Secure Compilation of Object-Oriented Components to Protected Module Architectures

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Outline

1. Protected Modules Architectures
2. Secure (Fully Abstract) Compilation
3. What Can Go Wrong With...
   - Dynamic Memory Allocation
   - Exceptions
   - Cross-package Inheritance

Protected Modules Architecture (PMA)

- assembly-level isolation mechanism

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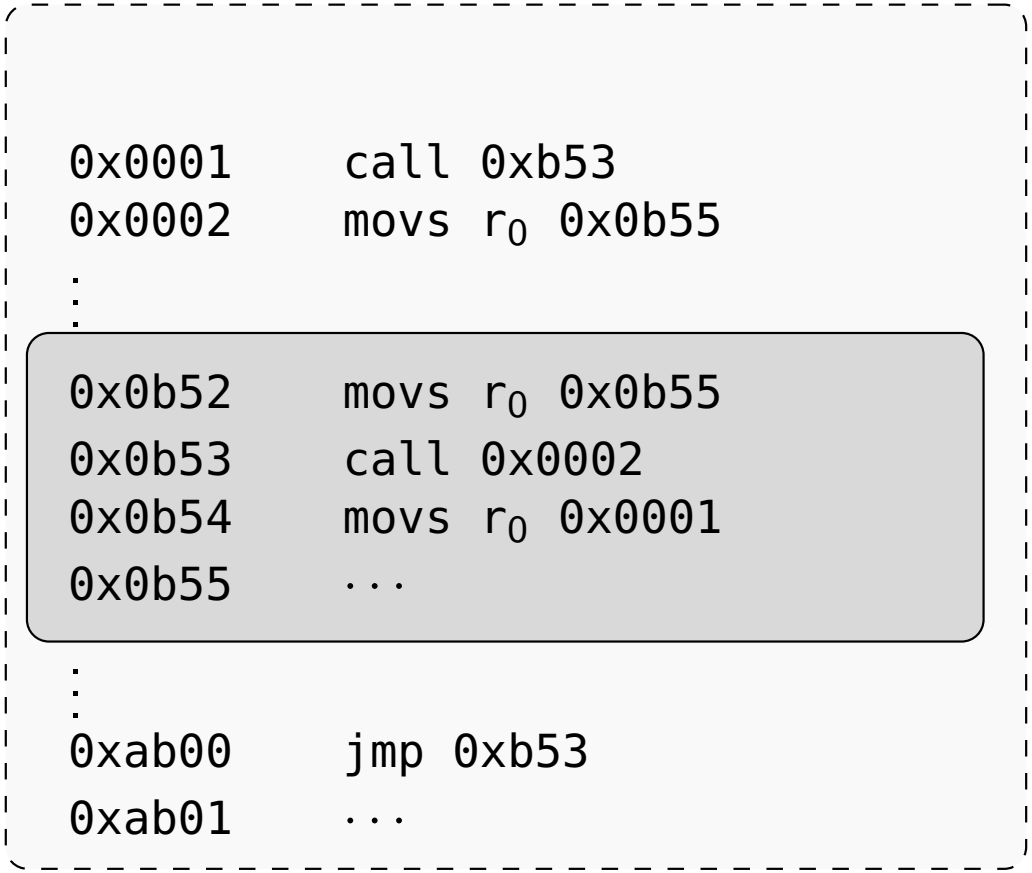
Let's see an example of PMA in action

PMA in Action

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

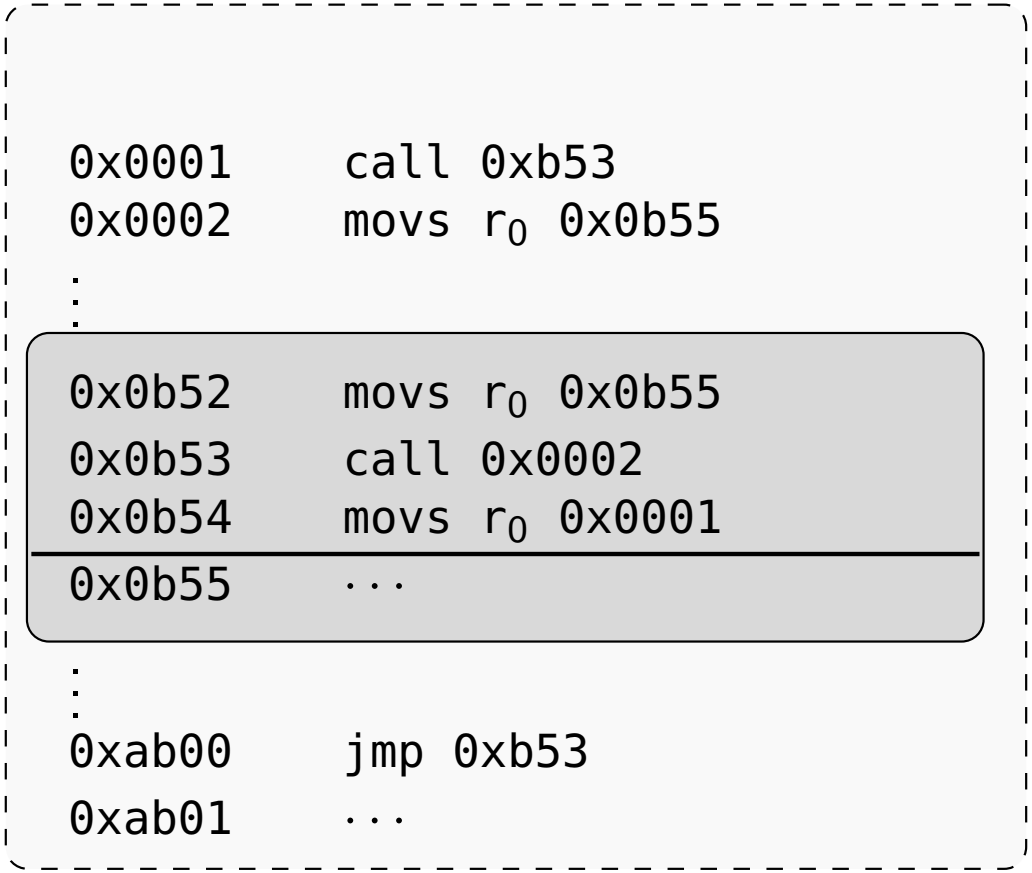
- memory space

PMA in Action



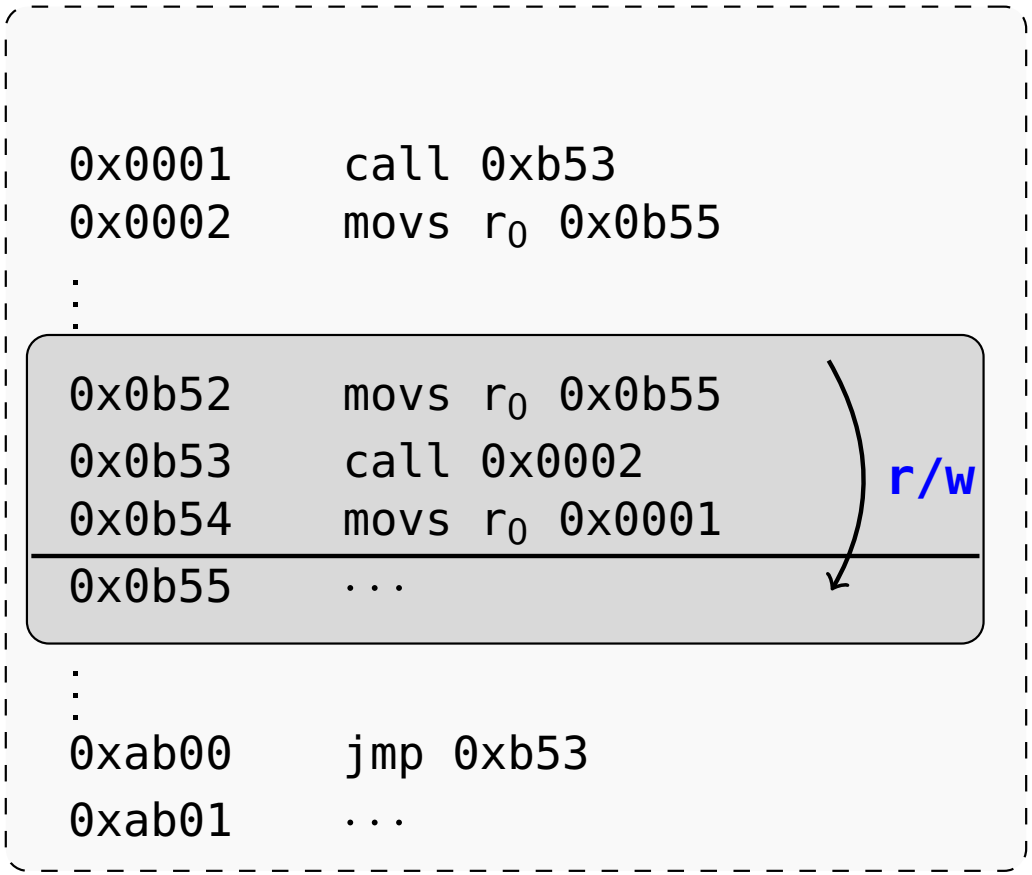
- memory space
- protected module = protected memory

PMA in Action



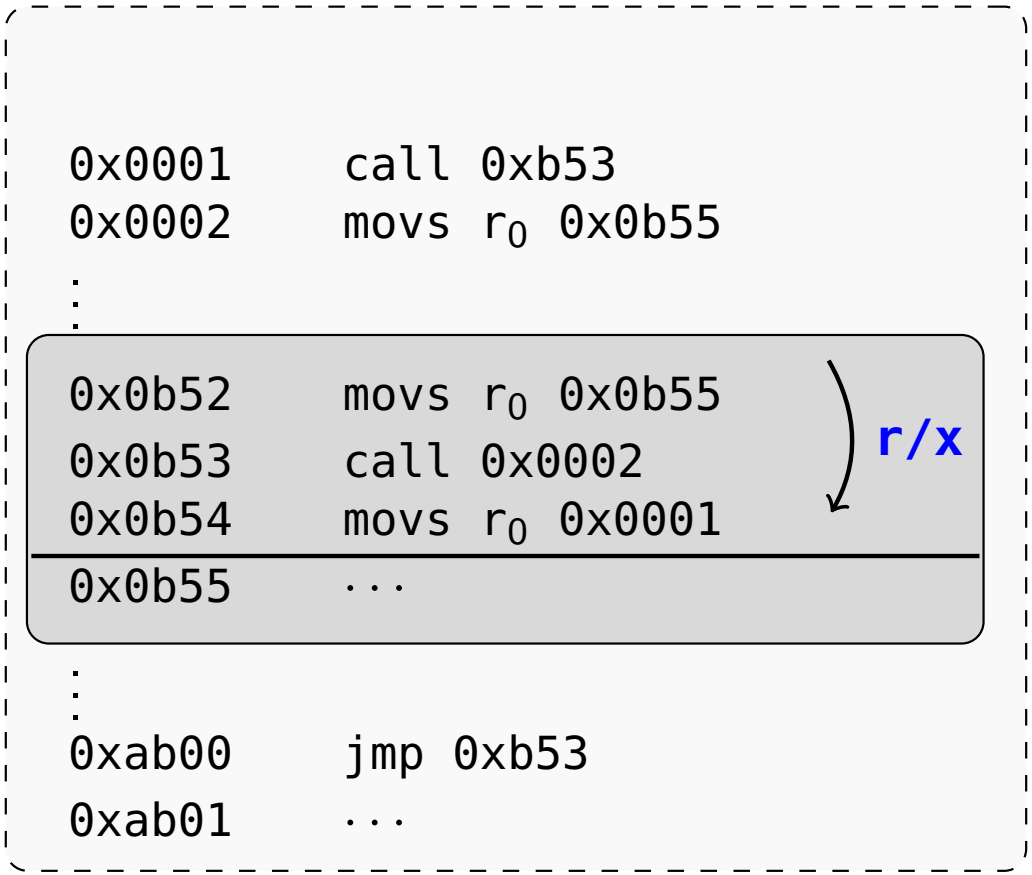
- memory space
- protected module = protected memory
- split in code and data

PMA in Action



- memory space
- protected module = protected memory
- split in code and data
- protected code is unrestricted

PMA in Action



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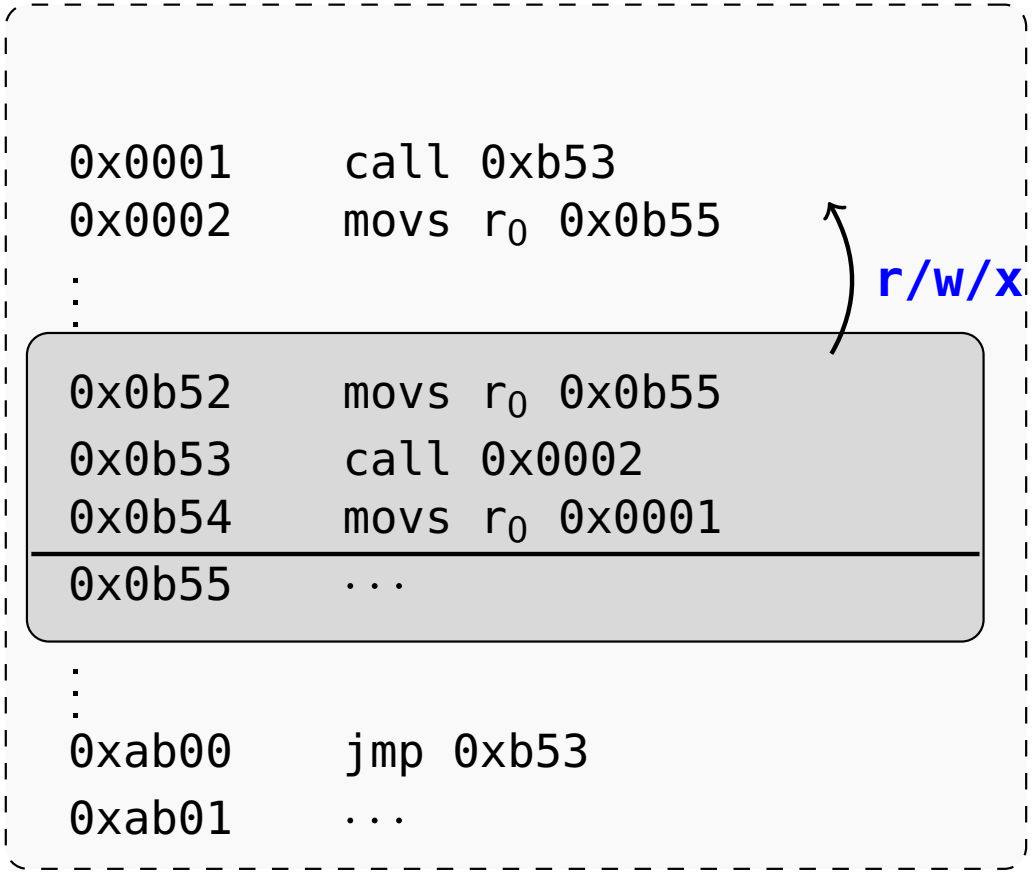

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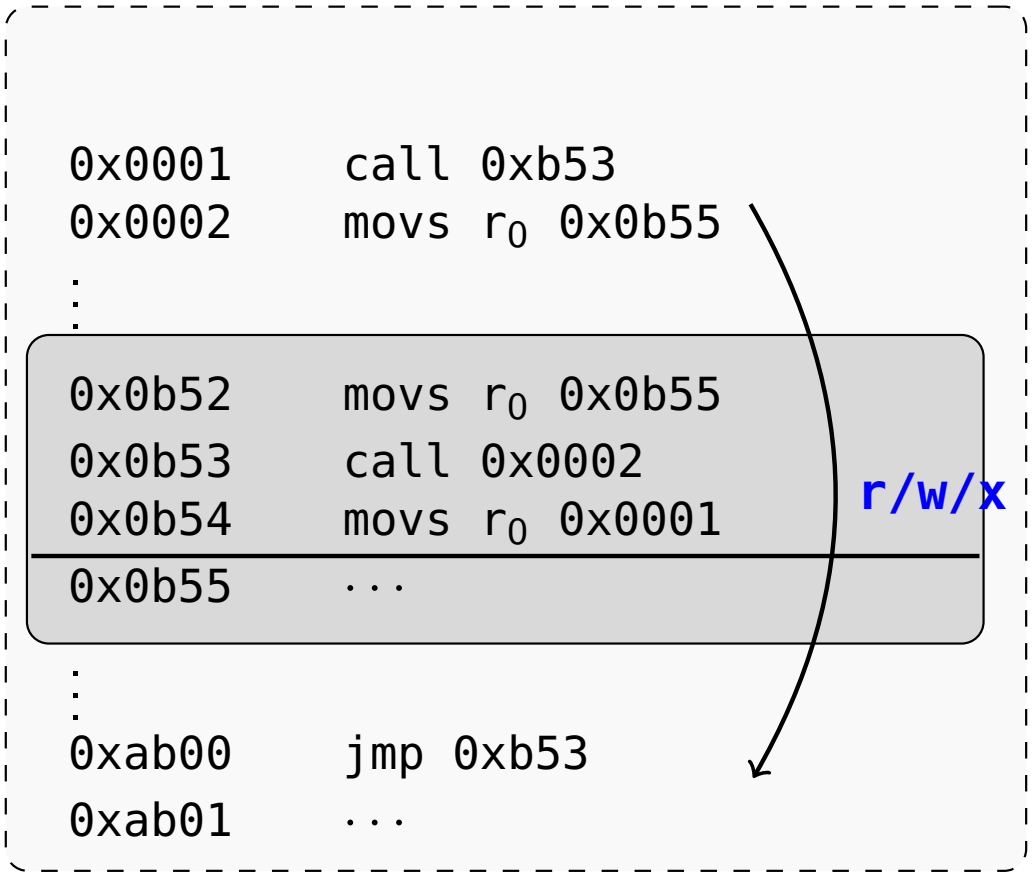

- memory space
- protected module = protected memory
- split in code and data
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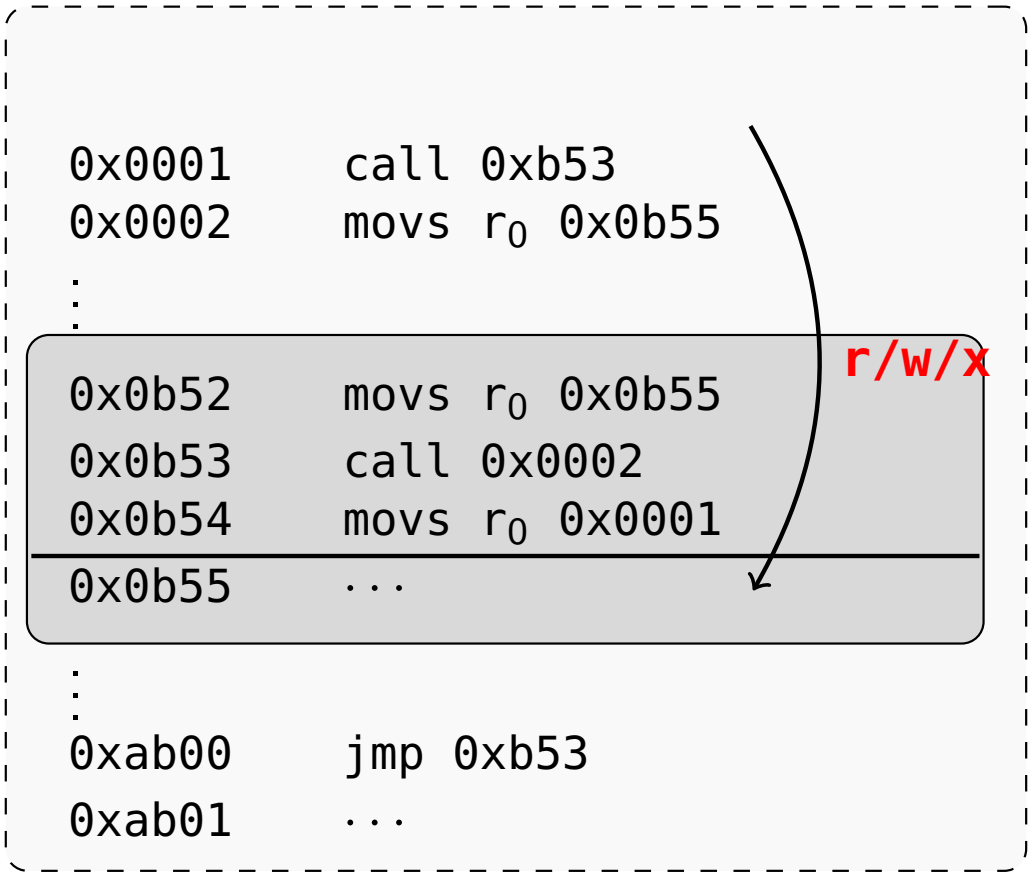

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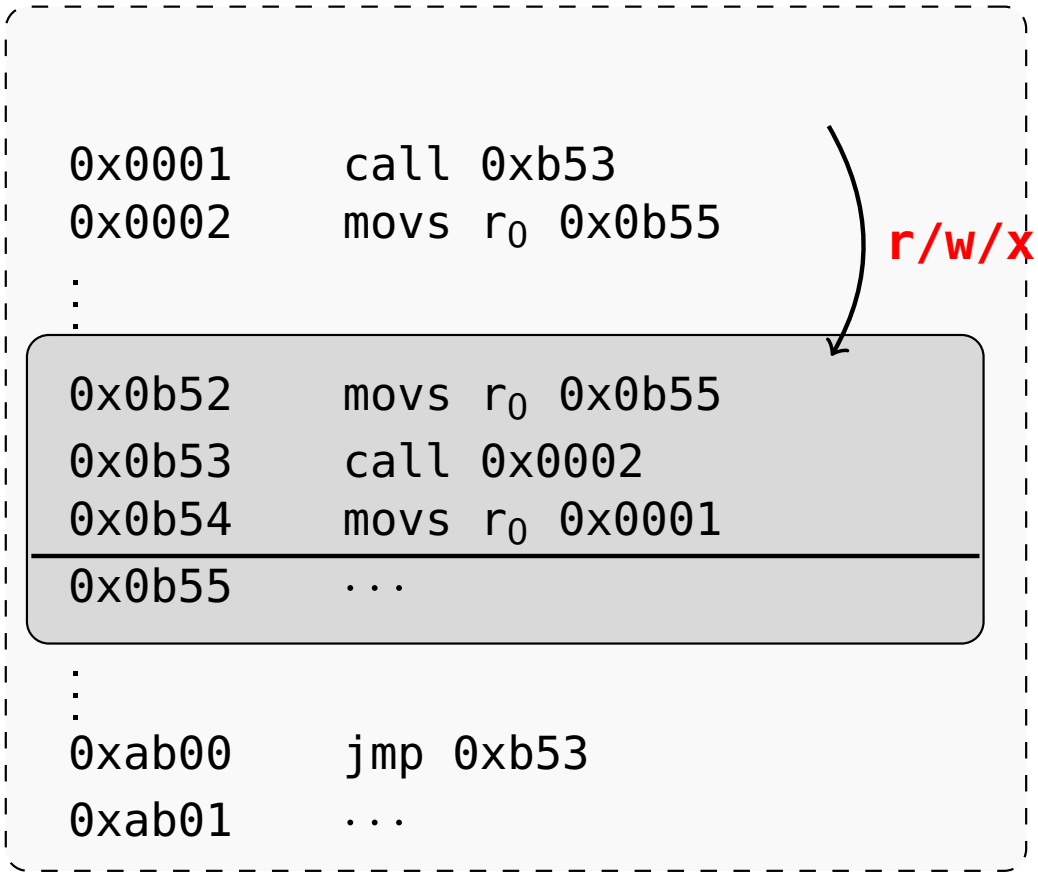

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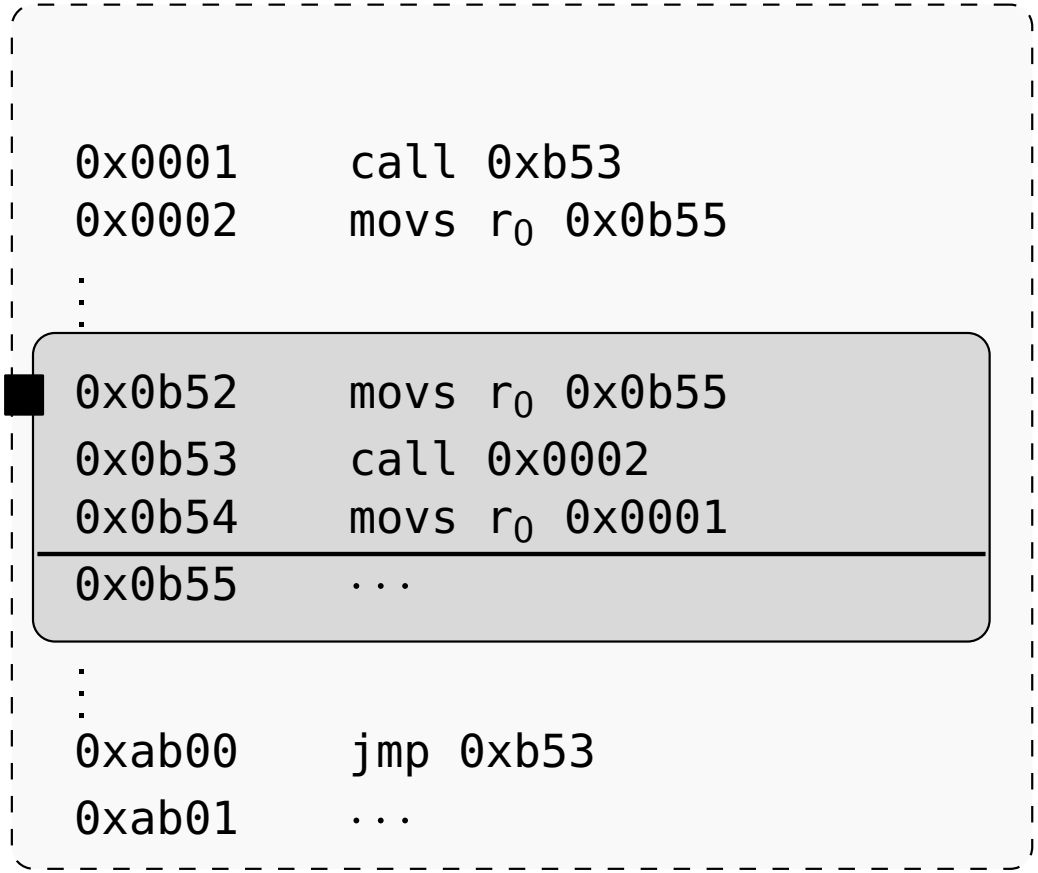

