On Modular and Fully-Abstract Compilation

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Goals

1. understand secure compilation failures due to linking

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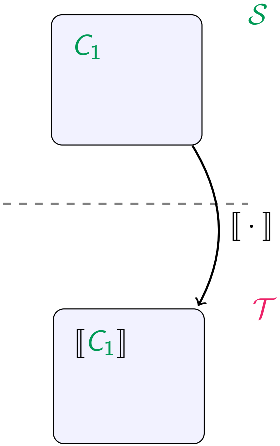
2. present solutions to them relying on Hardware isolation

What is a Secure Compiler?

- *compiler*: function from source to target **components**



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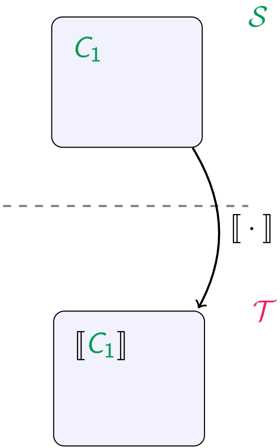

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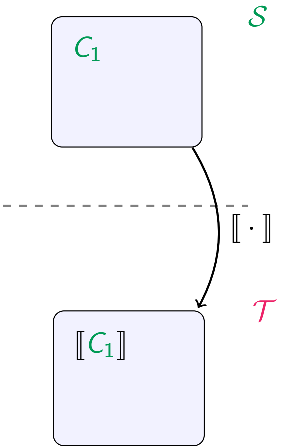
- *secure compiler*: preserves source-level security properties in the generated components
- *literature example*: fully-abstract compiler



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- behaviour preservation (and reflection) means preservation of security properties

Indicating behaviour: Contextual equivalence

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- $C_1 \simeq^{\mathcal{L}} C_2 \triangleq \forall \mathbb{C},\ \mathbb{C}[C_1] \Uparrow \iff \mathbb{C}[C_2] \Uparrow$

Fully Abstract Compilation Formally

$\forall C_1, C_2 \in \mathcal{S}.$

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$$\Updownarrow$$

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$$[\![C_1]\!] \simeq^{\mathcal{T}} [\![C_2]\!]$$

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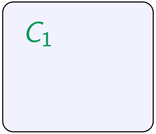
- $\mathbb{C}$ models the attacker
- *attacker model*: protection against code injection attacks

Compiler INsecurity



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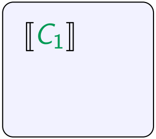

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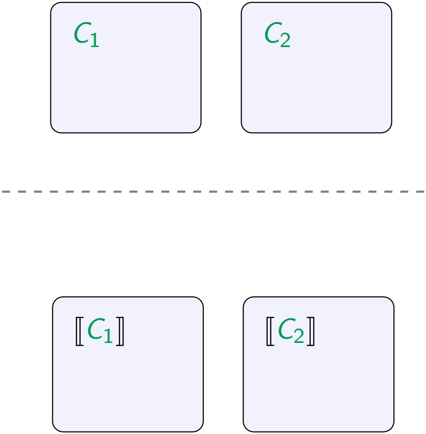

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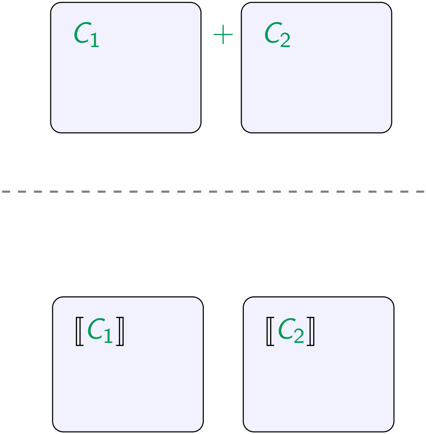

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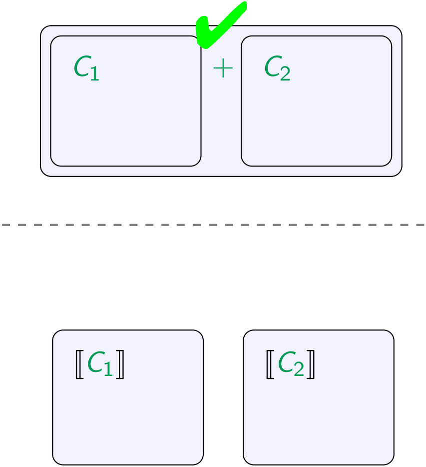

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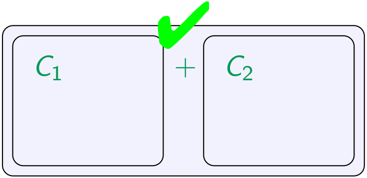

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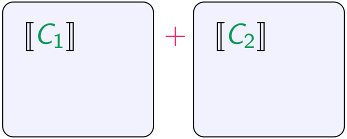

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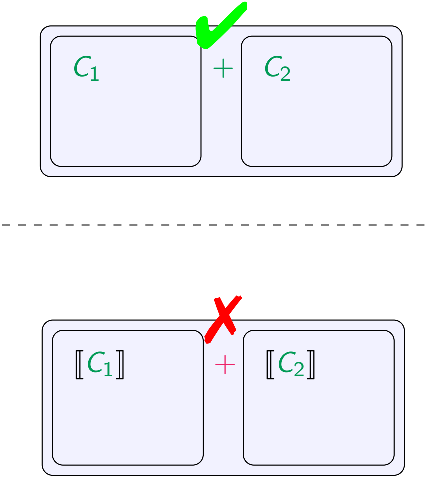

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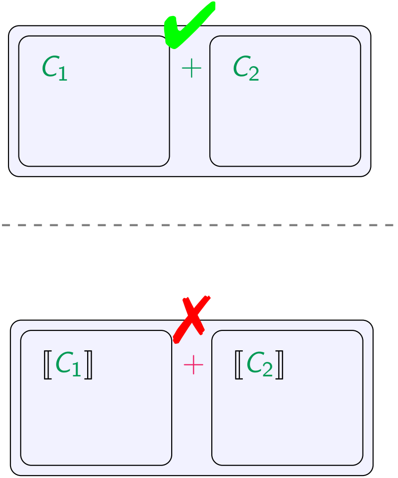

