Secure Compilation to Protected Module Architectures

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25 January 2016

Goal of the Talk

- present my research on secure compilation

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- define secure (fully-abstract) compilation

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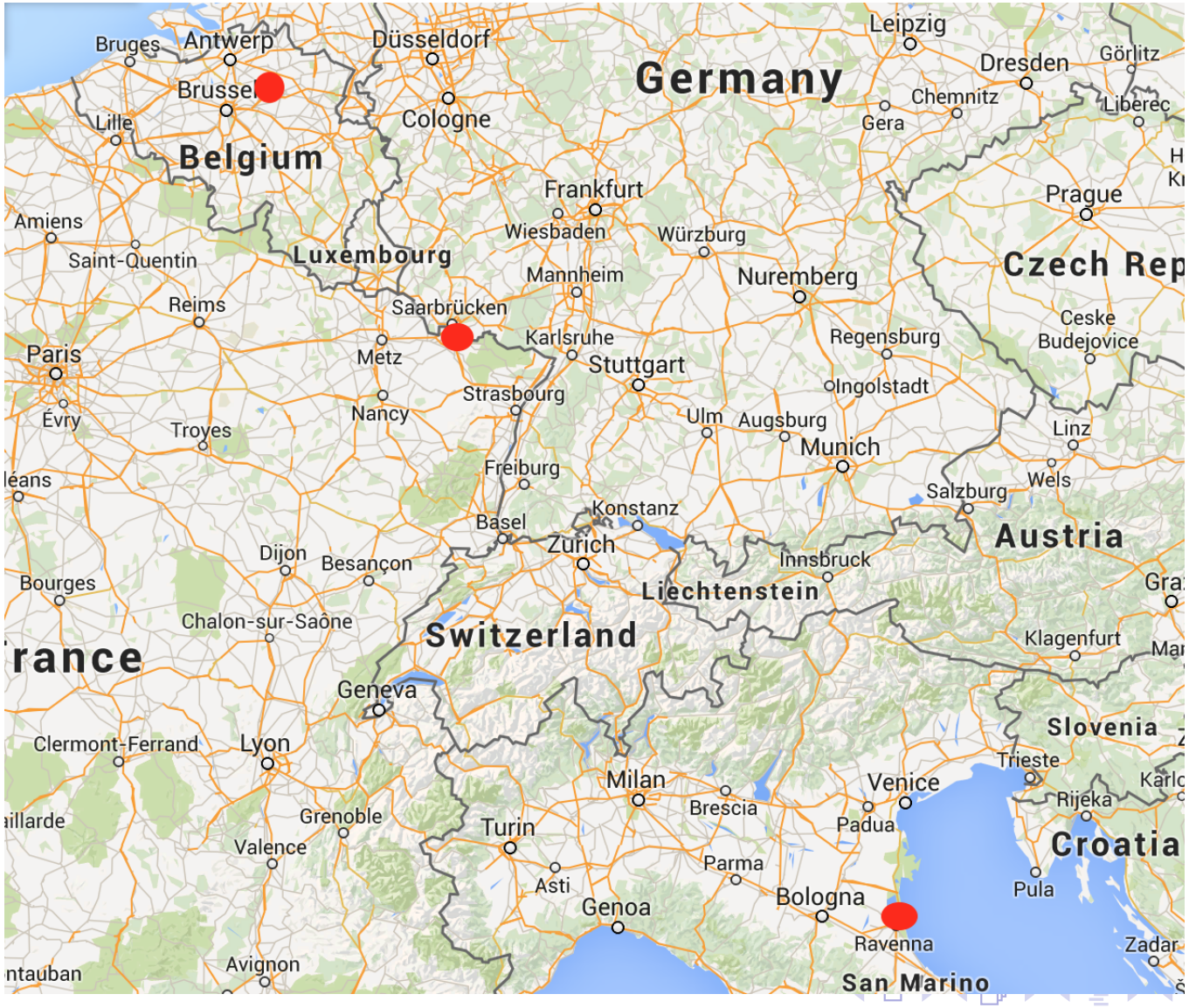
- present my research on secure compilation
- define secure (fully-abstract) compilation
- discuss present and future work

Me


Bruges
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Nancy
Ulm
Augsburg
Linz
Troyes
Munich
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Salzburg
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Besançon
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Outline

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- a security property is one expressible via program equivalence (e.g. confidentiality, integrity, etc.)

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- a fully abstract compiler is a secure compiler

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Fully abstract compilation preserves source-level abstractions in target-level languages

- protect against code injection attacks
- enables source-level reasoning

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- Intel wants to port it to future processors (SGX)