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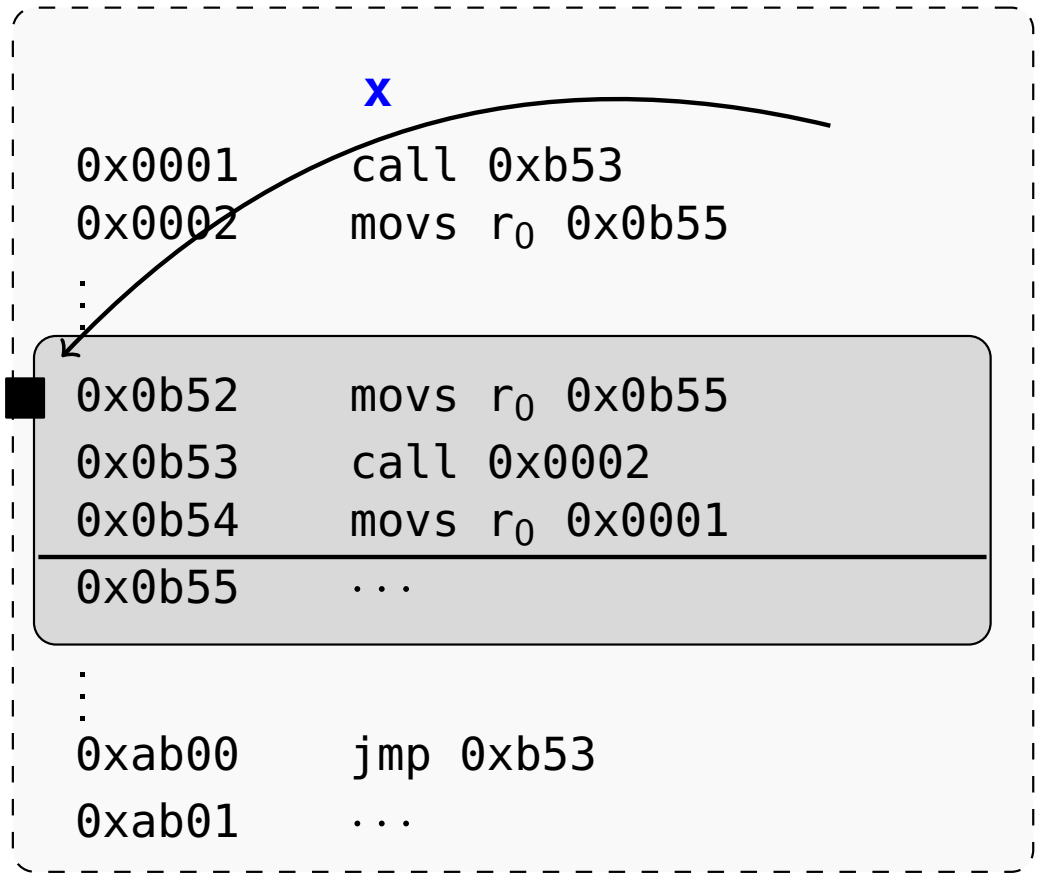

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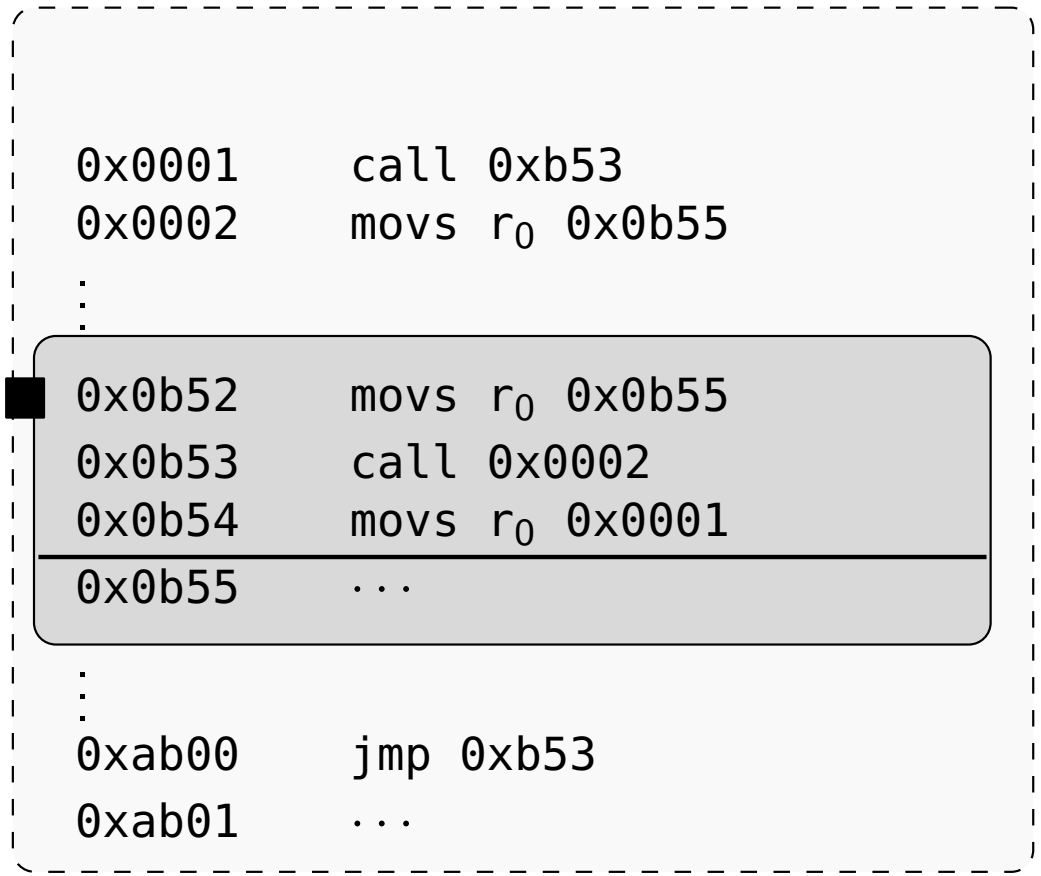

- memory space
- protected module = protected memory
- split in code and data
- protected code is unrestricted
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- entry points for communication (■)
- we need only 1 module