Compiler INsecurity

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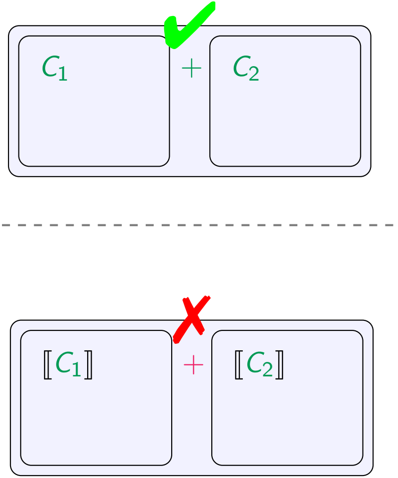
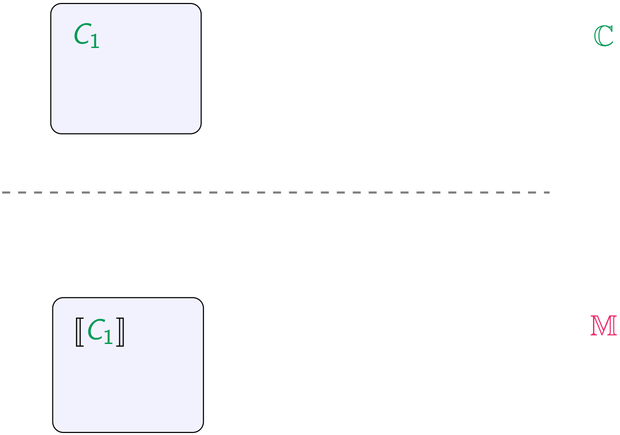
- we adopt an *object − based language* and an *assembly* one



Call Stack Shortcutting - 1 module



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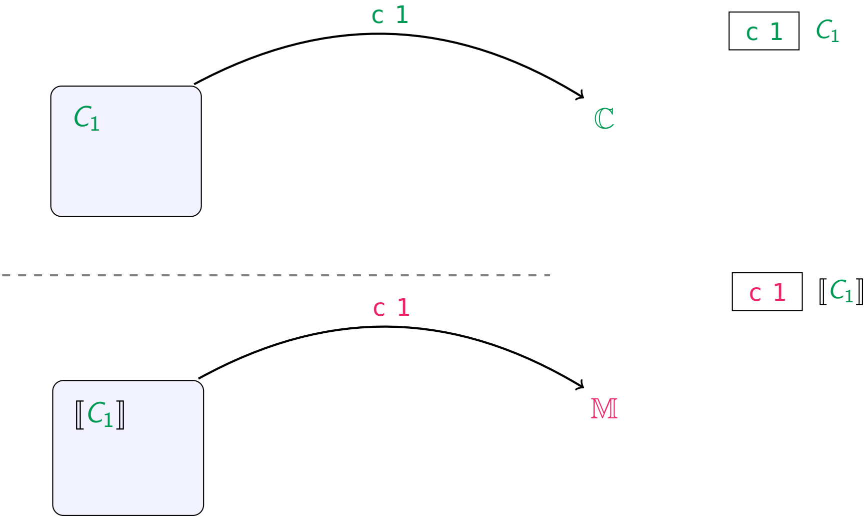

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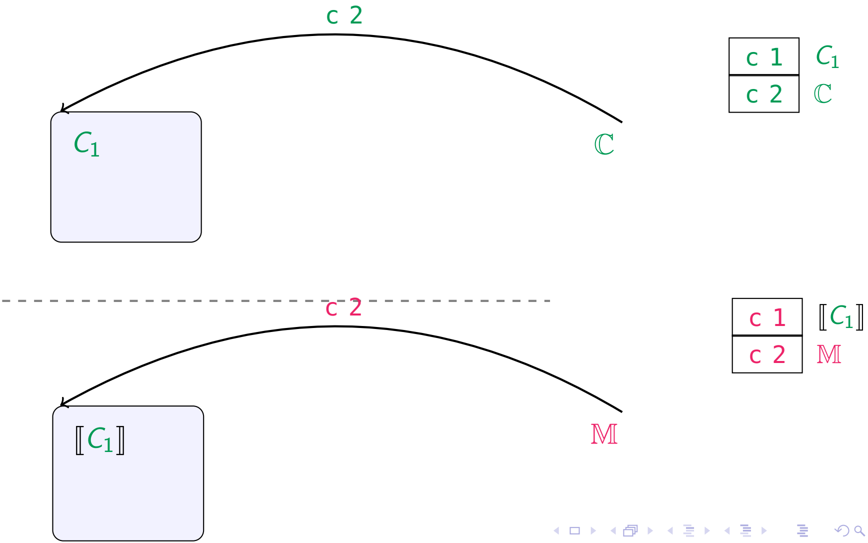

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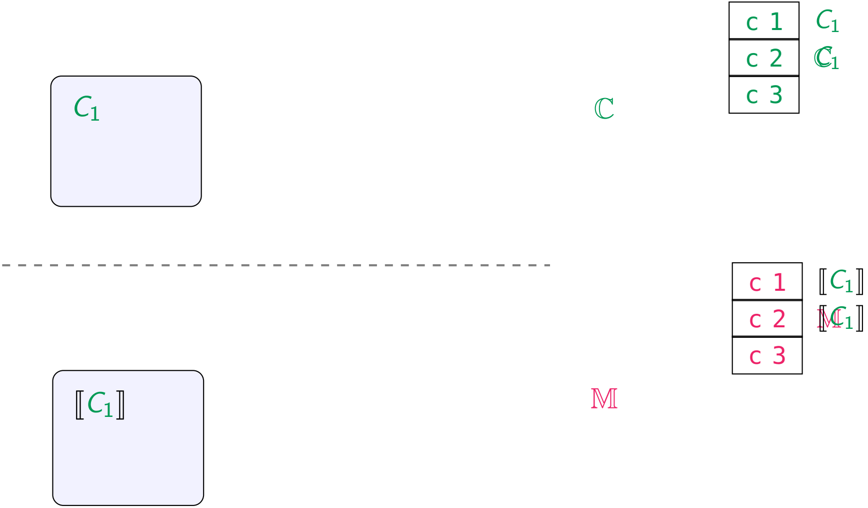