A+I: Untyped Assembly + PMA

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0x0001    call 0xb53
0x0002    movs r0 0x0b55
⋮
0x0b52    movs r0 0x0b55
0x0b53    call 0x0002
0x0b54    movs r0 0x0001
0x0b55    ...
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0xab00    jmp 0xb53
0xab01    ...
```

- memory space

A+I: Untyped Assembly + PMA

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r/w

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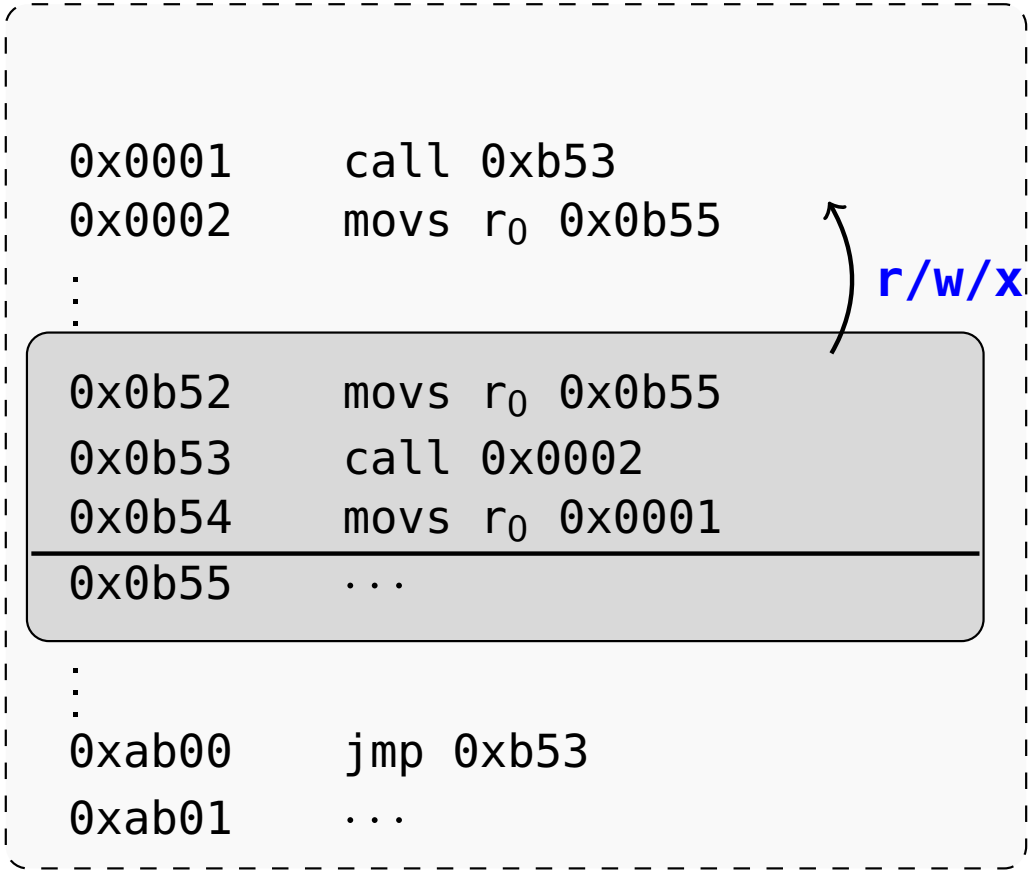

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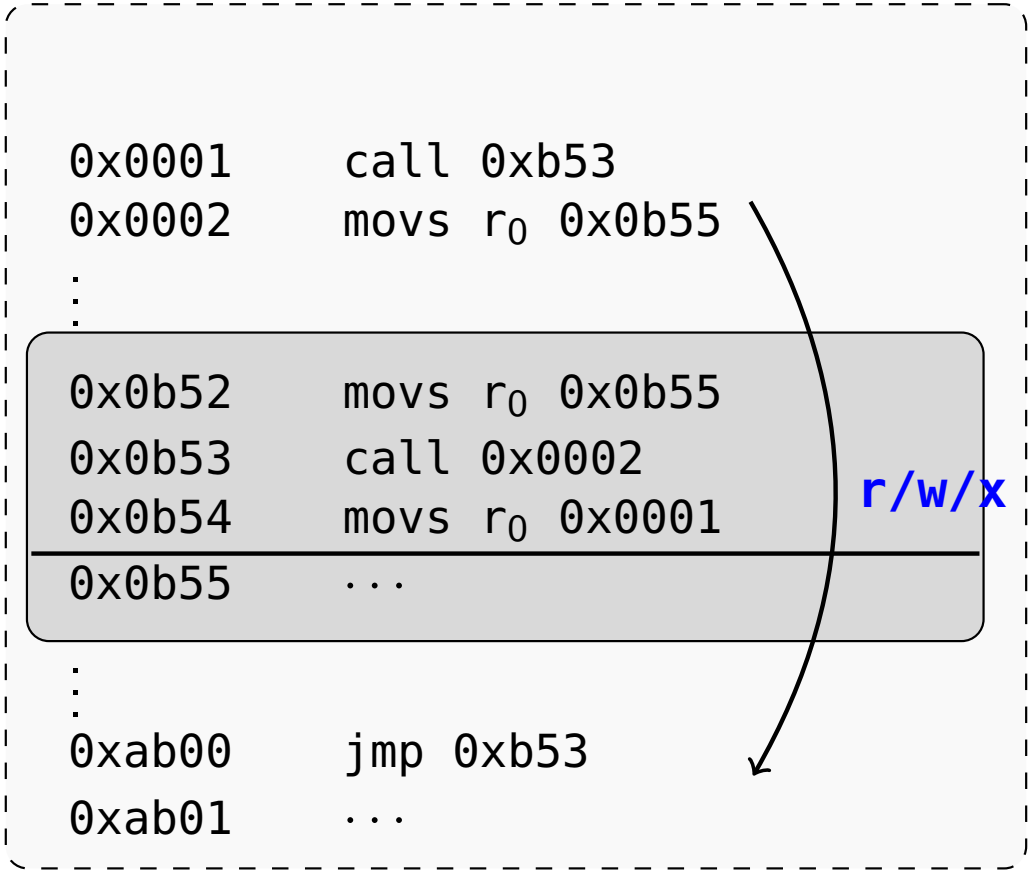

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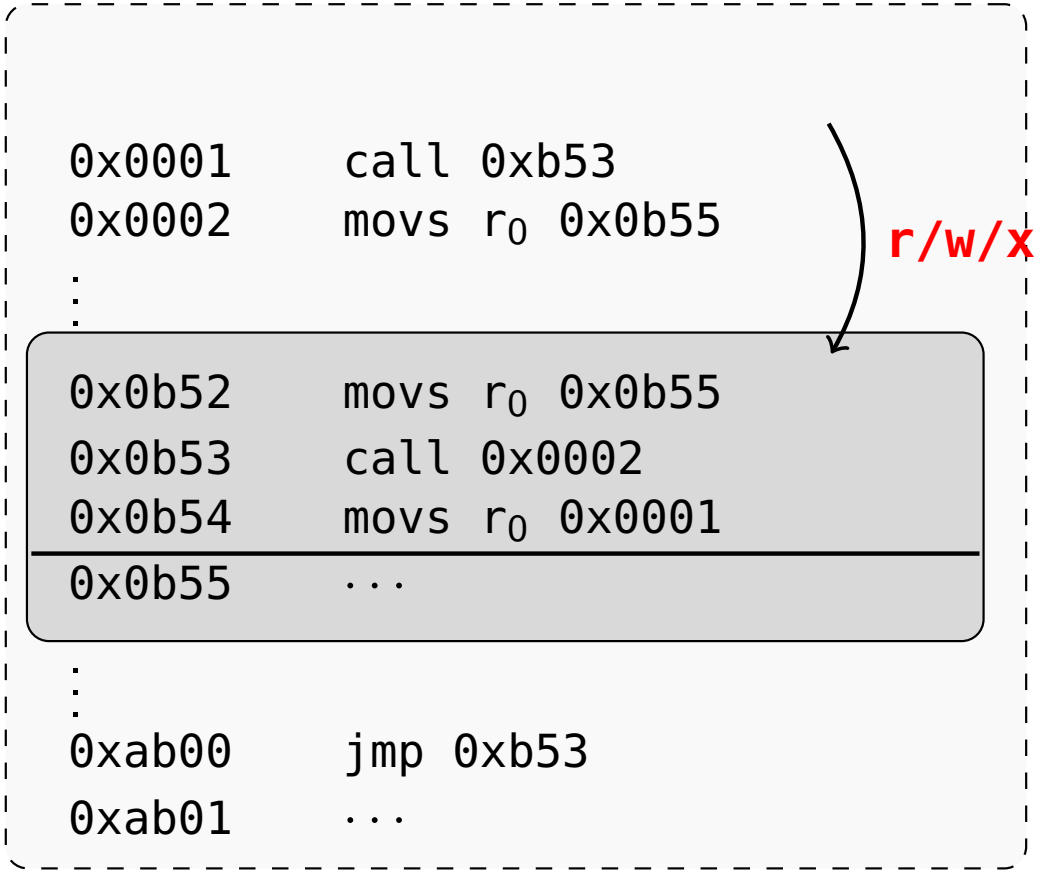

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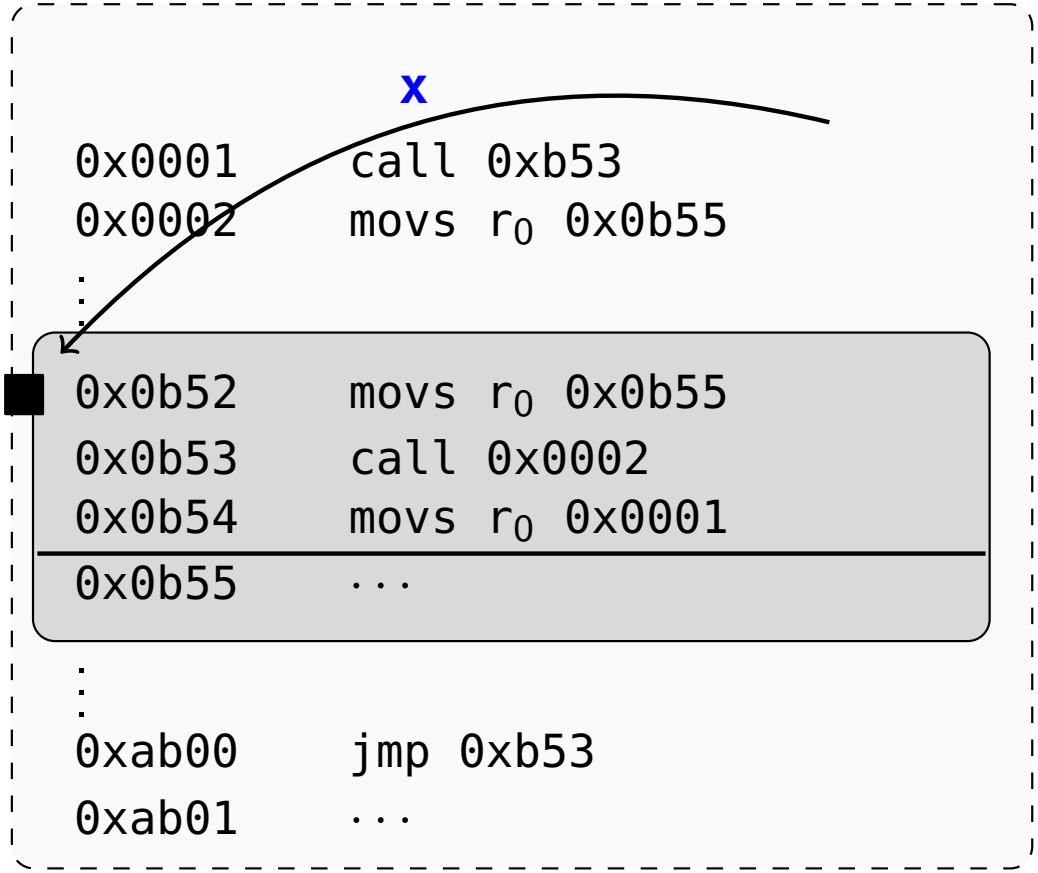

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Trace Semantics for PMA

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  `call in, ret 1`
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- behaviour in this case is: `call in`, `ret 1` or `call in`, `call out`
- traces rely only on the PMA code
- they describe what can be observed from the outside of protected PMA code

Outline

J+E: Java-like Language

- source language: +/- Java jr

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  - component-based
  - private fields
  - programming to an interface
  - exceptions

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2    interface Account {
3      public createAccount() : Foo;
4    }
5    extern extAccount : Account;
6
7  package PE;
8    class AccountClass
9      implements PI.Account {
10     AccountClass() { counter = 0; }
11     public createAccount() : Account {
12       return new PE.AccountClass();
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15     private counter : Int;
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J+E: Java-like Language

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Q: How to securely compile this code?

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J+E: Java-like Language

Dynamic dispatch

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v-tables

Secure stack

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J+E: Java-like Language

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J+E: Java-like Language

- proxy to `createAccount`

  `createAccount` body

  constructor

Dynamic dispatch

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v-tables

Secure stack

  extAccount
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PMA for Secure Compilation

Source level

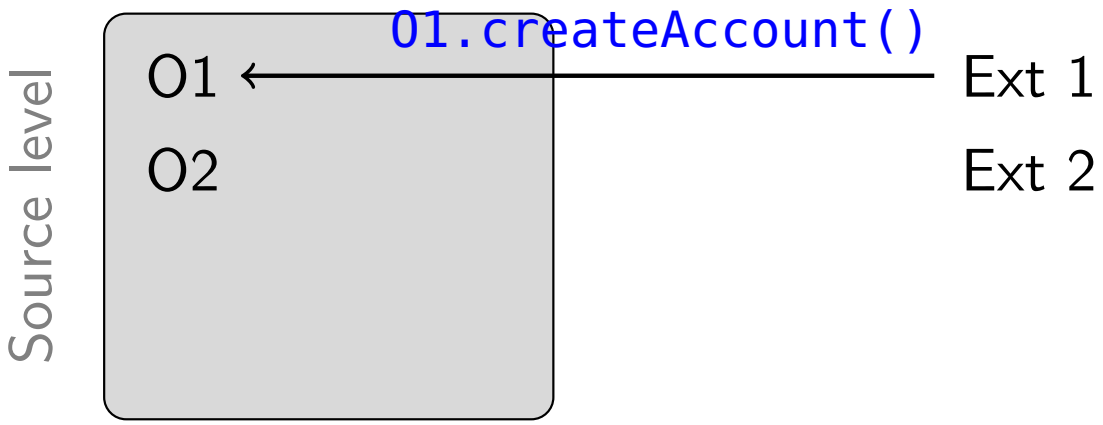
O1

O2

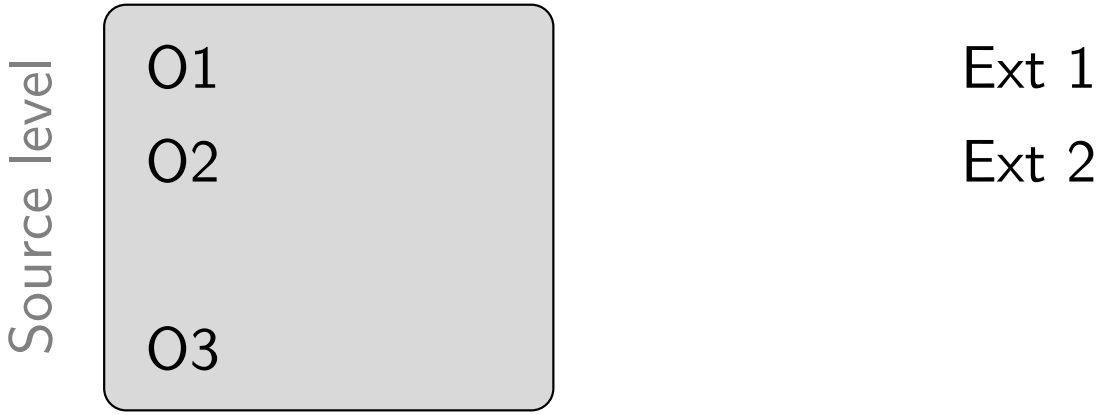
Ext 1

Ext 2

PMA for Secure Compilation



PMA for Secure Compilation



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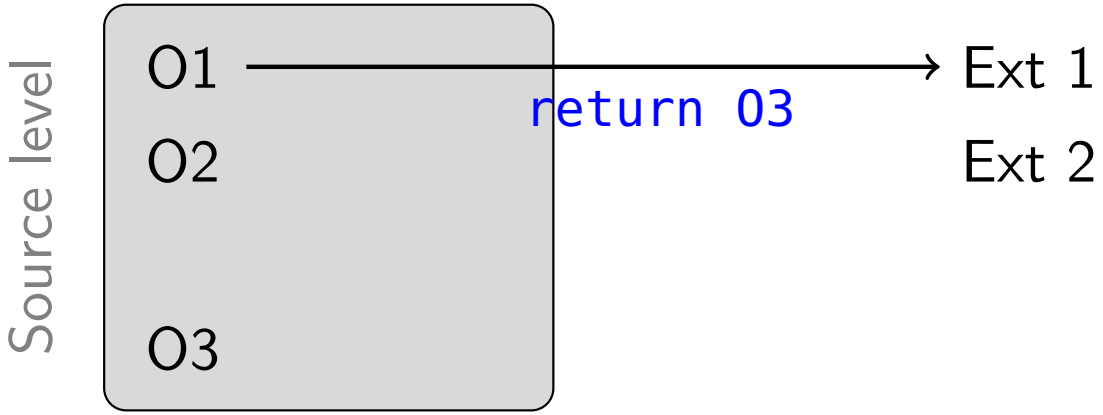

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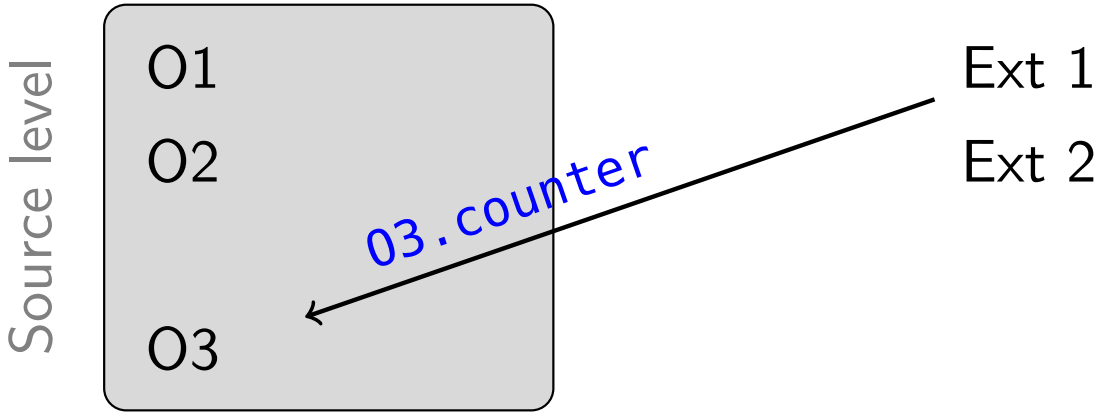

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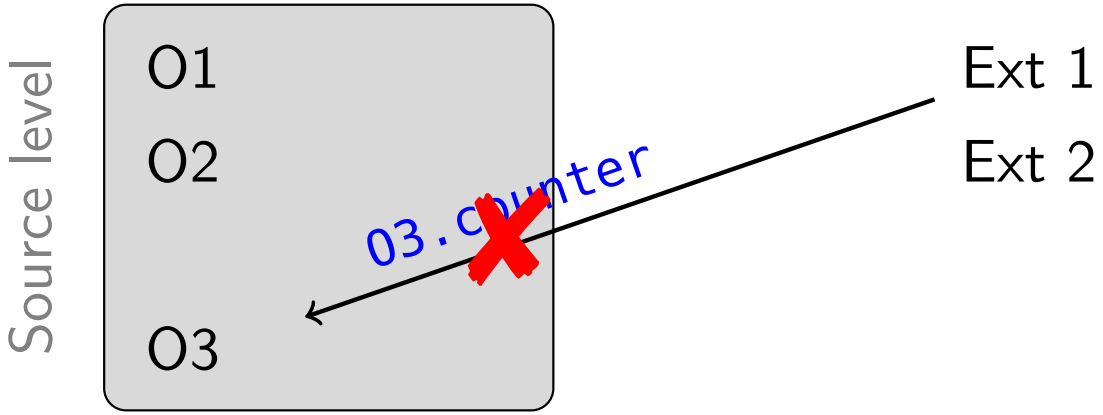

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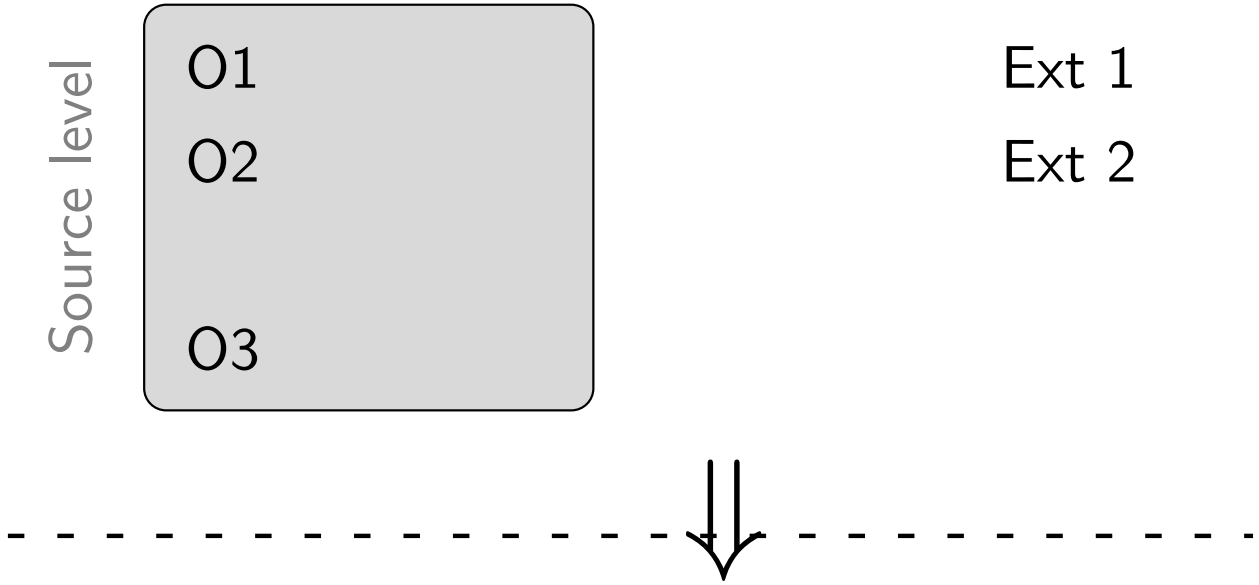

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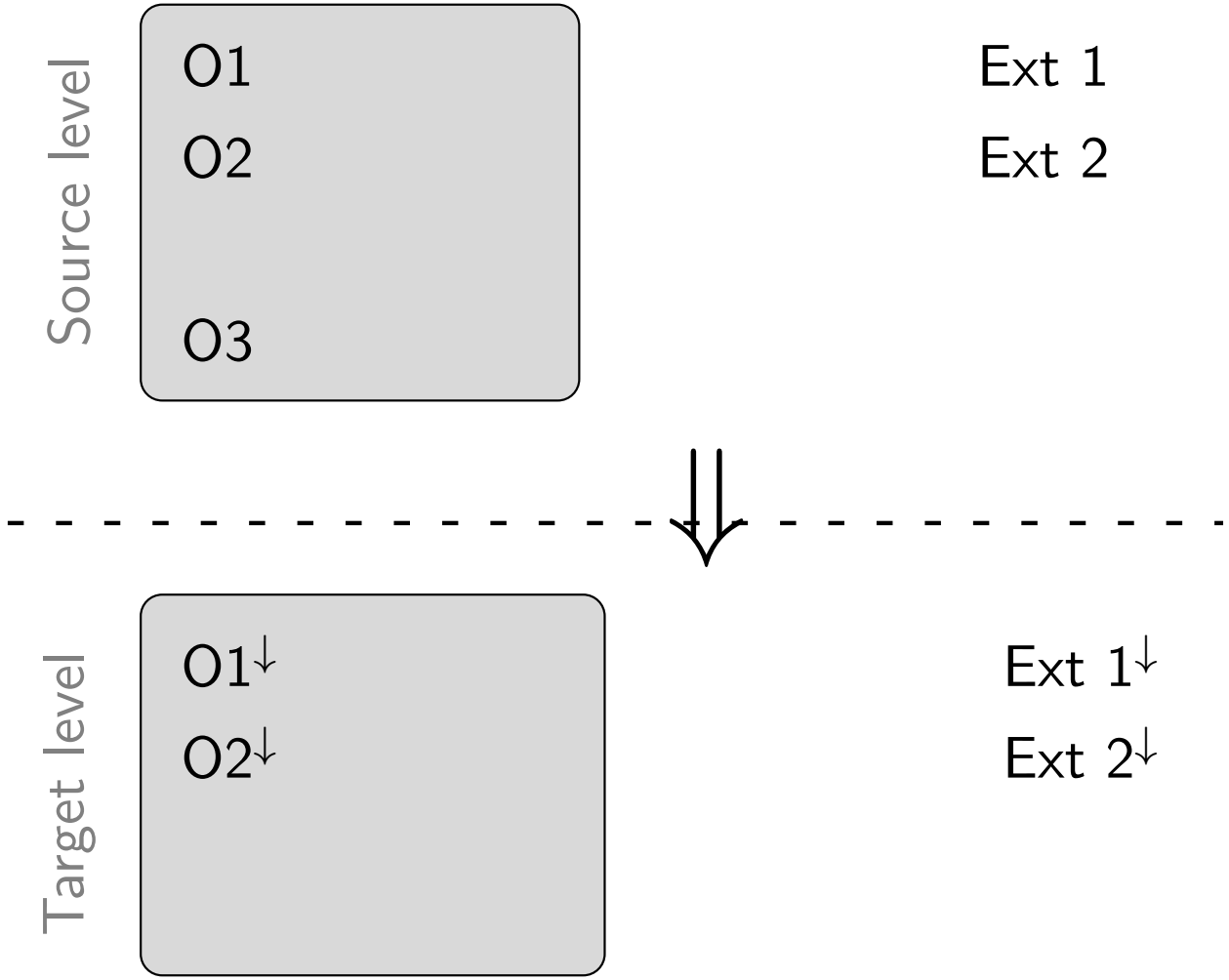

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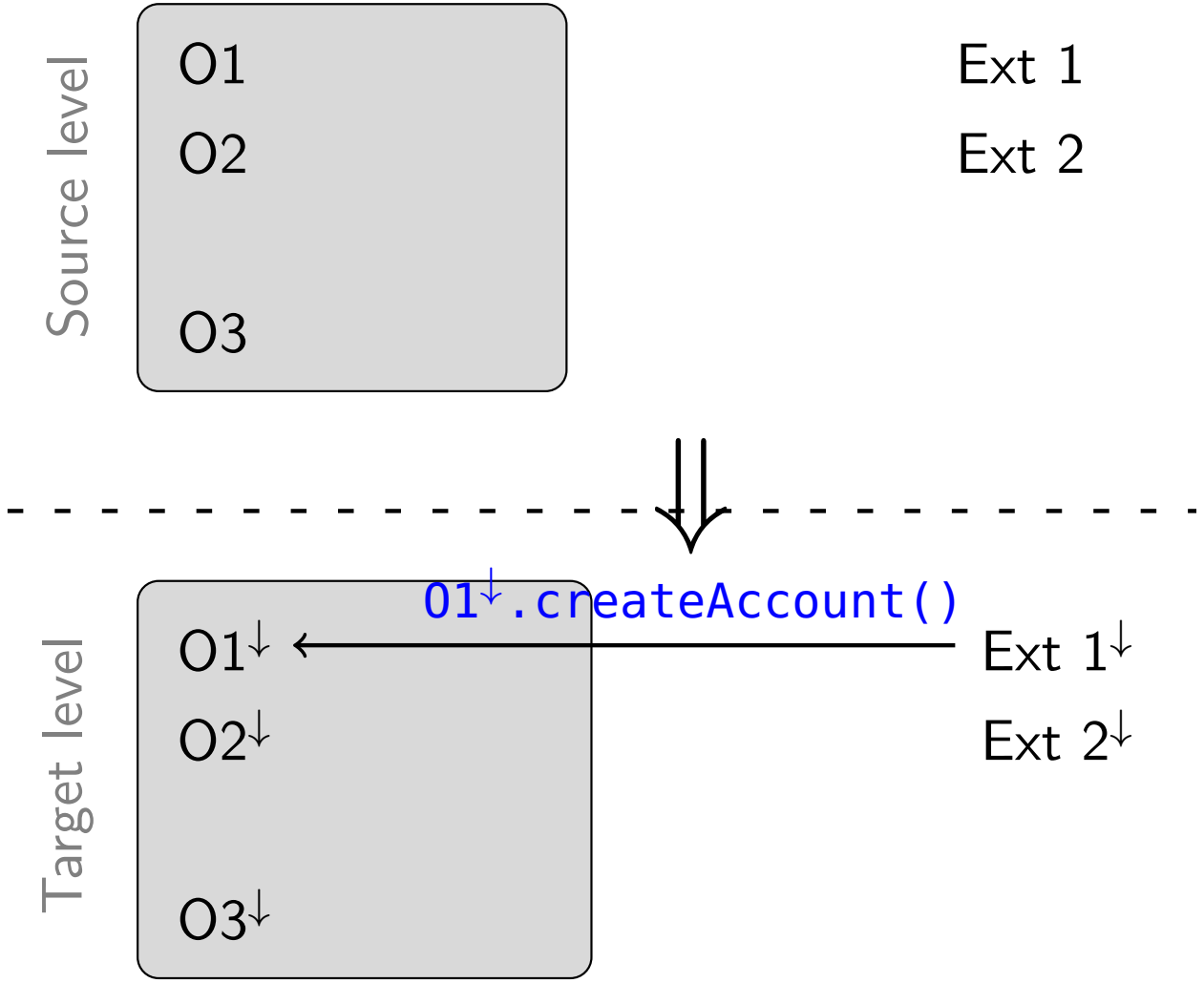

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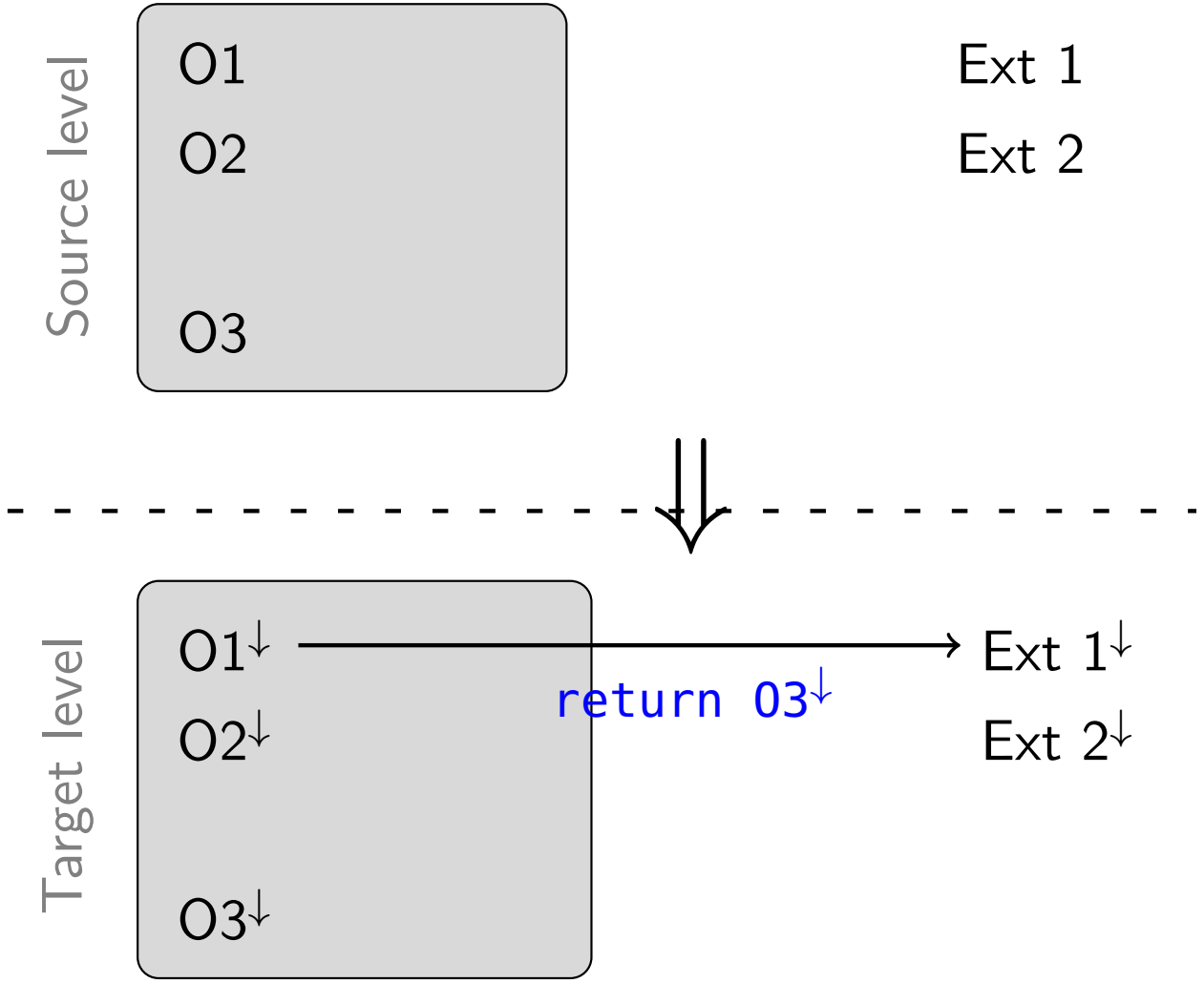

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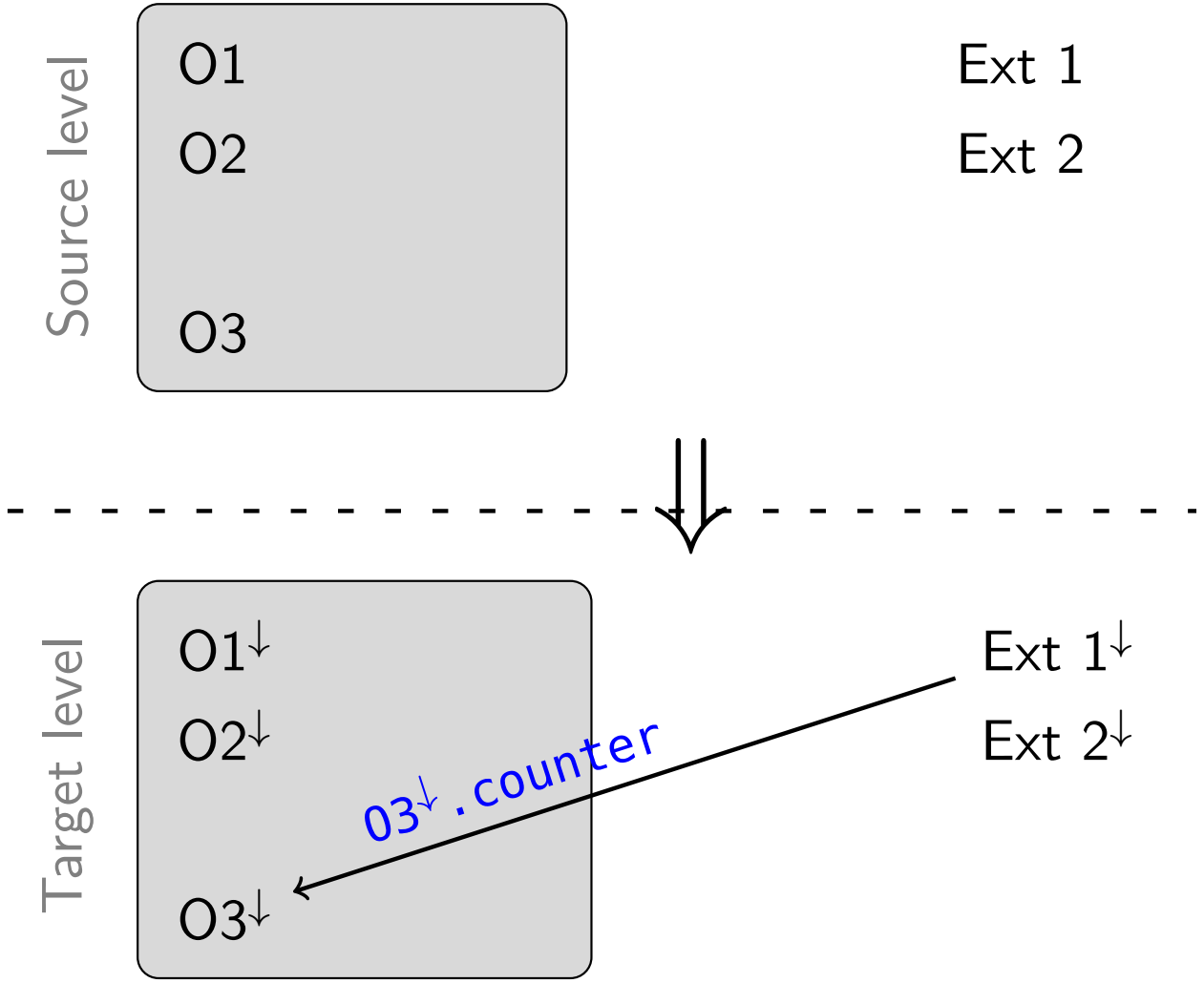

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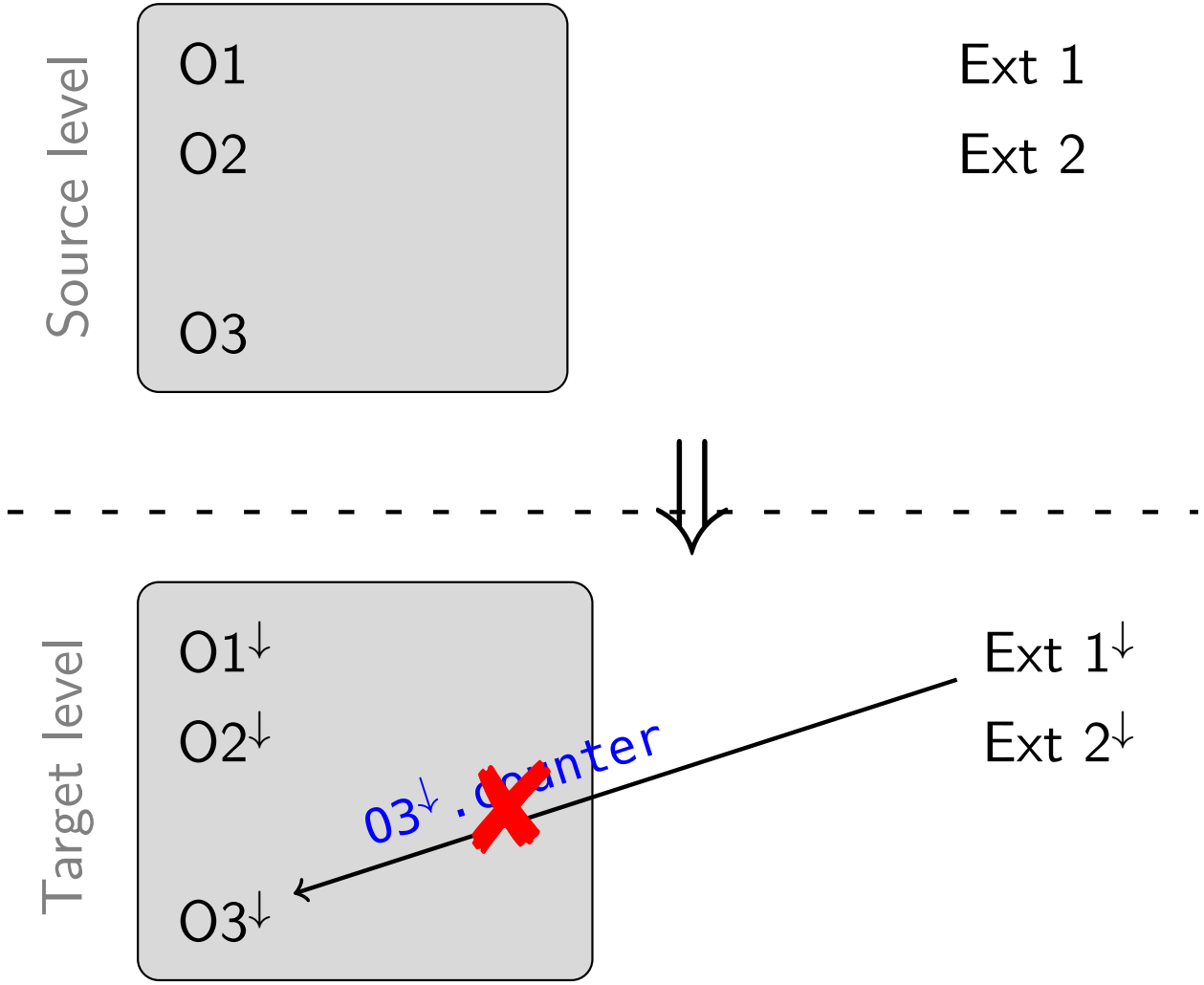

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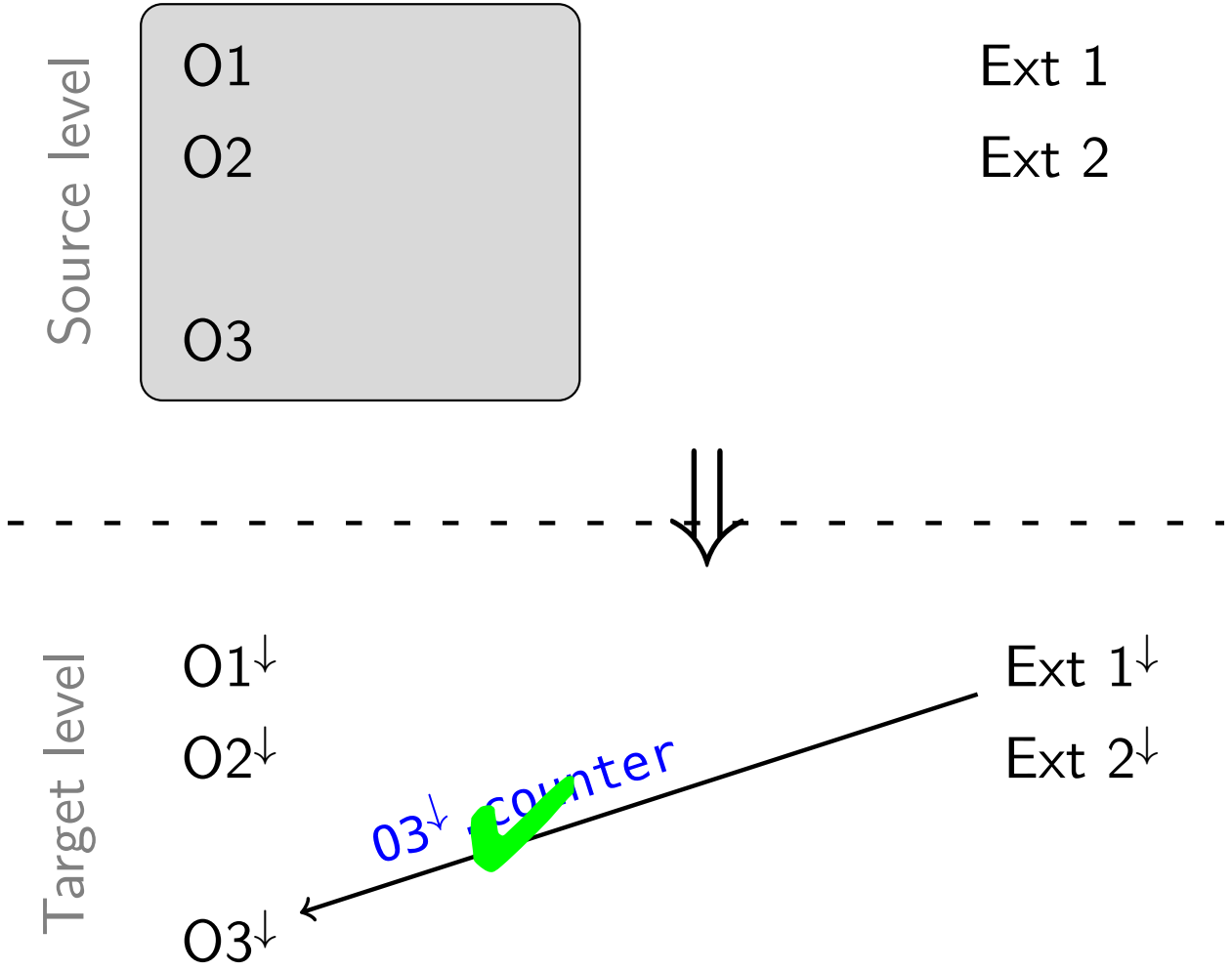

- Protect against low-level attackers
- Target code is vulnerable without PMA

Secure Compilation of Outcalls

Q: : Is that all?

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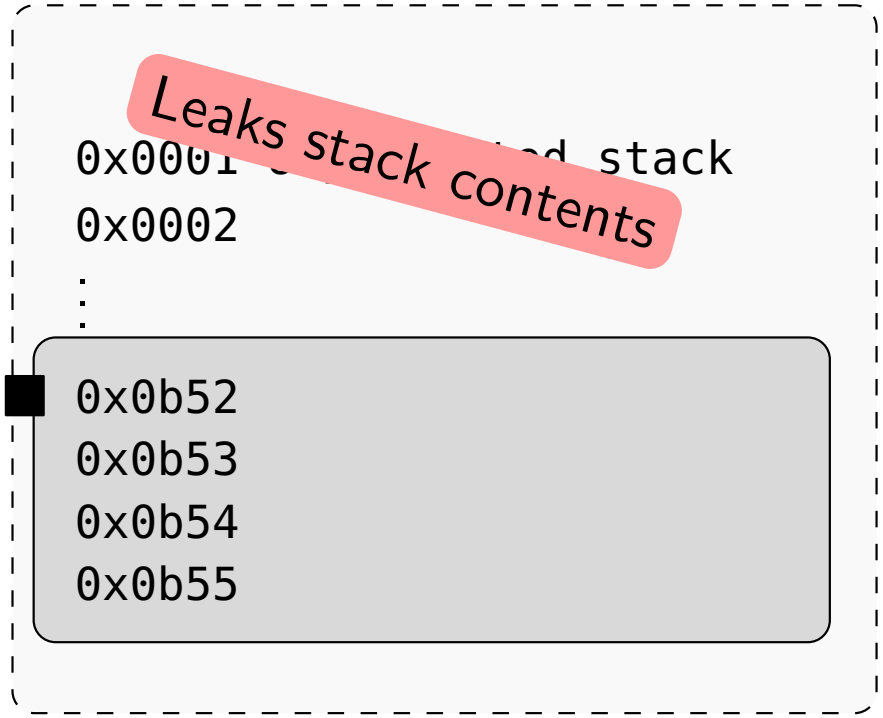
- protected stack



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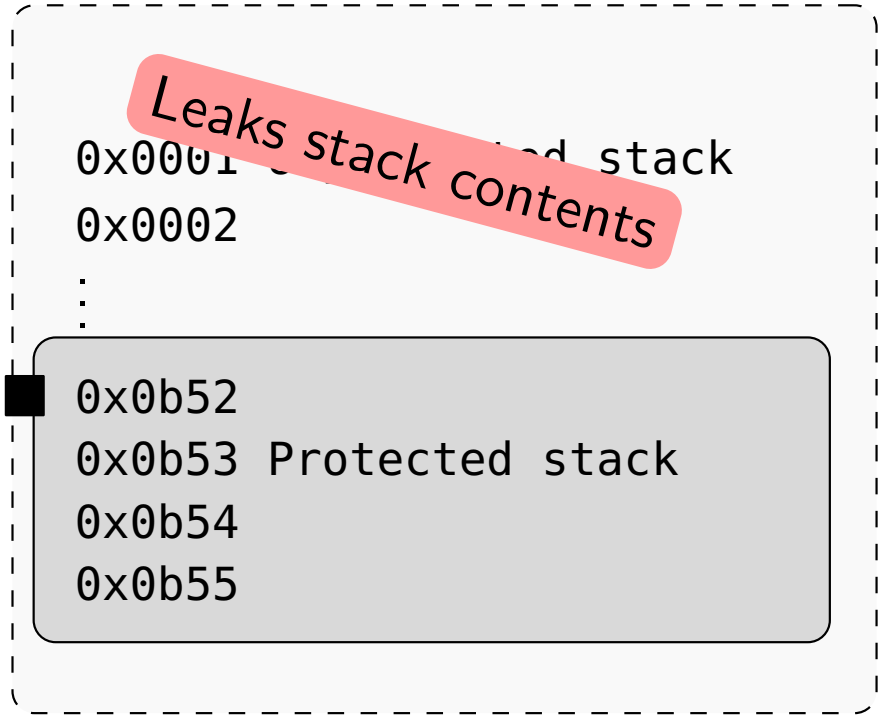

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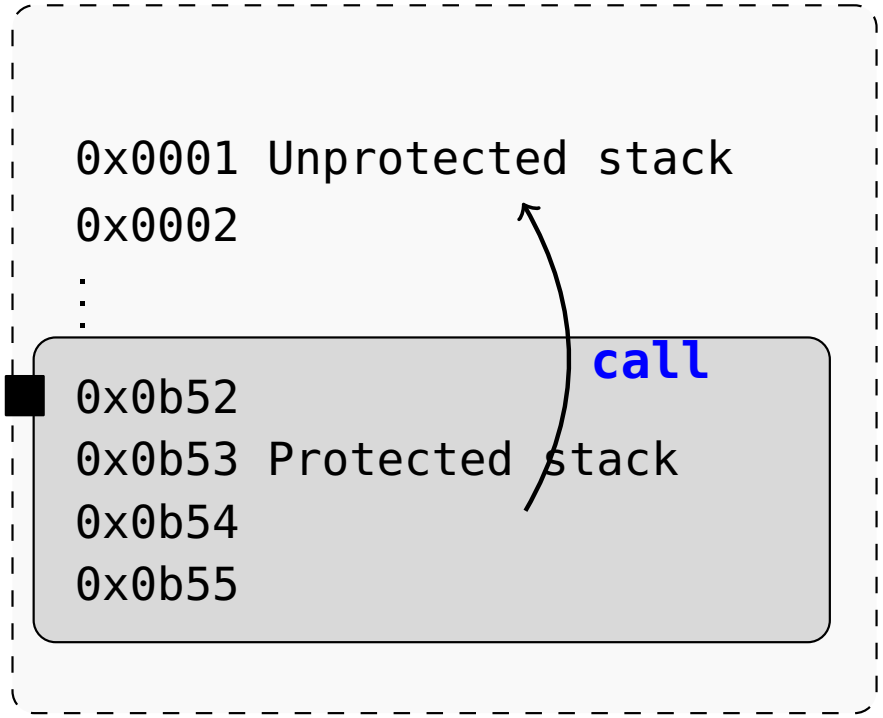

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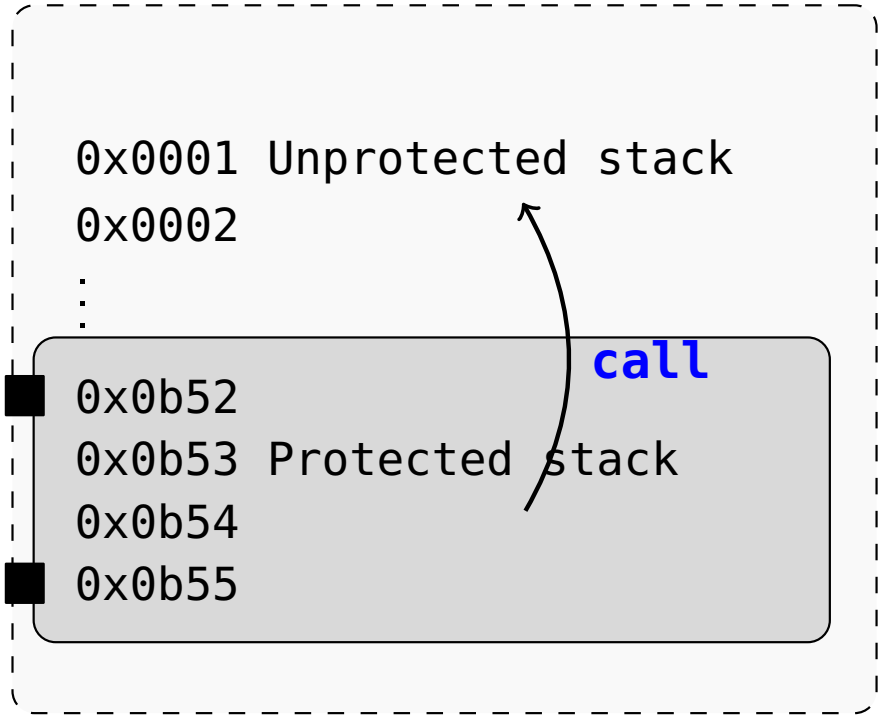

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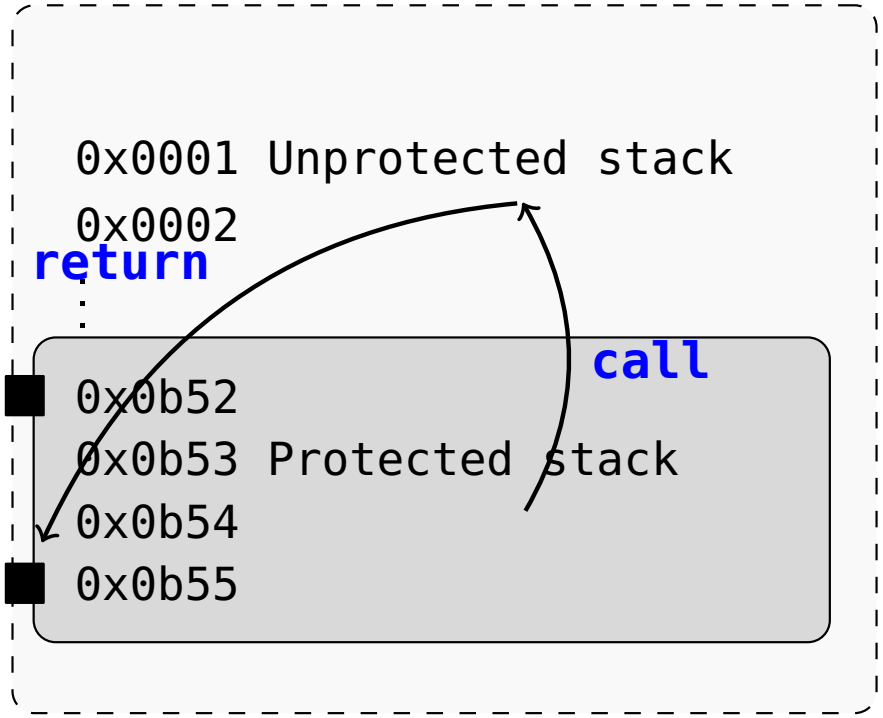

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0x0002
⋮
0x0b52
0x0b53 Protected stack
0x0b54 je ···
0x0b55
```