Languages of the Compiler

- target language: assembly

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Languages of the Compiler

- target language: assembly
- source language: +/- Java jr [JR05]
  - component-based
  - private fields
  - programming to an interface
  - exceptions

```
1  package PI;
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();
13     }
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15     private counter : Int;
16   }
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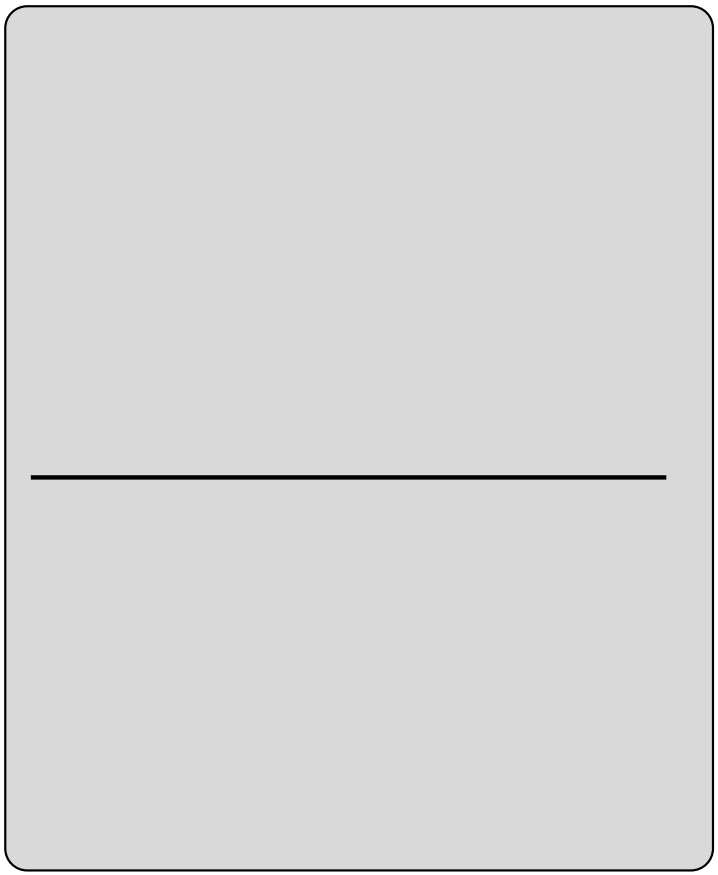

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Languages of the Compiler

Dynamic dispatch

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v-tables

Secure stack

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- proxy to `createAccount`
- `createAccount` body
- constructor

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- proxy to `createAccount`

  `createAccount` body

  constructor

  Dynamic dispatch

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v-tables

Secure stack

extAccount
counter

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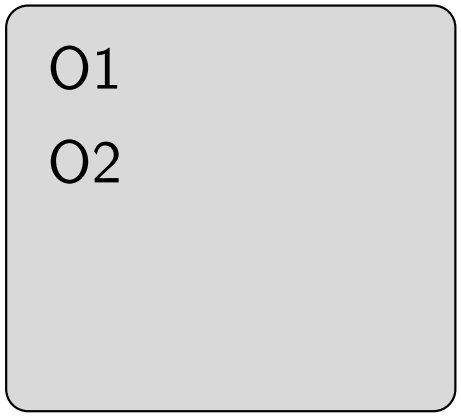
Secure Compilation, Informally

Source level

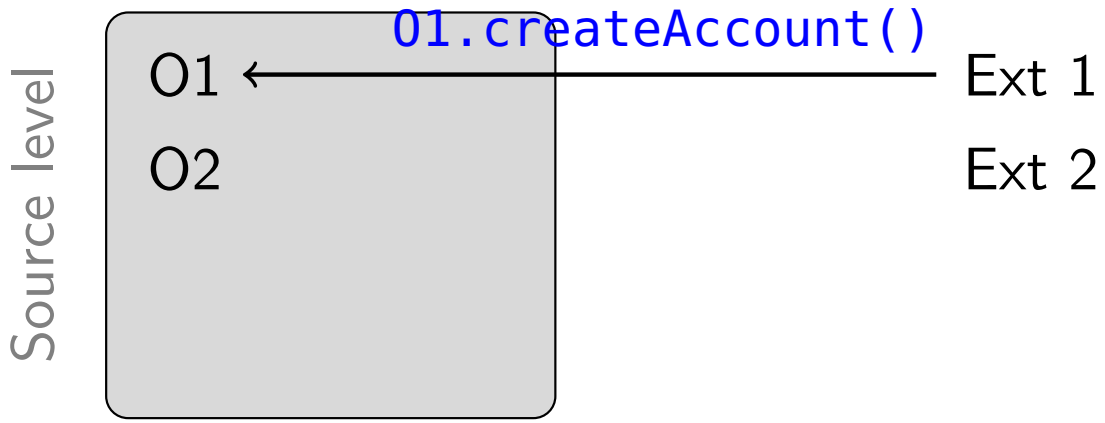


Ext 1

Ext 2

- Protect against low-level attackers

Secure Compilation, Informally



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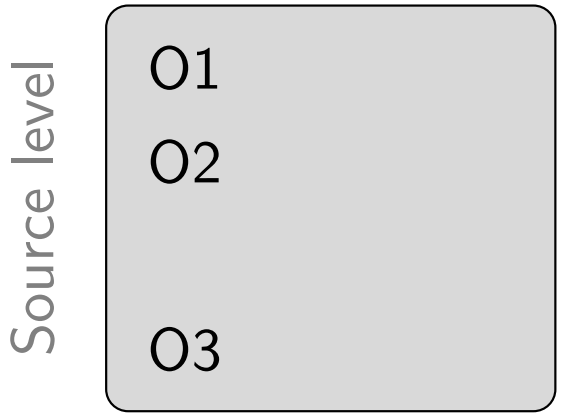

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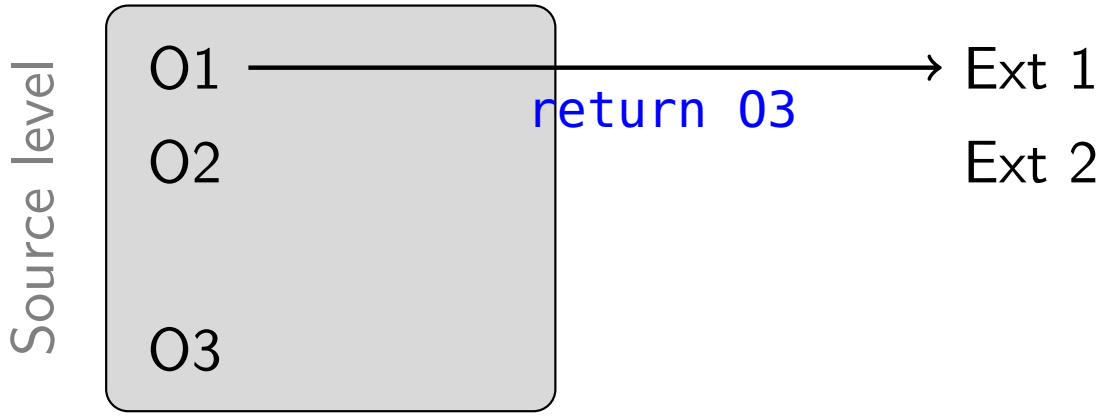

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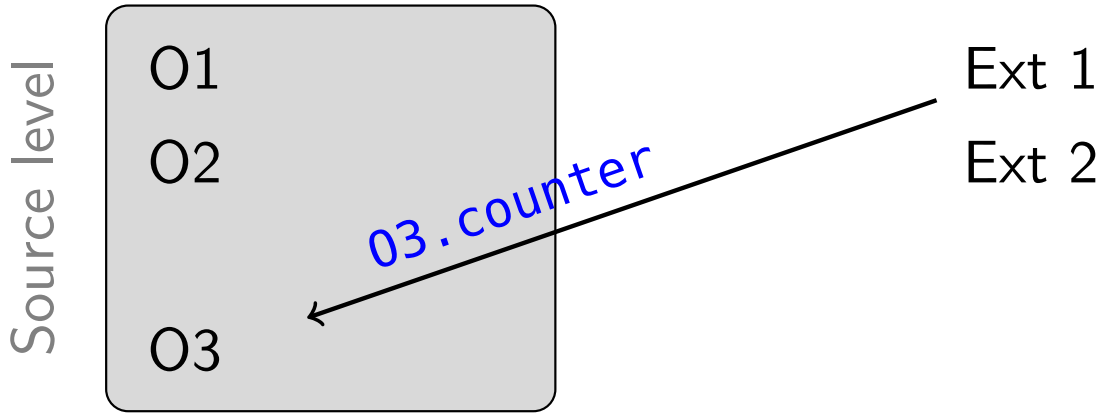