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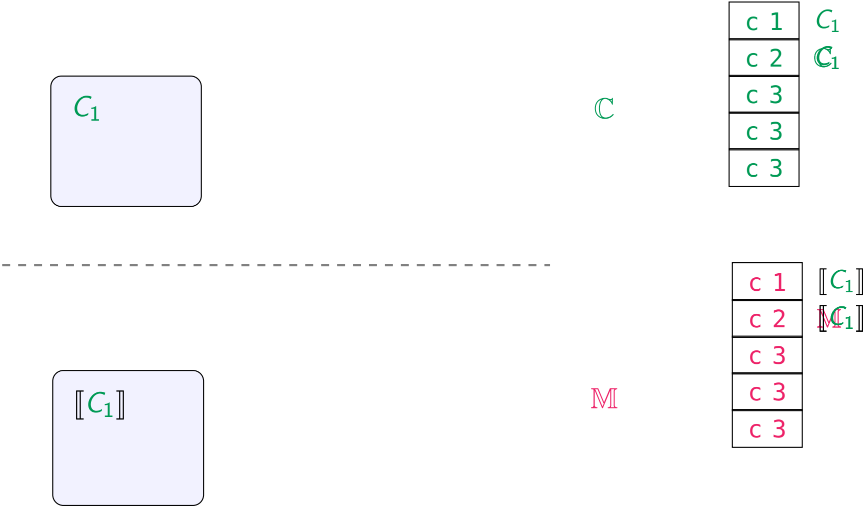

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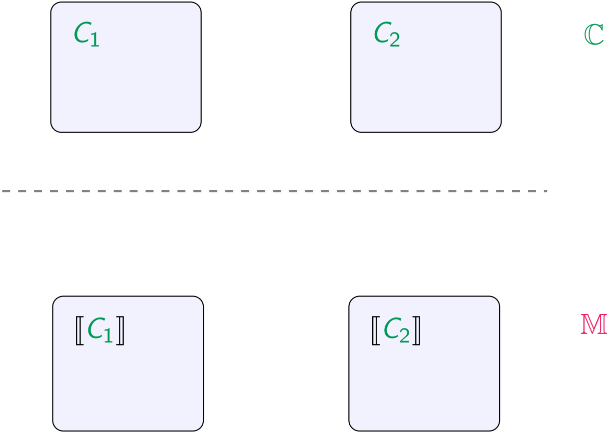

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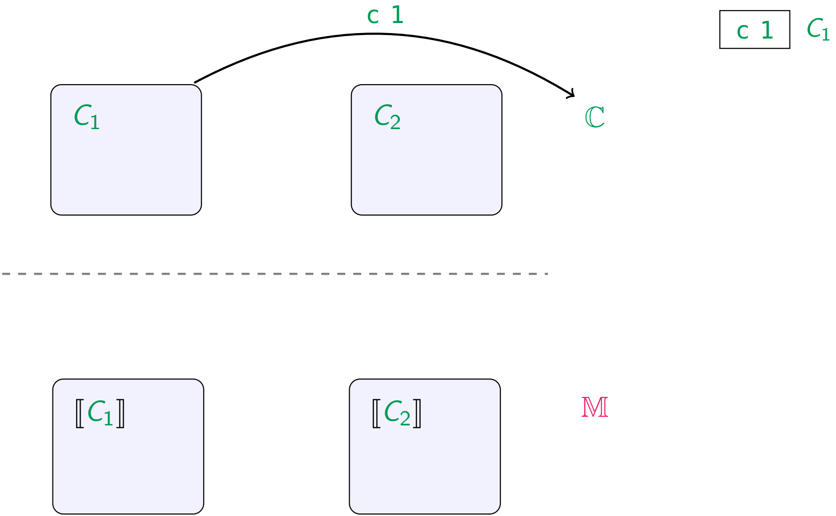

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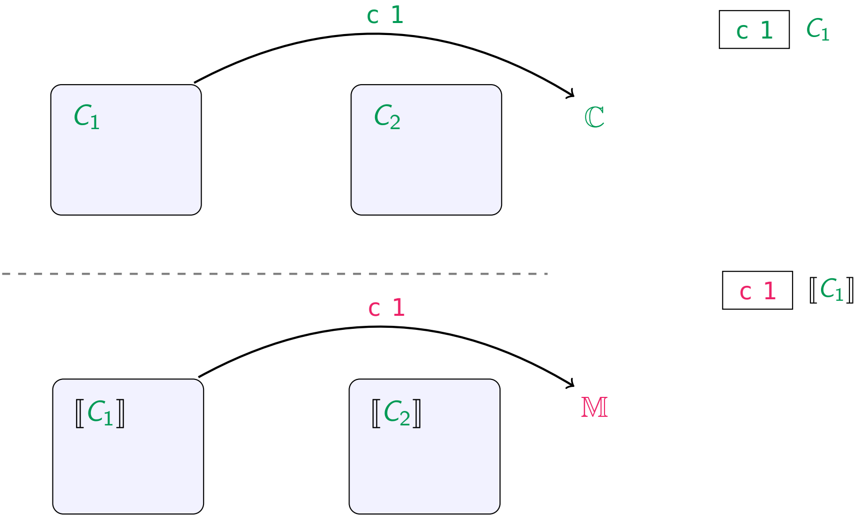