Secure Compilation of Outcalls

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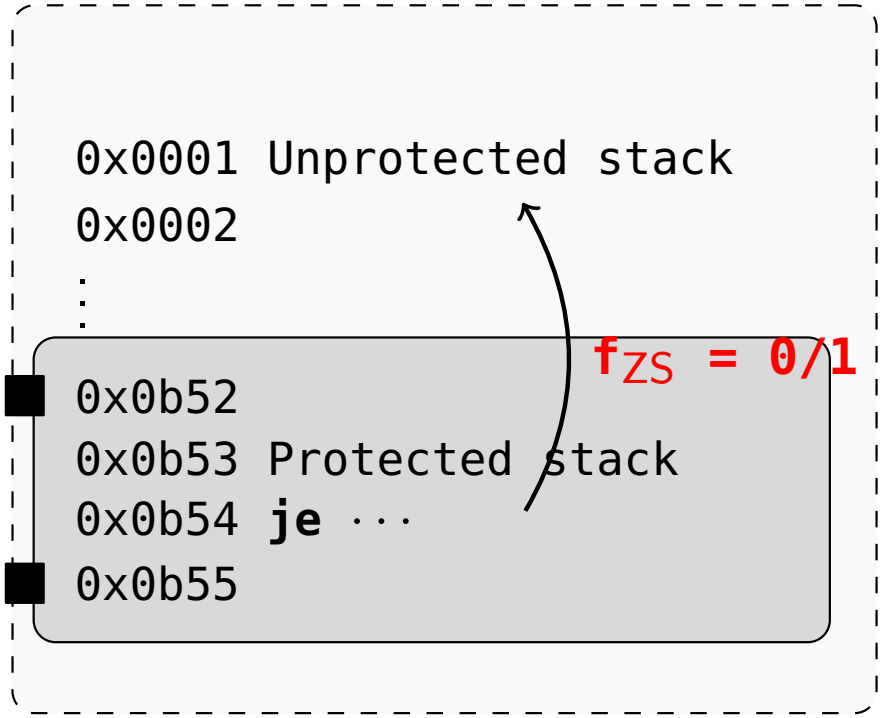

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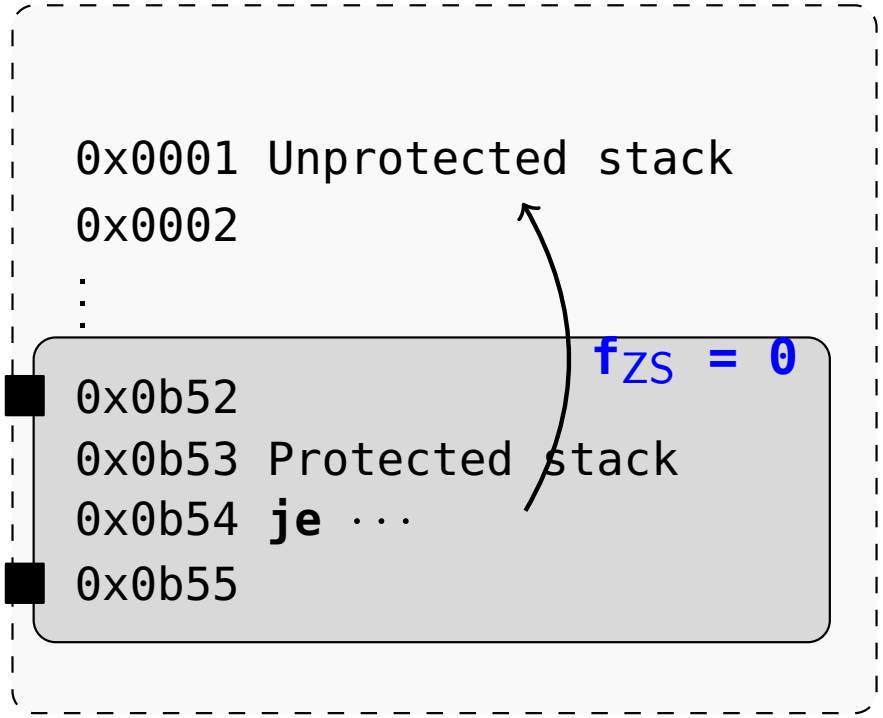

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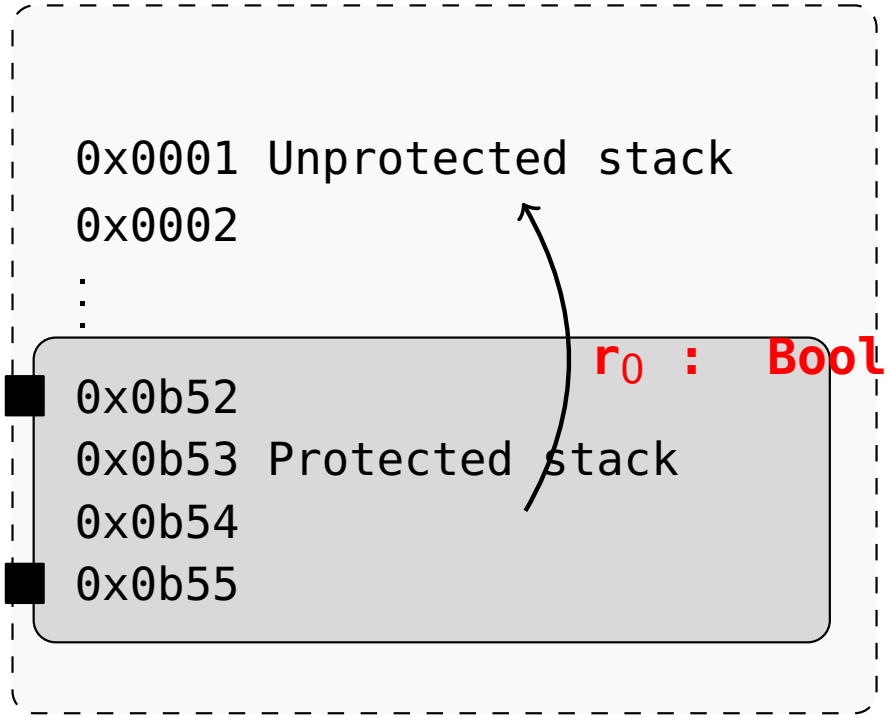
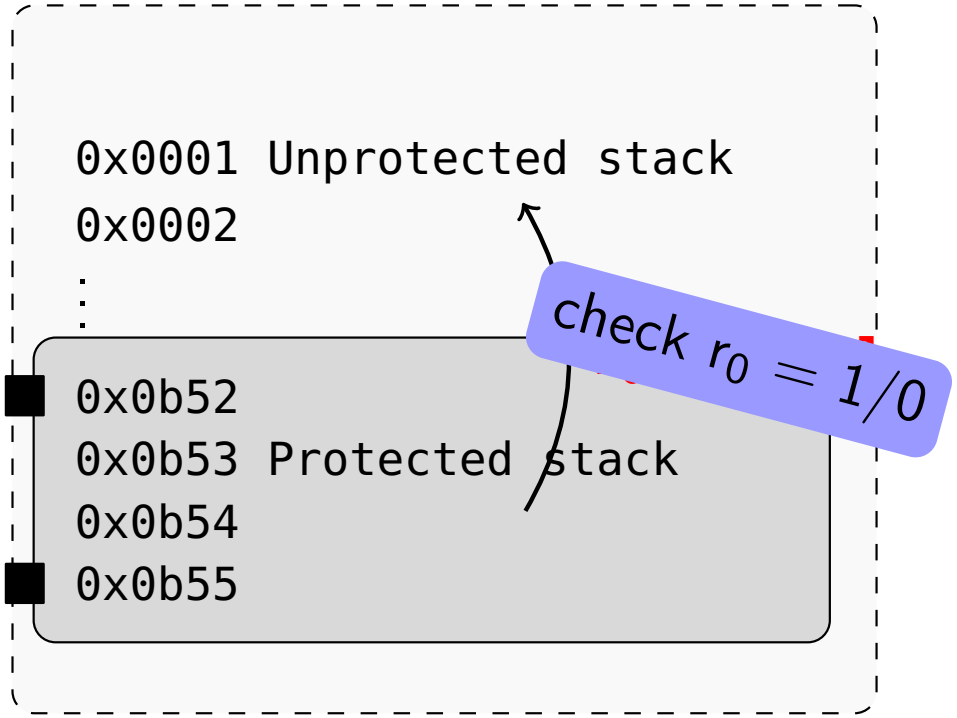


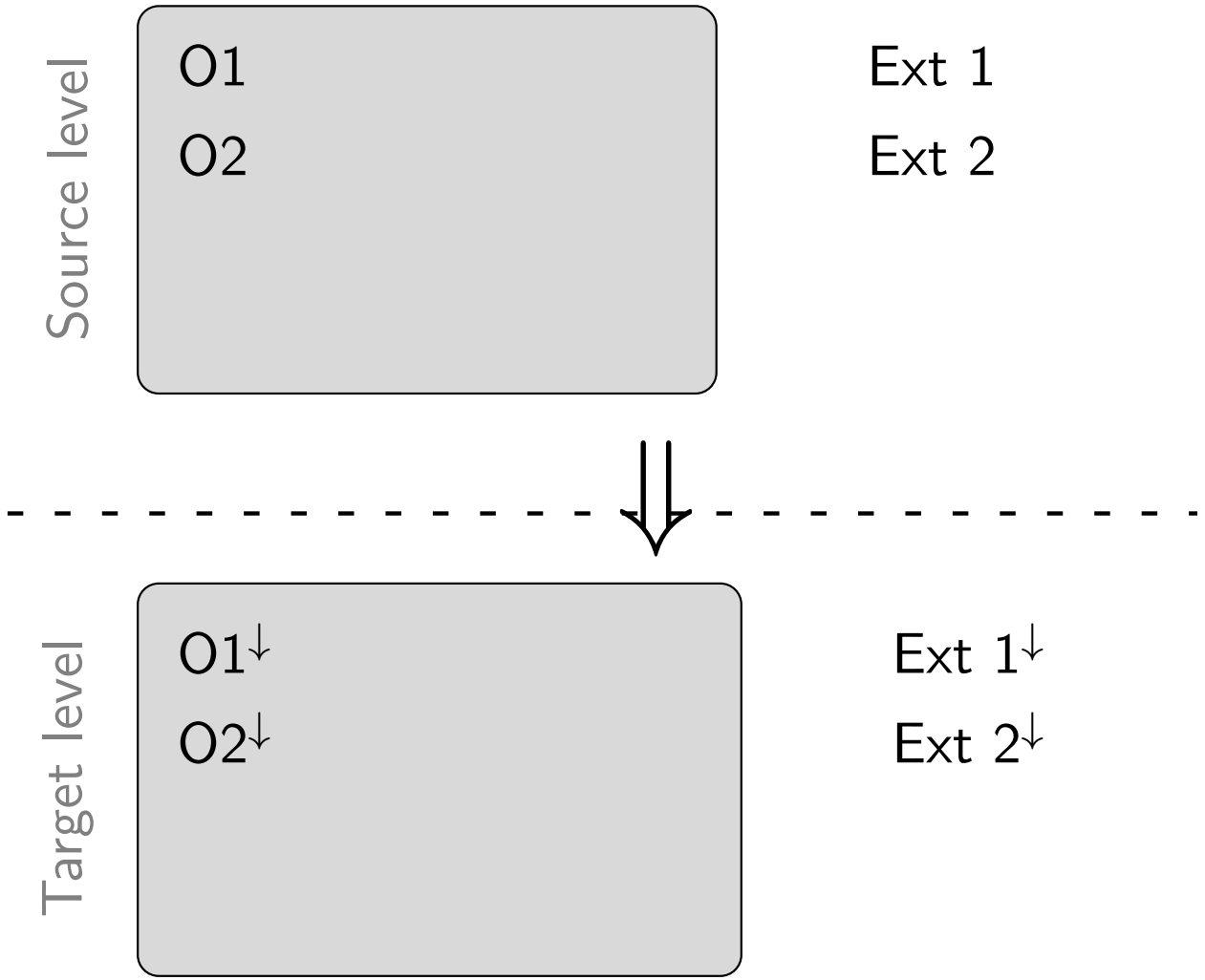
Secure Compilation of Outcalls

Q: : Is that all?