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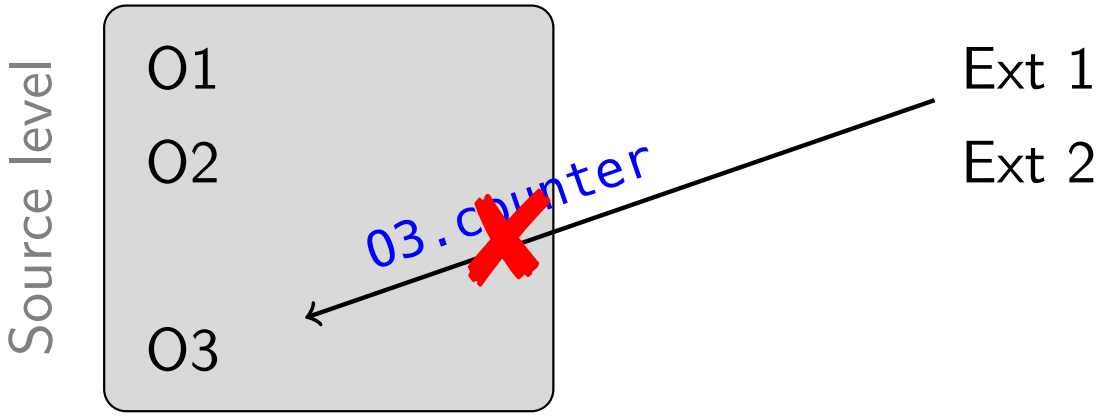

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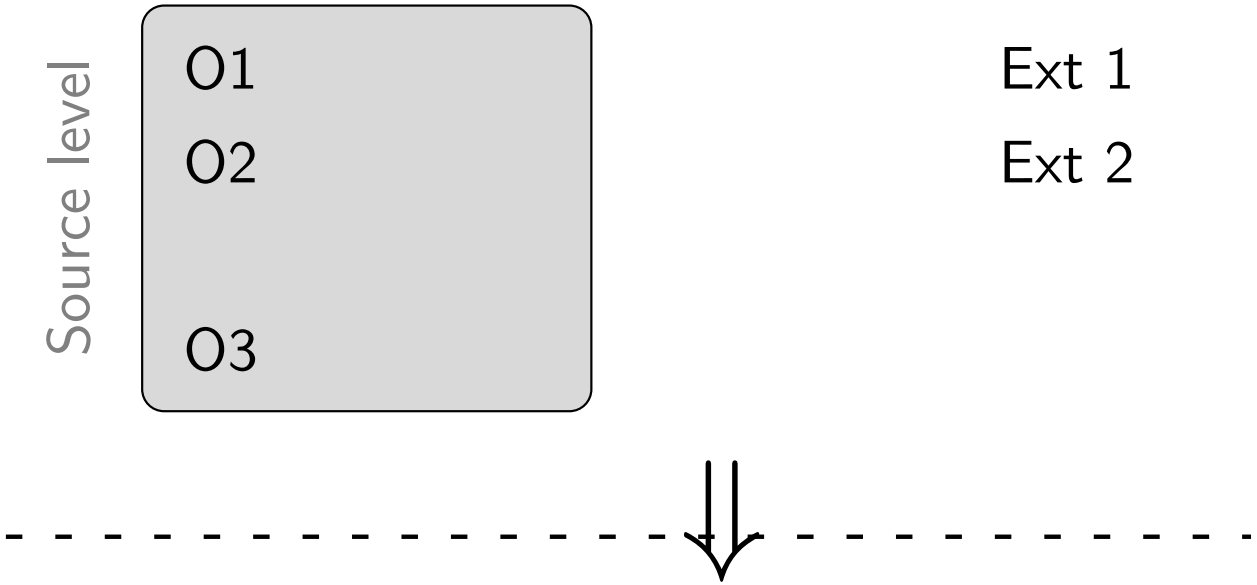

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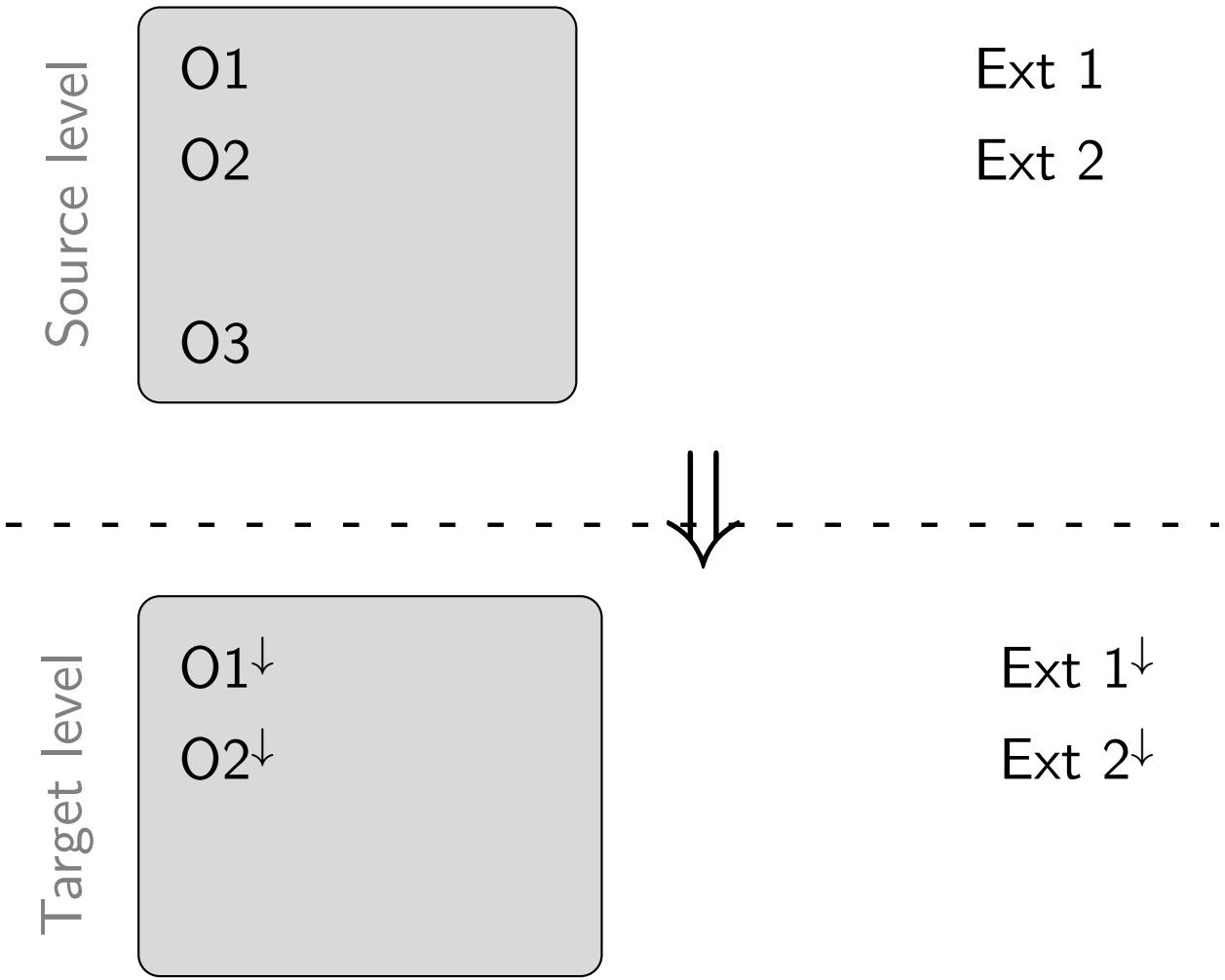

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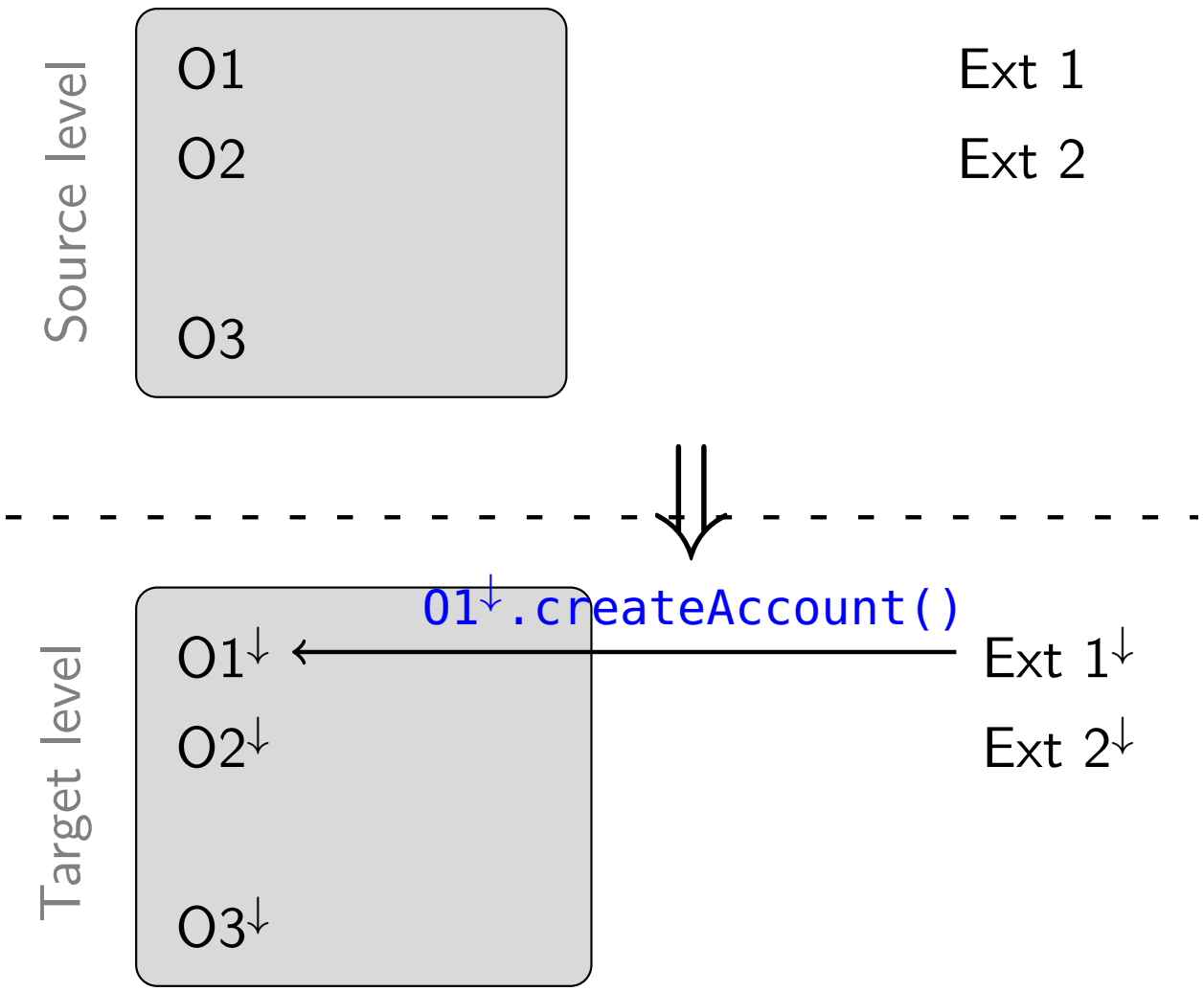

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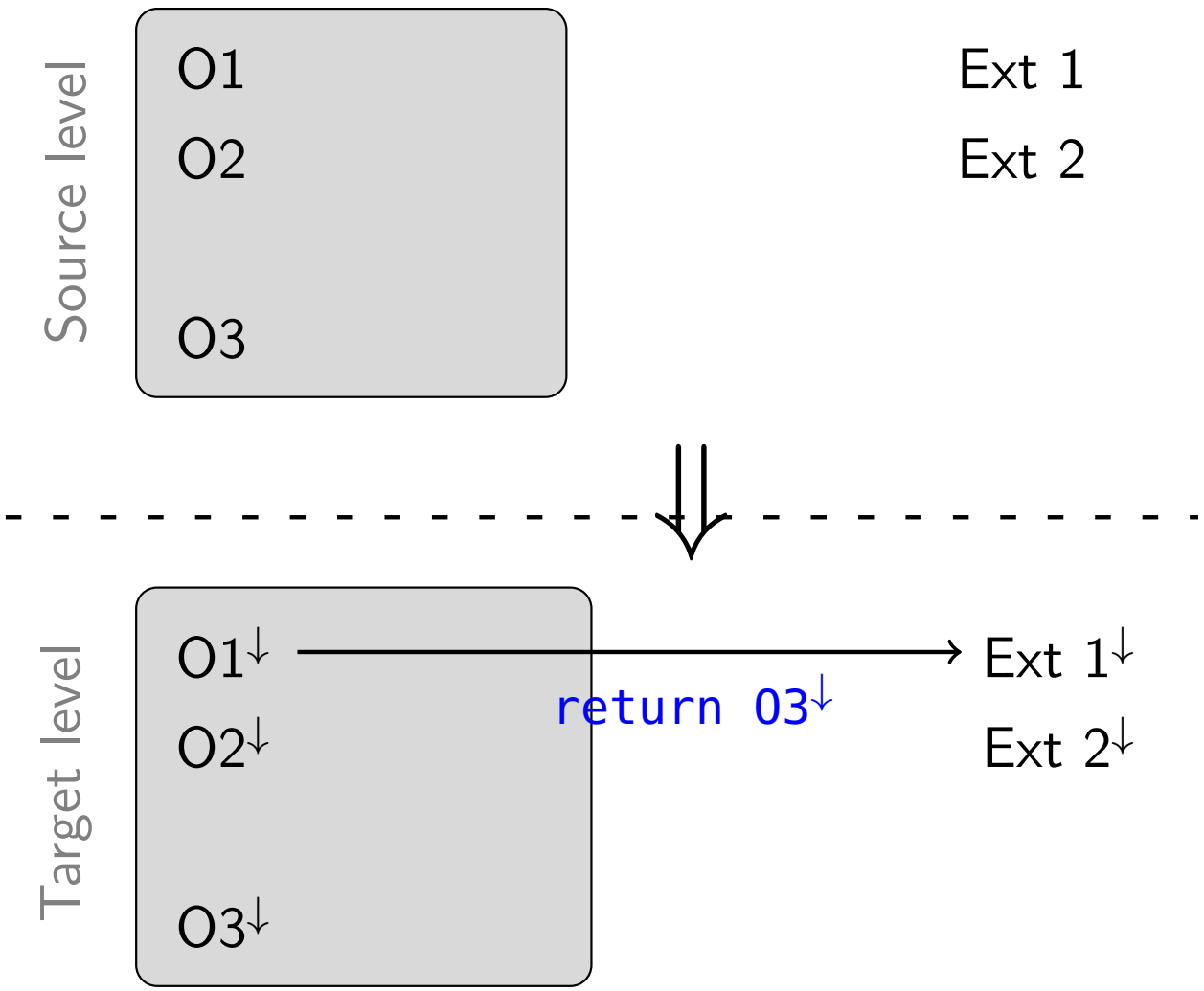

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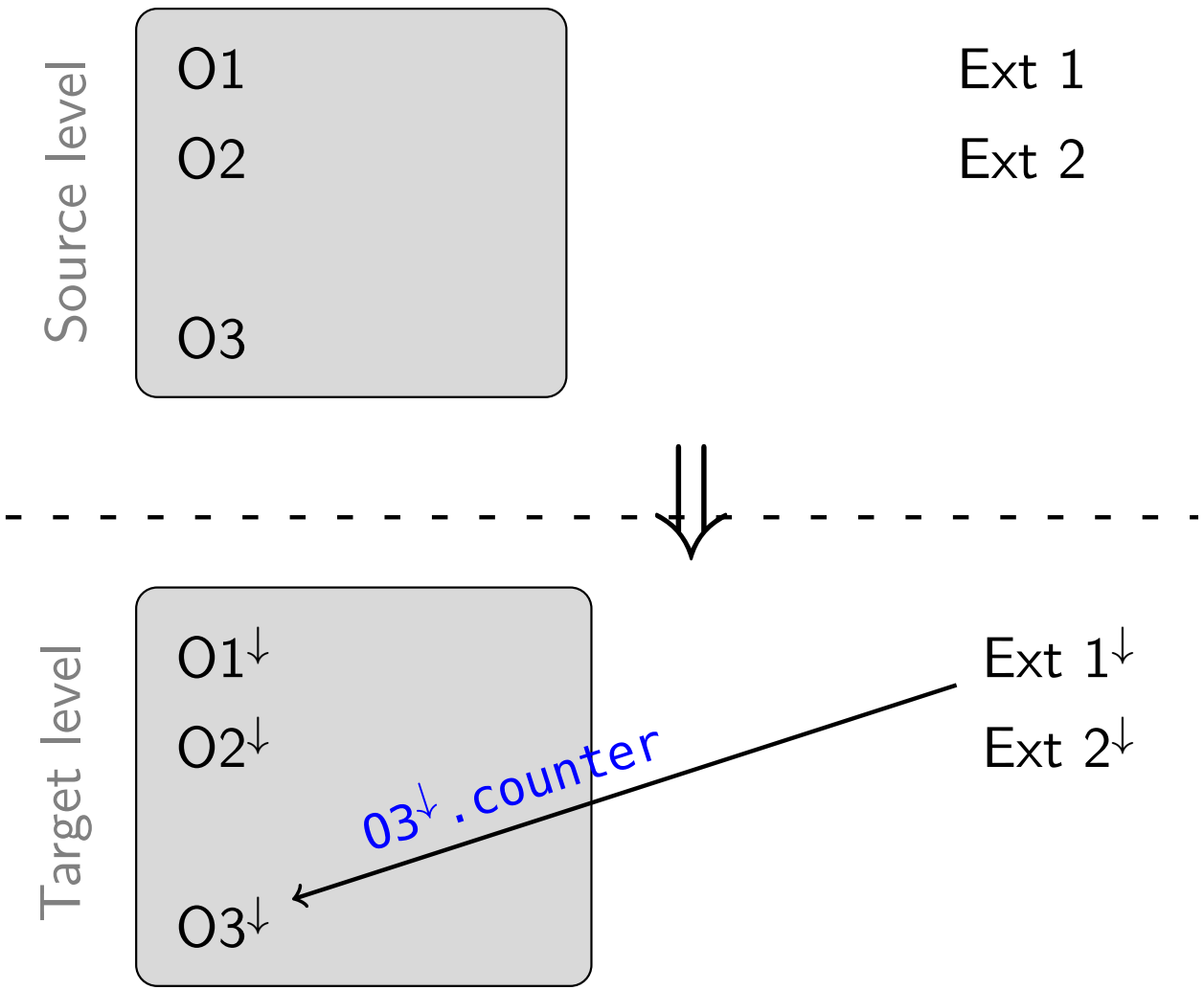

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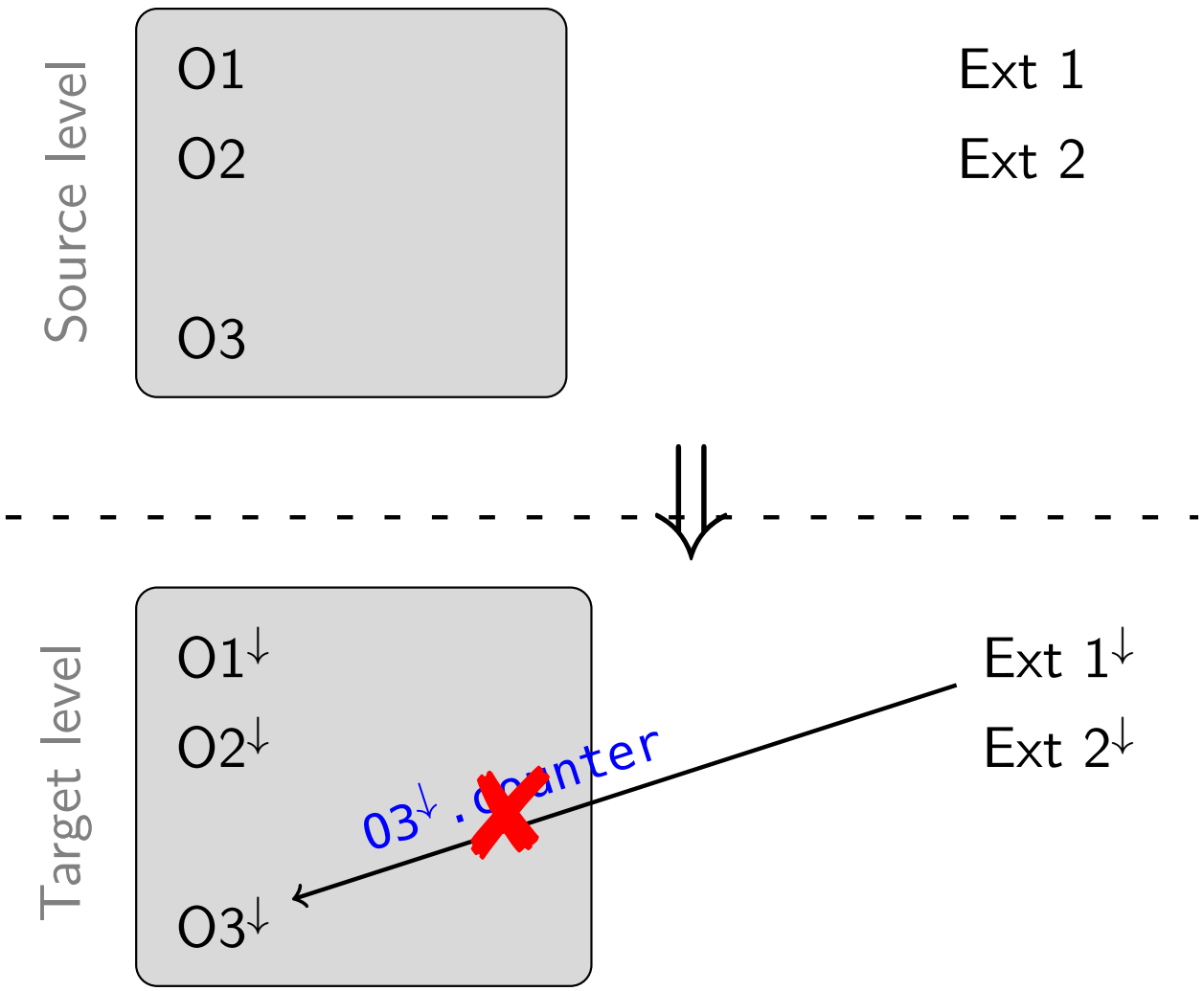

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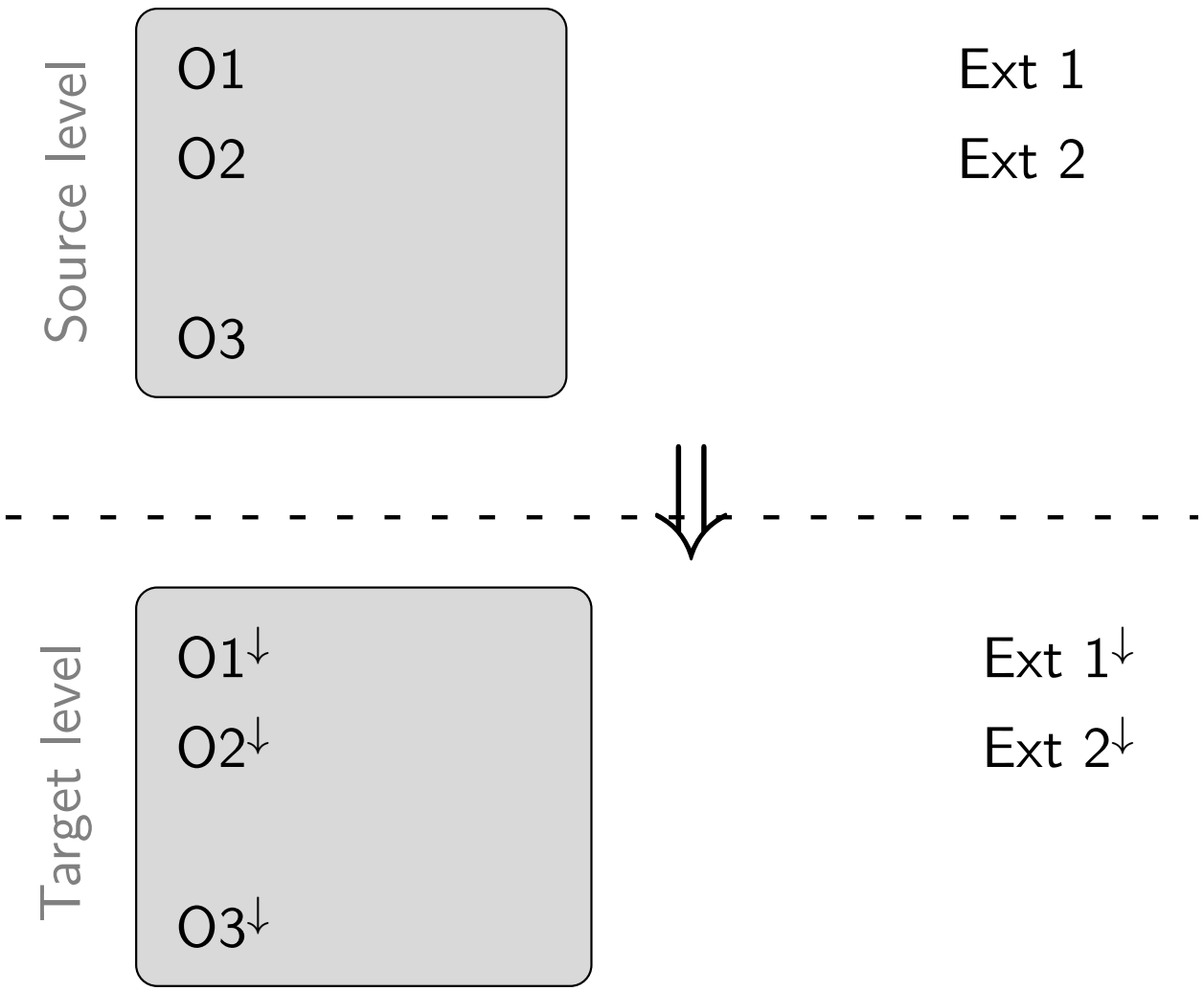

- Protect against low-level attackers
- Preservation of contextual equivalence

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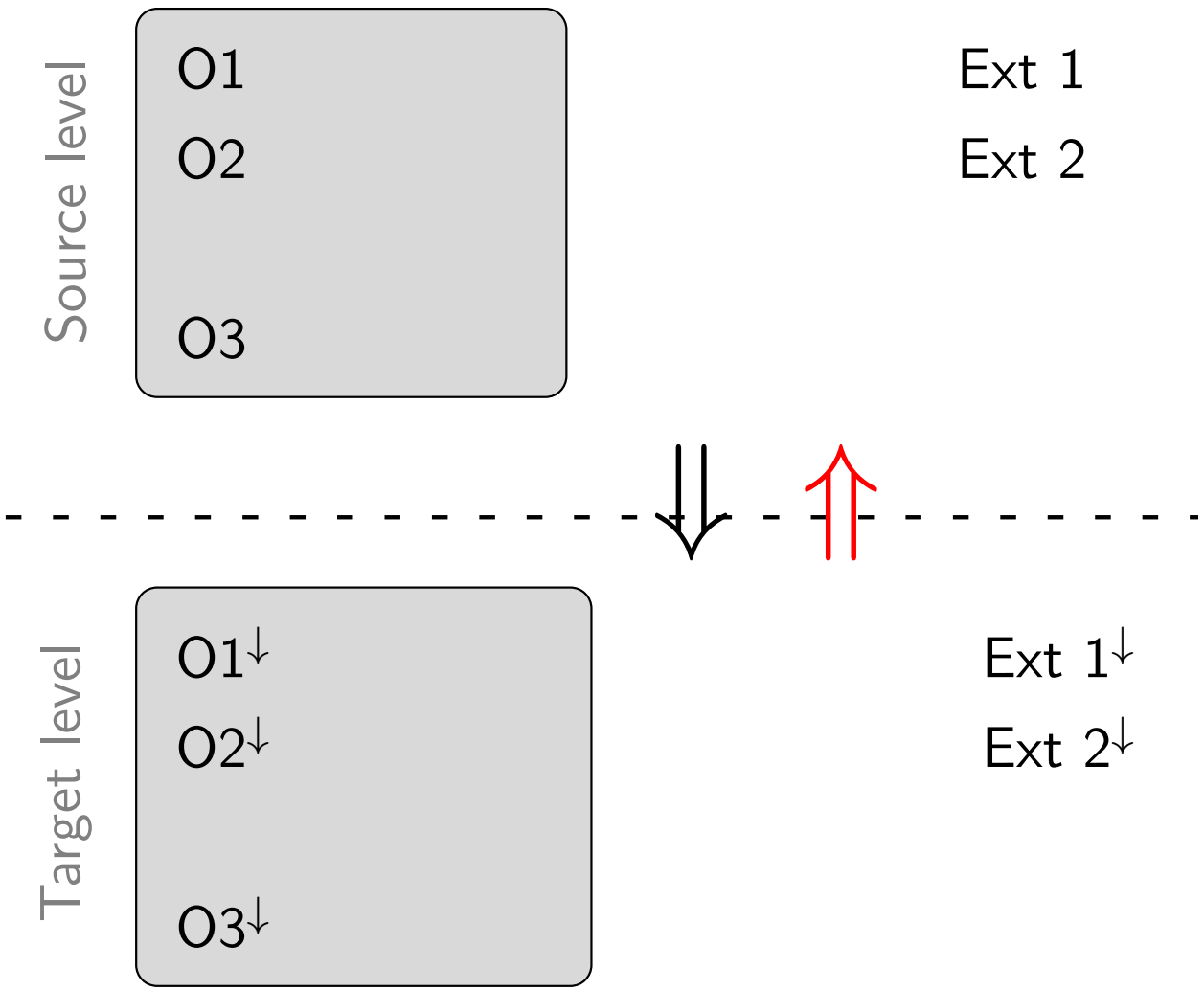

- Protect against low-level attackers
- Preservation of contextual equivalence
- Reflection of contextual equivalence (checks needed)

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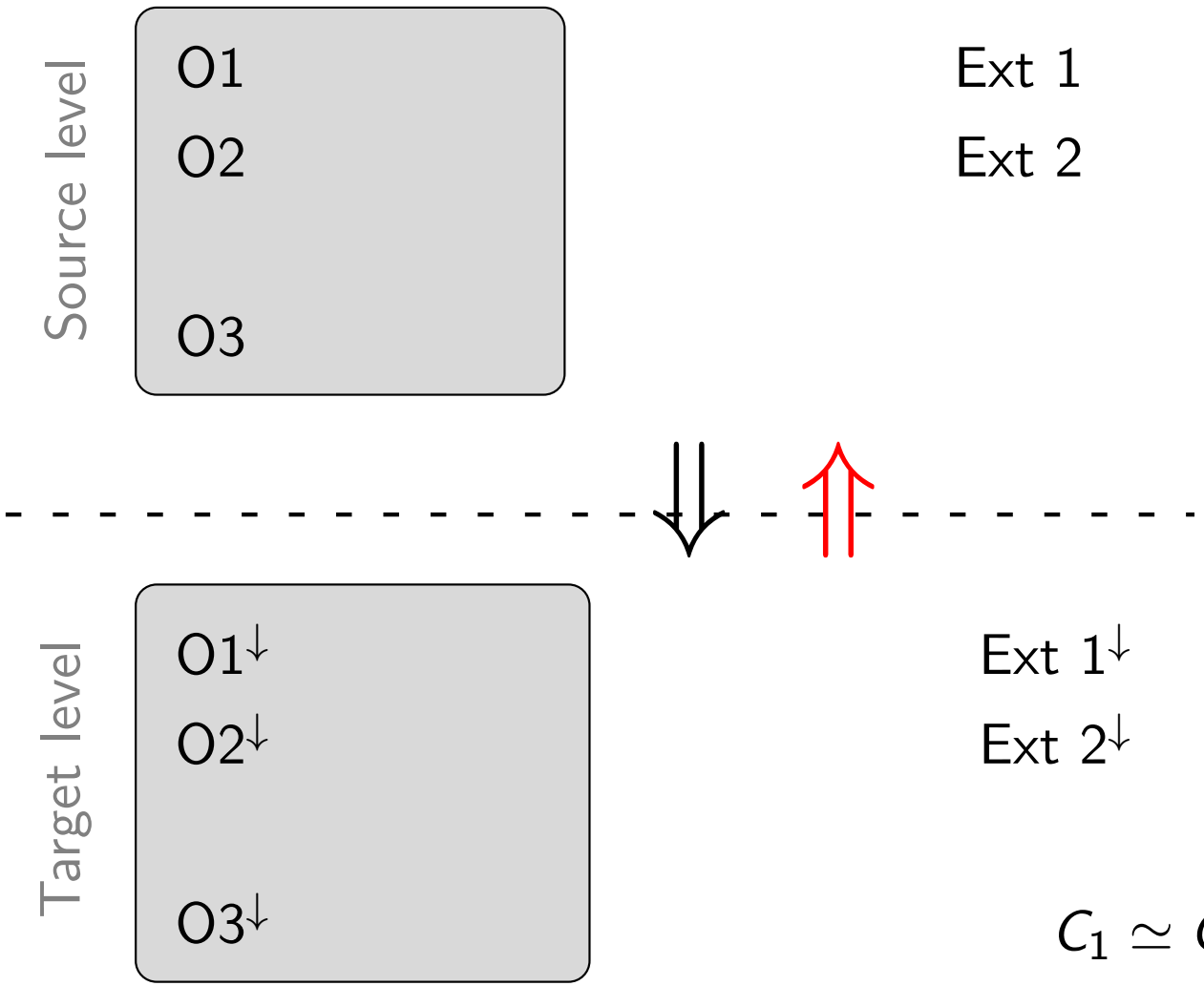


- Protect against low-level attackers
- Preservation of contextual equivalence
- Reflection of contextual equivalence (checks needed)
- Formally:

$$C_1 \simeq C_2 \iff C_1^{\downarrow} \simeq^{\downarrow} C_2^{\downarrow}$$

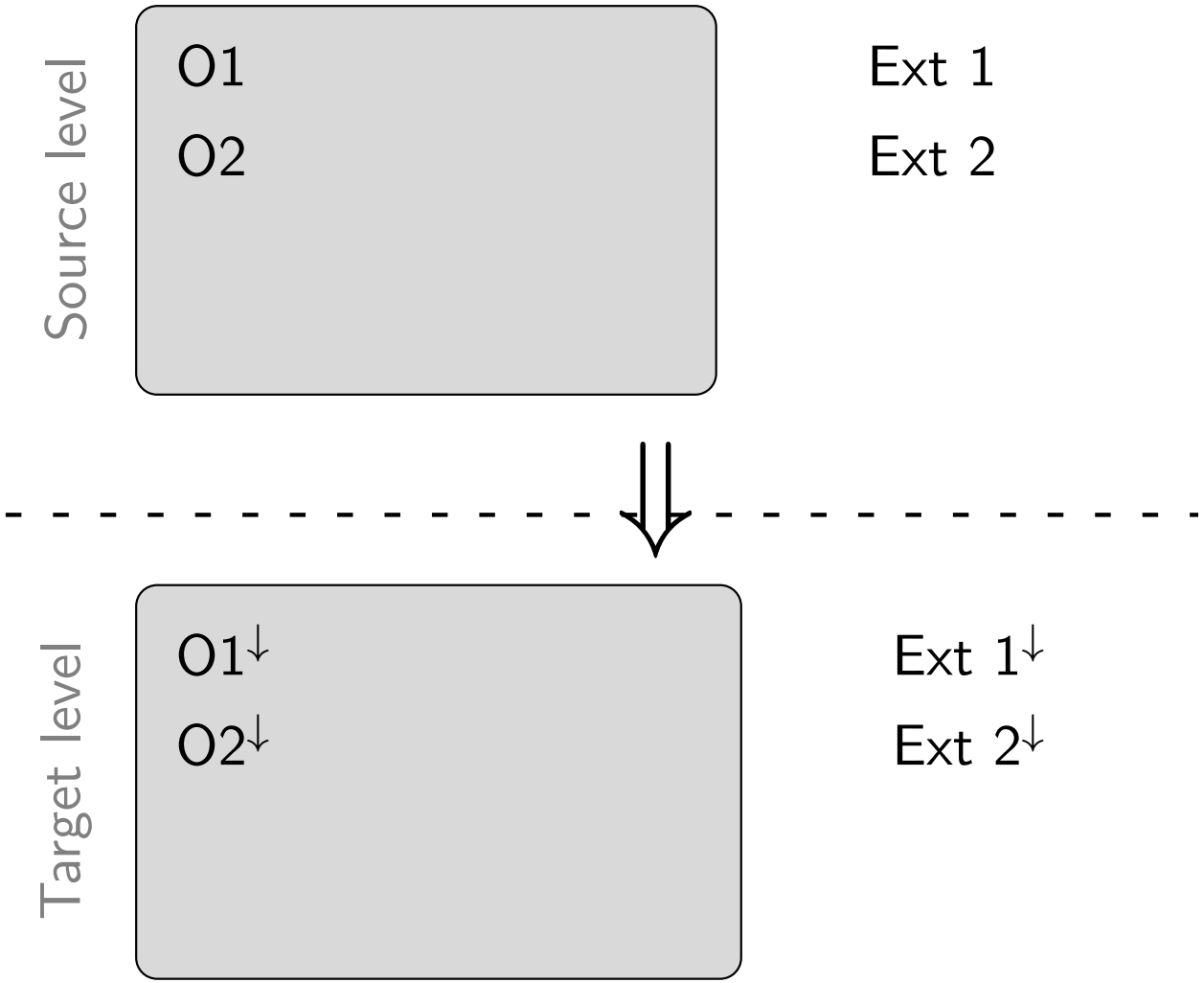
Things That Can Go Wrong

1 Protected Modules Architectures

2 Secure (Fully Abstract) Compilation

3 What Can Go Wrong With...
- Dynamic Memory Allocation
- Exceptions
- Cross-package Inheritance

Dynamic Memory Allocation