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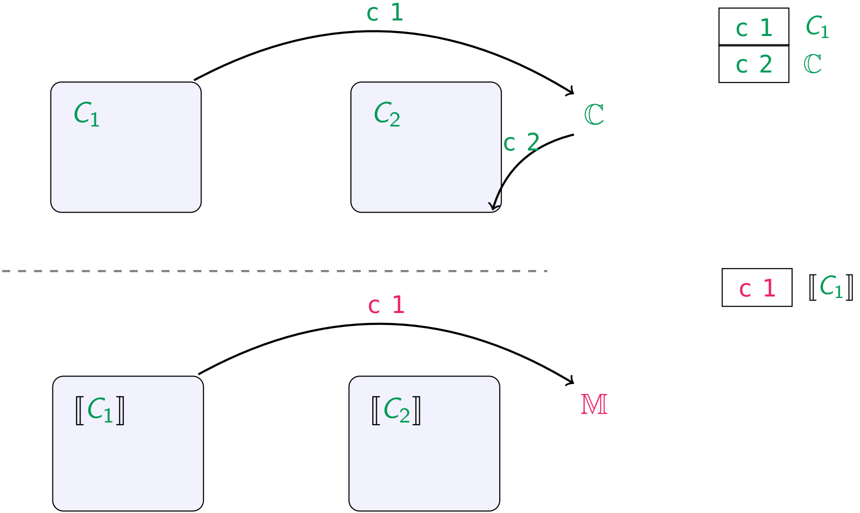

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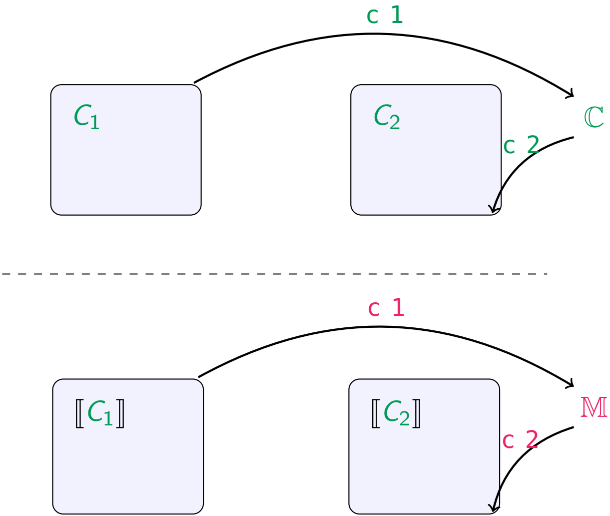

c 1	C_1
c 2	$\mathbb{C}$

c 1	$[\![C_1]\!]$
c 2	$\mathbb{M}$

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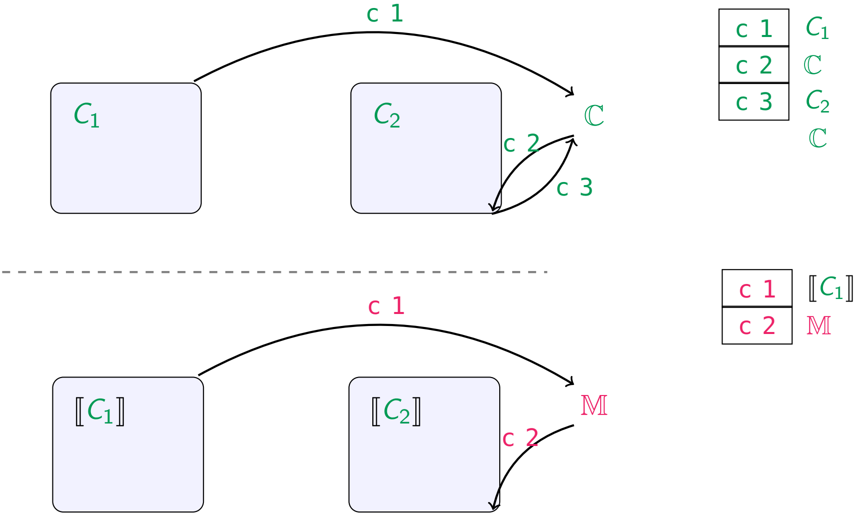

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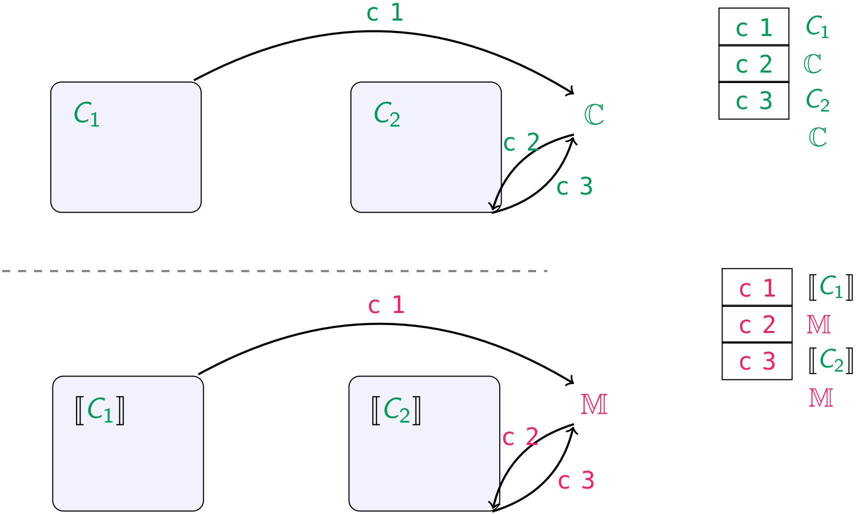

