathbf{n}} \sim \mathbb{C}$ requires

- back-translation of terms
- reasoning at the type of back-translated terms
- needed for all kinds of back-translation
- needed for RSC too

$[\![\mathbf{P1}]\!] \overset{?}{\simeq}_{ctx} [\![\mathbf{P2}]\!]$

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$[\![\mathbf{P1}]\!] \overset{?}{\simeq}_{ctx} [\![\mathbf{P2}]\!]$

approx. compiler security

Proving FAC with Logical Relations

$$\mathbf{P1} \simeq_{ctx} \mathbf{P2}$$

$$\langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathrm{n}}[\mathbf{P1}]\Downarrow\_ \quad \overset{(?)}{\Rightarrow} \quad \langle\!\langle \mathbb{C} \rangle\!\rangle_{\mathrm{n}}[\mathbf{P2}]\Downarrow\_$$

COURSE

coming up next semester

(and next year)

$$\mathbb{C}\Big[[\![\mathbf{P1}]\!]\Big]\Downarrow_{\mathrm{n}} \quad \overset{?}{\Rightarrow} \quad \mathbb{C}\Big[[\![\mathbf{P2}]\!]\Big]\Downarrow\_$$

$$[\![\mathbf{P1}]\!] \overset{?}{\simeq}_{ctx} [\![\mathbf{P2}]\!]$$

approx. compiler security

Conclusion

- motivations for secure compilation

Conclusion

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- secure compilation criterion: fully abstract compilation

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- secure compilation criterion: fully abstract compilation
- secure compilation criterion: robustly-safe compilation

Conclusion

- motivations for secure compilation
- secure compilation criterion: fully abstract compilation
- secure compilation criterion: robustly-safe compilation
- proof techniques for secure compilation

Research Field Prospect

- secure compilation workshop: PrISC 3rd ed. (co-located with POPL) https://popl19.sigplan.org/track/prisc-2019
- secure compilation classes: Winter quarter ’18-19, Spring quarter ’19-20 (?)
- introductory survey: *Patrignani, Ahmed, Clarke. ACM CSUR ’19*
- lots of challenging open problems to work on (talk to me!)

Questions?