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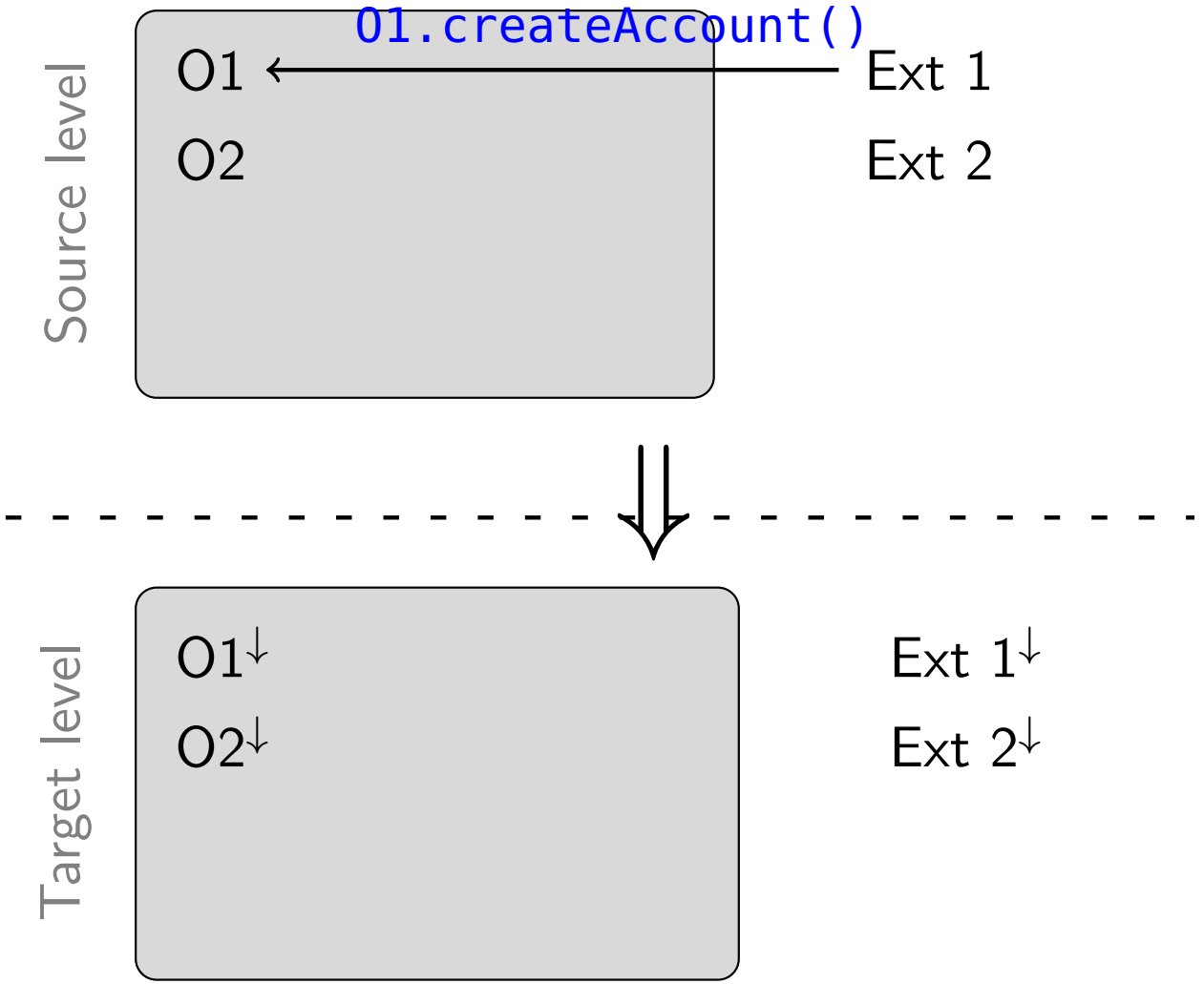

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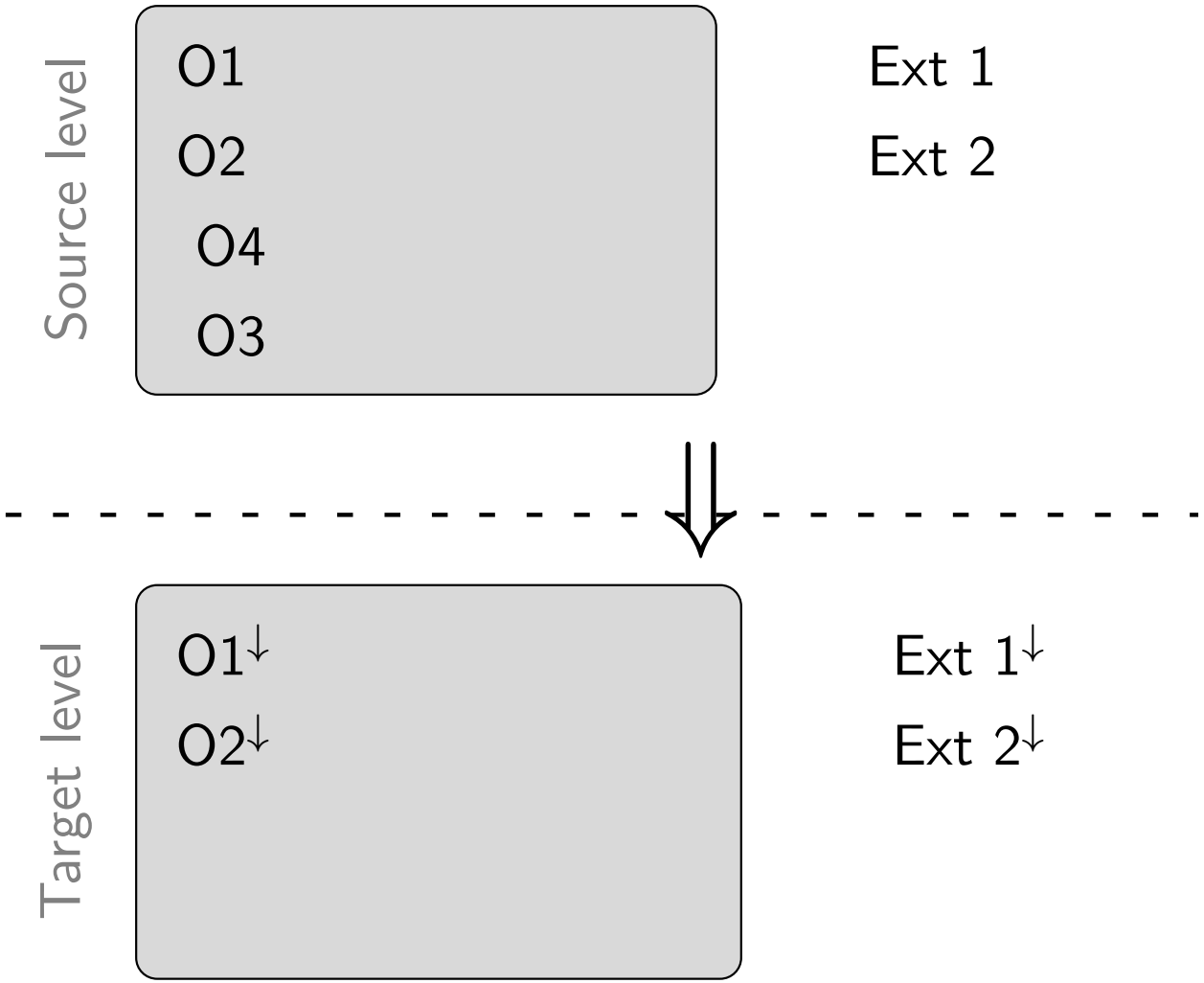

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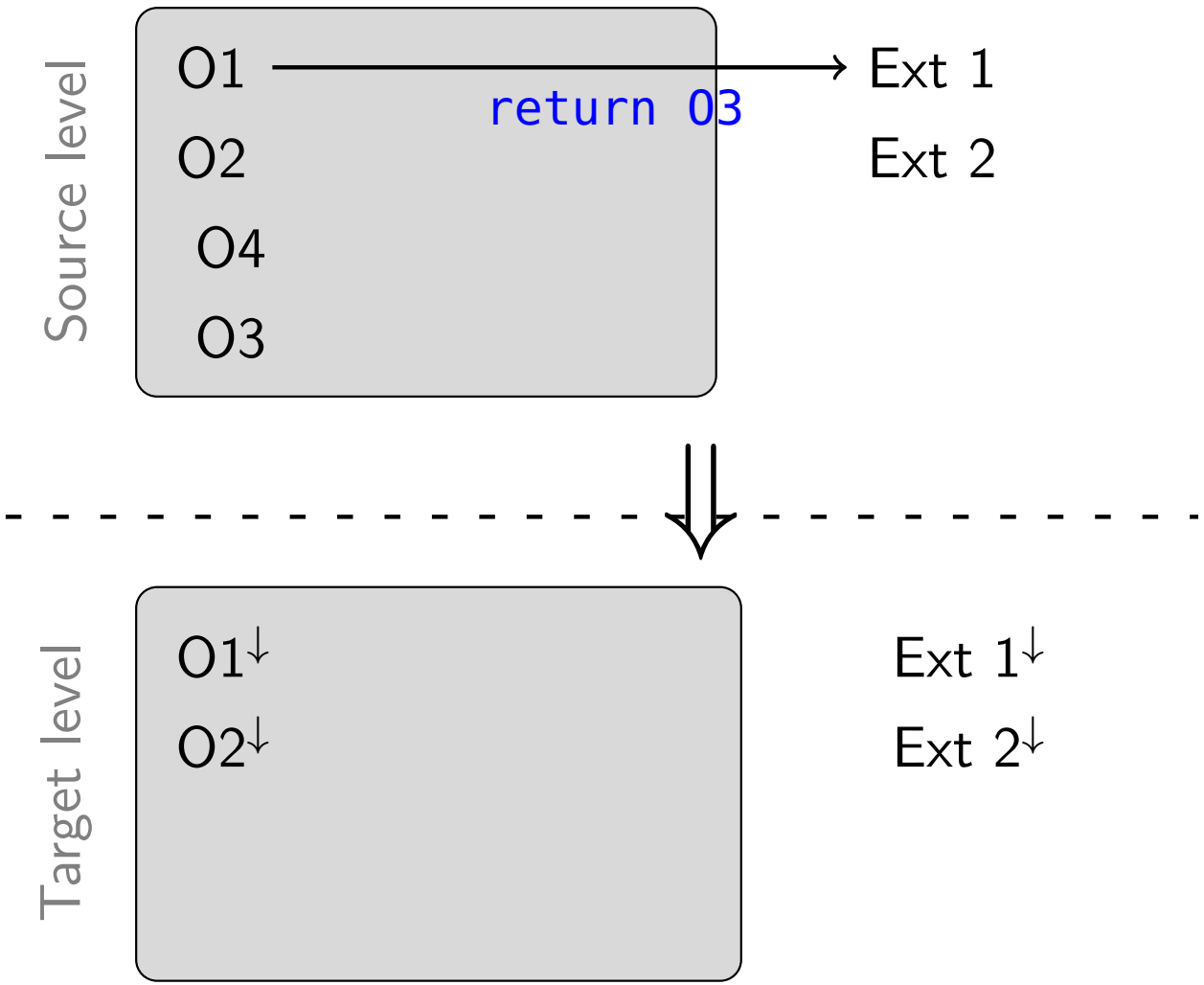

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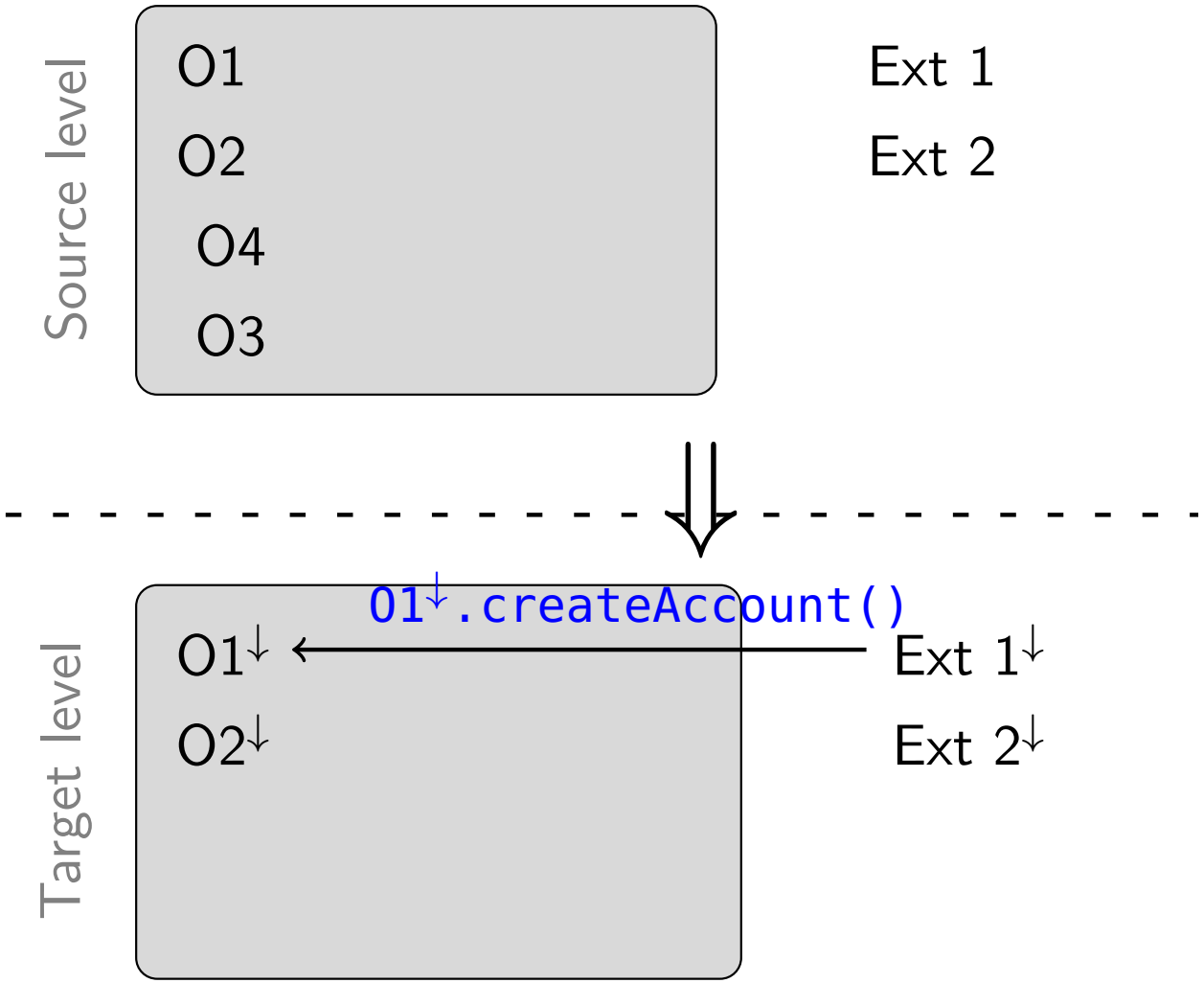

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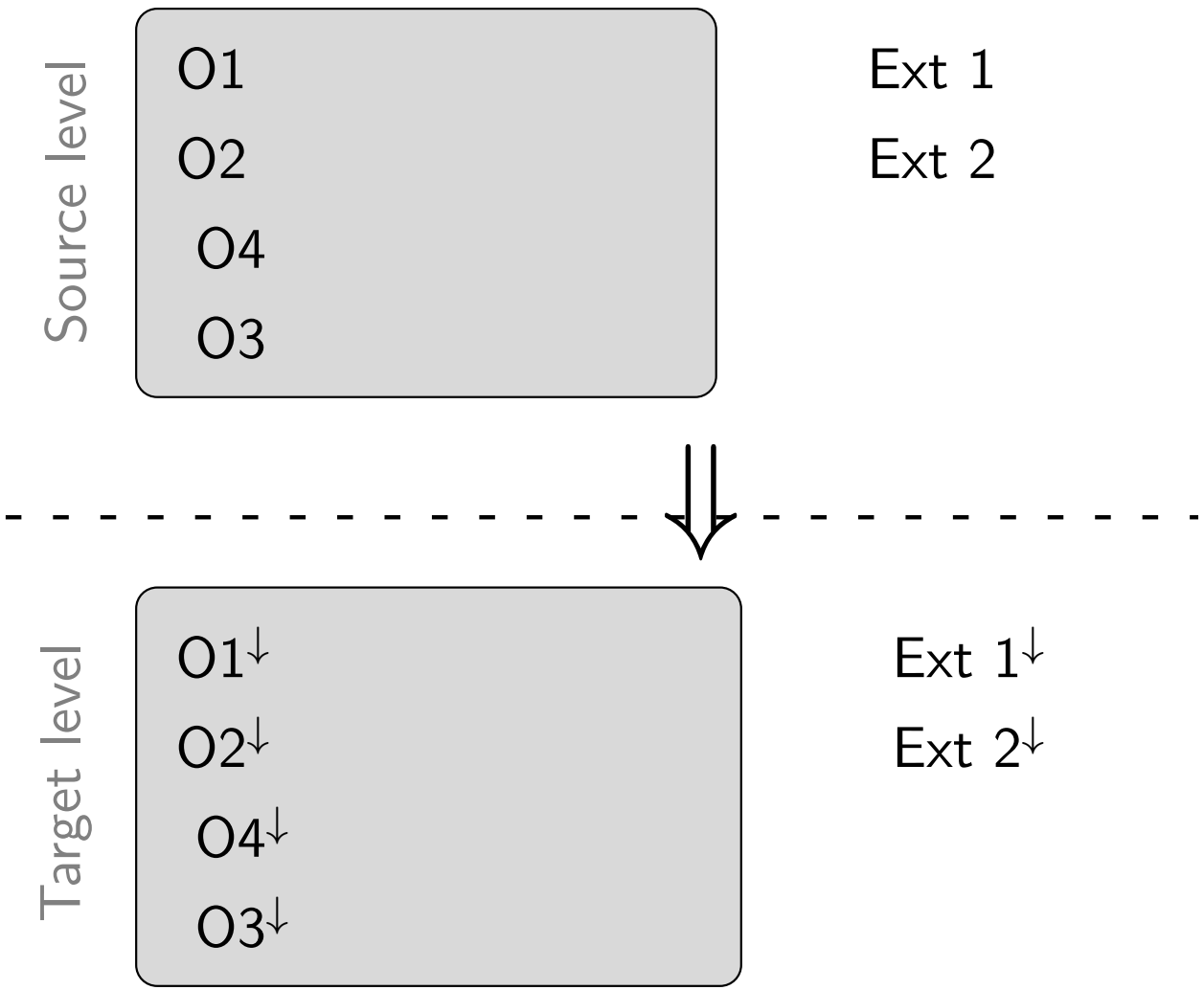

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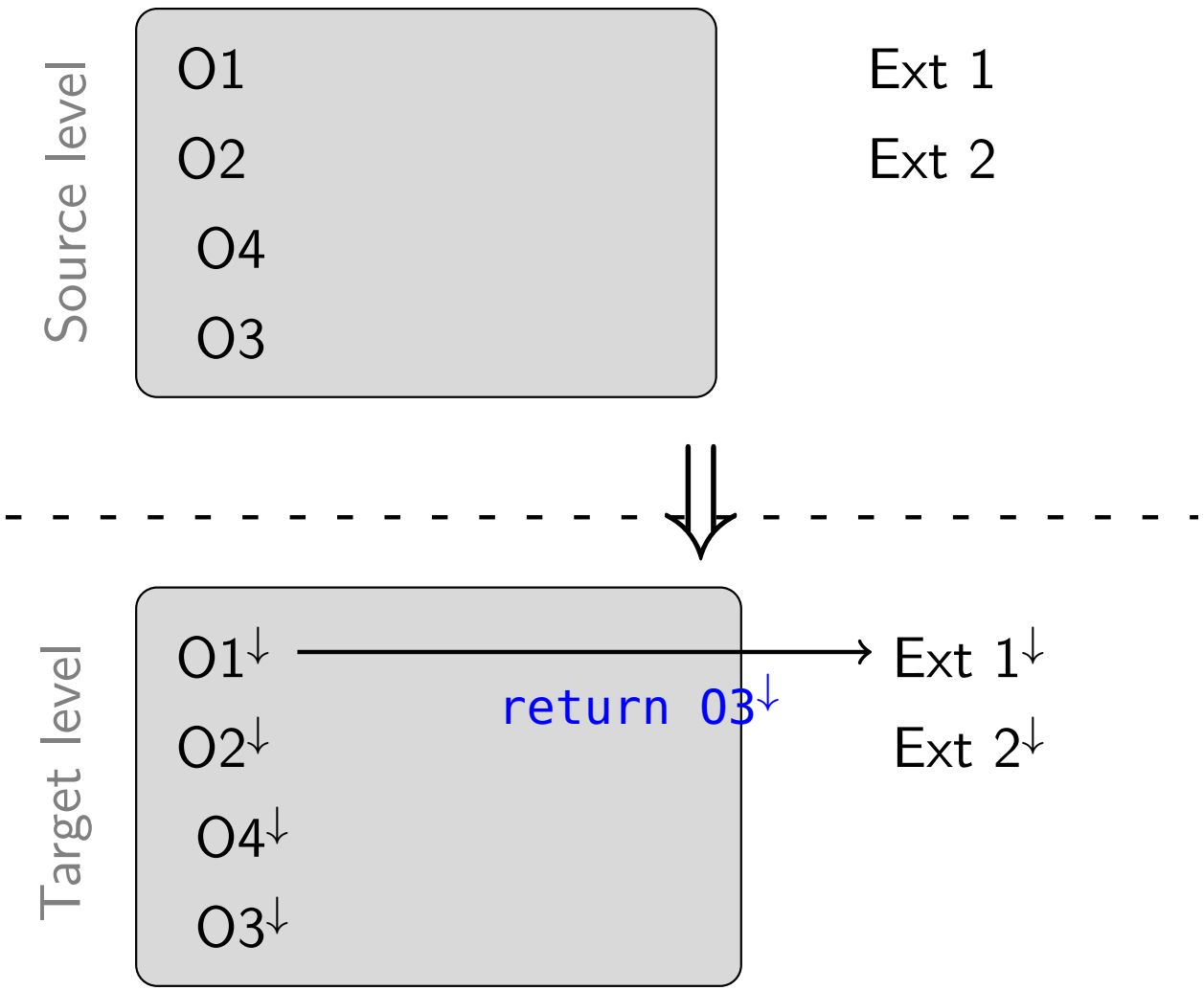

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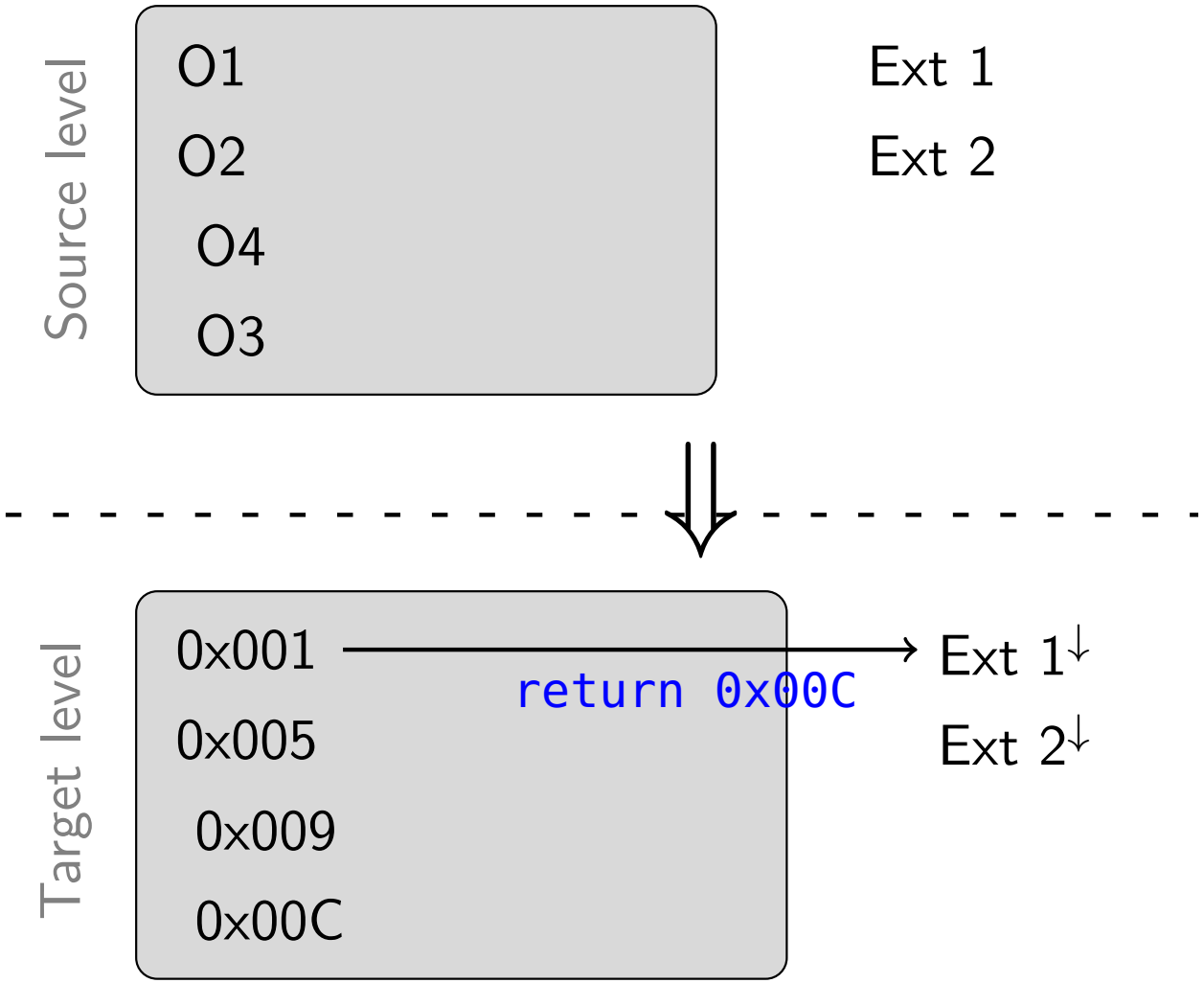
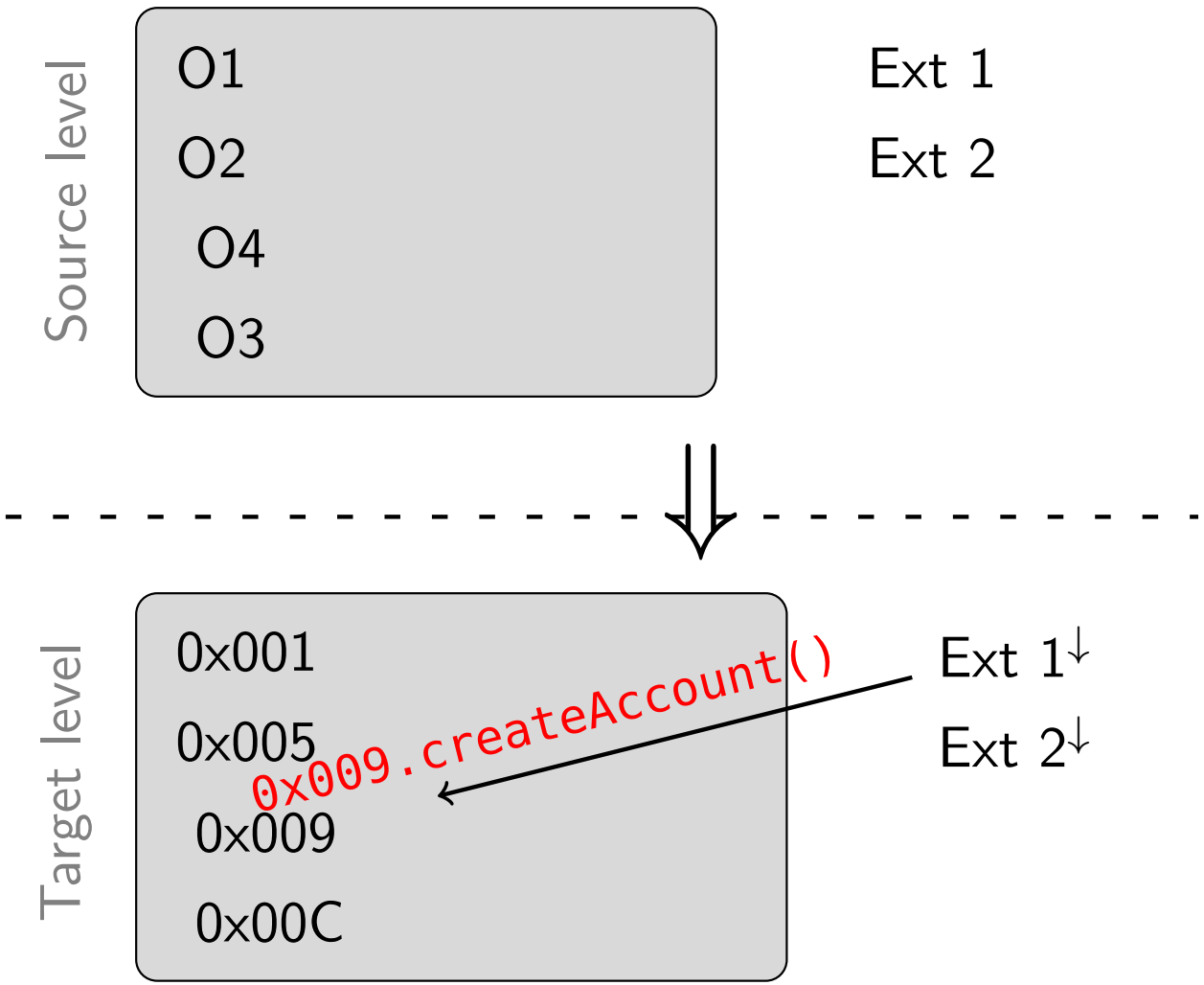
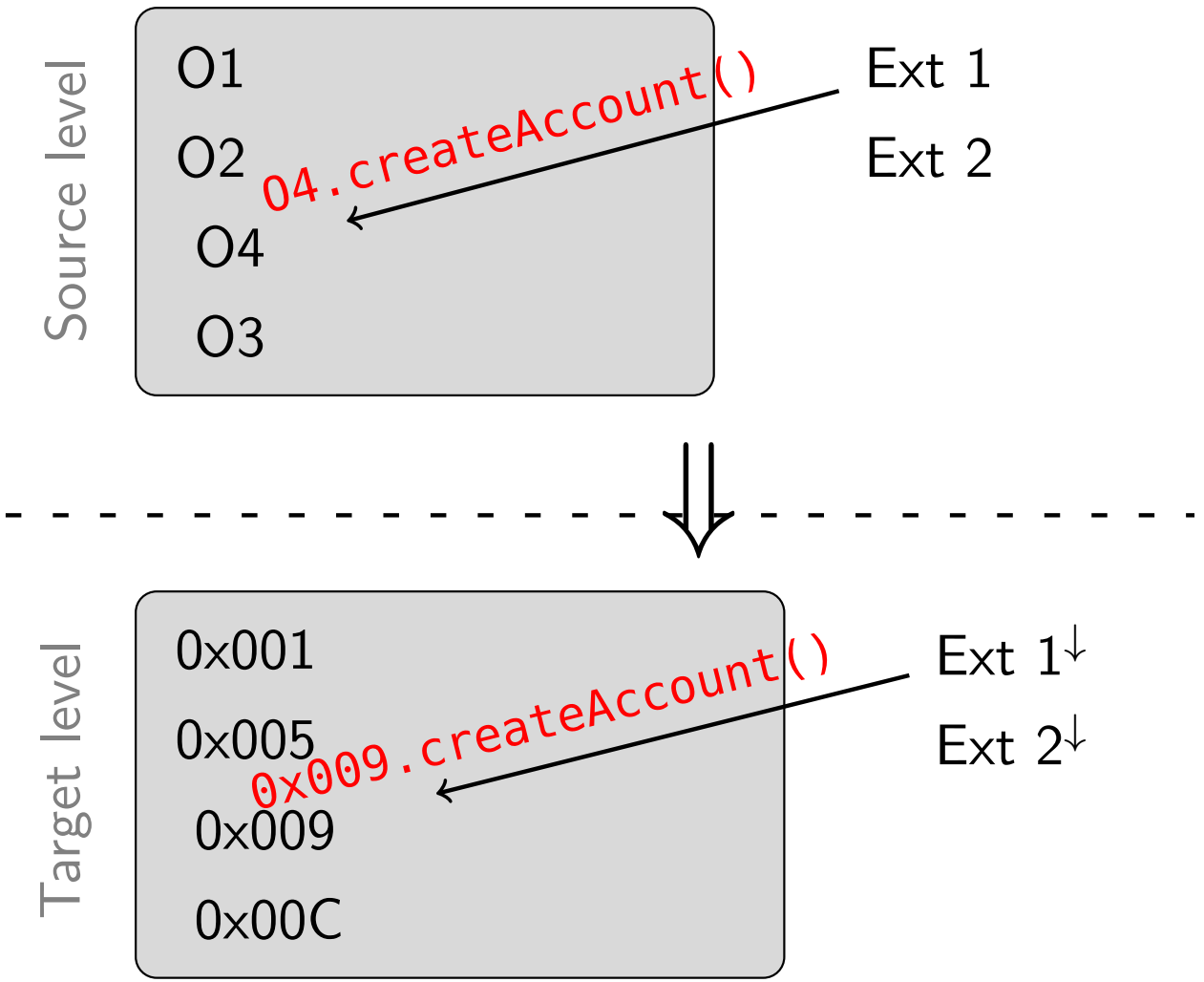


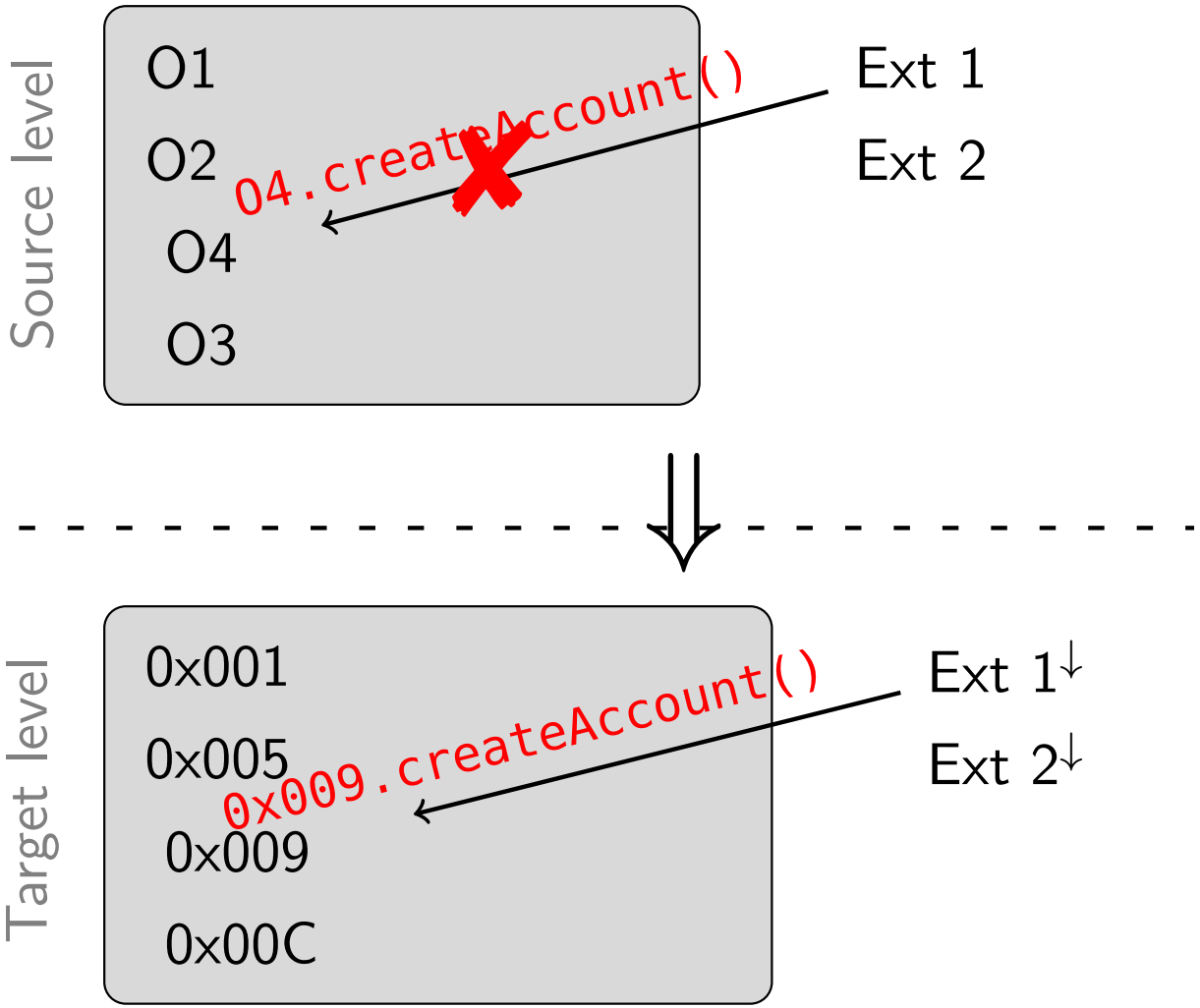
Dynamic Memory Allocation



Dynamic Memory Allocation

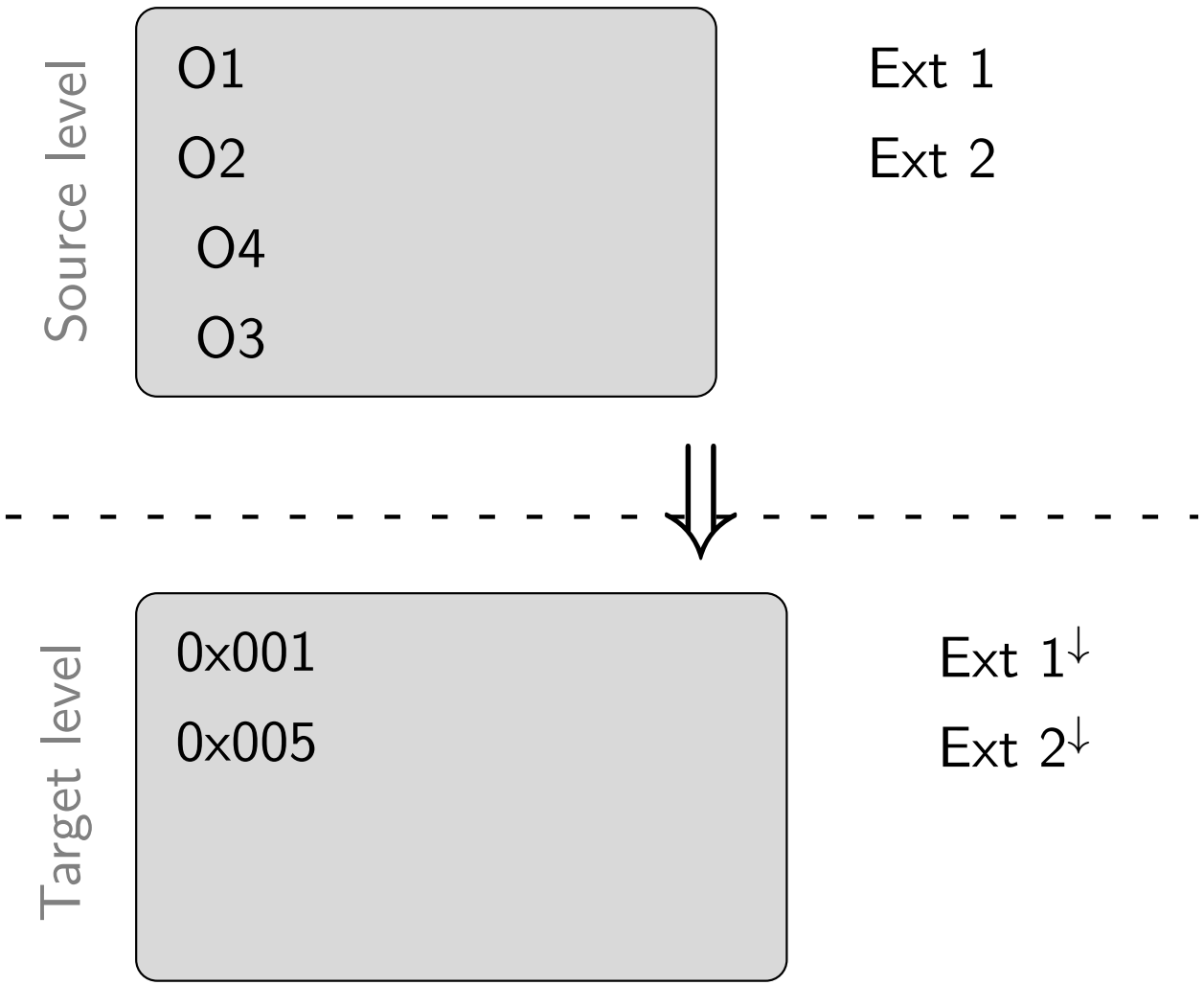


Dynamic Memory Allocation



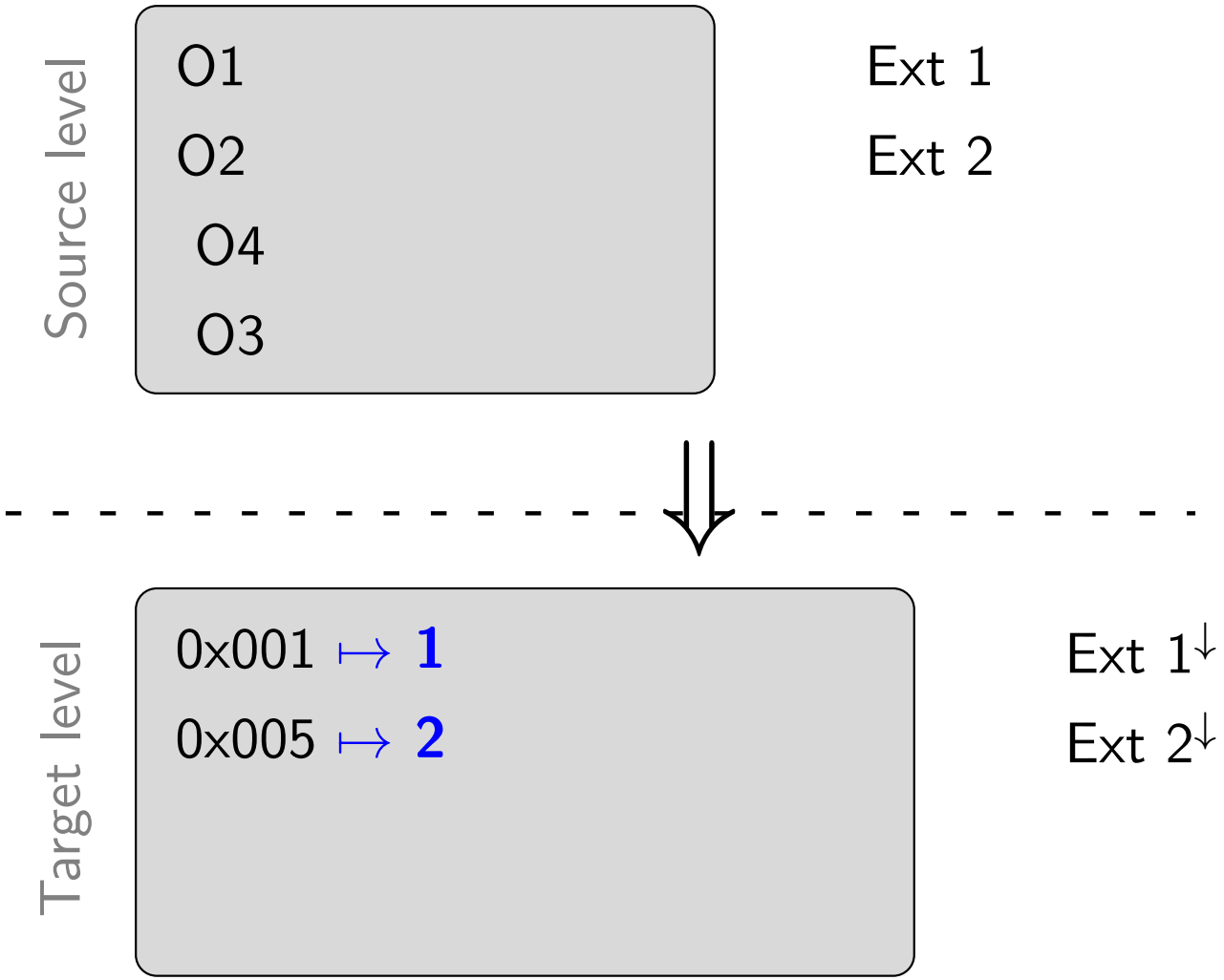
- Object id guessing

Dynamic Memory Allocation



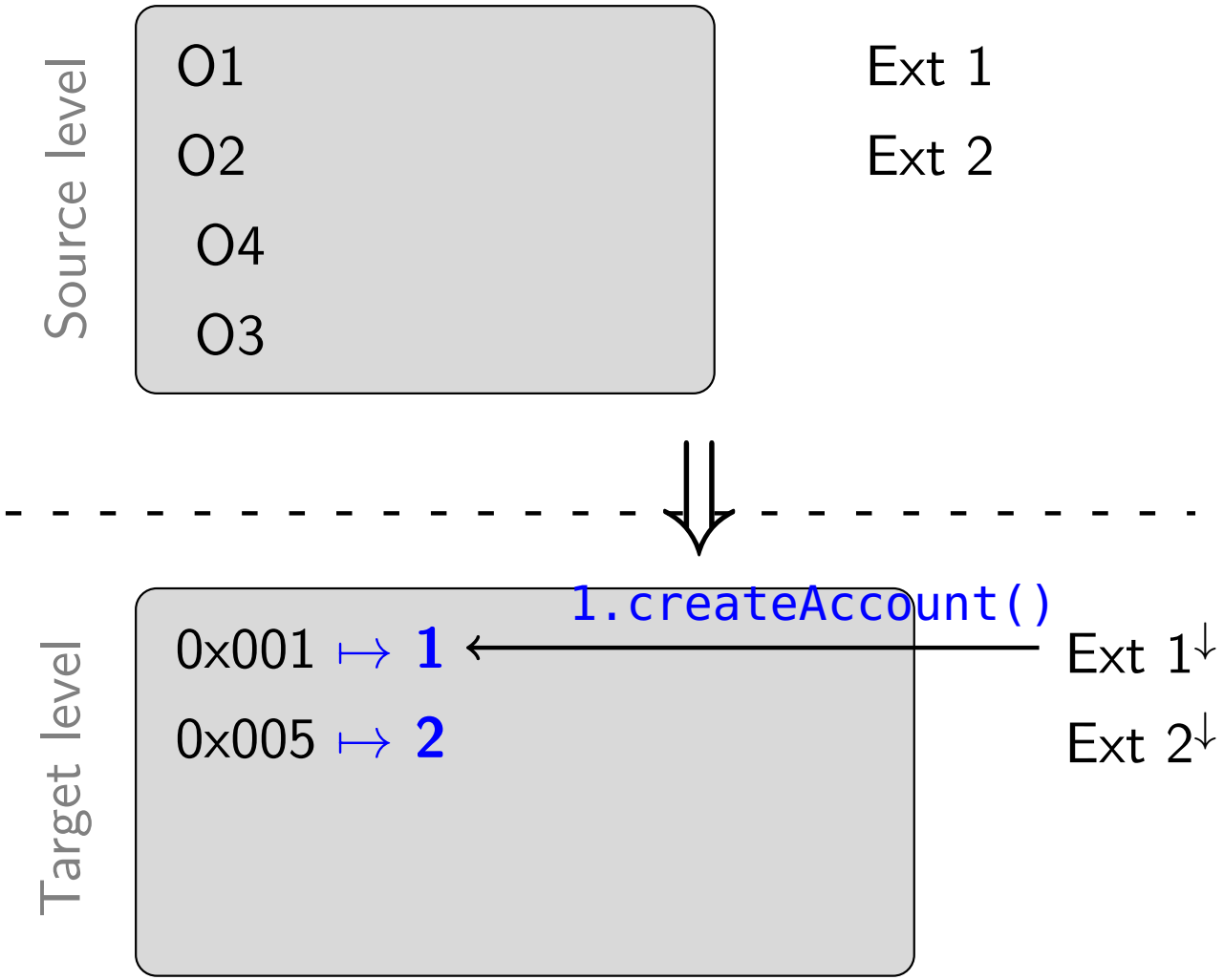
- Object id guessing
- map Oid to natural numbers

Dynamic Memory Allocation



- Object id guessing
- map Oid to natural numbers

Dynamic Memory Allocation



- Object id guessing
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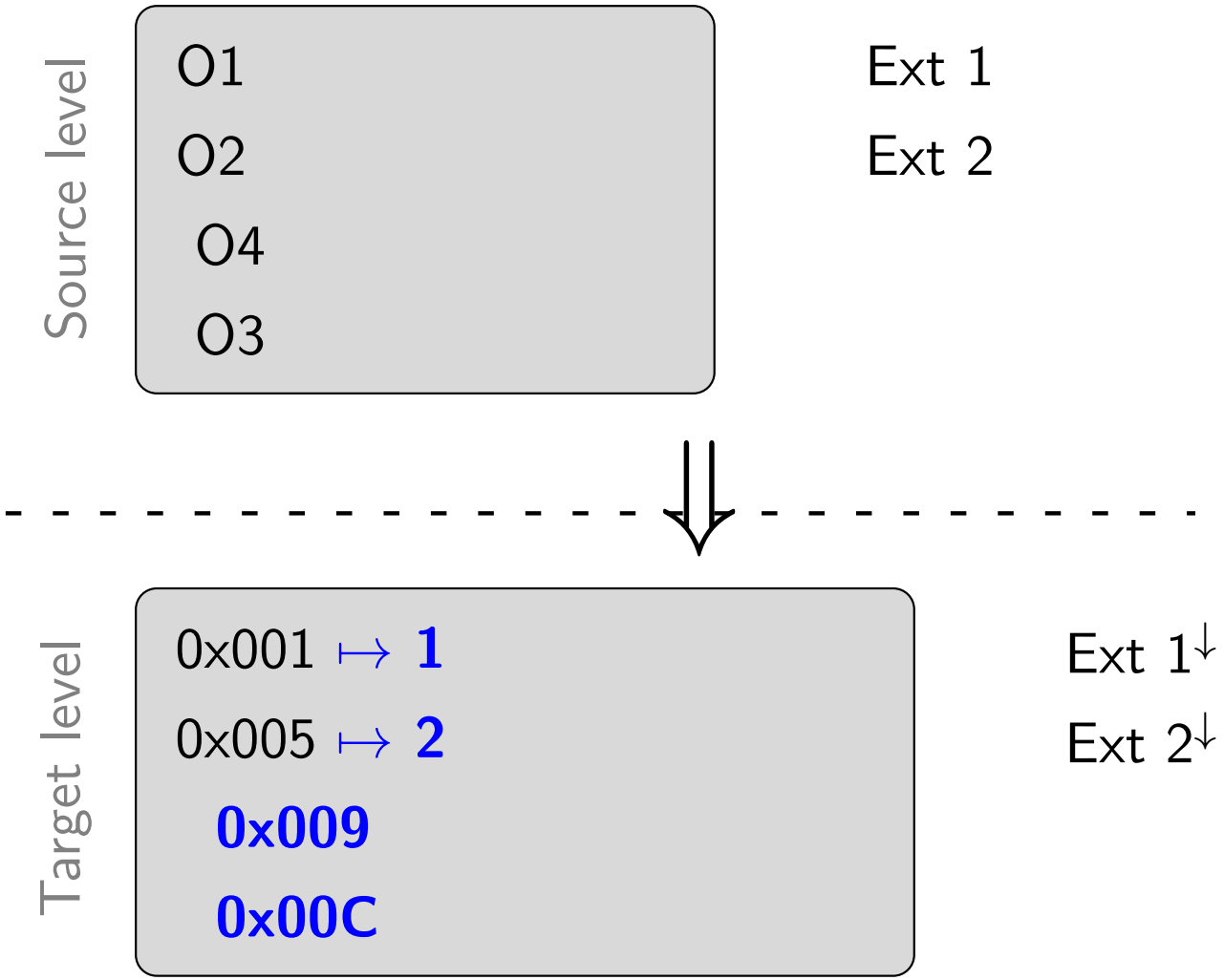
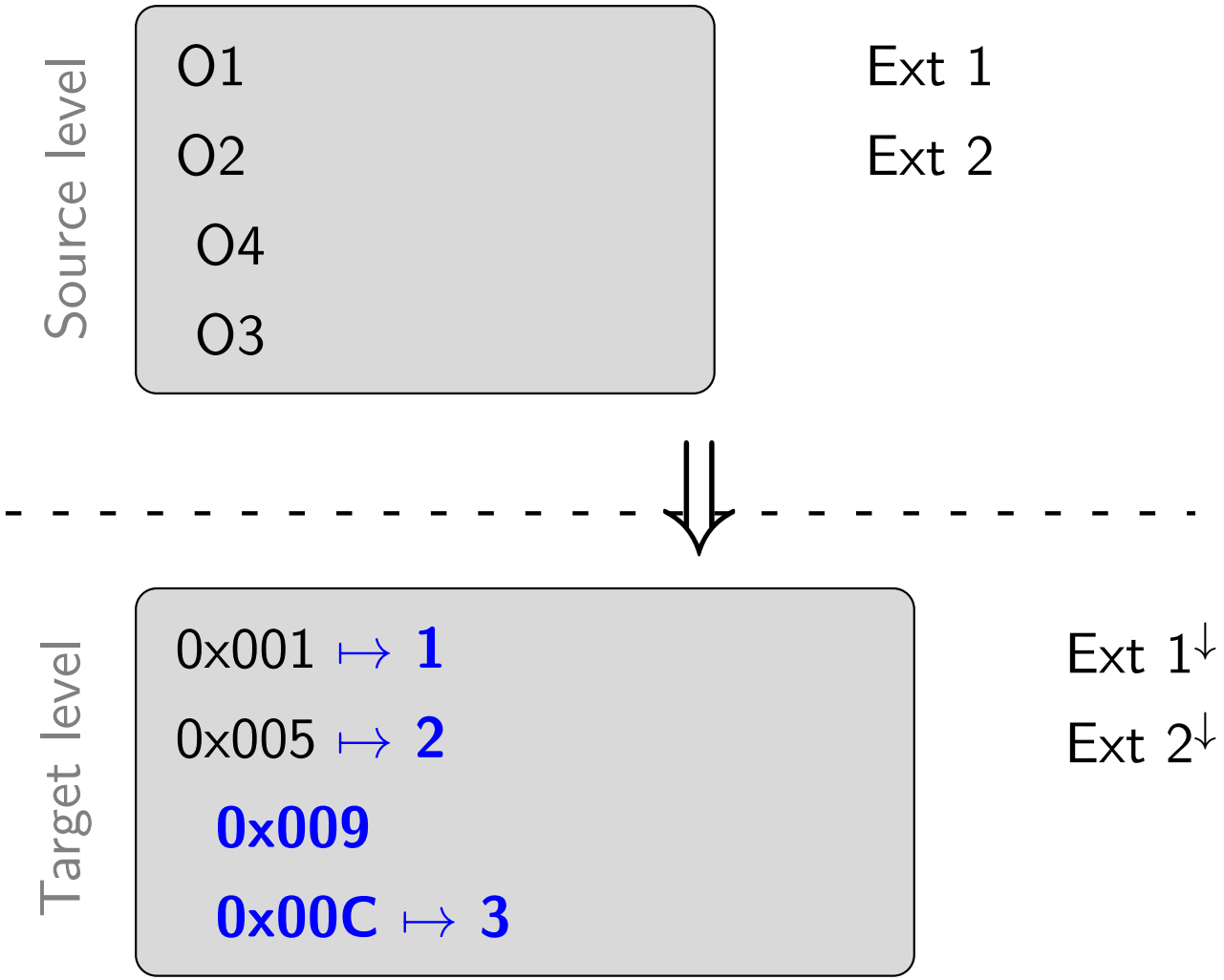
Dynamic Memory Allocation



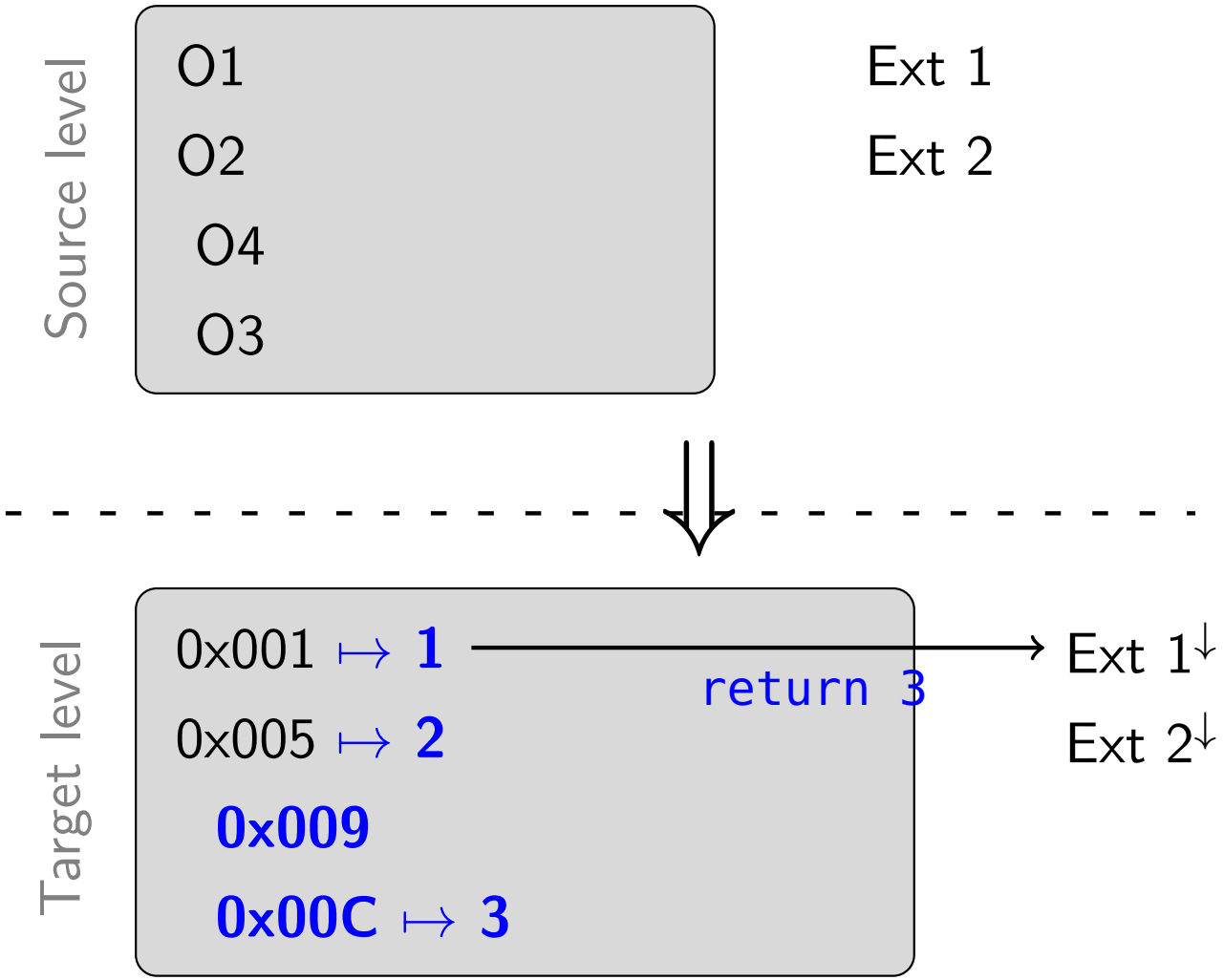
- Object id guessing
- map Oid to natural numbers

Dynamic Memory Allocation



- Object id guessing
- map Oid to natural numbers
- add Oid to map

Dynamic Memory Allocation



- Object id guessing
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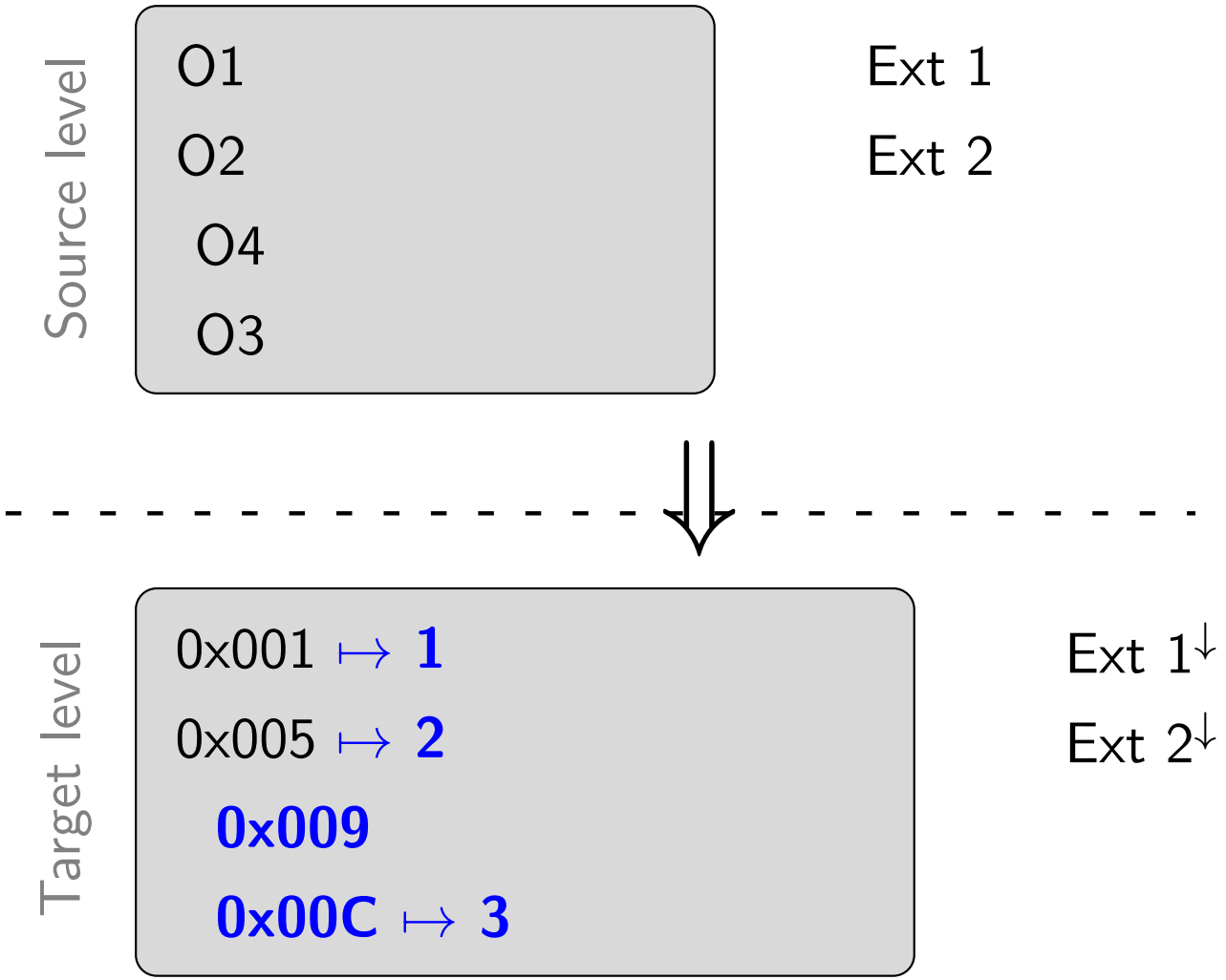