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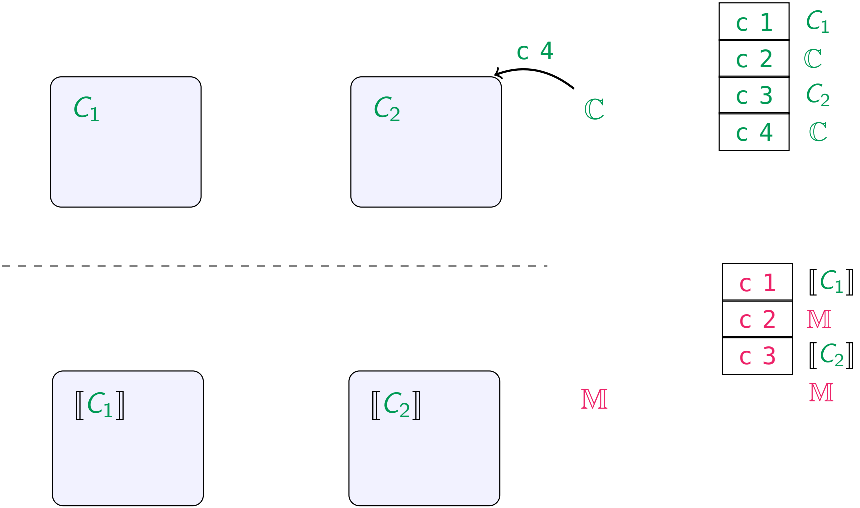

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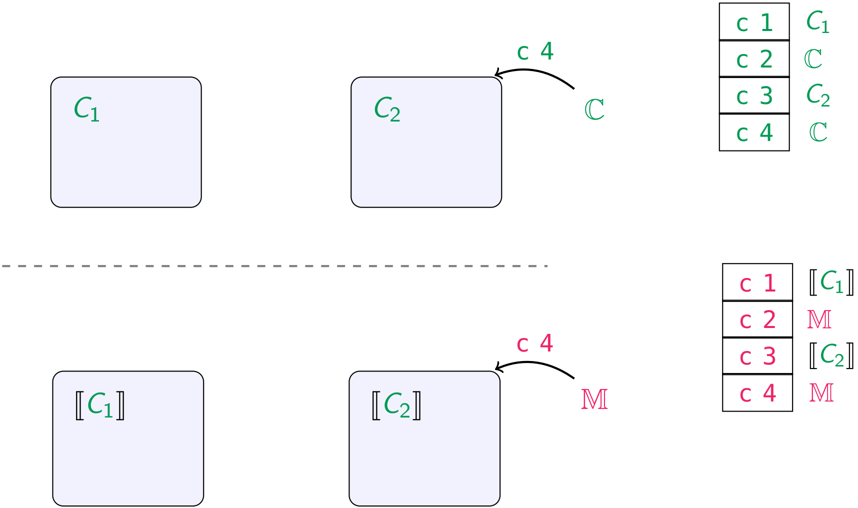

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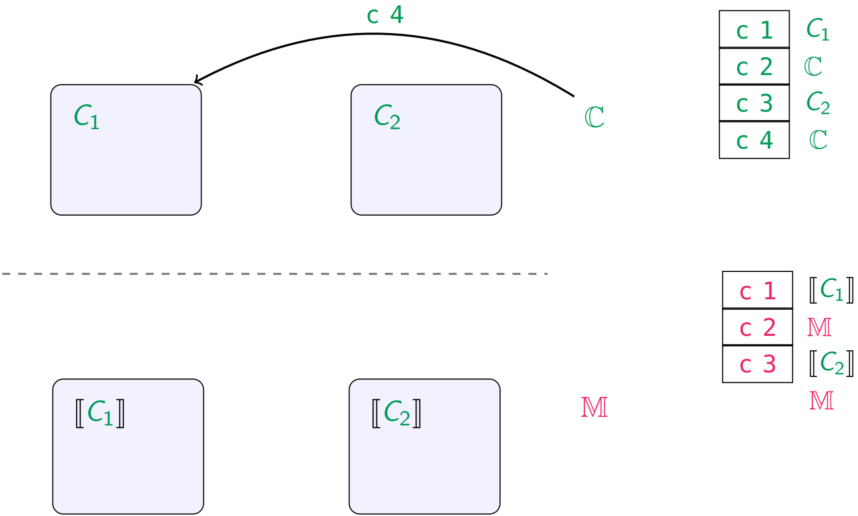

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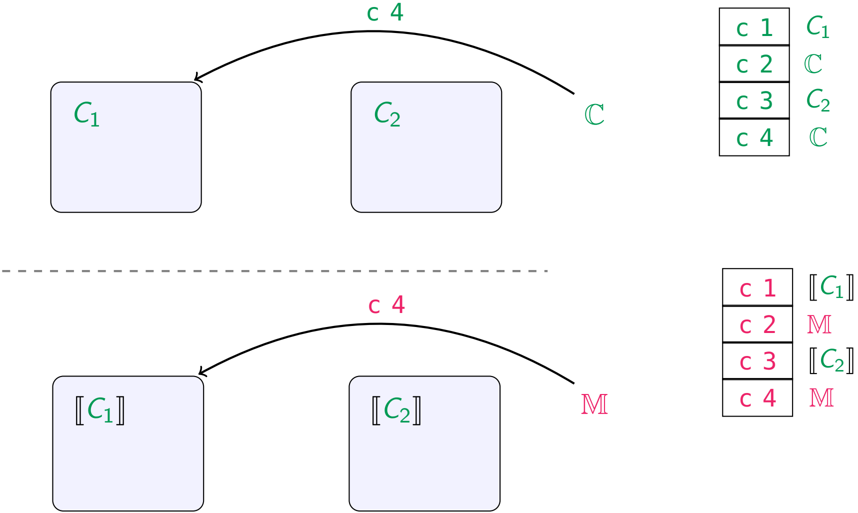