- protected stack
- returnback entry point
- reset flags and registers
- ground-typed values check



Dynamic Memory Allocation



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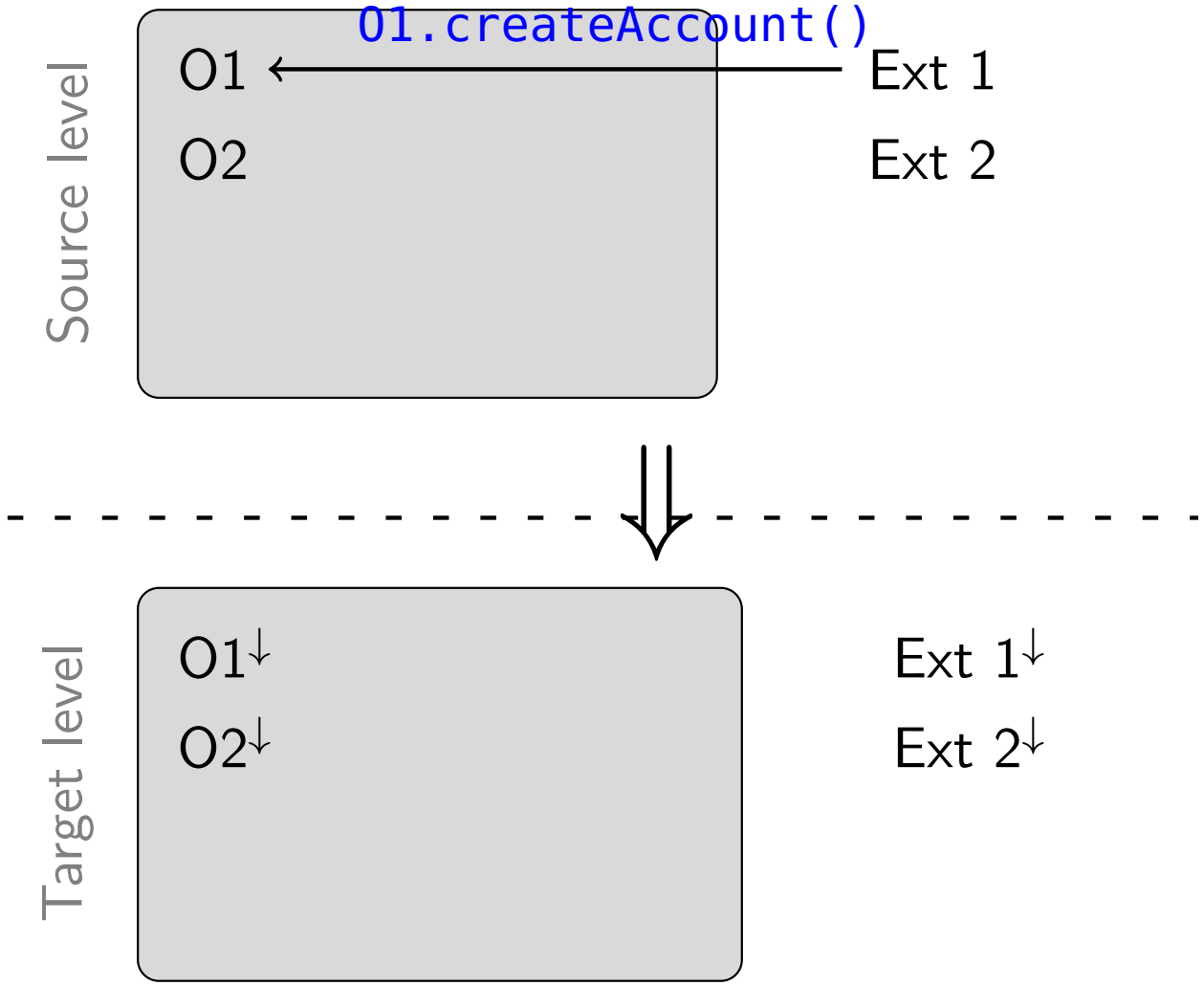

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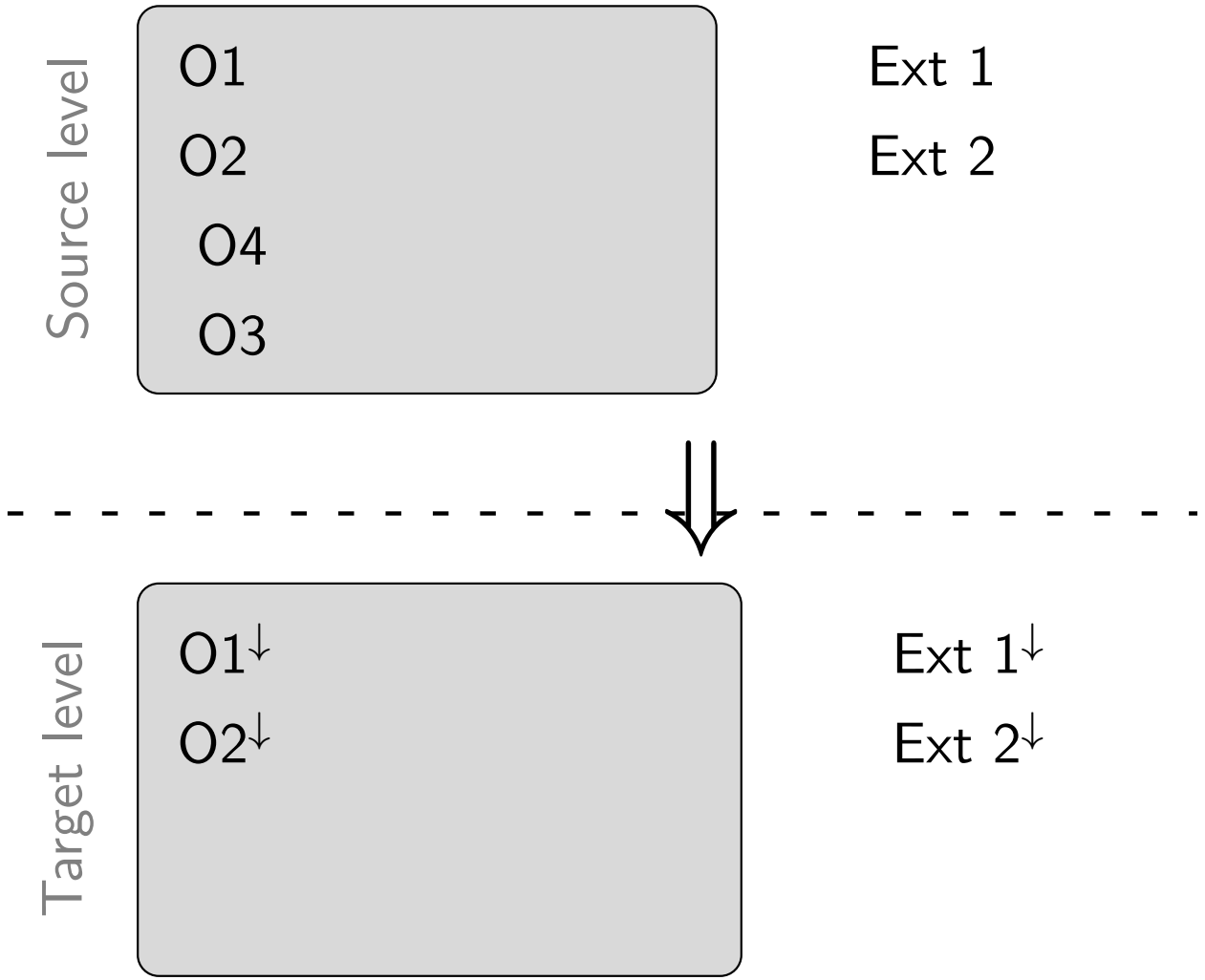

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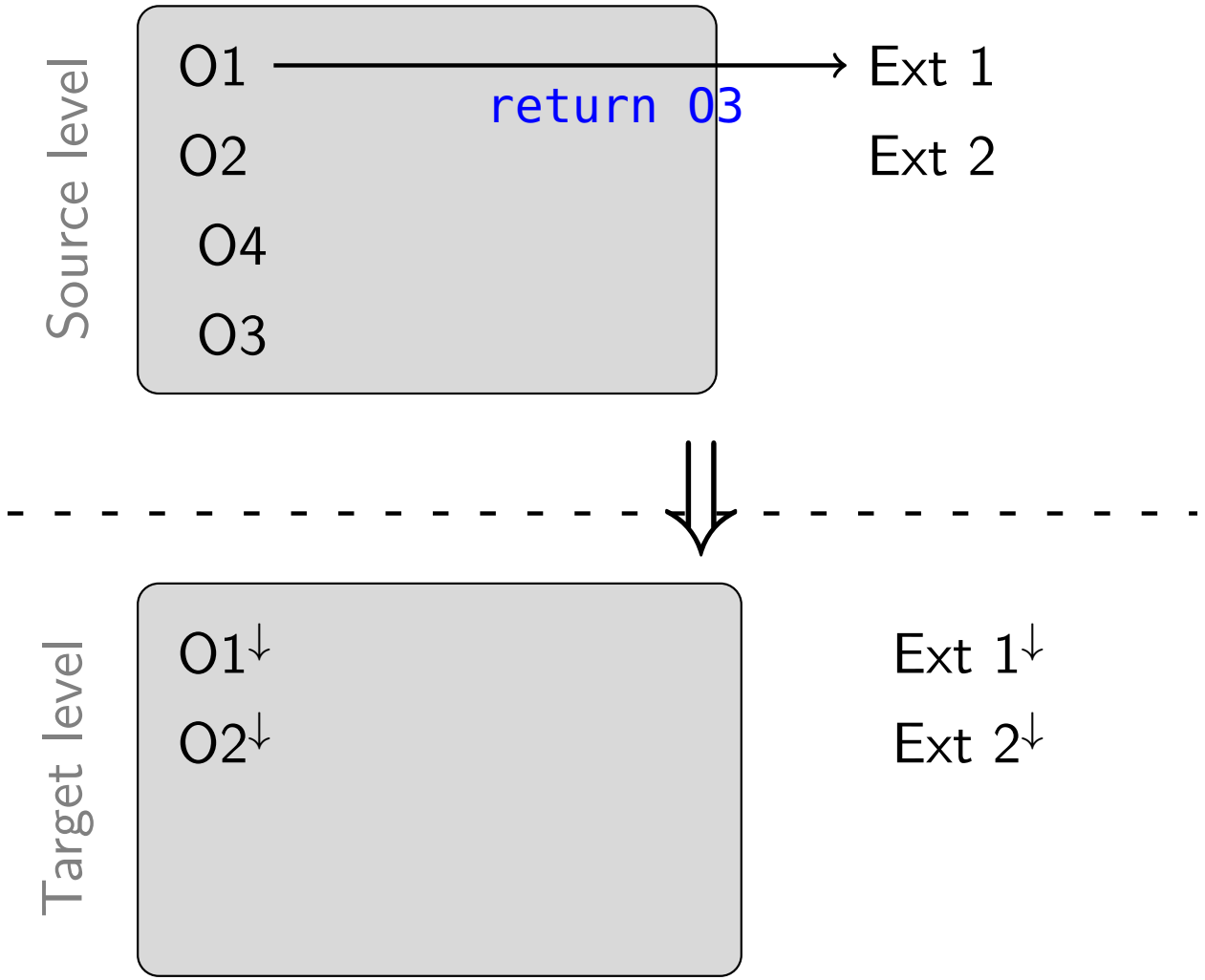

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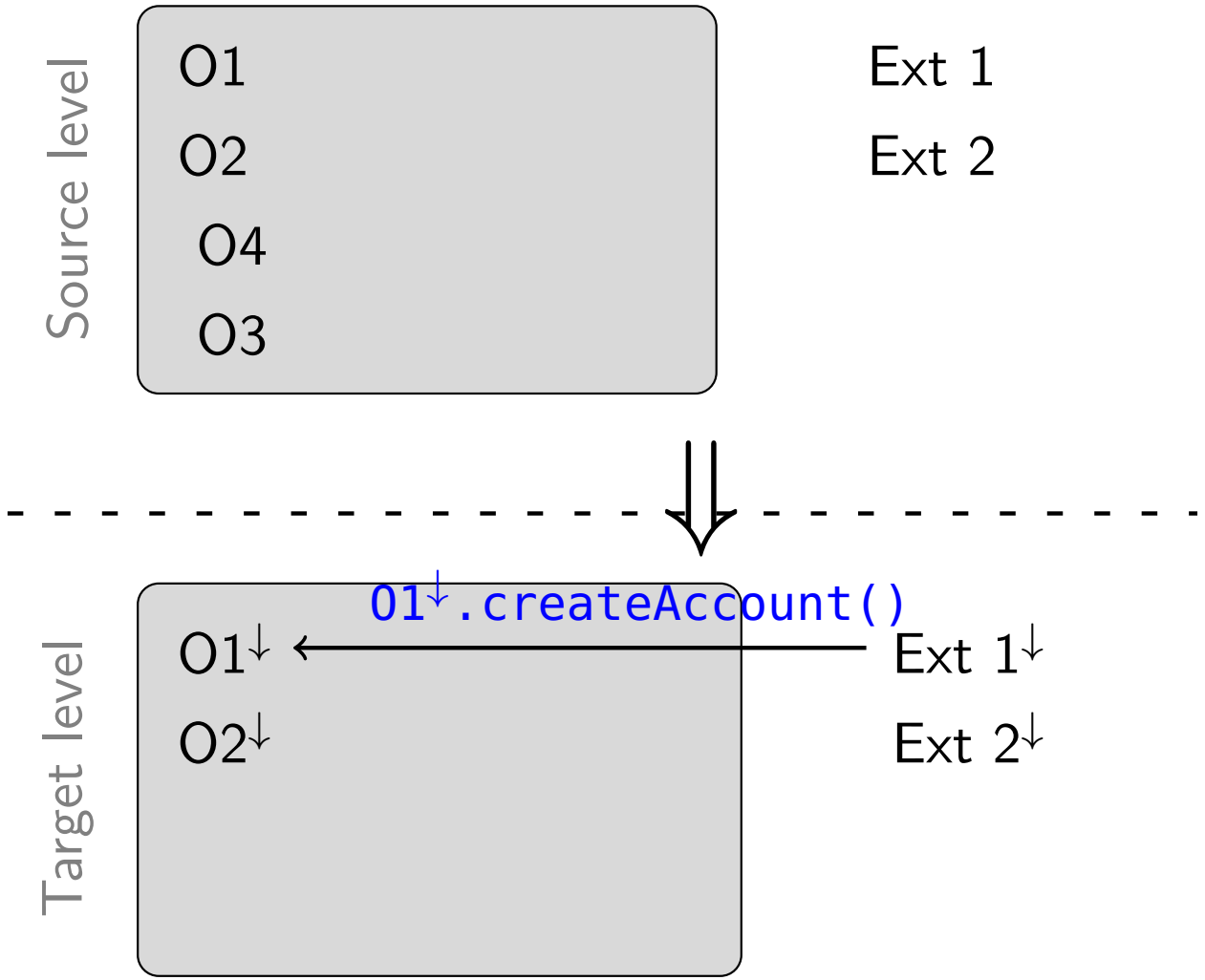

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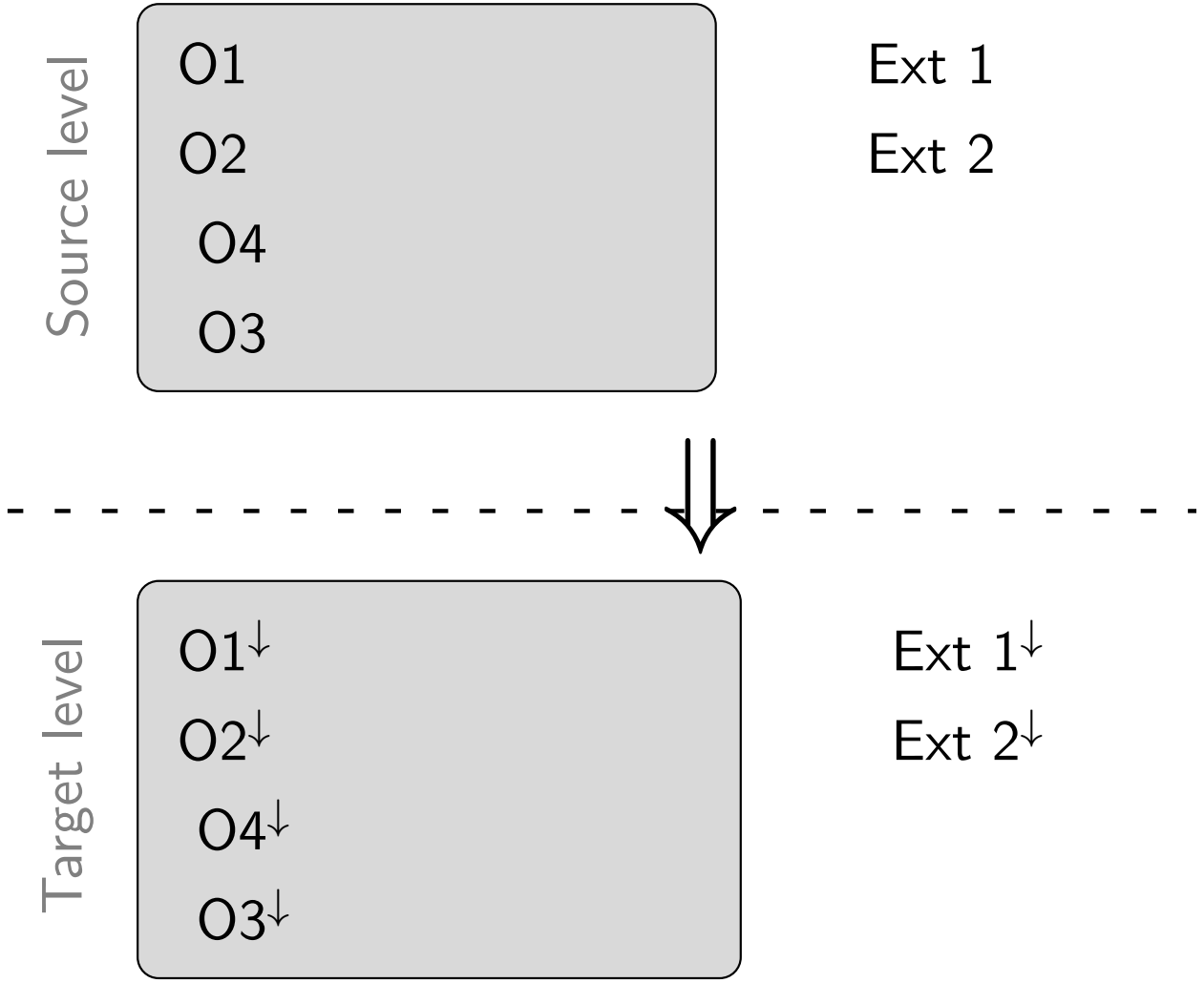
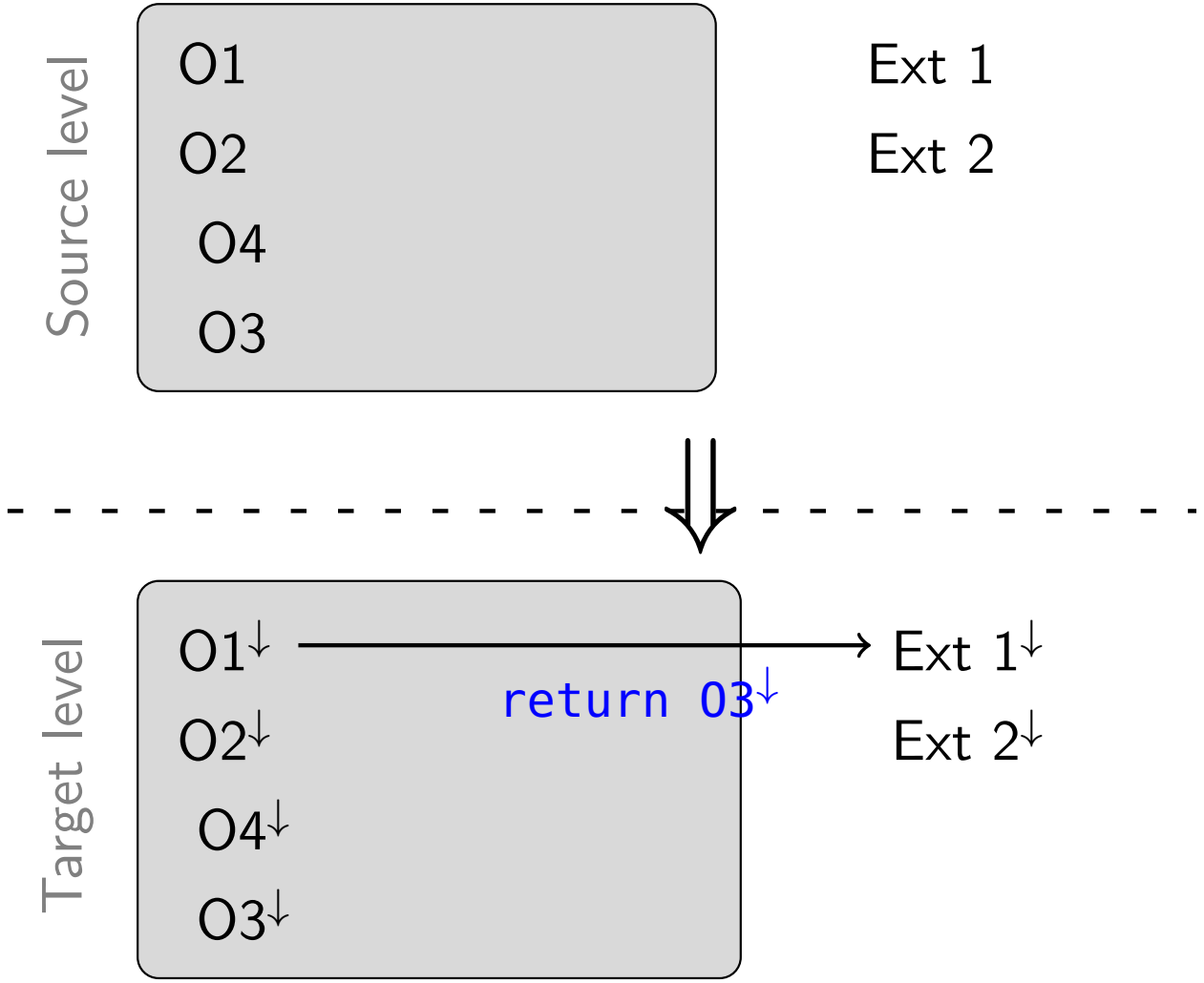
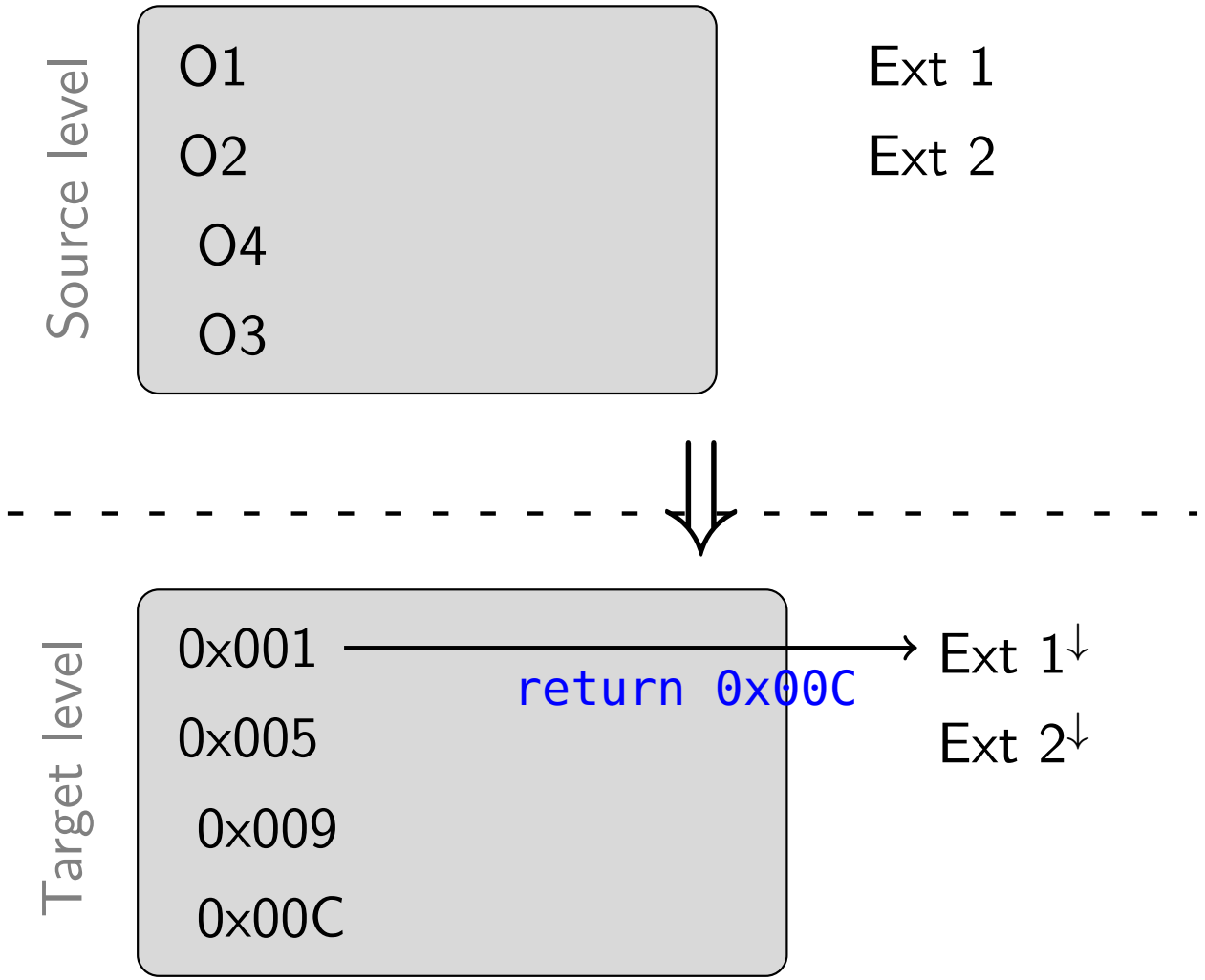