Dynamic Memory Allocation

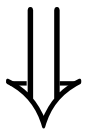


- Object id guessing
- map Oid to natural numbers
- add Oid to map
- lookup ($\mathbf{O}(1)$) when number is received

Dynamic Memory Allocation

Source level

O1 : Account
O2 : Pair
O4
O3



Target level

0x001 ↦ **1**
0x005 ↦ **2**
0x009
0x00C ↦ **3**

Ext 1

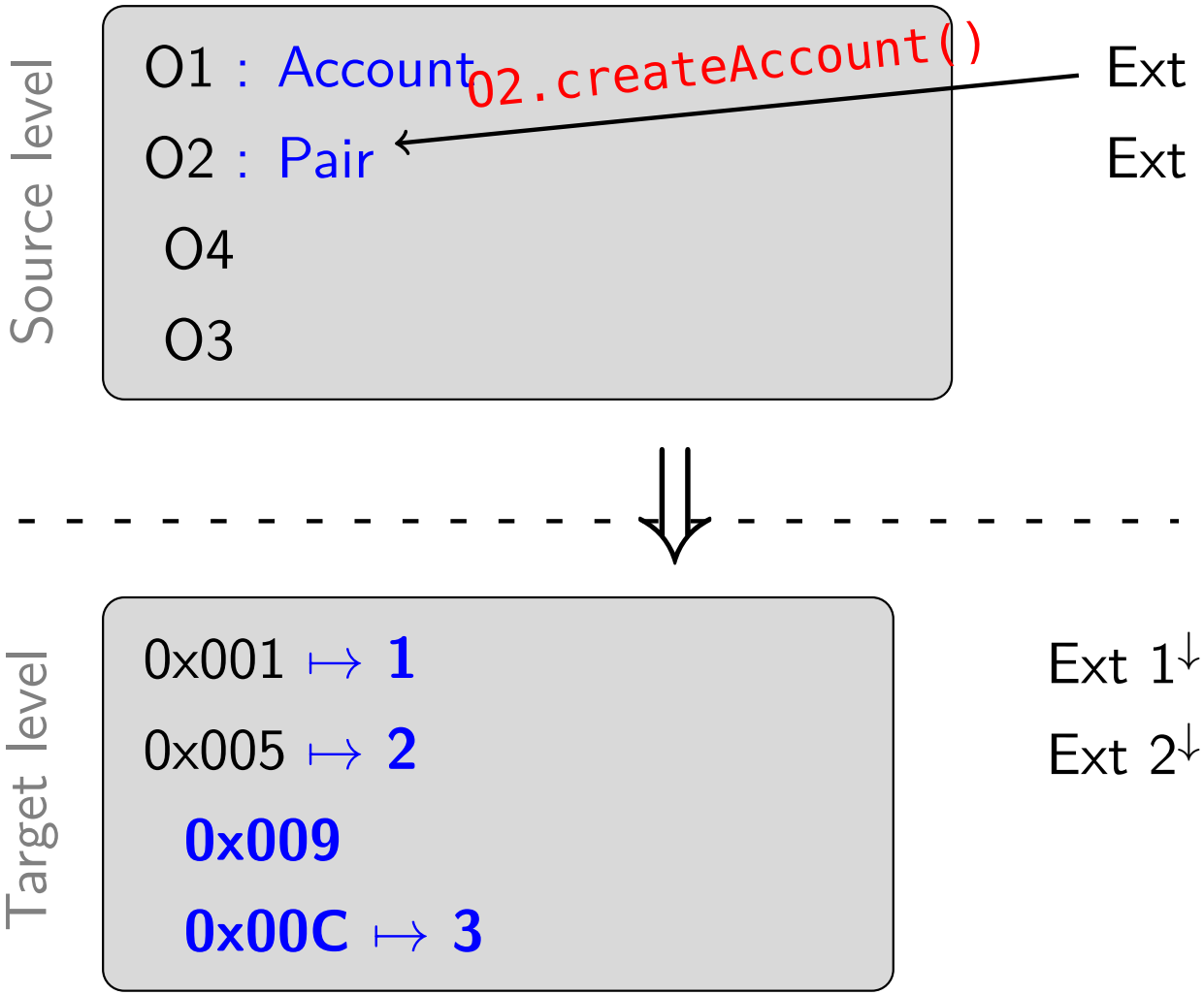
Ext 2

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

Ext $1^{\downarrow}$

Ext $2^{\downarrow}$

Dynamic Memory Allocation



- Object id guessing
- map Oid to natural numbers
- add Oid to map
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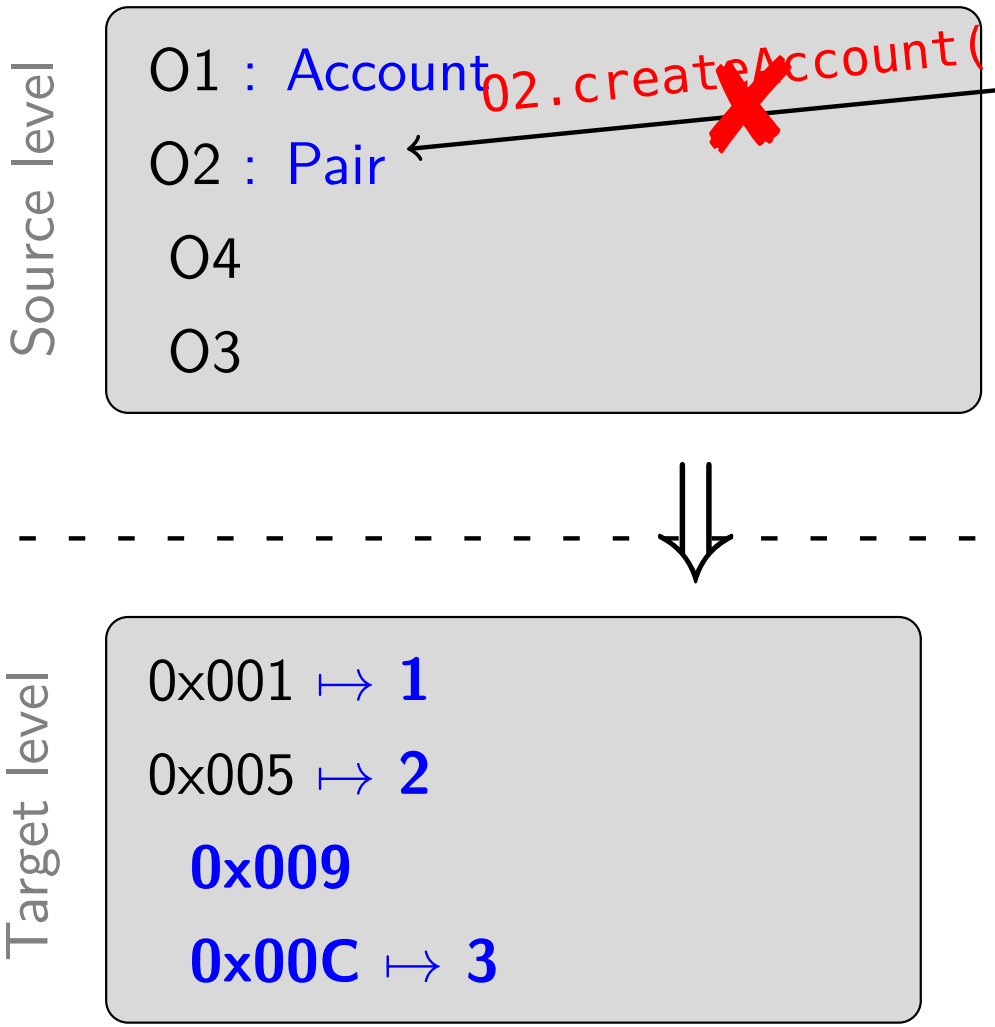
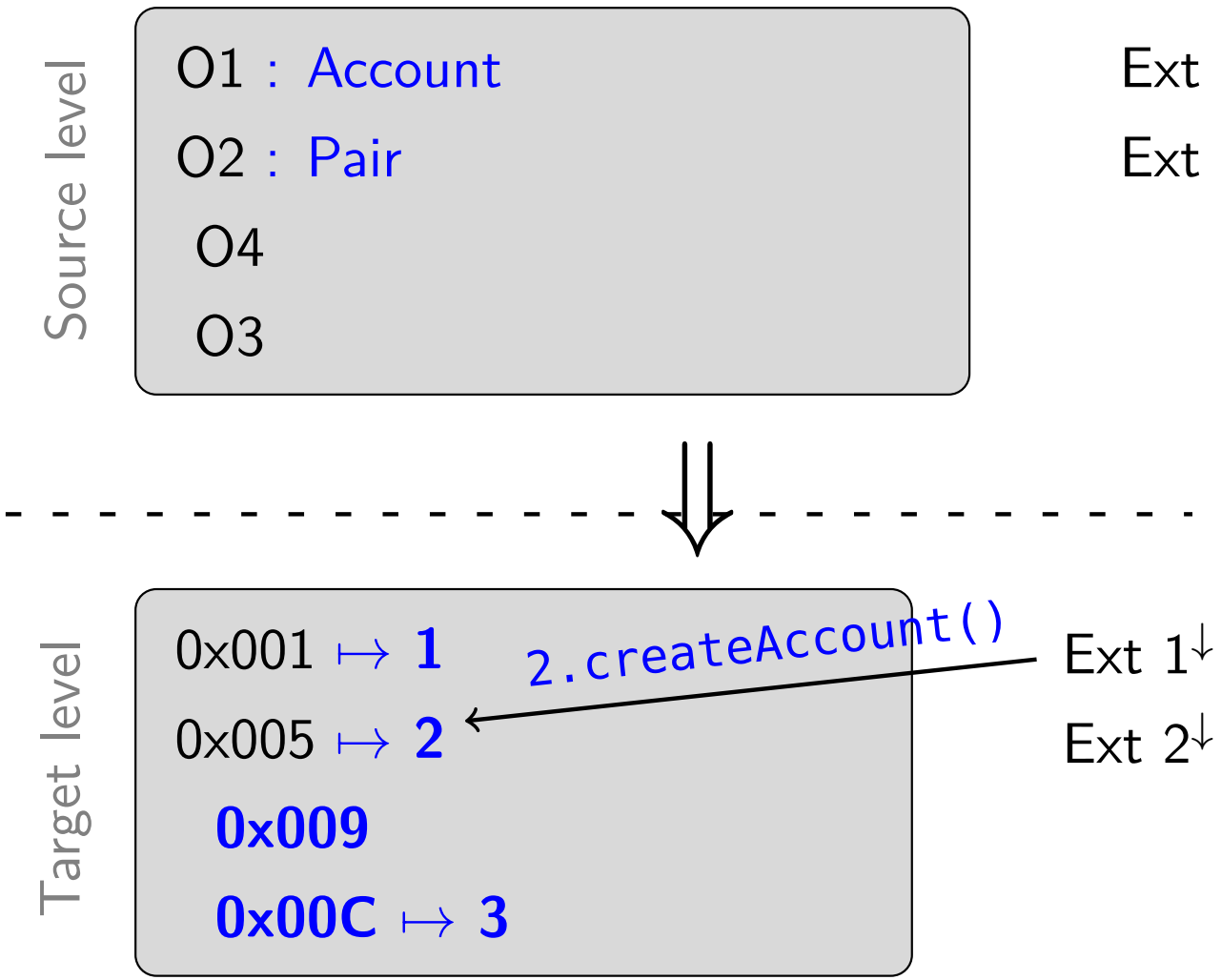
Dynamic Memory Allocation



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

Dynamic Memory Allocation

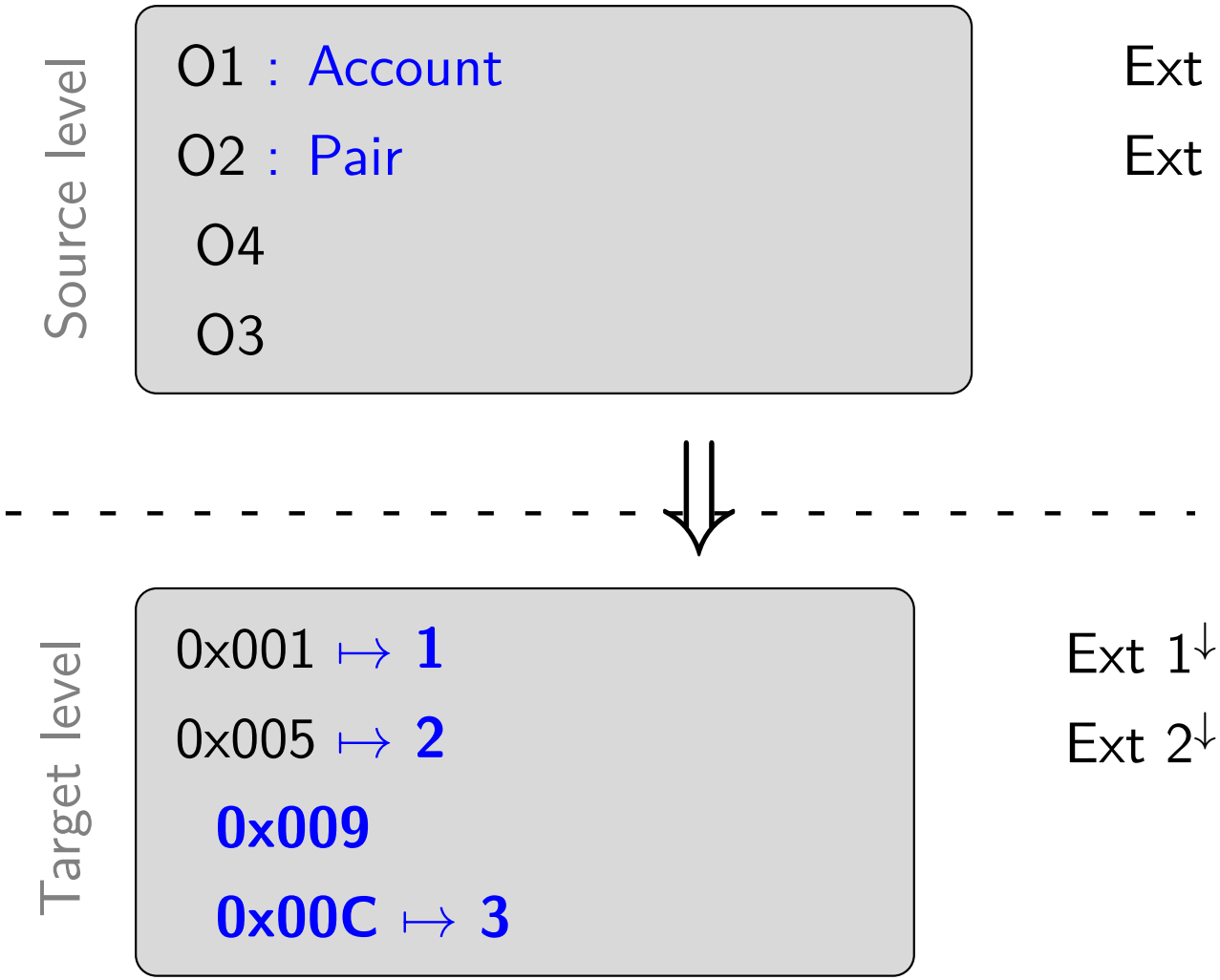


Ext 1

Ext 2

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

Dynamic Memory Allocation



Ext 1

Ext 2

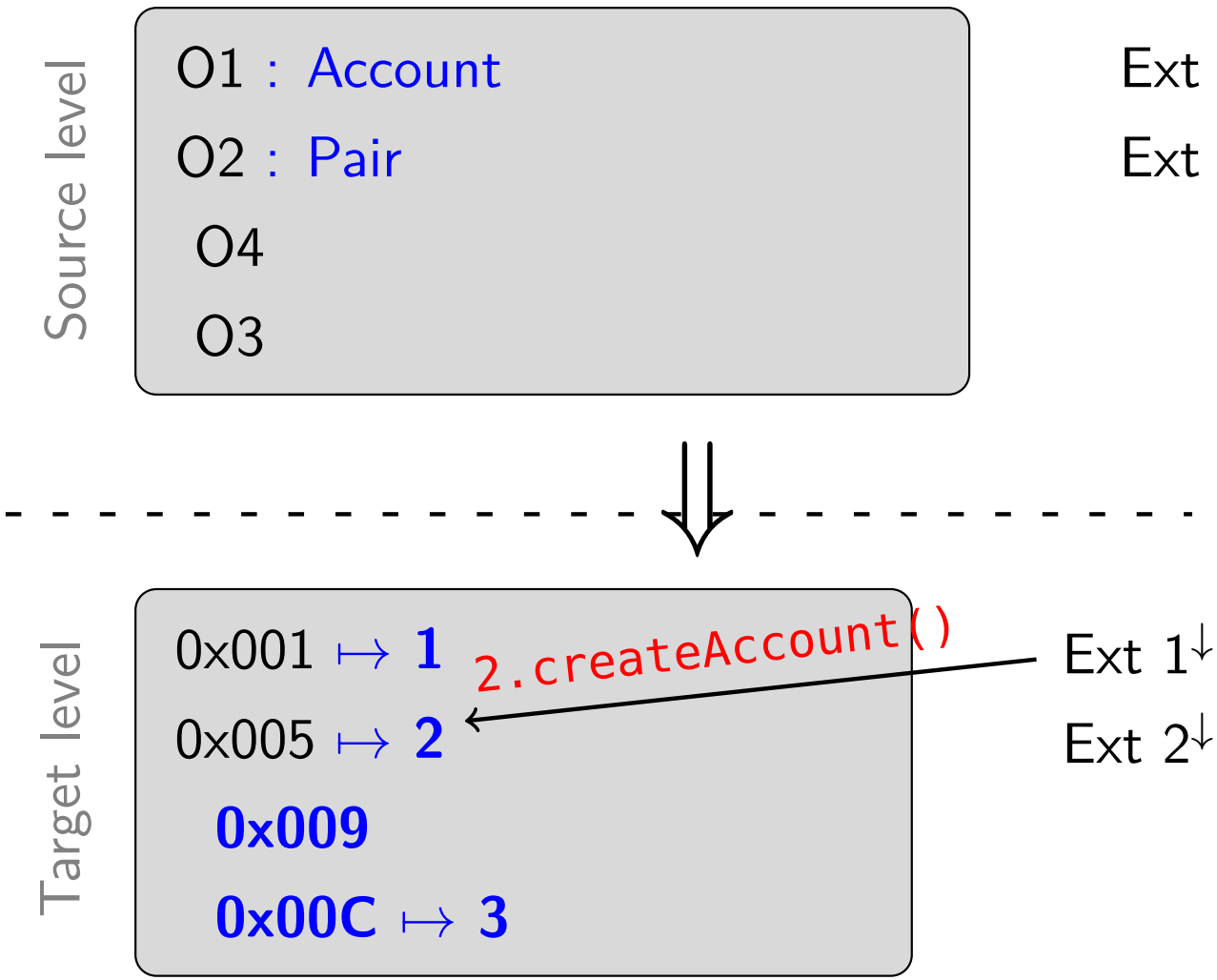
- Object id guessing
- map Oid to natural numbers
- add Oid to map
- lookup ($\mathbf{O}(1)$) when number is received

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

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

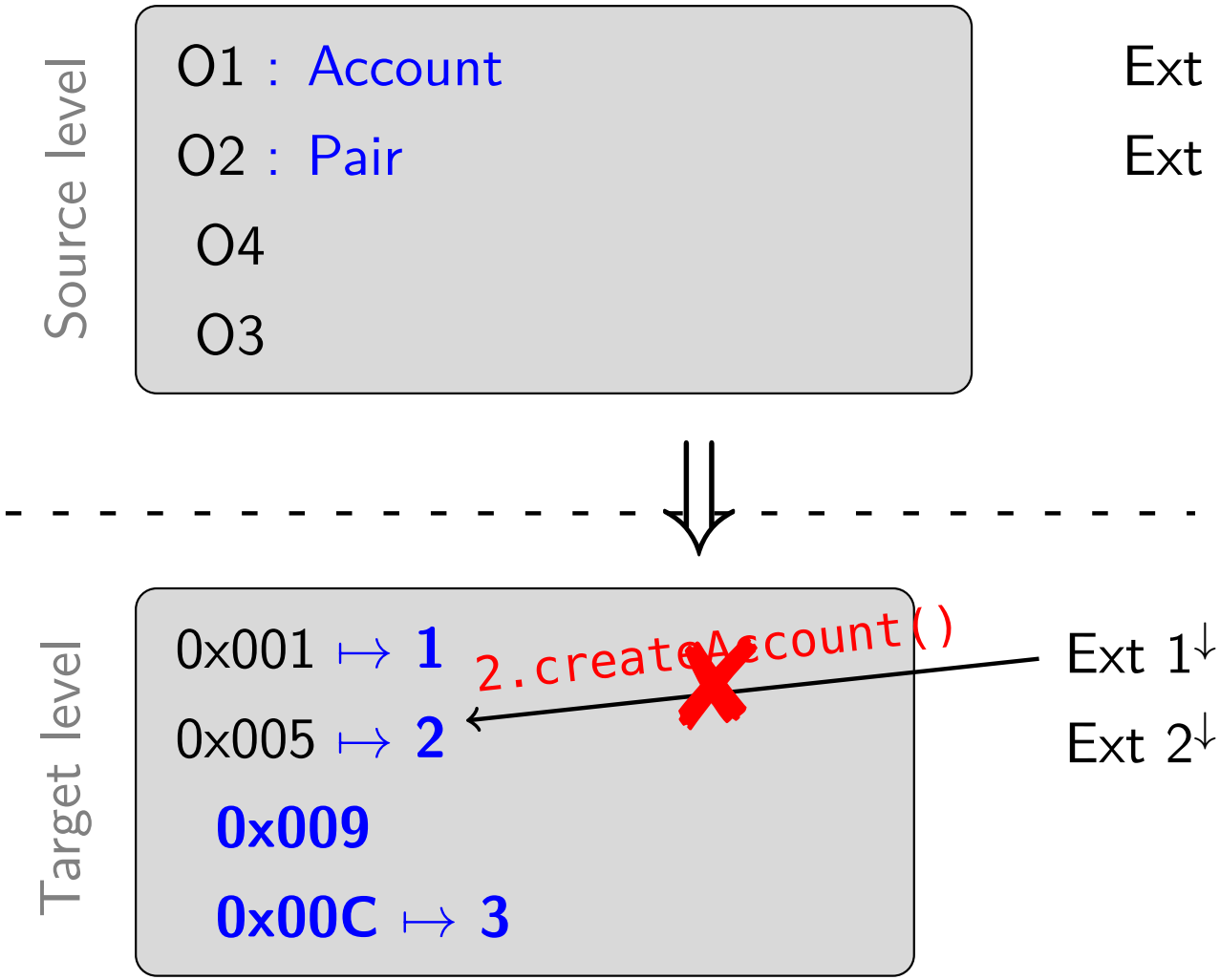
- dynamic typecheck for: current object

Dynamic Memory Allocation



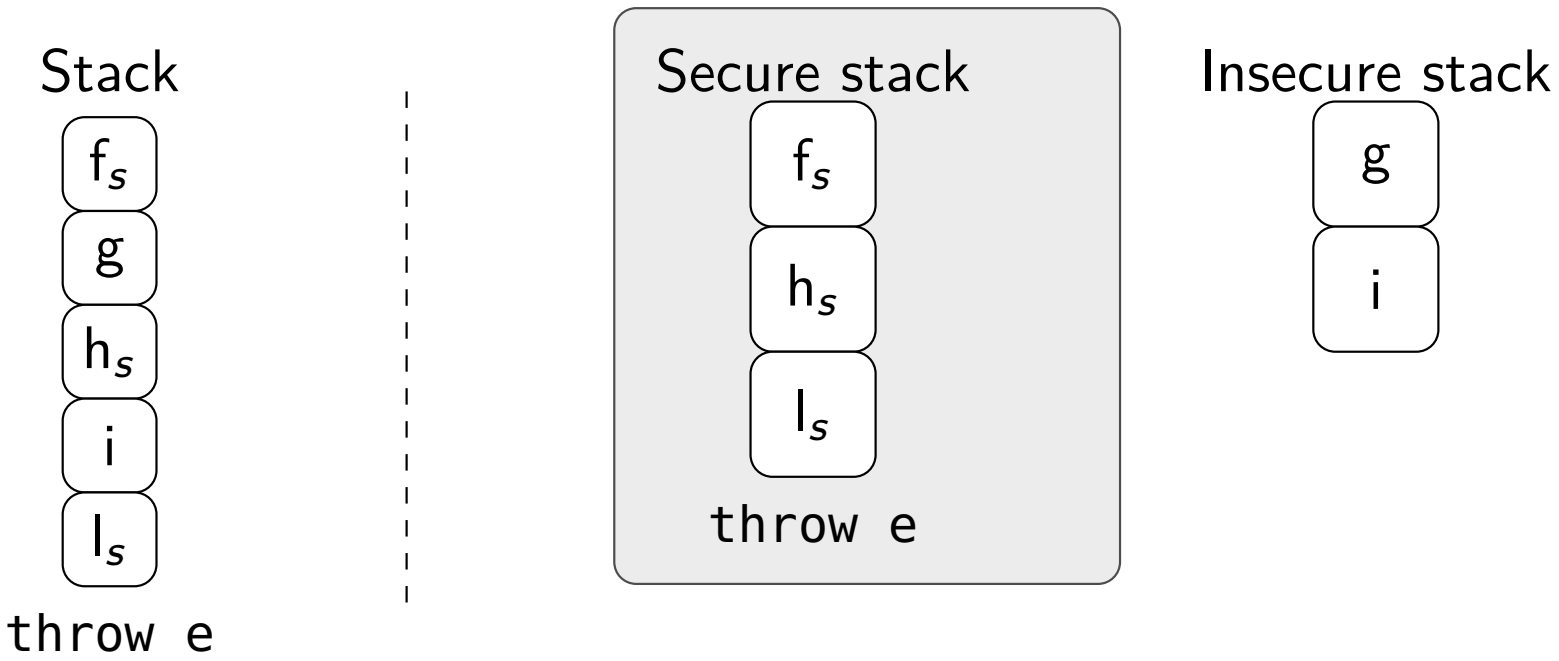
- Object id guessing
- map Oid to natural numbers
- add Oid to map
- lookup ($\mathbf{O}(1)$) when number is received
- dynamic typecheck for: current object arguments

Dynamic Memory Allocation

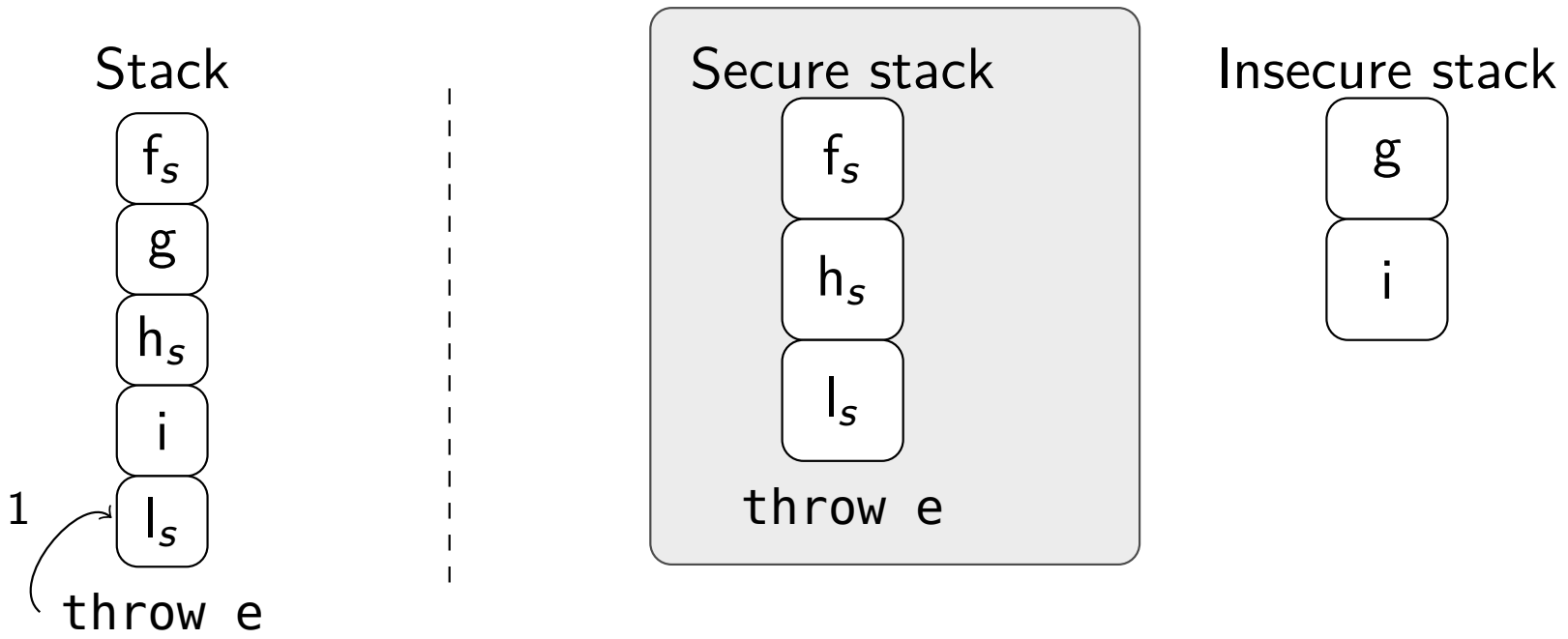