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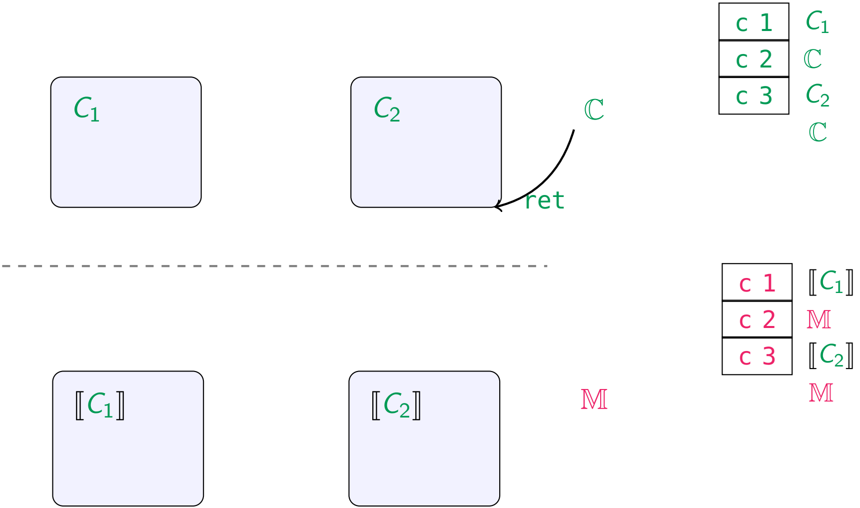

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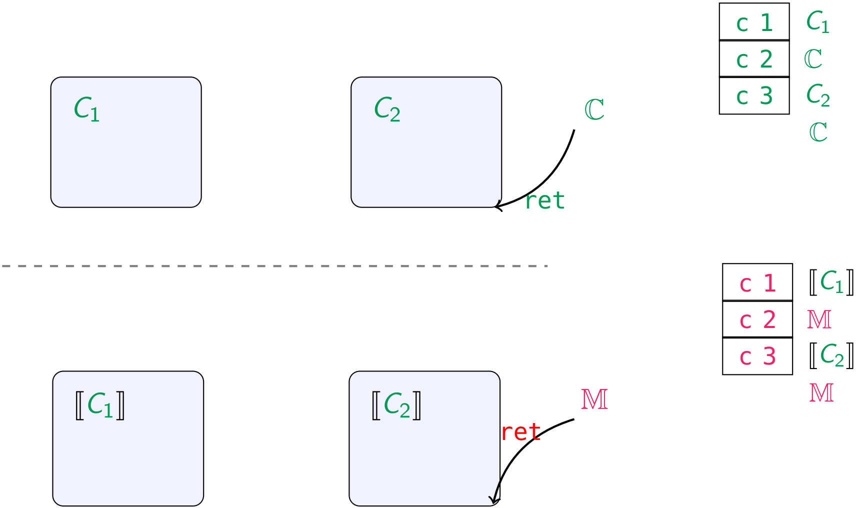

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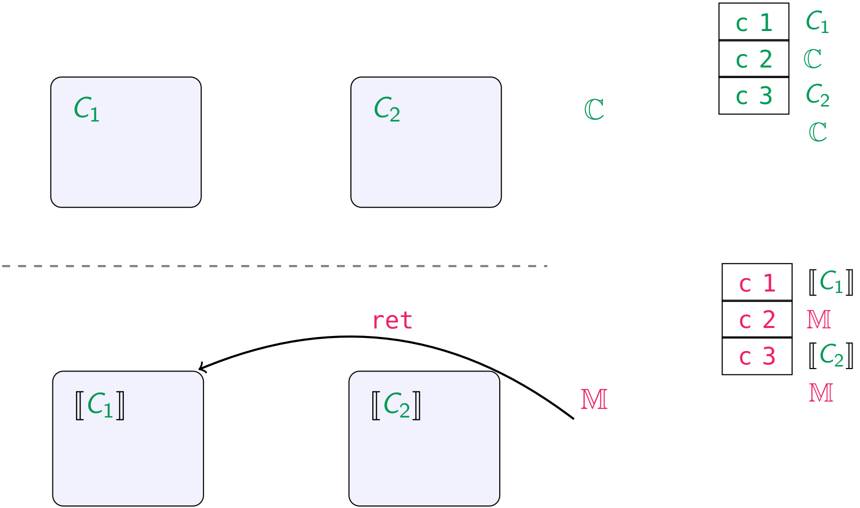

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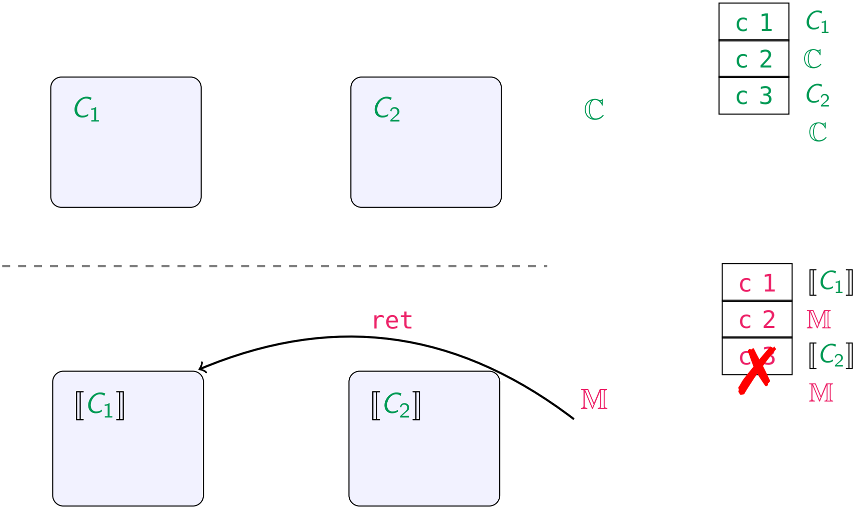

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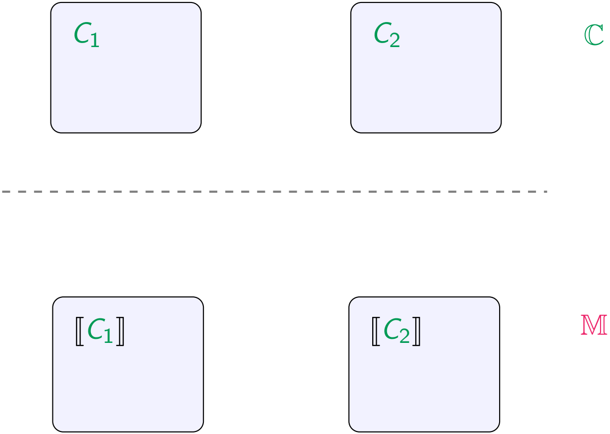