Dynamic Memory Allocation



Dynamic Memory Allocation



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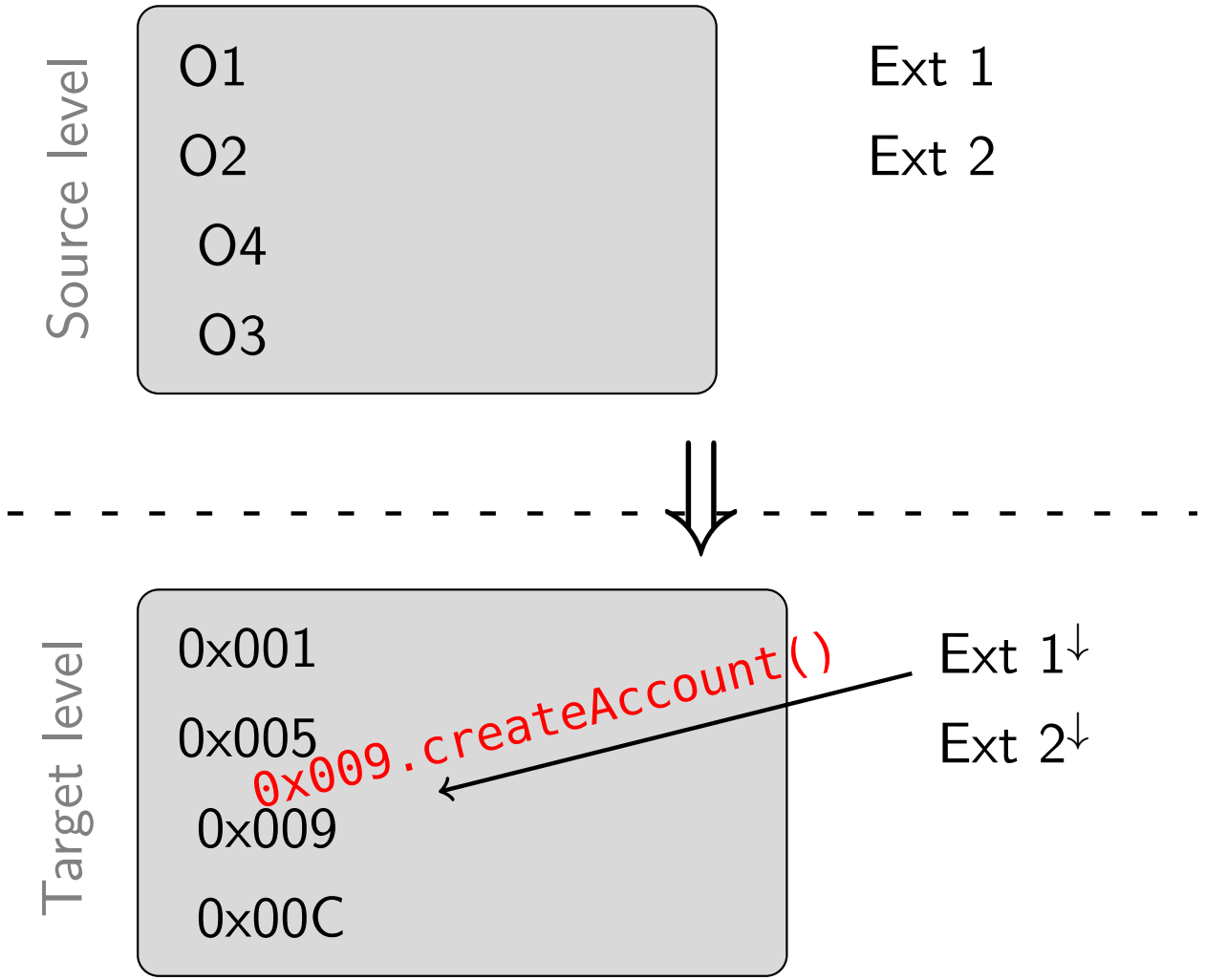
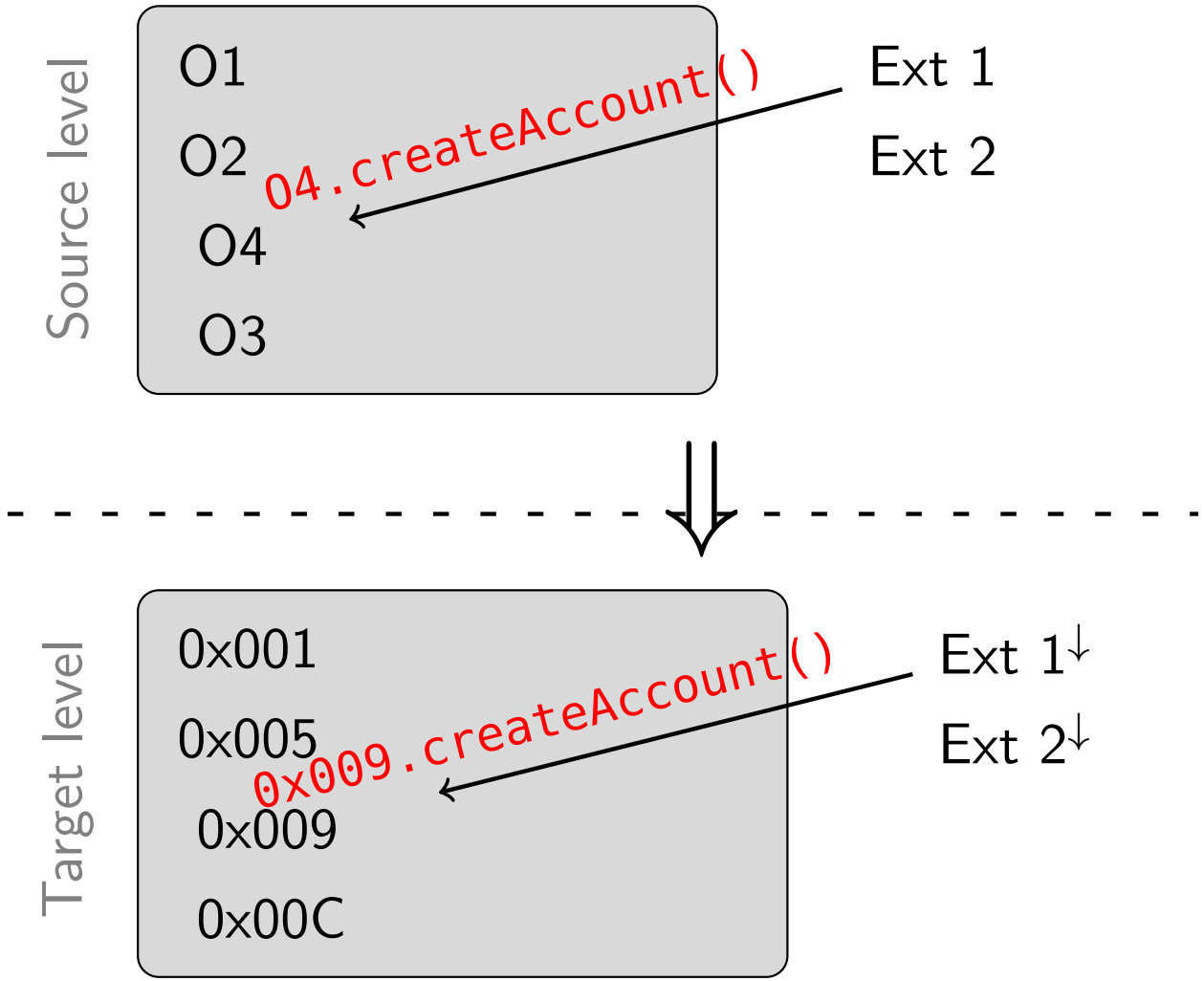
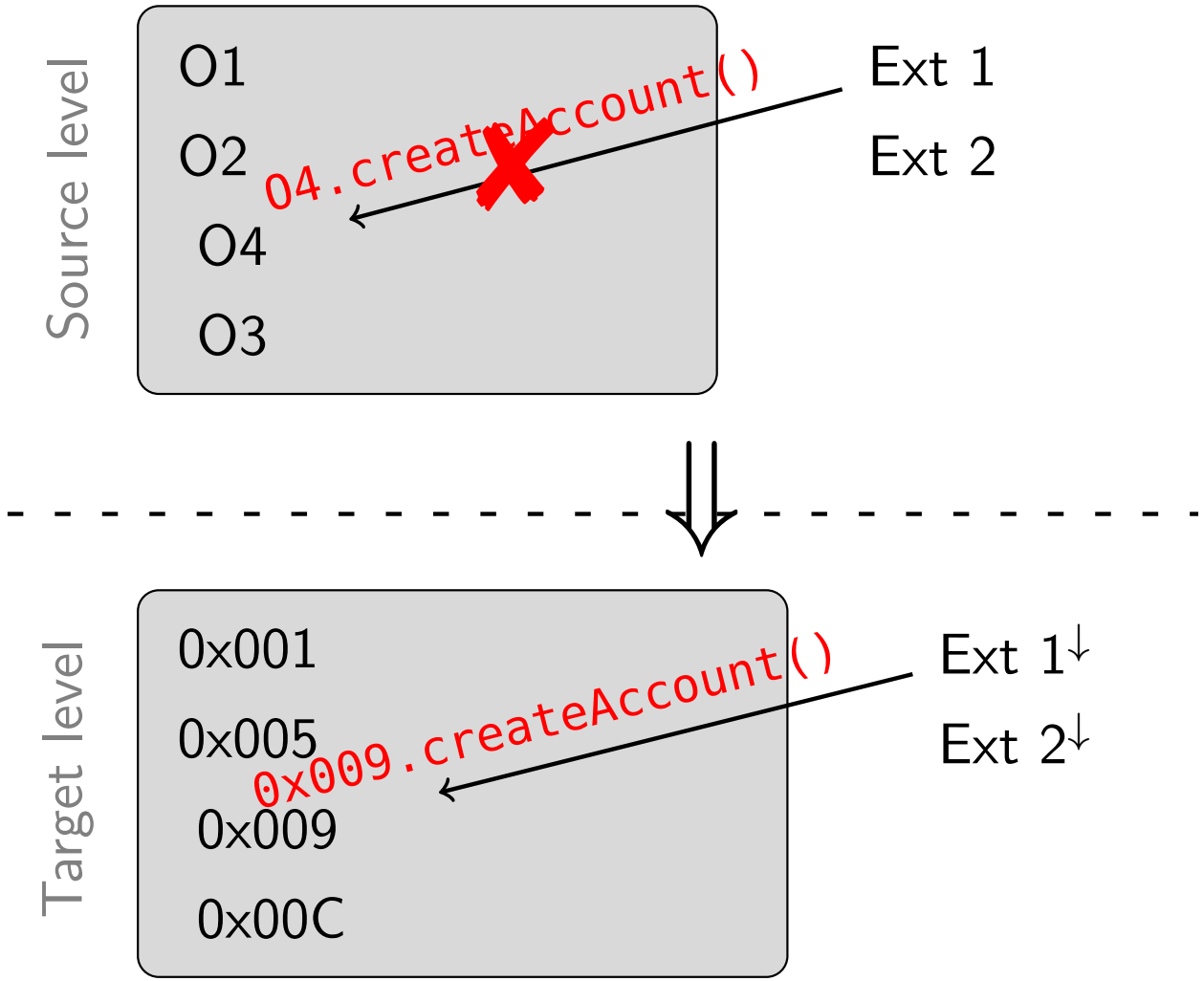


Dynamic Memory Allocation

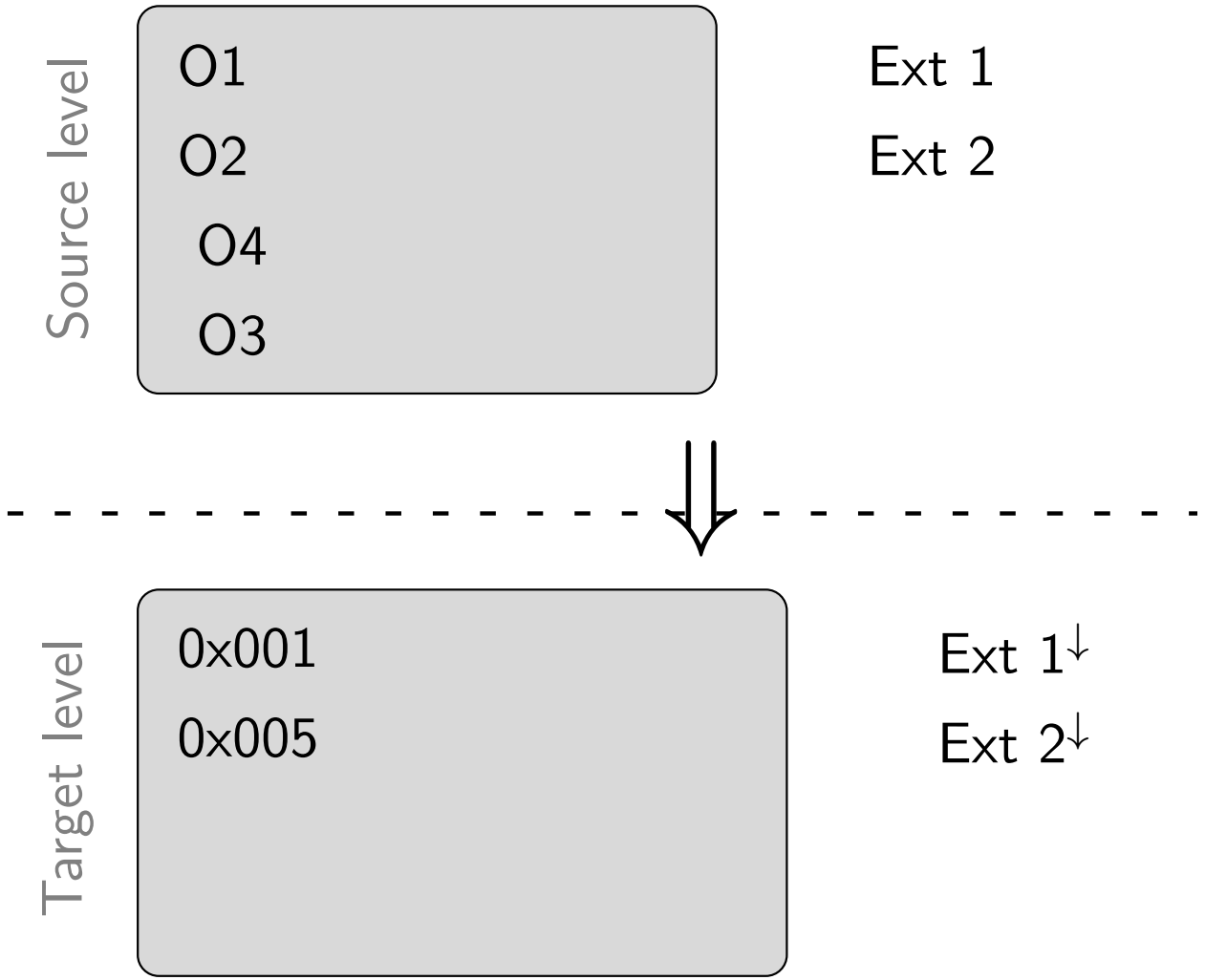


Dynamic Memory Allocation



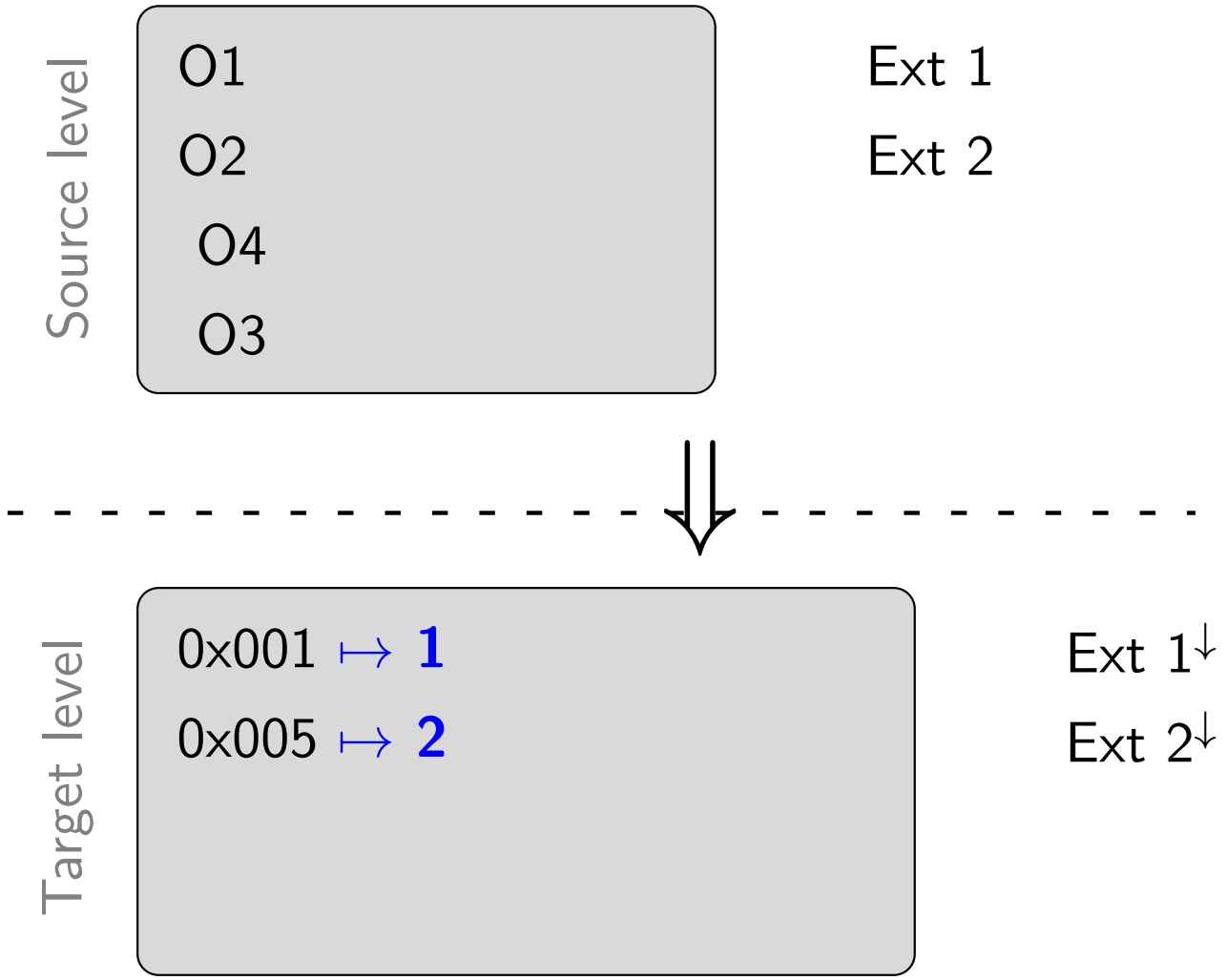
- Object id guessing

Dynamic Memory Allocation



- Object id guessing
- map Oid to natural numbers

Dynamic Memory Allocation



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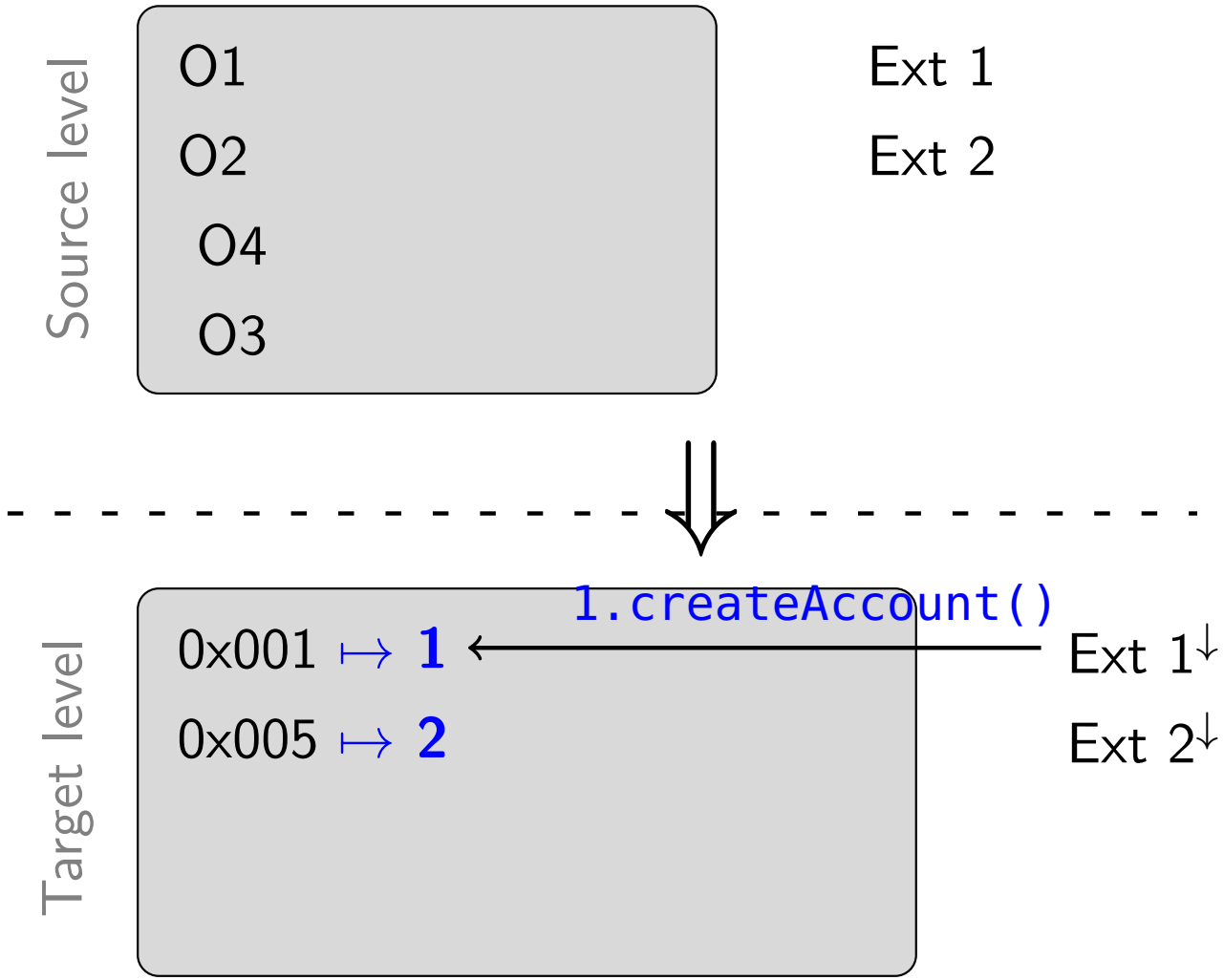