- Object id guessing
- map Oid to natural numbers
- add Oid to map
- lookup ($\mathbf{O}(1)$) when number is received
- dynamic typecheck for: current object arguments
- no need of extra information

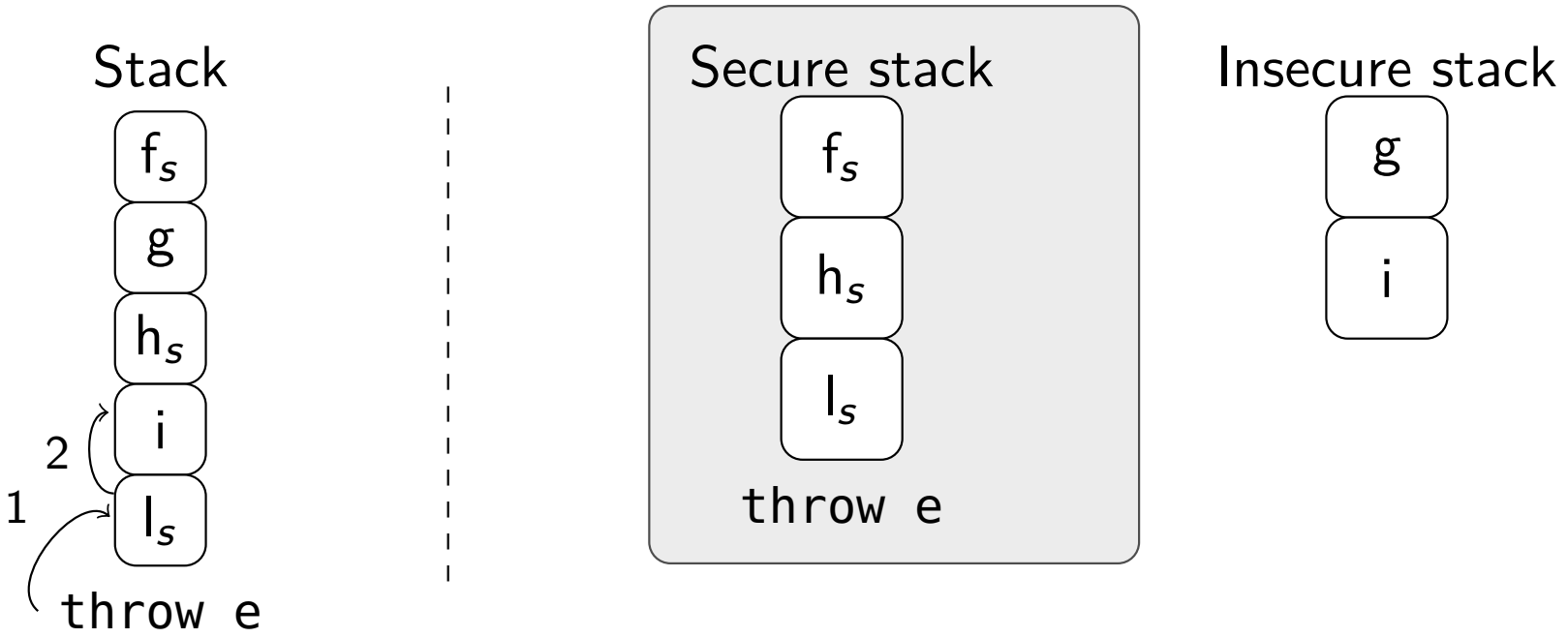
Exceptions


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

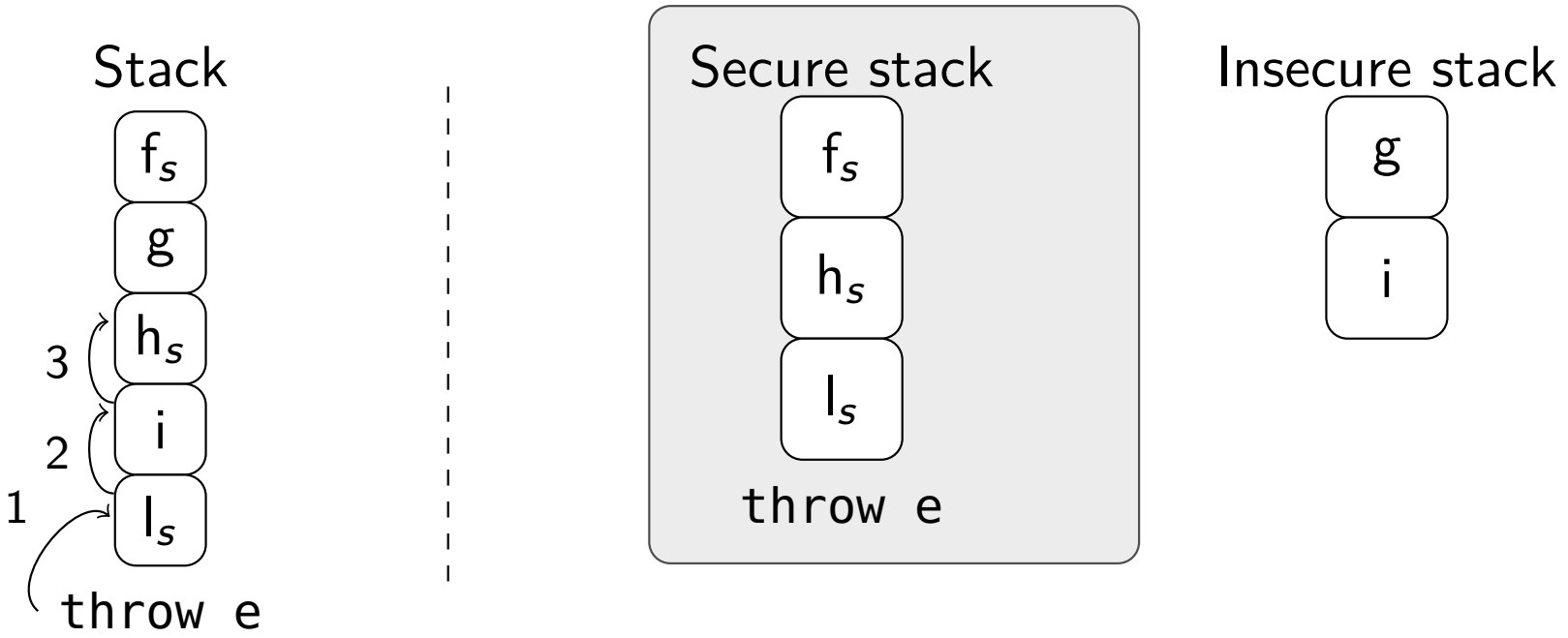
Exceptions


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

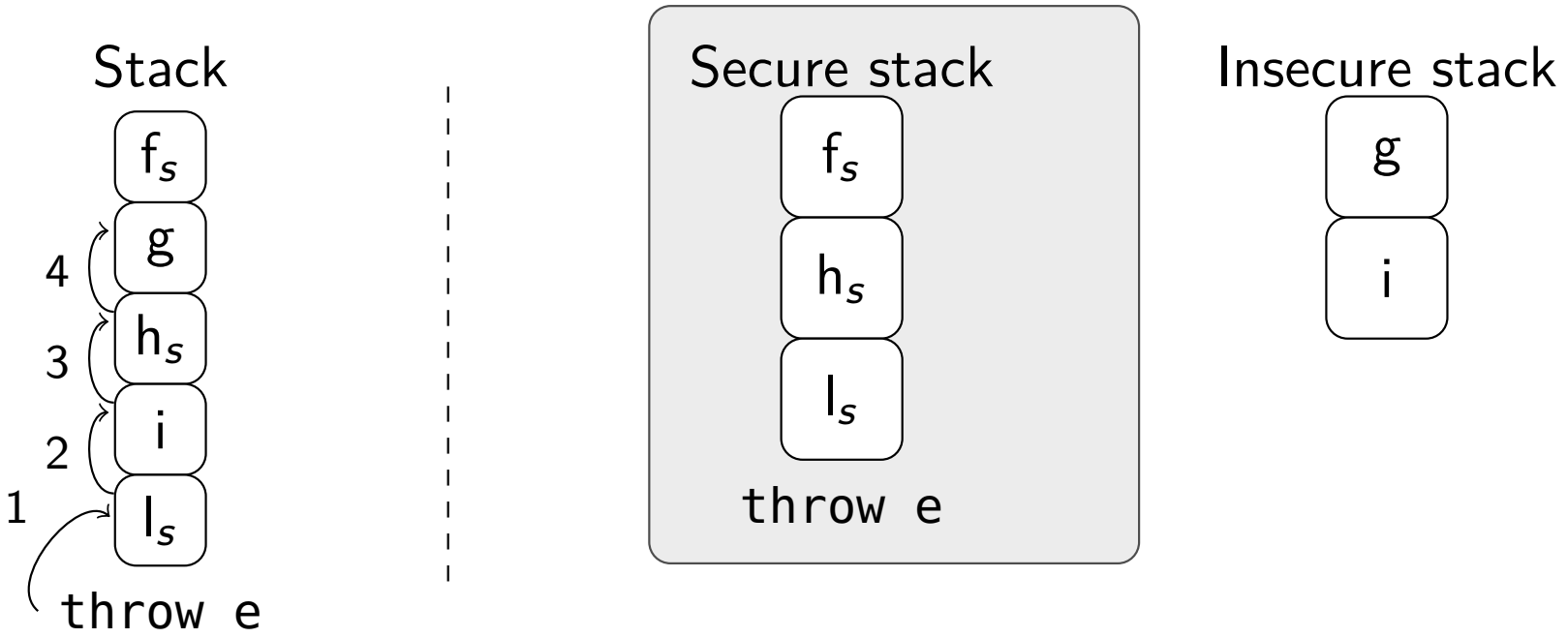
Exceptions


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

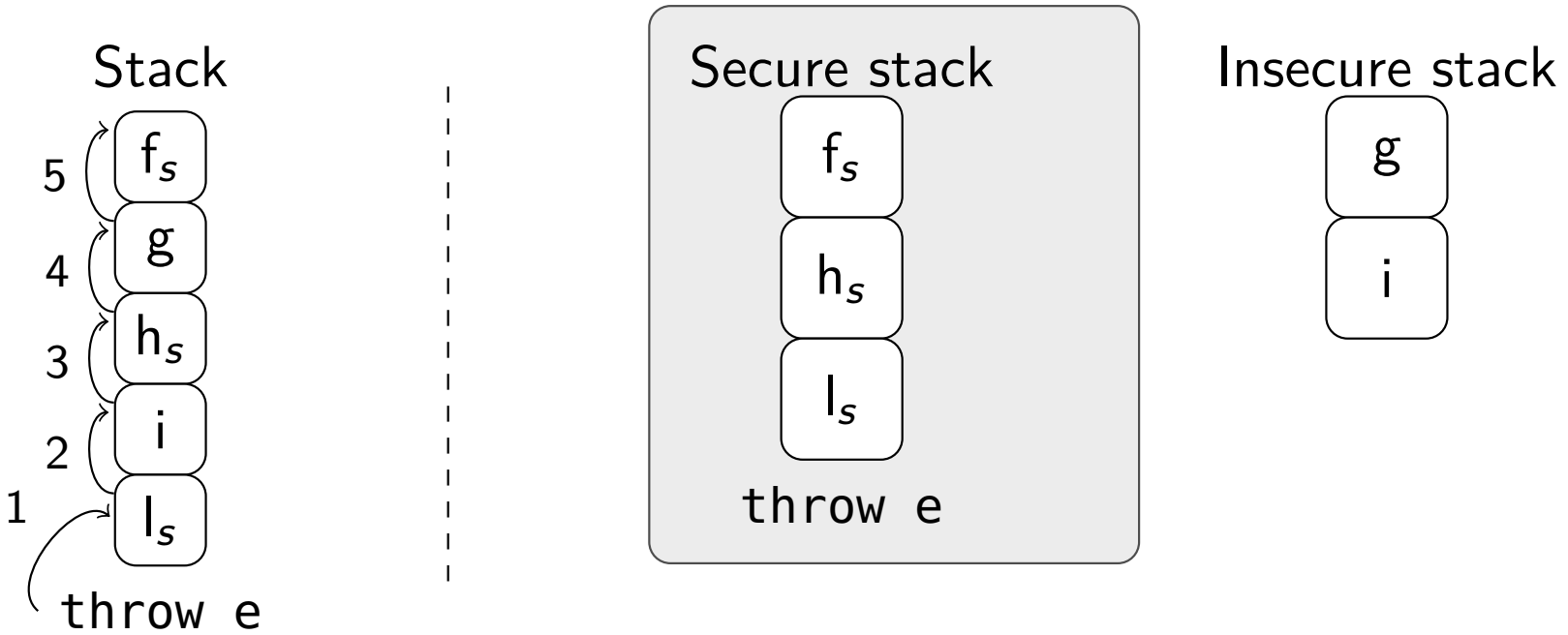
Exceptions


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

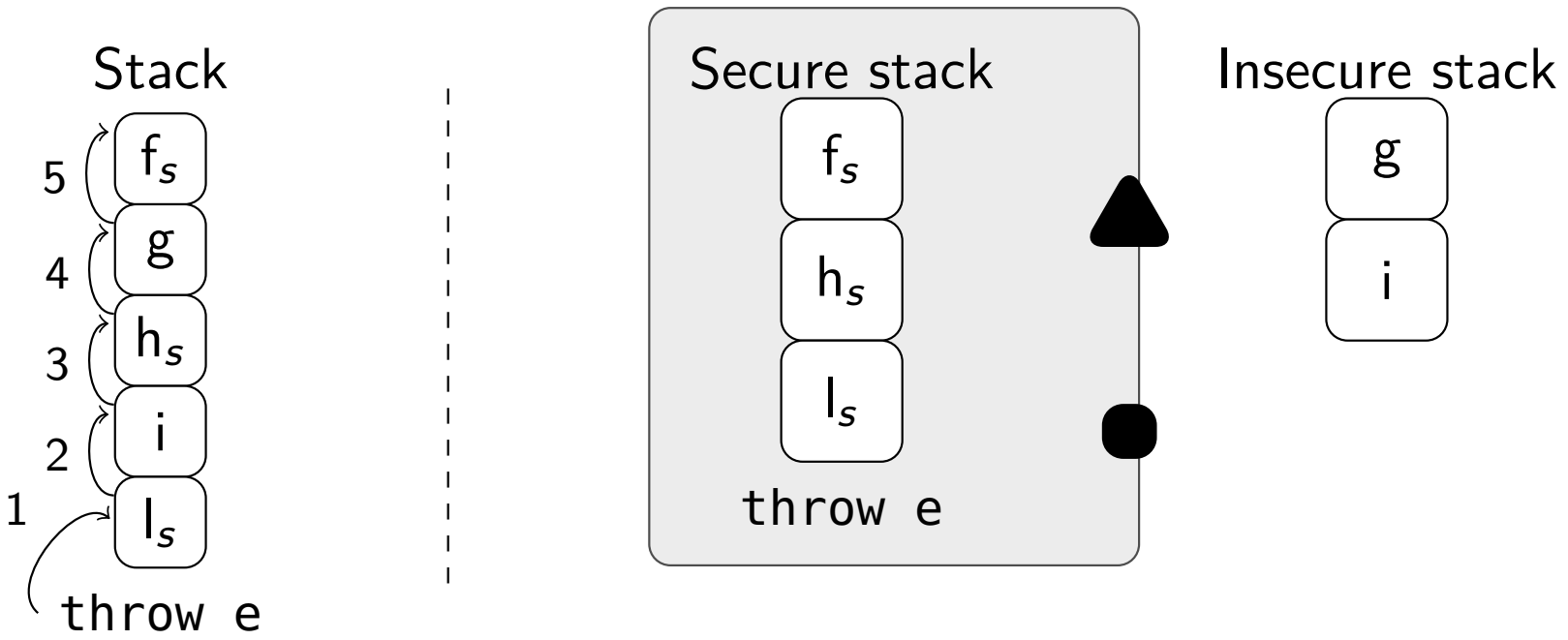
Exceptions


Stack
f_s
g
h_s
i
l_s
4
3
2
1
throw e
Secure stack
f_s
h_s
l_s
throw e
Insecure stack
g
i

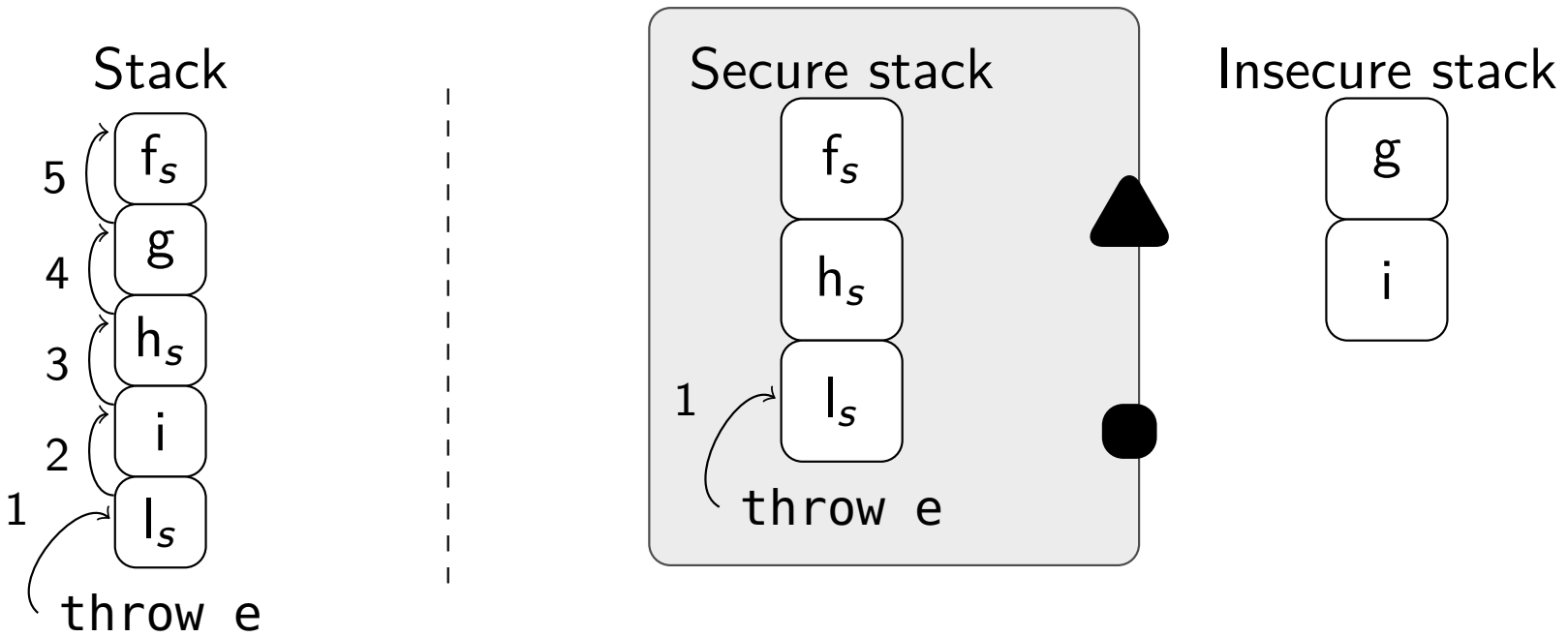
Exceptions


Stack
5
4
3
2
1
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
5
4
3
2
1
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
5
4
3
2
1
f_s
g
h_s
i
l_s
throw e
Secure stack
f_s
h_s
1
l_s
throw e
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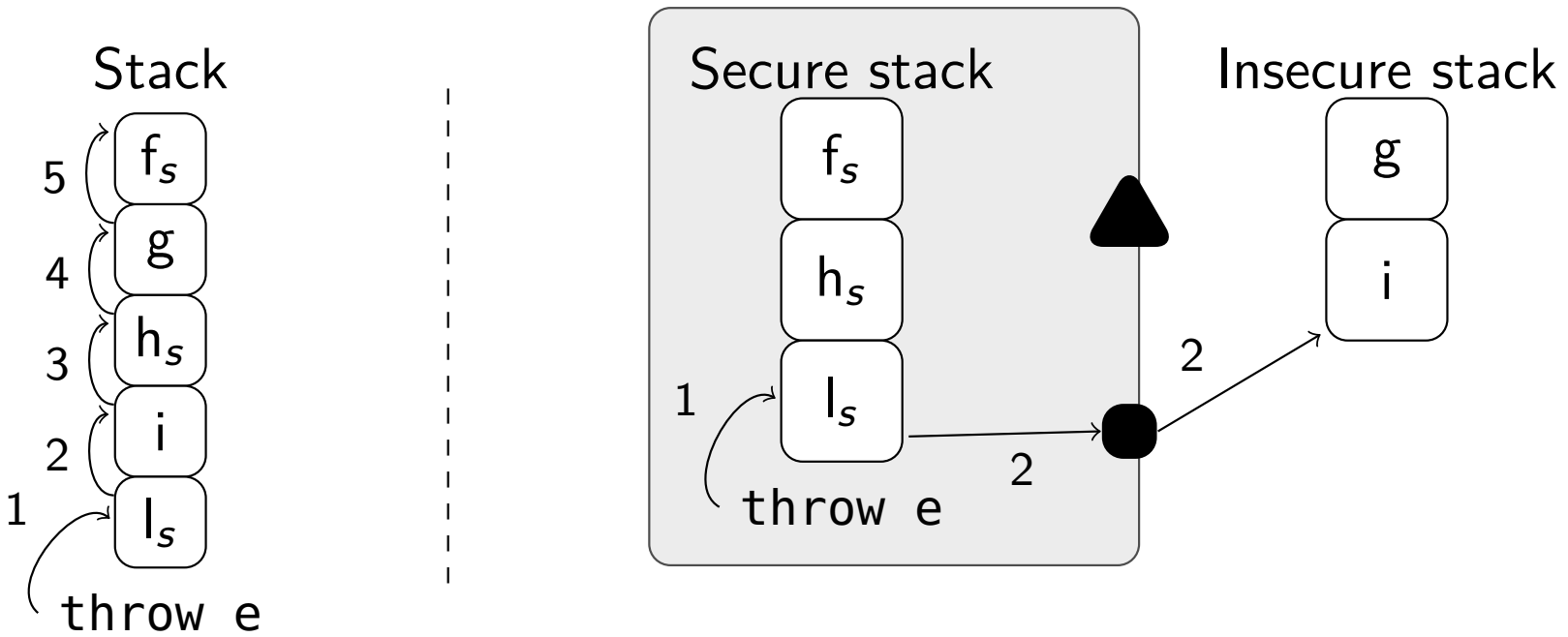
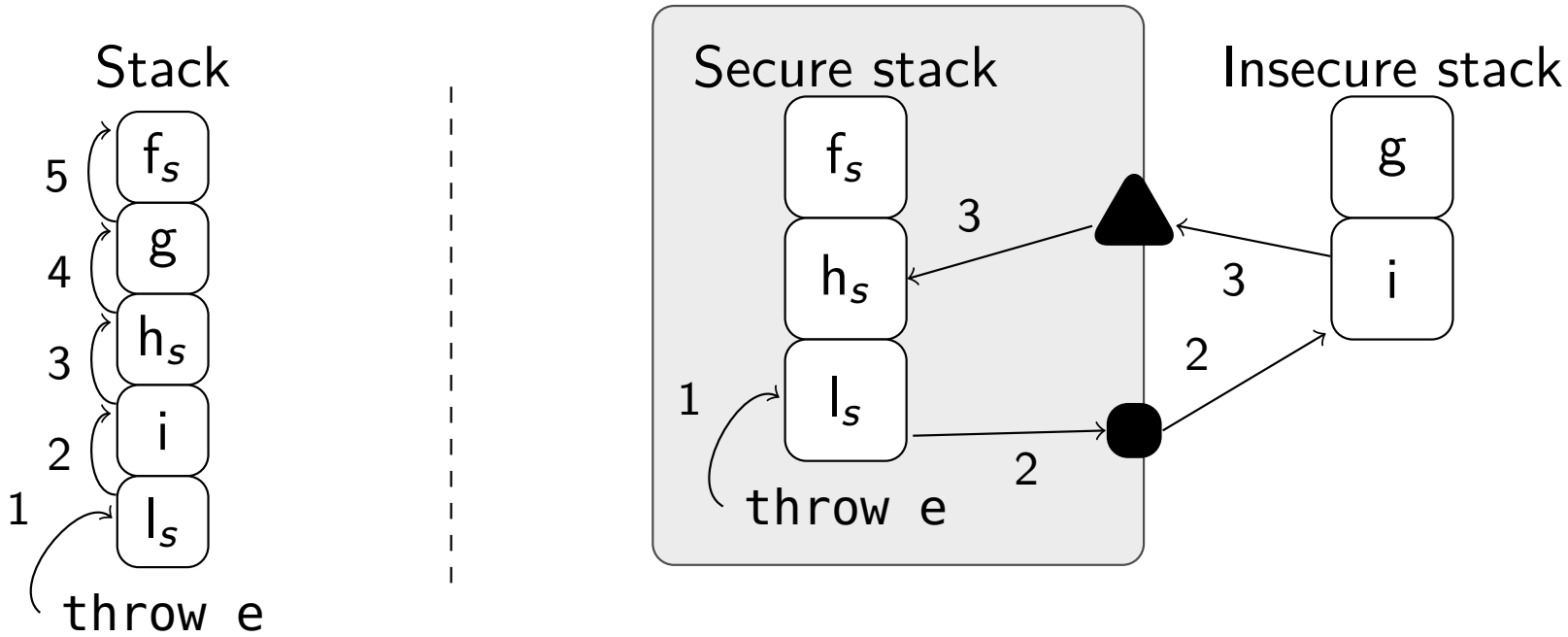
g
i

Exceptions



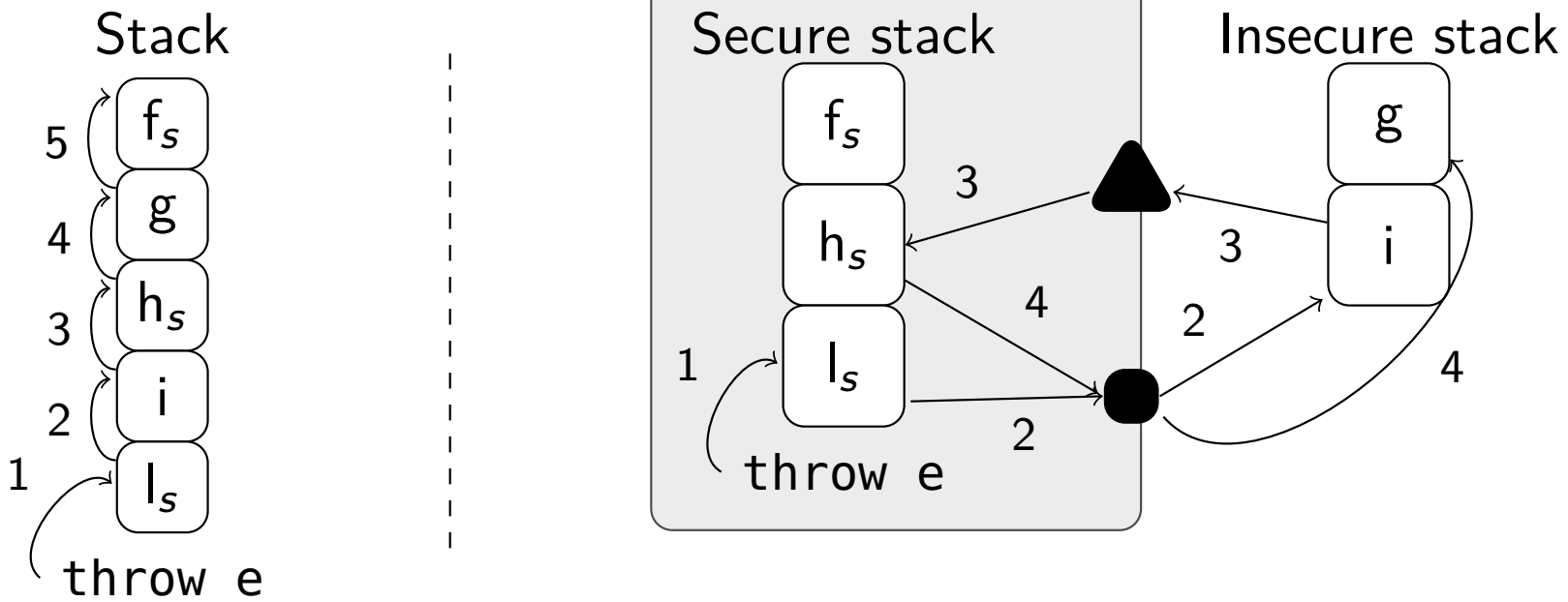
Record passed exceptions

Exceptions



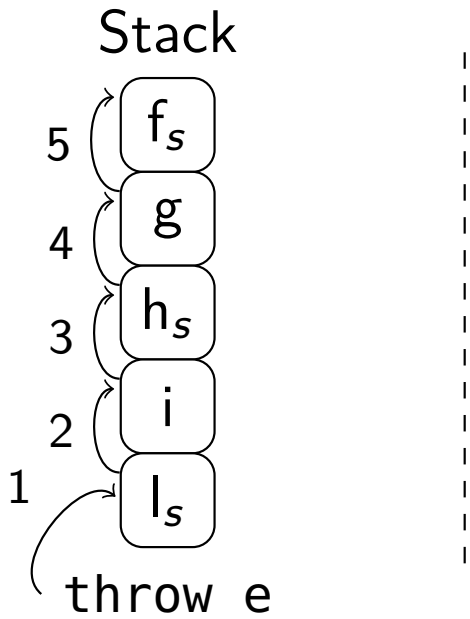
Record passed exceptions
Check that exception could be thrown

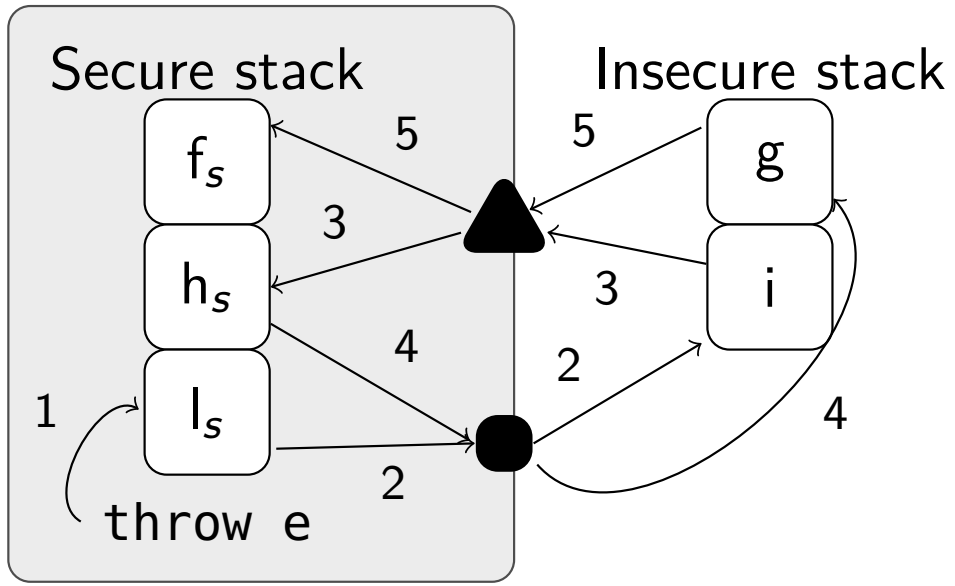
Exceptions



Record passed exceptions
Check that exception could be thrown

Exceptions





Record passed exceptions
Check that exception could be thrown

Cross-package Inheritance

Source level

O1 : JointAccount

O1.counter

O1.limit