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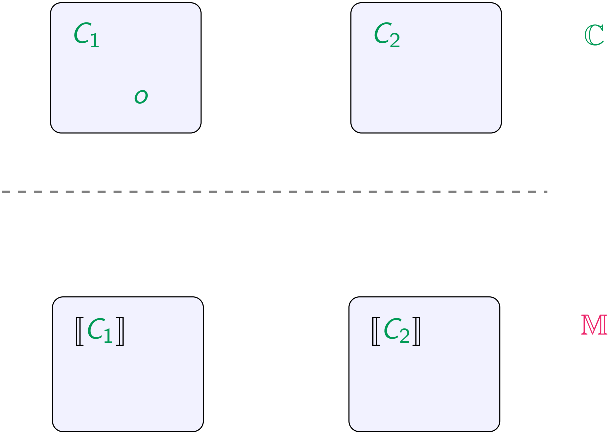

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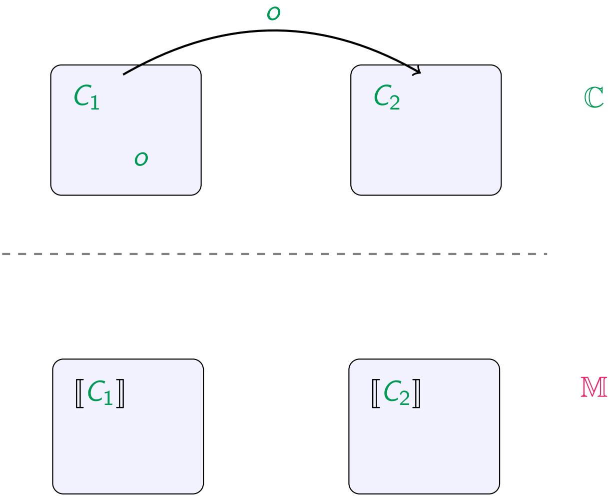

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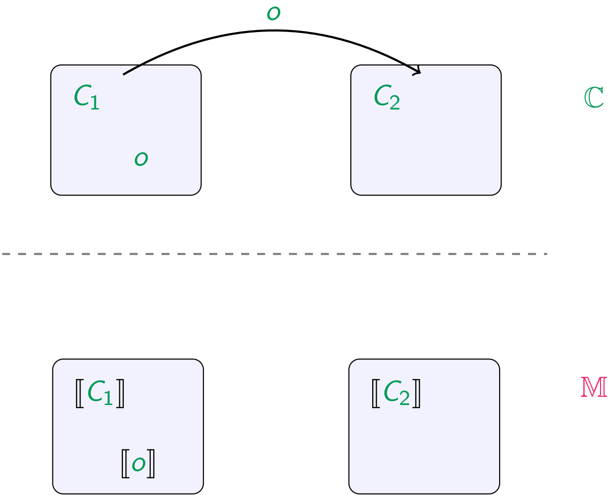

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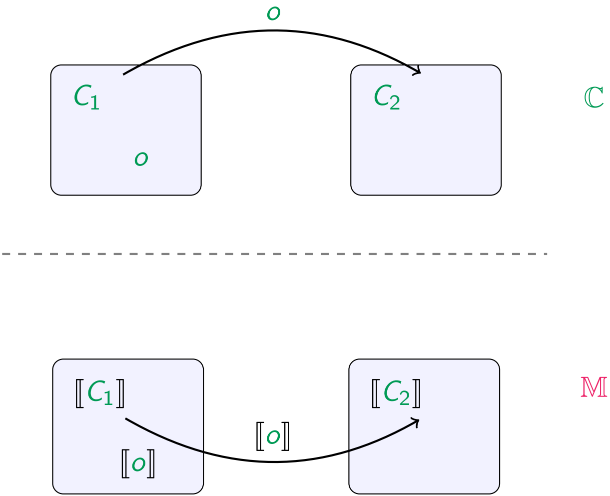

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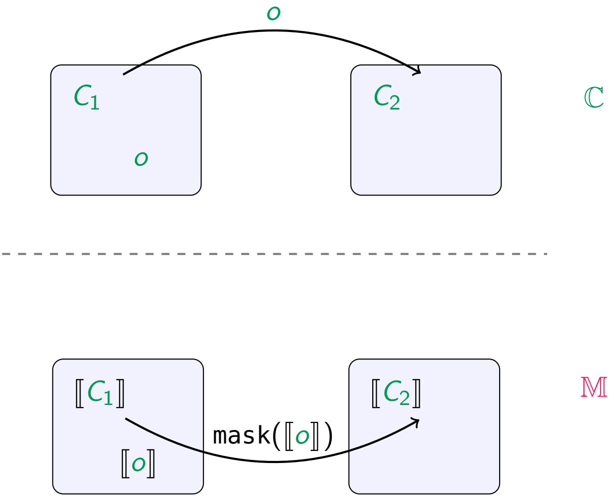

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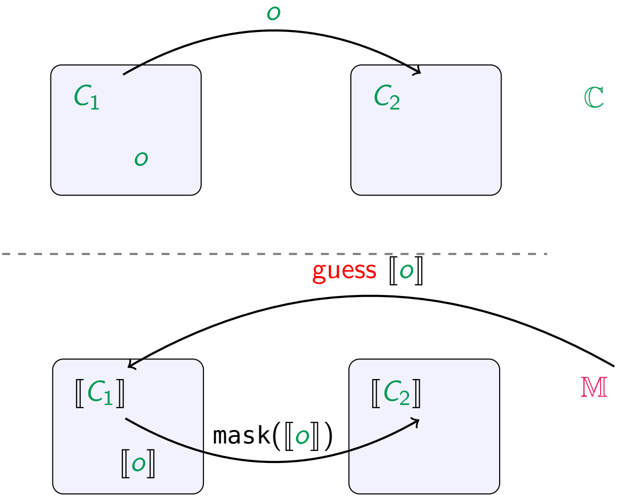