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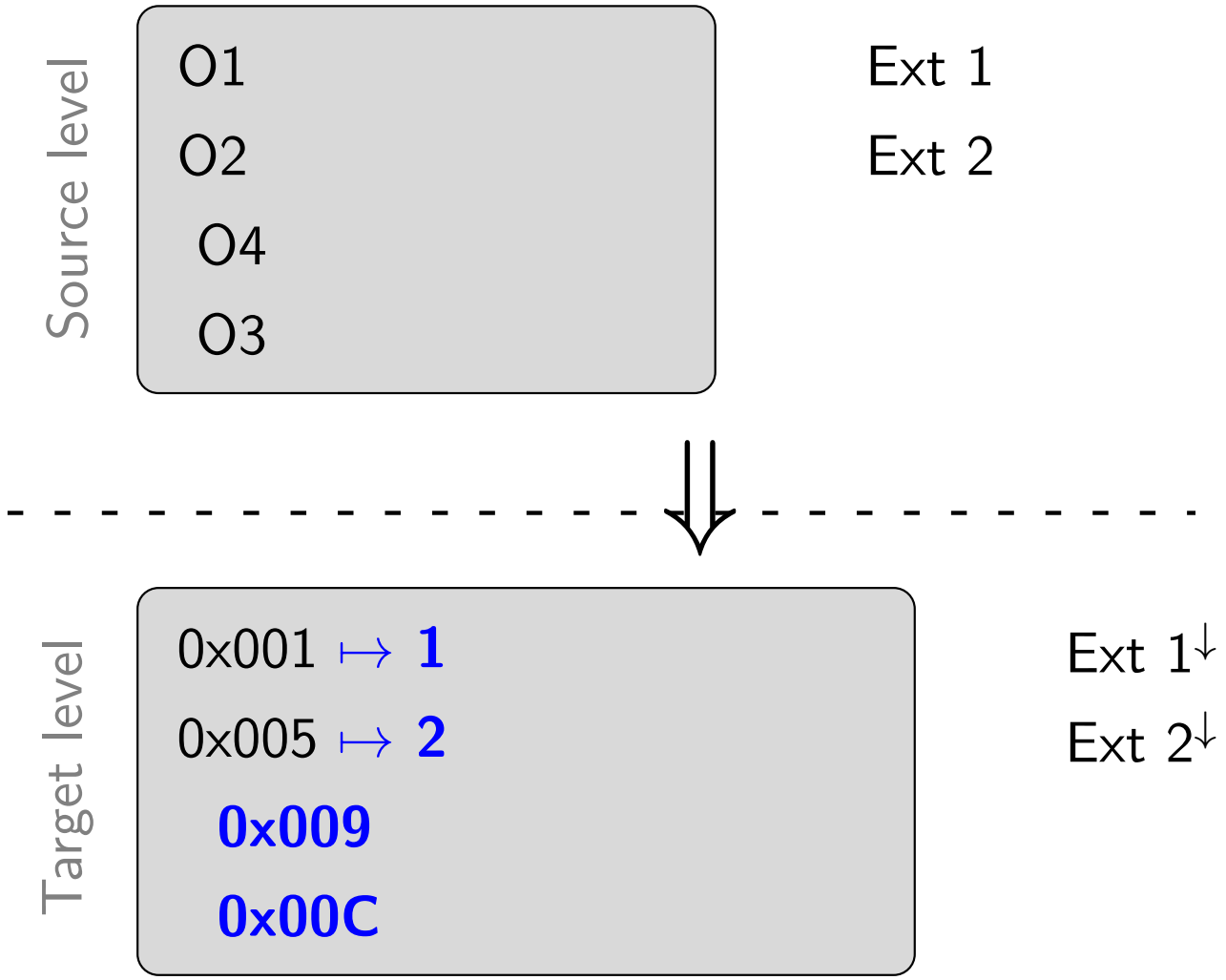
Dynamic Memory Allocation



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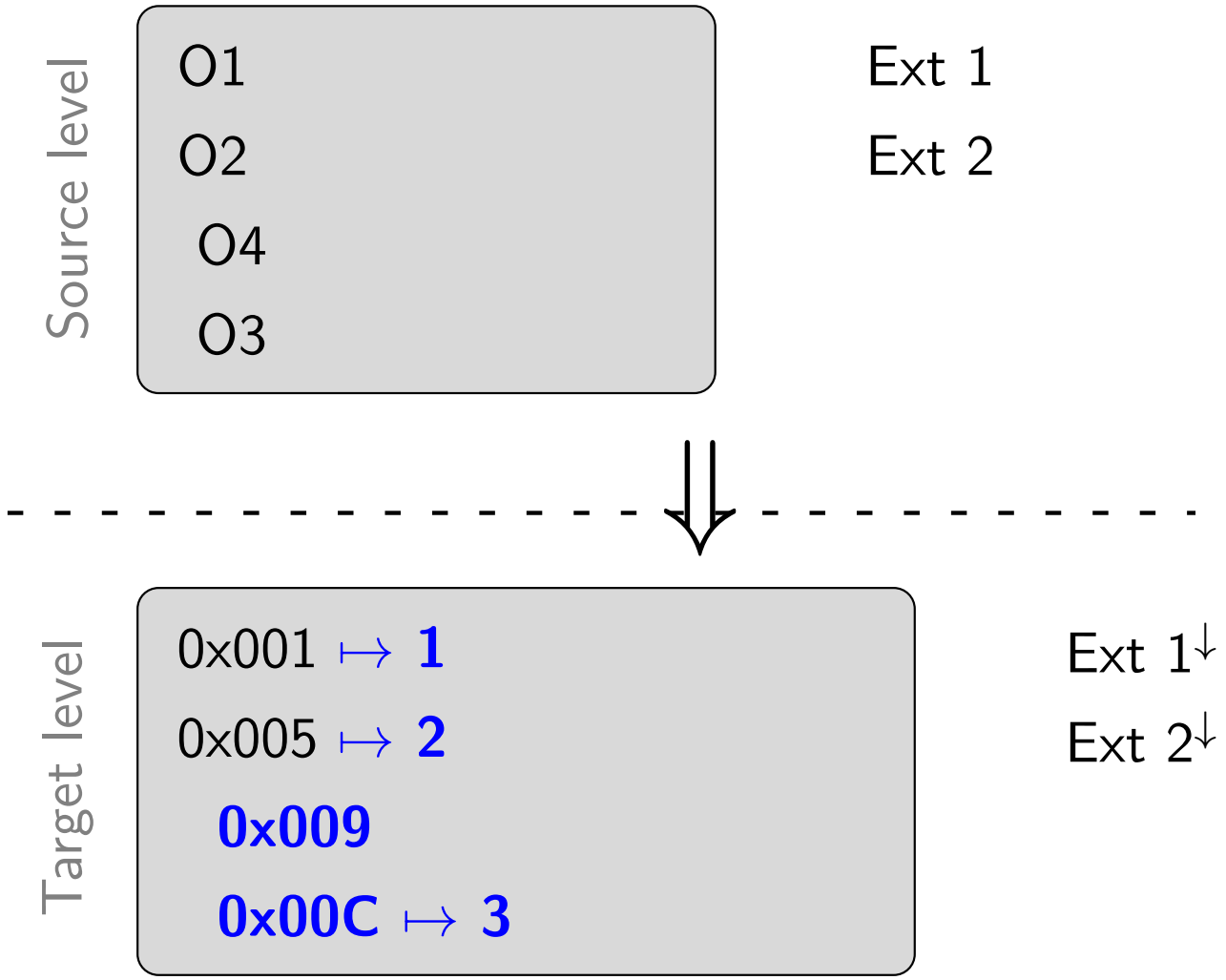

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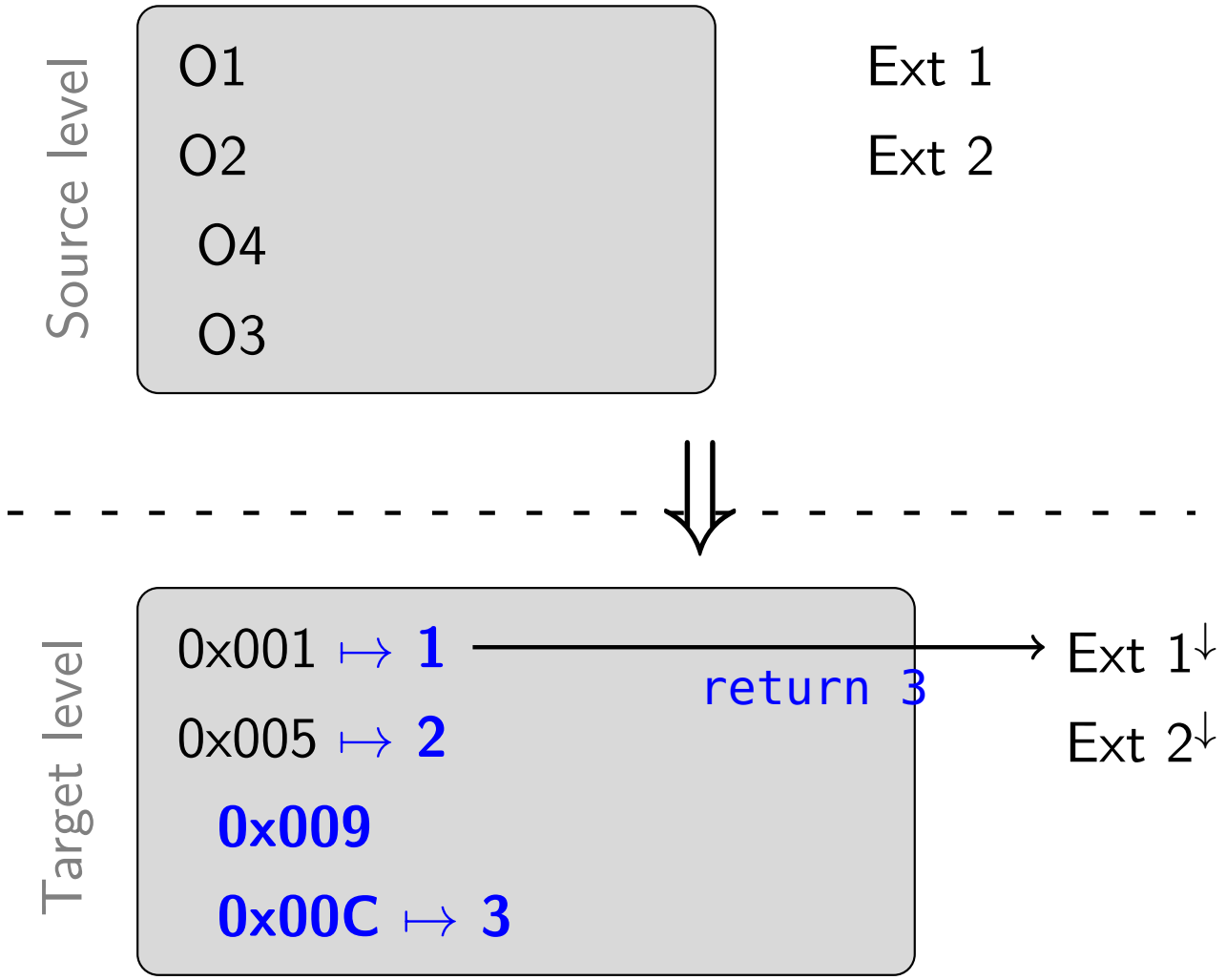

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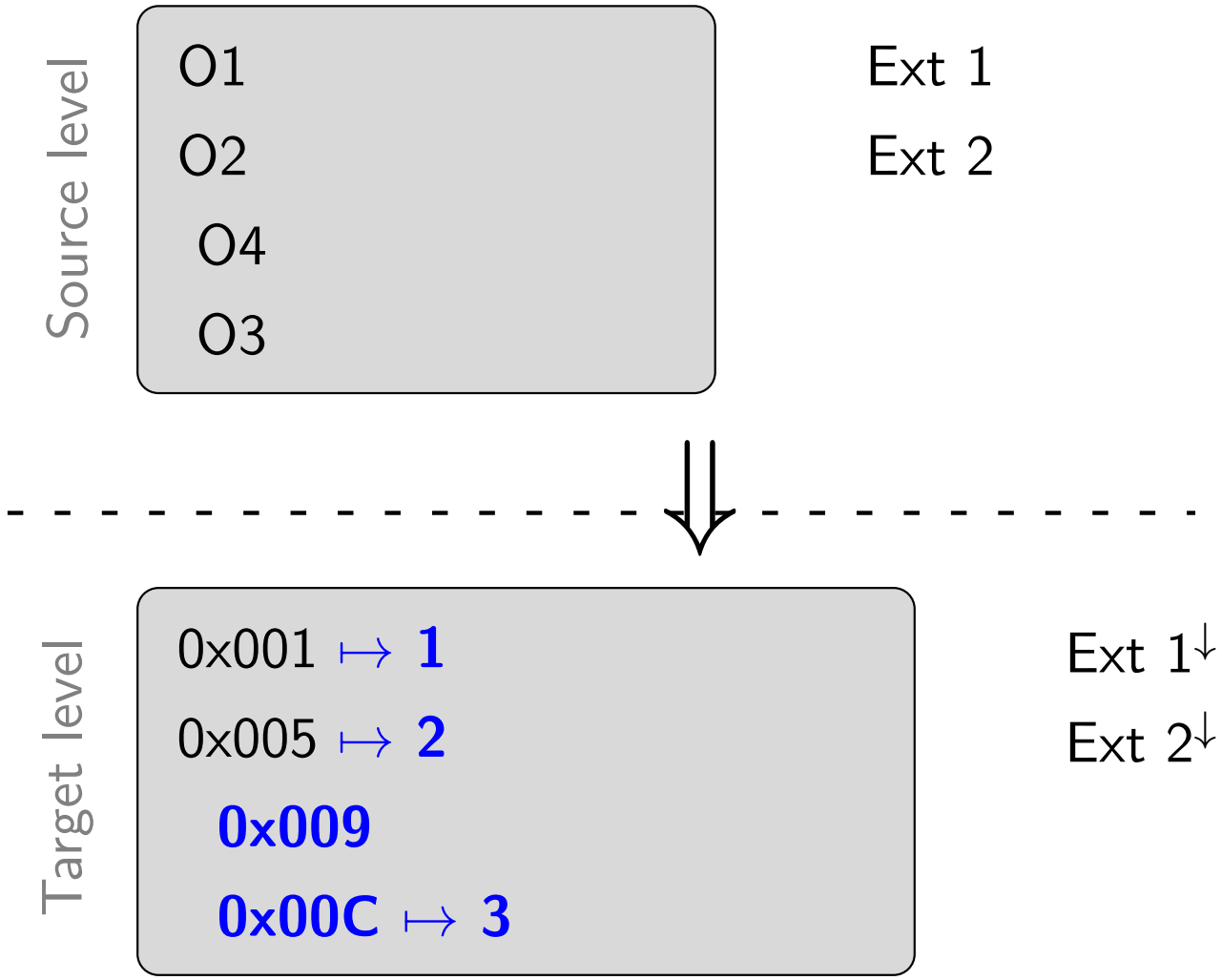
Dynamic Memory Allocation



- Object id guessing
- map Oid to natural numbers
- add Oid to map
- lookup ($\mathbf{O}(1)$) when number is received

Dynamic Memory Allocation

Source level

O1 : Account
O2 : Pair
O4
O3

Ext 1
Ext 2

- Object id guessing
- map Oid to natural numbers
- add Oid to map
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$\Downarrow$

Target level

0x001 $\mapsto$ **1**
0x005 $\mapsto$ **2**
0x009
0x00C $\mapsto$ **3**

Ext $1^{\downarrow}$
Ext $2^{\downarrow}$

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O1 : Account
O2 : Pair
O4
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`O2.createAccount()`

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Ext 2

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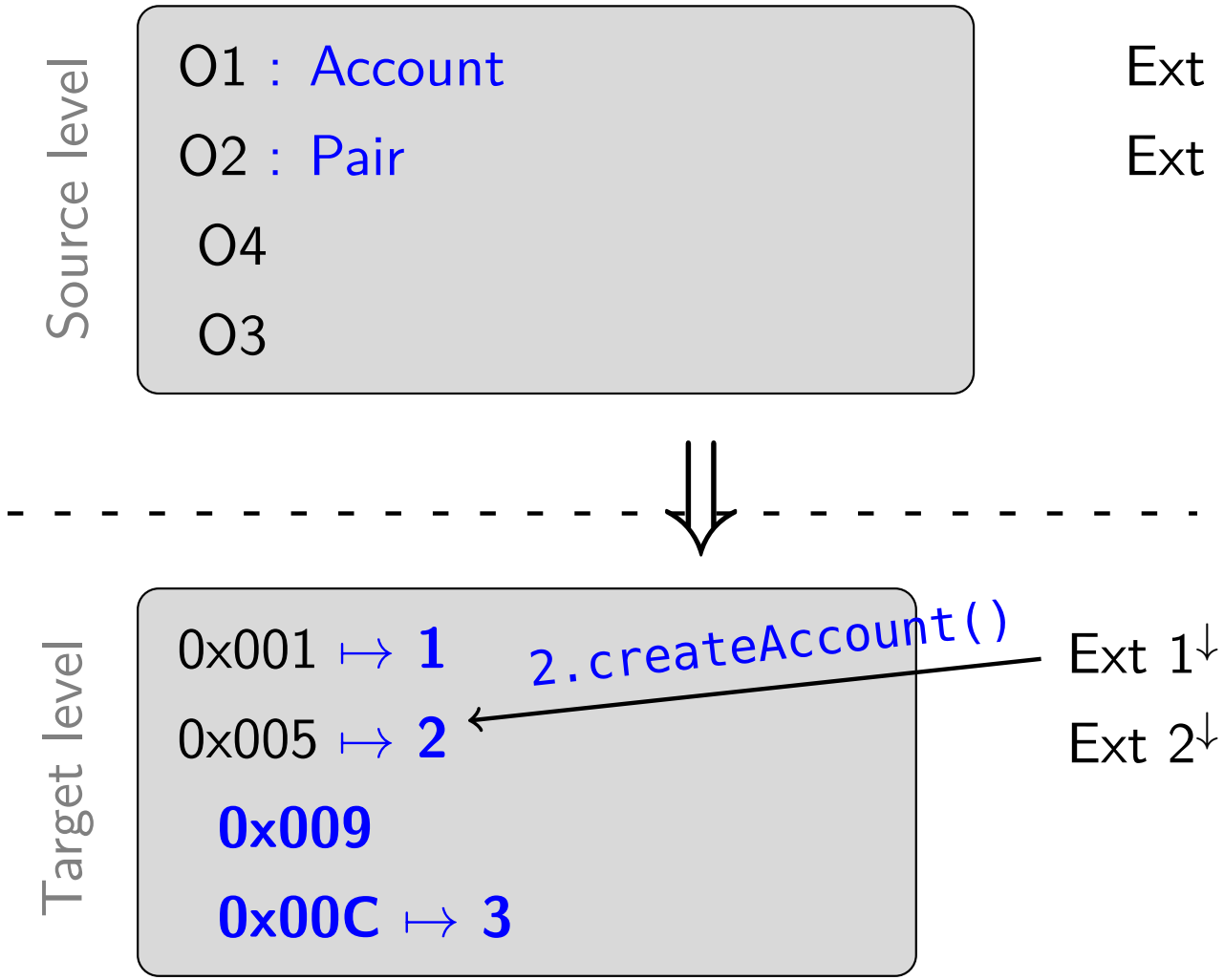

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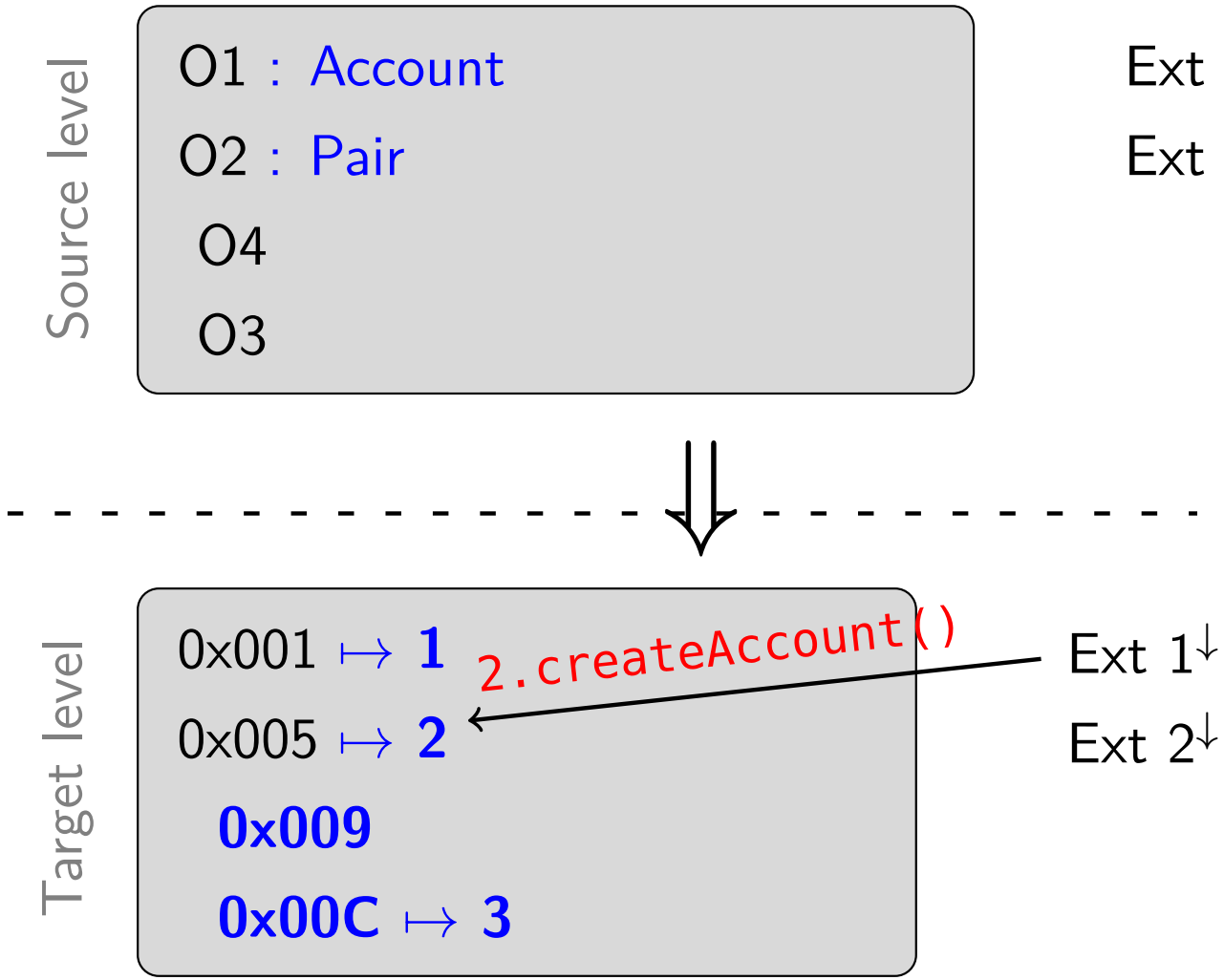