```
1  package PSUP;
2    class Account {
3      public getBalance():Int {
4        ...
5      }
6      private counter : Int;
7    }
8
9  package PSUB;
10   class JuniorAccount extends
11       PSUP.Account {
12     public getBalance() : Int {
13       return super.getBalance();
14     }
15     private limit : Int;
16   }
```

- PSUP protected PSUB no

Cross-package Inheritance

Source level

O1 : JointAccount

O1.counter

O1.limit

Target level

$O1^{\downarrow}$

$O1^{\downarrow}$.counter

$O1^{\downarrow}$.limit

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- PSUP protected PSUB no

Cross-package Inheritance

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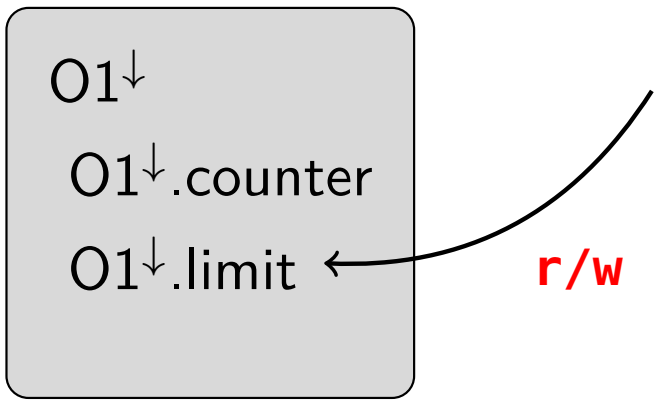


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Cross-package Inheritance

Source level

O1 : JointAccount

O1.counter

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- - - - - - - - - - - - - - - - - - - -

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$O1^{\downarrow}$

$O1^{\downarrow}$.counter

$O1^{\downarrow}$.limit

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Cross-package Inheritance

Source level

O1 : JointAccount

O1.counter

O1.limit

- - - - - - - - - - - - - - - - - - - -

Target level

$O1^{\downarrow}$

$O1^{\downarrow}$.counter

r/w

$O1^{\downarrow}$.limit

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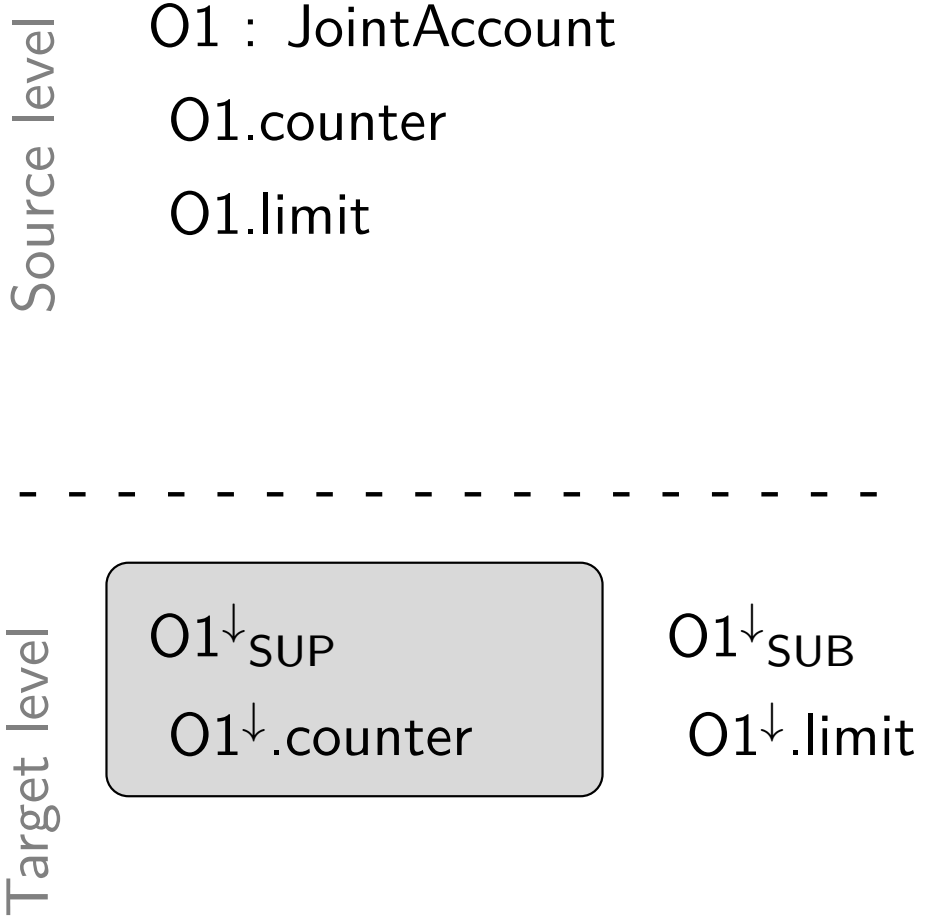
Cross-package Inheritance

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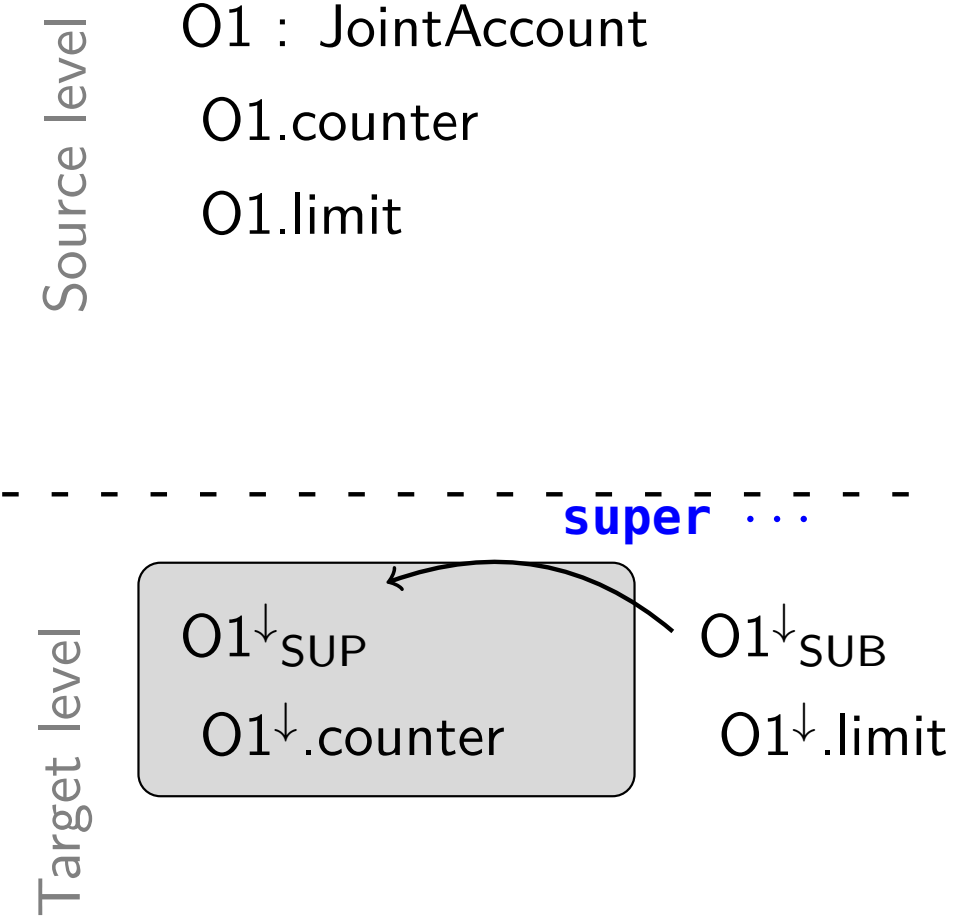
Cross-package Inheritance




```
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Conclusion

- PMA allows the creation of secure (fully abstract) compilers

Conclusion

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- identified naïve mistakes

Conclusion

- PMA allows the creation of secure (fully abstract) compilers
- identified naïve mistakes
- proposed sound solution

Questions

?

Bibliographical References I


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