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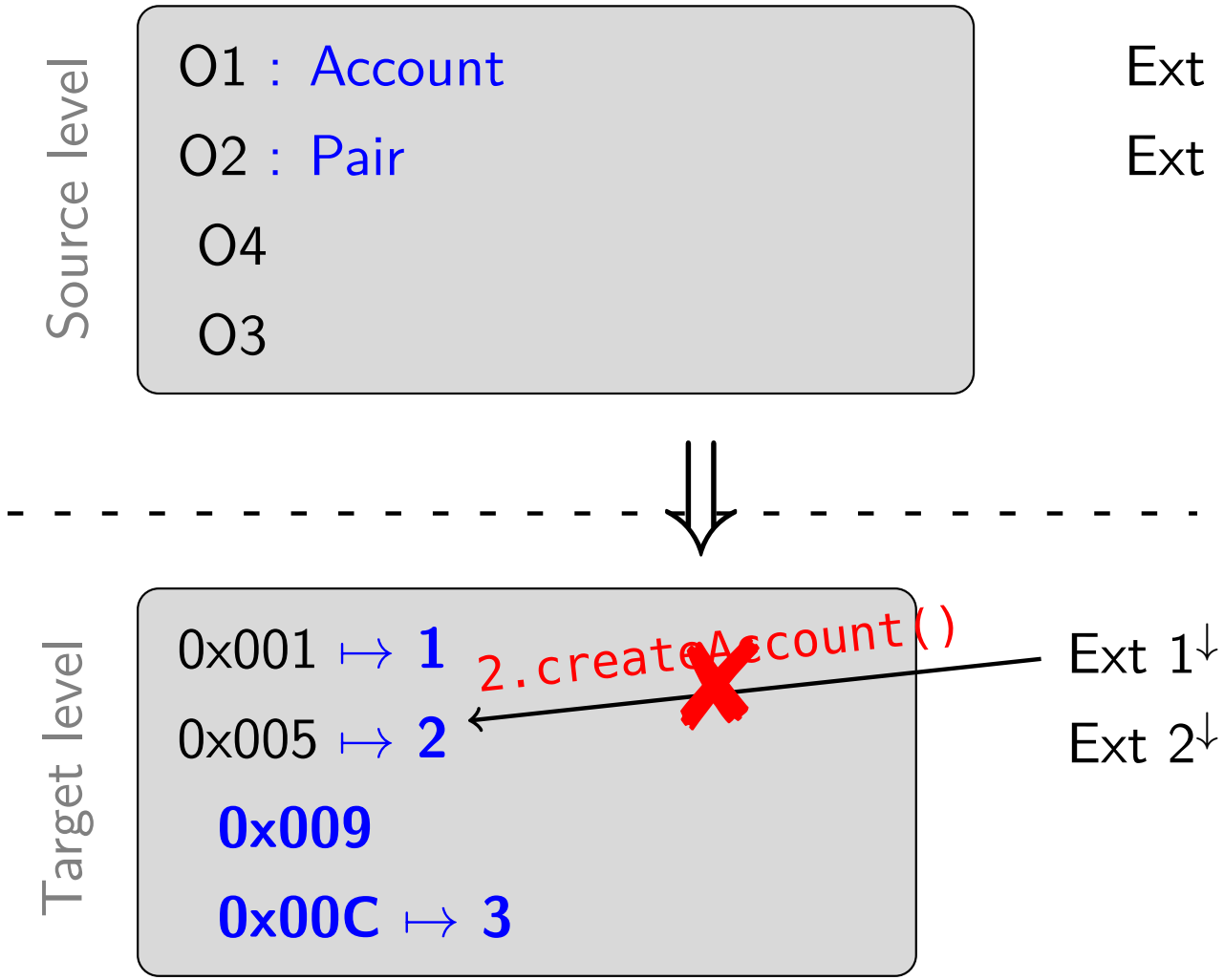
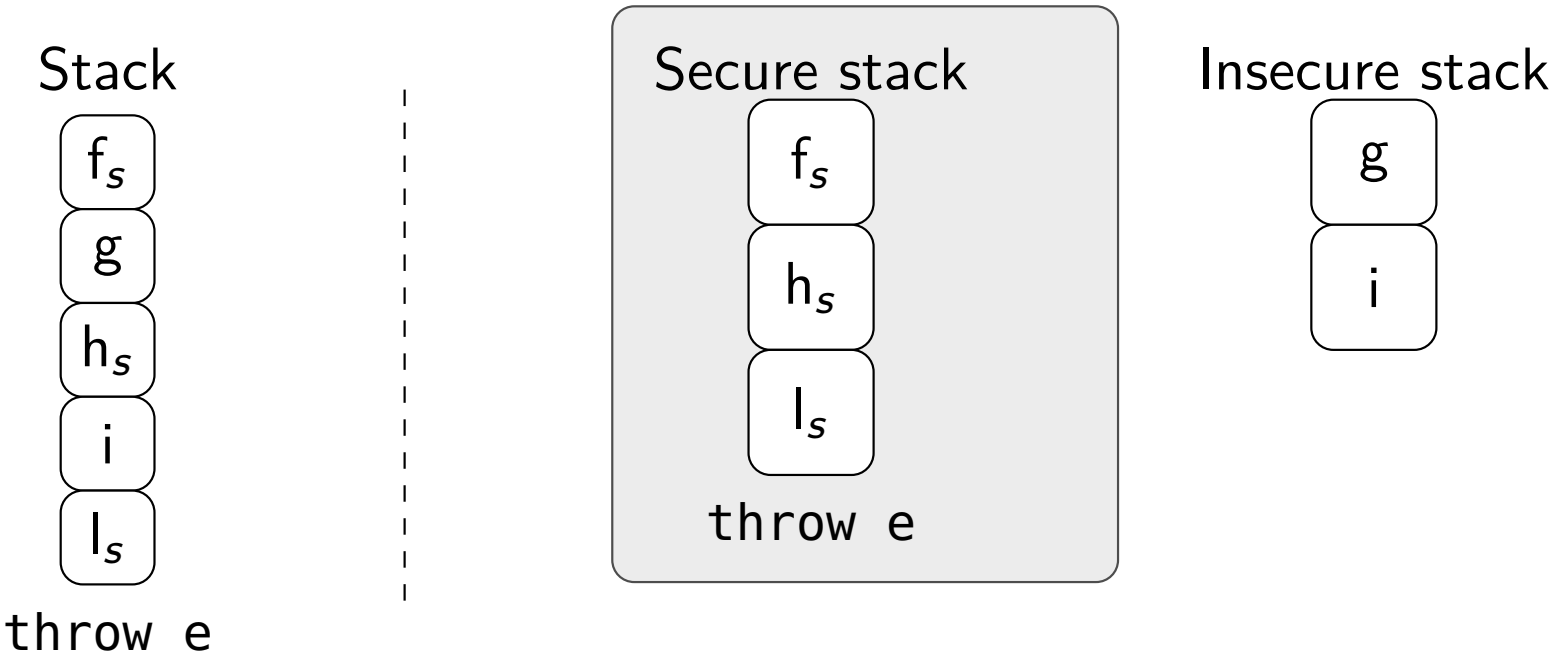
Dynamic Memory Allocation

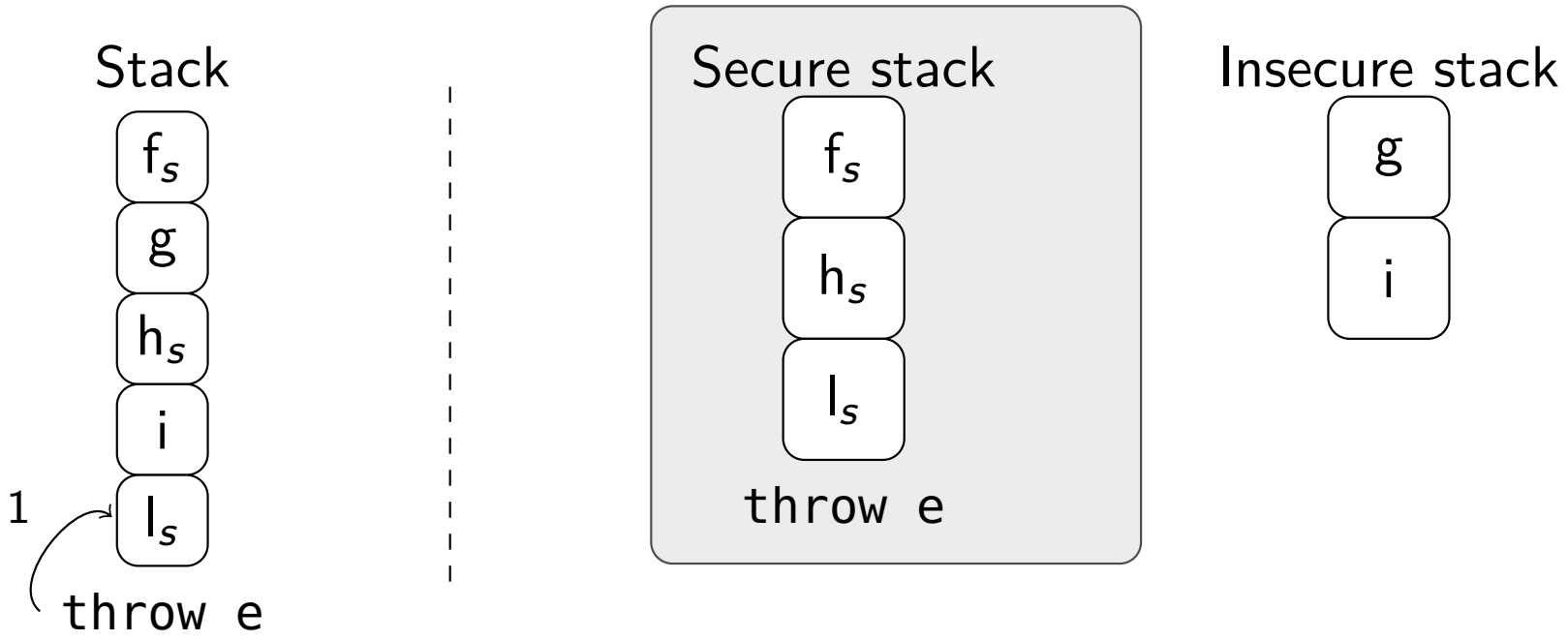


- Object id guessing
- map Oid to natural numbers
- add Oid to map
- lookup ($\mathbf{O}(1)$) when number is received
- dynamic typecheck for: current object arguments
- no need of extra information

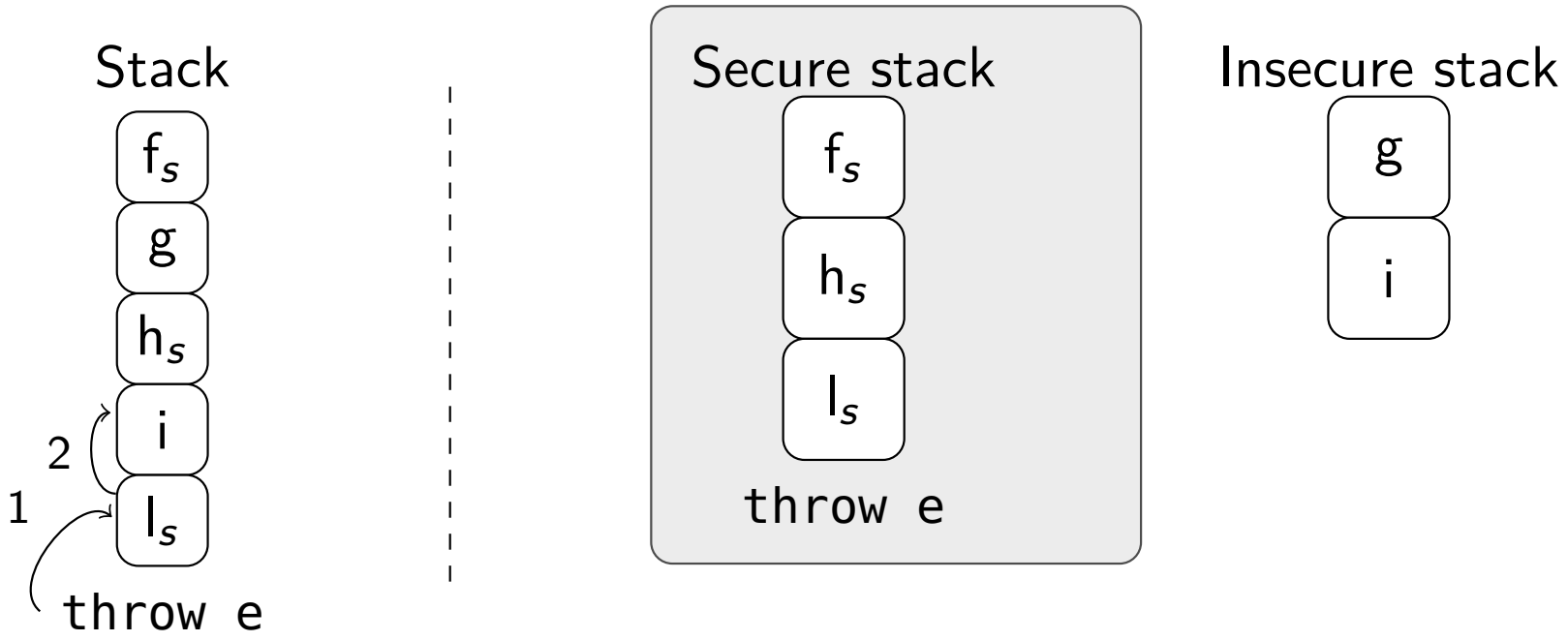
Exceptions


Stack
f_s
g
h_s
i
l_s
throw e
Secure stack
f_s
h_s
l_s
throw e
Insecure stack
g
i

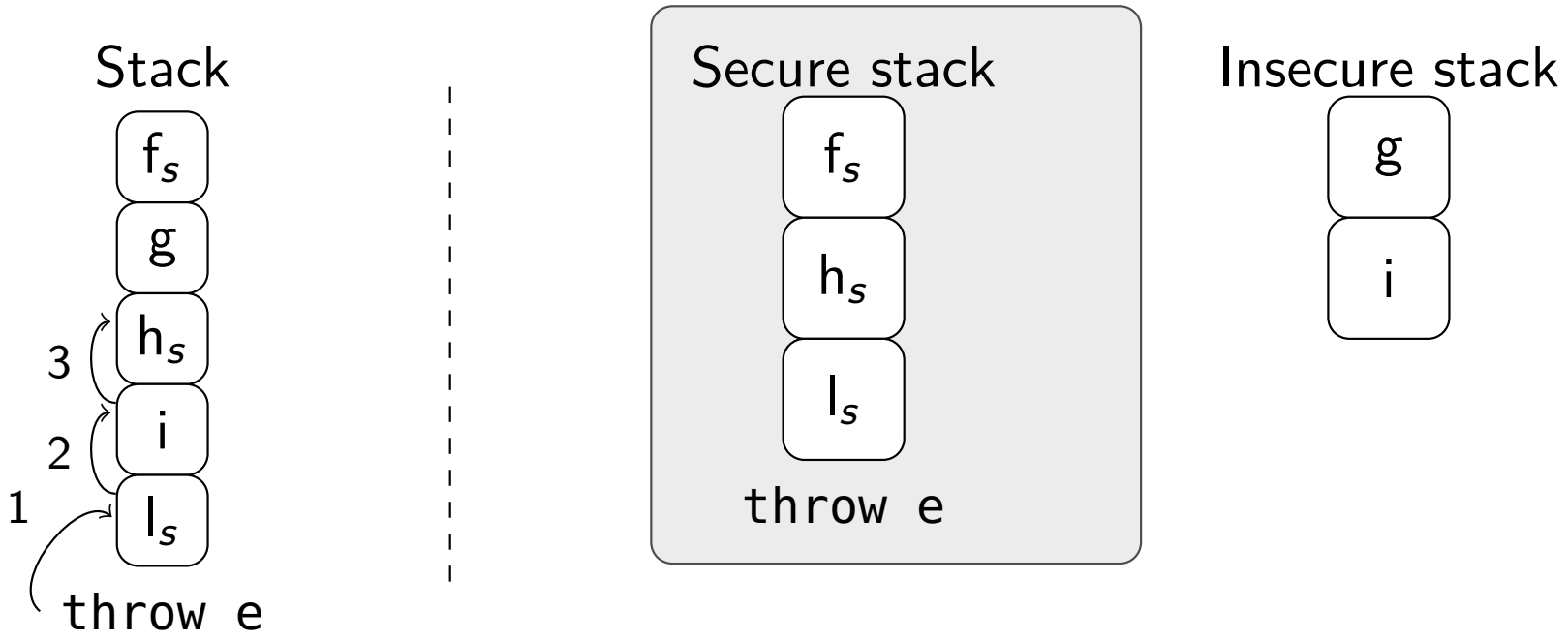
Exceptions


Stack
f_s
g
h_s
i
1
l_s
throw e
Secure stack
f_s
h_s
l_s
throw e
Insecure stack
g
i

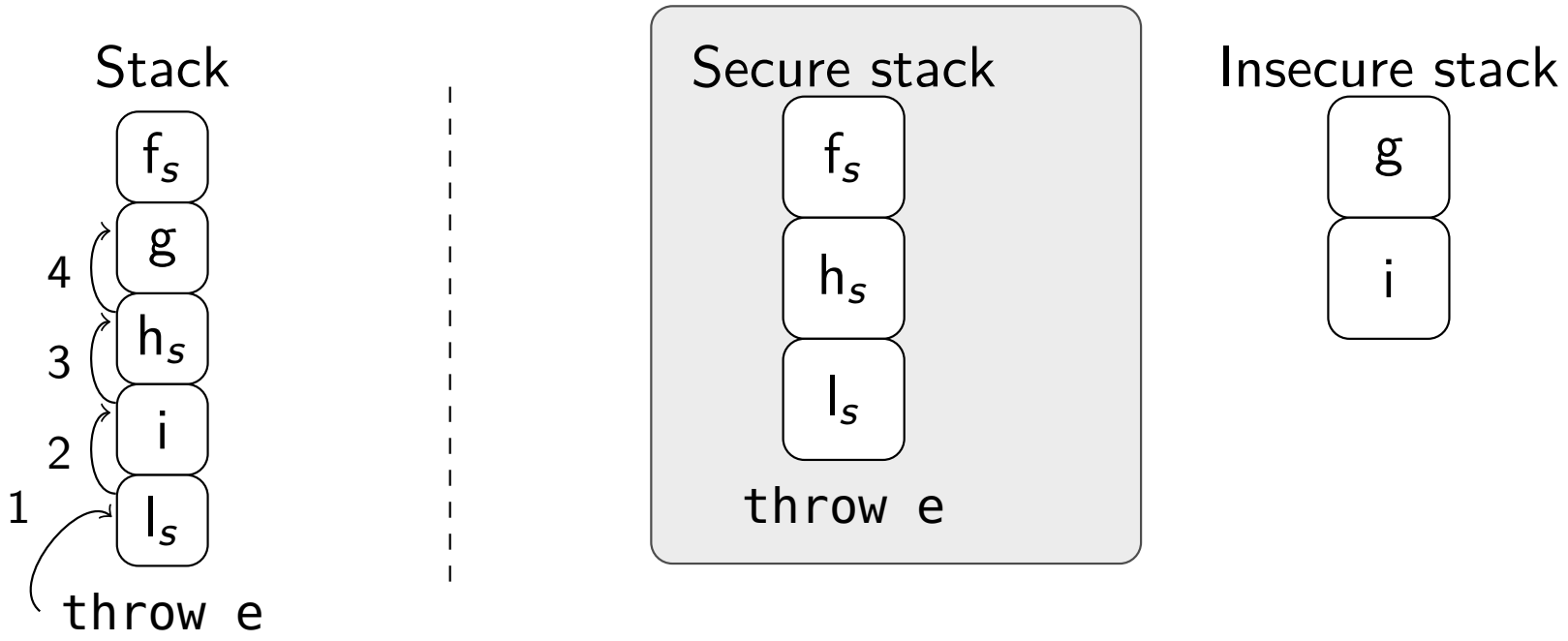
Exceptions


Stack
f_s
g
h_s
i
l_s
2
1
throw e
Secure stack
f_s
h_s
l_s
throw e
Insecure stack
g
i

Exceptions


Stack
f_s
g
h_s
i
l_s
3
2
1
throw e
Secure stack
f_s
h_s
l_s
throw e
Insecure stack
g
i

Exceptions


Stack
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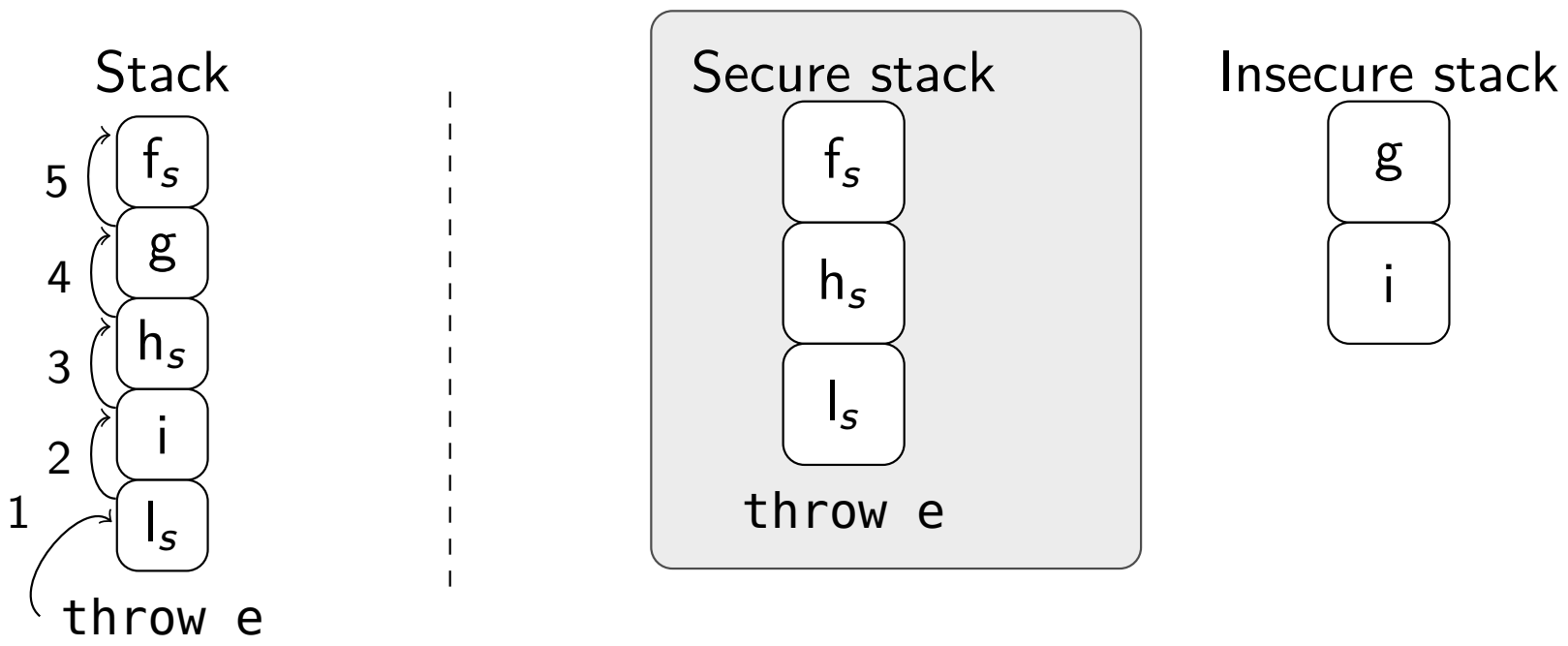
Stack
5
4
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2
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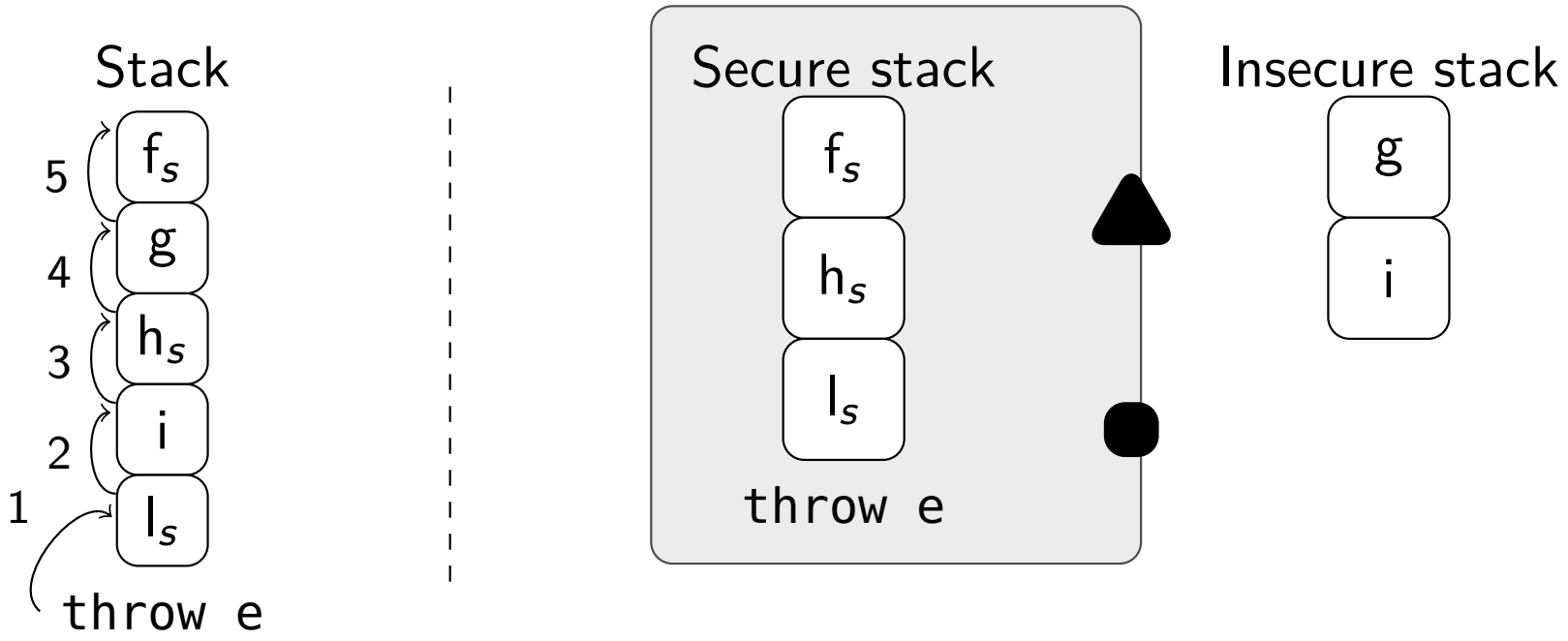
Exceptions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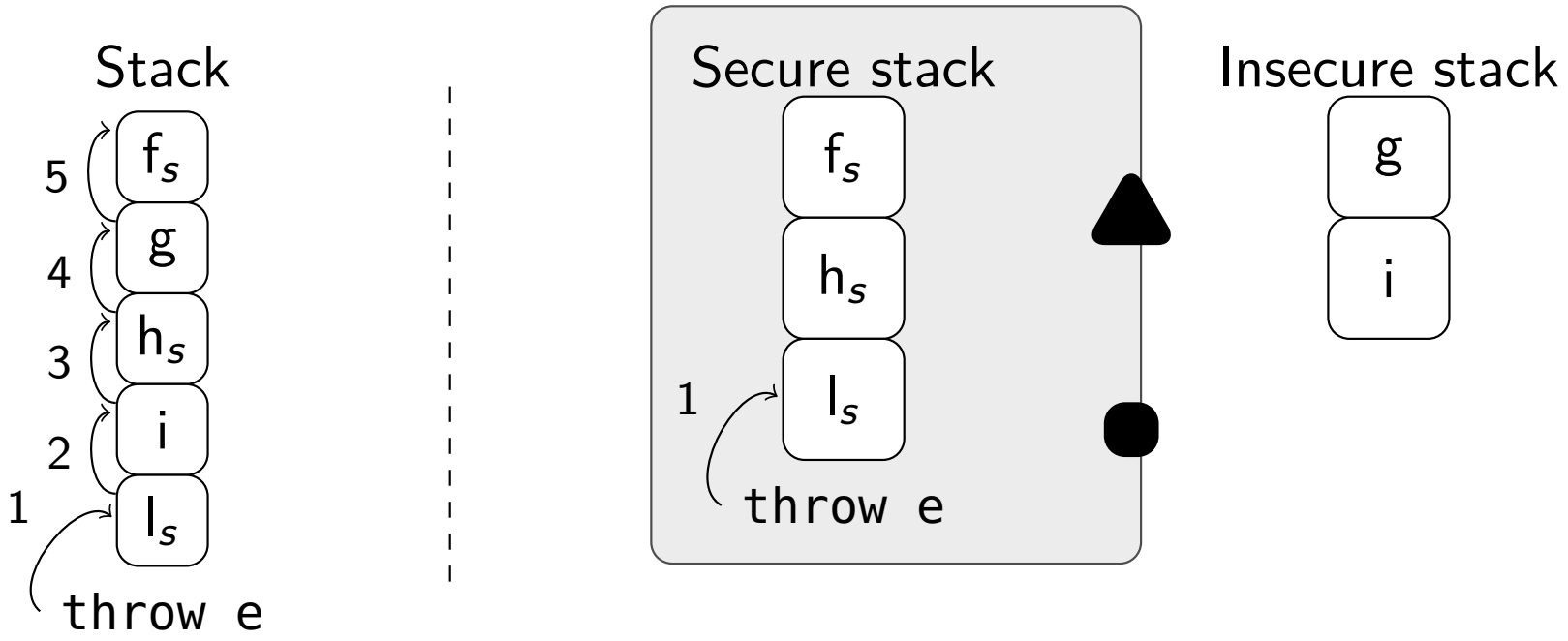
Exceptions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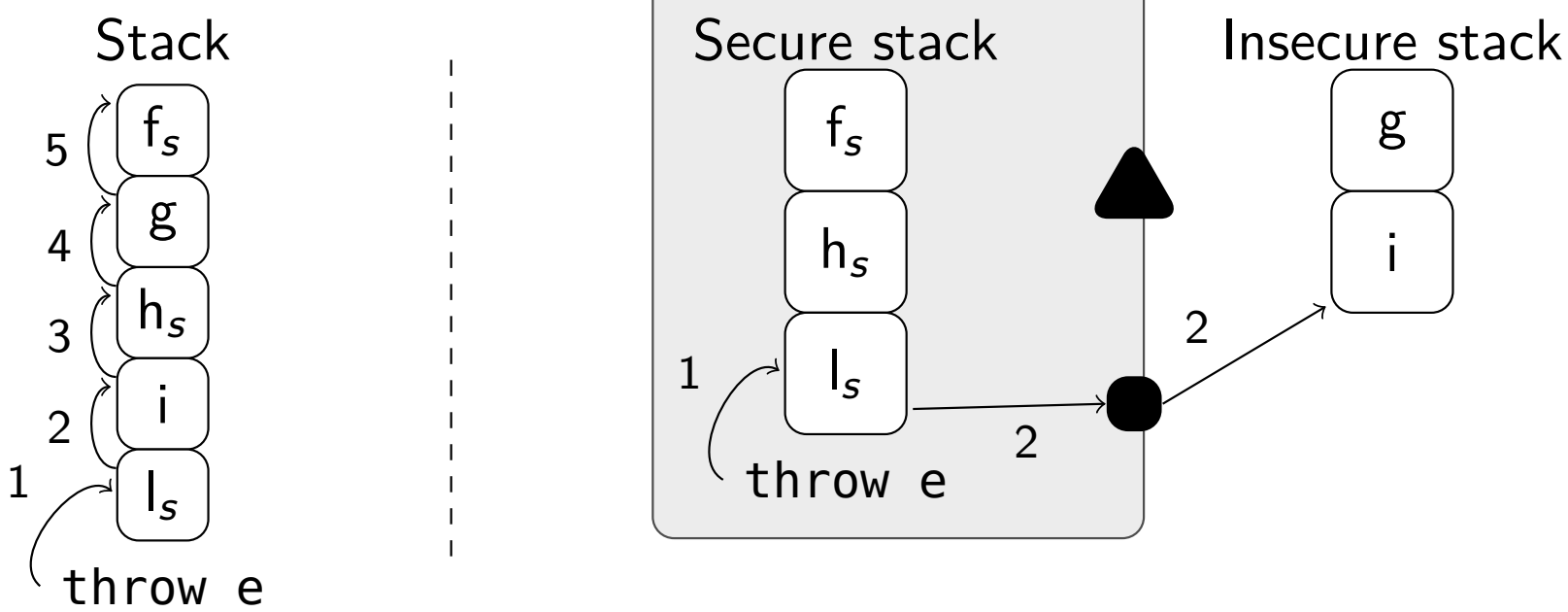
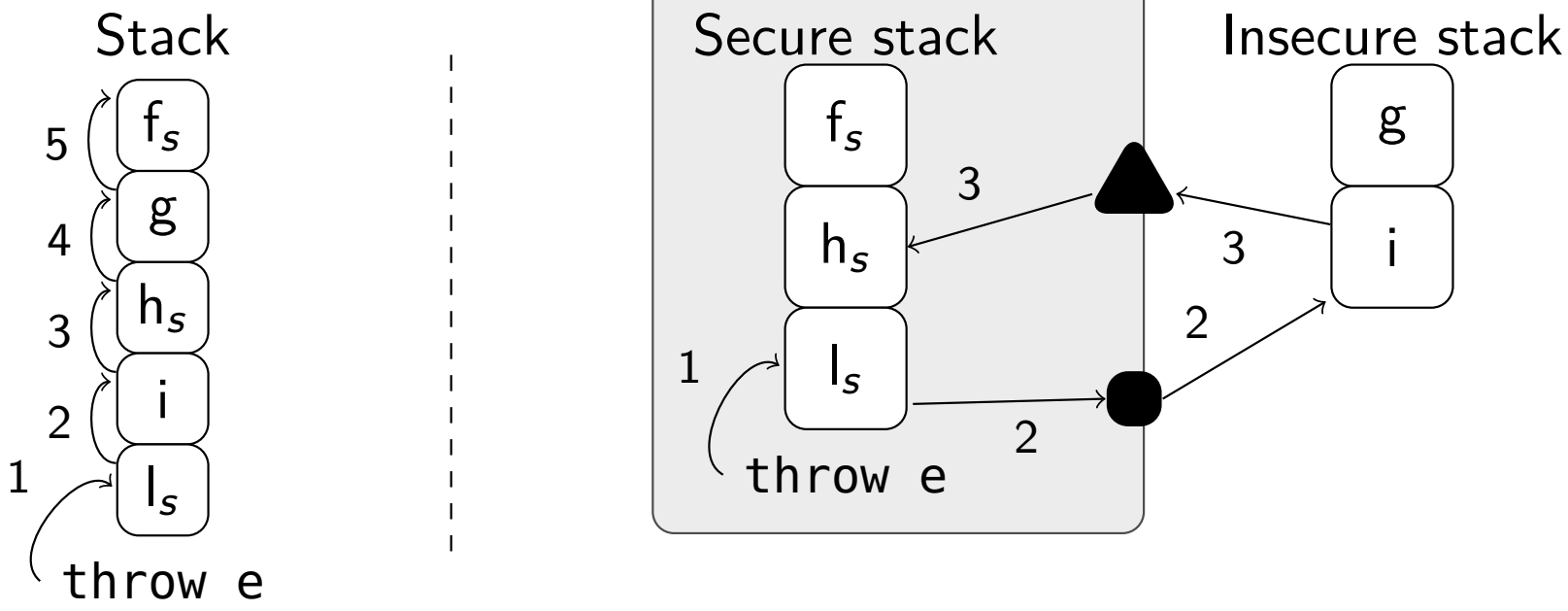


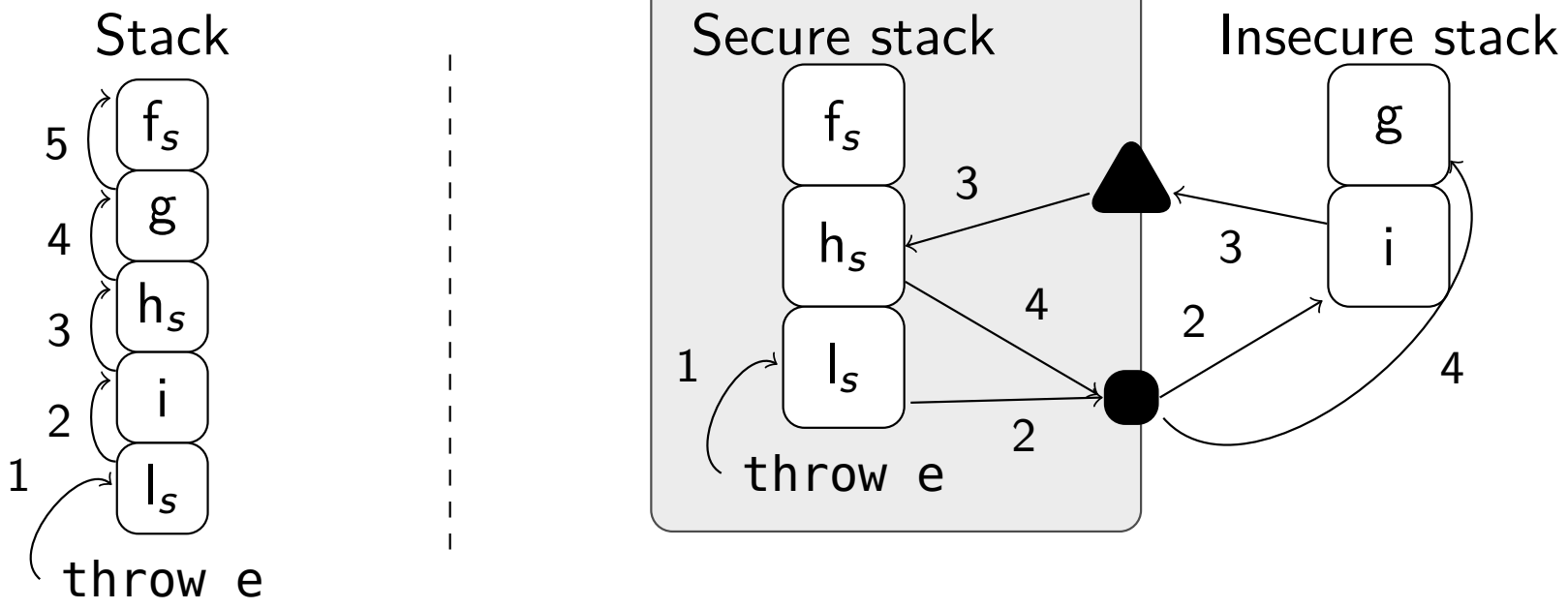
Record passed exceptions

Exceptions



Record passed exceptions
Check that exception could be thrown

Exceptions



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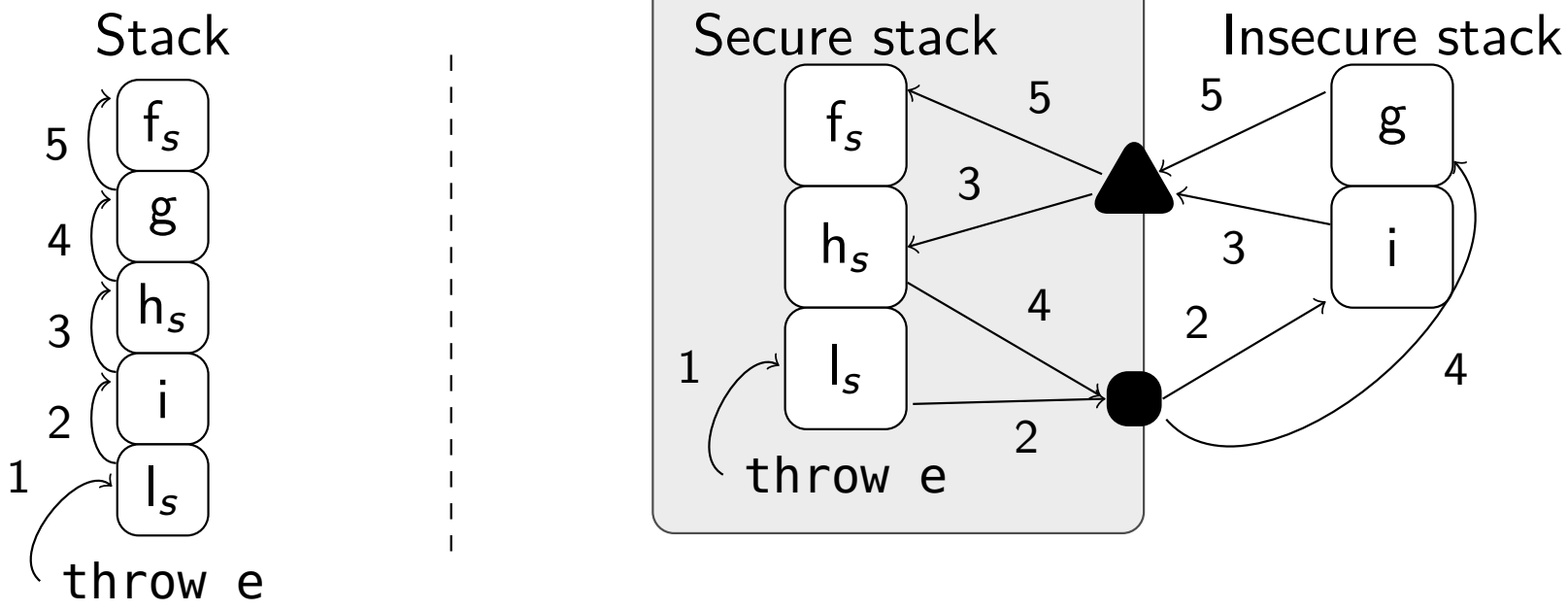

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So now...

- We have a strategy to securely compile J+E code

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Q: What is missing?

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A PROOF!

Secure Compilation, Formally

$$C_1 \simeq^{\mathsf{J+E}} C_2 \iff C_1^{\downarrow} \simeq^{\mathsf{A+I}} C_2^{\downarrow}$$

Secure Compilation, Formally

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Contextual Equivalence

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$$C_1 \simeq^{\mathcal{S}} C_2 \triangleq \forall \mathbb{C}.\ \mathbb{C}[C_1]\Uparrow \iff \mathbb{C}[C_2]\Uparrow$$

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All contexts

Secure Compilation

$$C_1 \simeq^{\mathsf{J+E}} C_2 \iff C_1^{\downarrow} \simeq^{\mathsf{A+I}} C_2^{\downarrow}$$

Secure Compilation

$$C_1 \simeq^{\mathsf{J+E}} C_2 \iff C_1^{\downarrow} \simeq^{\mathsf{A+I}} C_2^{\downarrow}$$

$$(\forall \mathbb{C}.\ \mathbb{C}[C_1]\Uparrow \iff \mathbb{C}[C_2]\Uparrow\ ) \iff (\forall \mathbb{M}.\ \mathbb{M}[C_1^{\downarrow}]\Uparrow \iff \mathbb{M}[C_2^{\downarrow}]\Uparrow\ )$$

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VERY COMPLEX!

Secure Compilation

$$C_1 \simeq^{\mathsf{J+E}} C_2 \iff C_1^{\downarrow} \simeq^{\mathsf{A+I}} C_2^{\downarrow}$$

Secure Compilation

$$C_1 \simeq^{\mathsf{J+E}} C_2 \quad \Leftarrow \quad C_1^{\downarrow} \simeq^{\mathsf{A+I}} C_2^{\downarrow}$$

Secure Compilation

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$$C_1 \simeq^{\mathsf{J+E}} C_2 \quad \Rightarrow \quad C_1^{\downarrow} \simeq^{\mathsf{A+I}} C_2^{\downarrow}$$

Secure Compilation

$$C_1 \simeq^{\mathsf{J+E}} C_2 \quad \Rightarrow \quad \boxed{\begin{array}{c} C_1^{\downarrow} \simeq^{\mathsf{A+I}} C_2^{\downarrow} \\ \Updownarrow \\ \mathsf{Traces}(C_1^{\downarrow}) = \mathsf{Traces}(C_2^{\downarrow}) \end{array}}$$

Fully Abstract Trace Semantics

Secure Compilation

$$C_1 \not\simeq^{\text{J+E}} C_2 \quad \Leftarrow \quad \text{Traces}(C_1^{\downarrow}) \neq \text{Traces}(C_2^{\downarrow})$$

Secure Compilation

$C_1 \not\simeq^{\text{J+E}} C_2$ ✔ $\Leftarrow$ $\quad \text{Traces}(C_1^{\downarrow}) \neq \text{Traces}(C_2^{\downarrow})$

Secure Compilation

$$C_1 \not\simeq^{\text{J+E}} C_2 \Leftarrow$$

$$C_1^{\downarrow} \simeq^{\text{A+I}} C_2^{\downarrow}$$

$$\Updownarrow$$

$$\text{Traces}(C_1^{\downarrow}) = \text{Traces}(C_2^{\downarrow})$$

Fully Abstract Trace Semantics

Outline

Modular, Secure Compilation

- current model has a single secure module

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- current model has a single secure module
- assembly-level linking of securely-compiled modules is not investigated

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Modular, Secure Compilation

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- assembly-level linking of securely-compiled modules is not investigated
- can we link securely-compiled modules securely?
- what attacks arise in the presence of linking?

Logical-relations Based Proof Technique

- Devirese *et al.*@ POPL'16

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- does full abtraction mean security?
- can it express all security properties?
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- can we relate it to hyperproperties (i.e., properties over sets of traces)?

Questions

Thank you!

Qs ?