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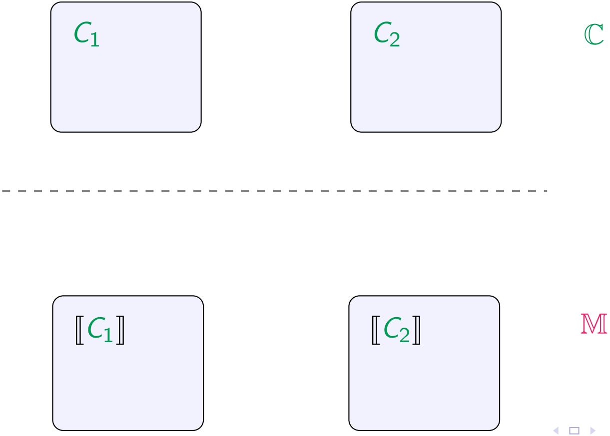

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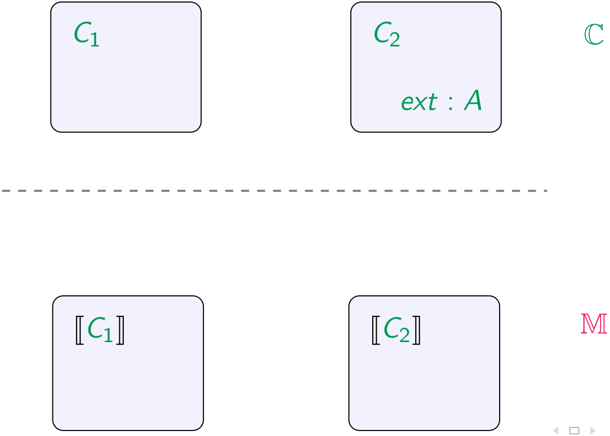

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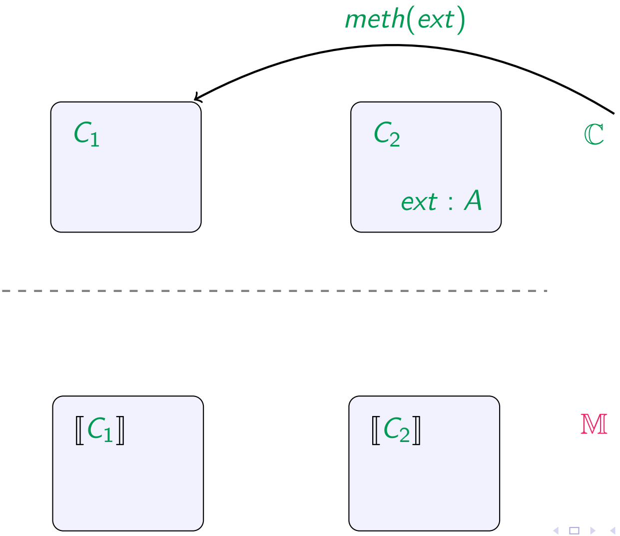

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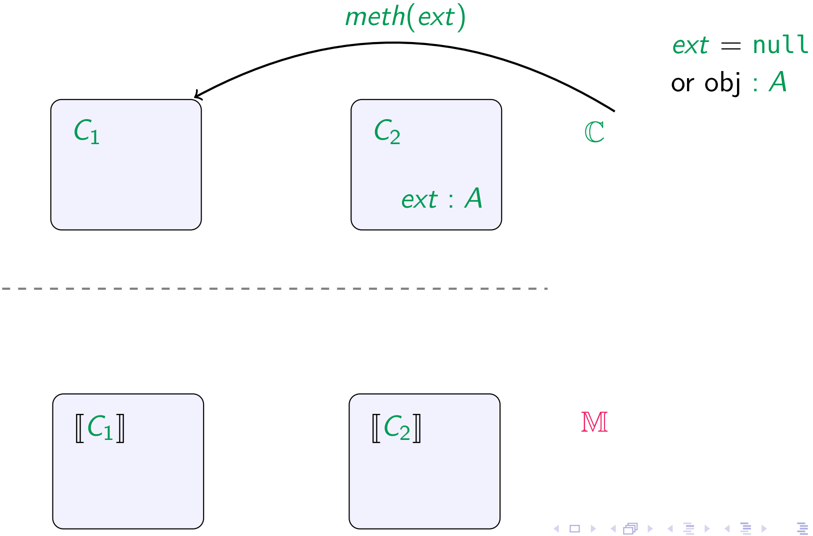

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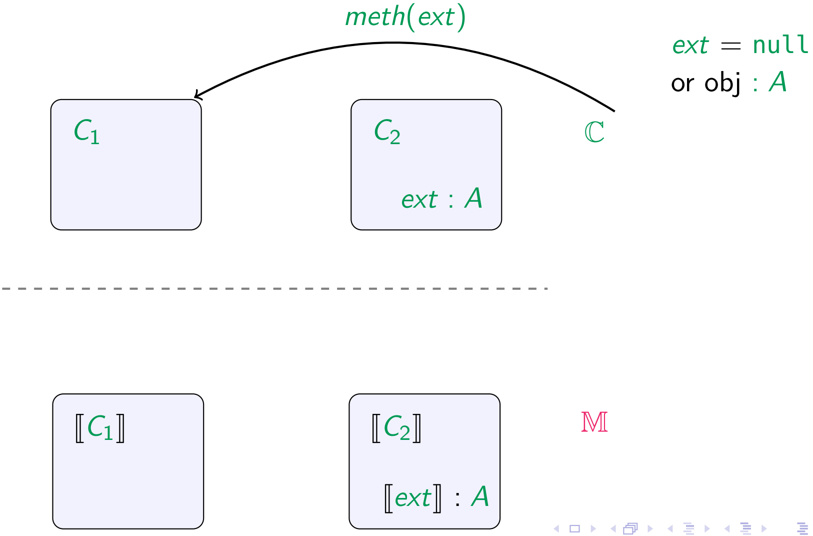

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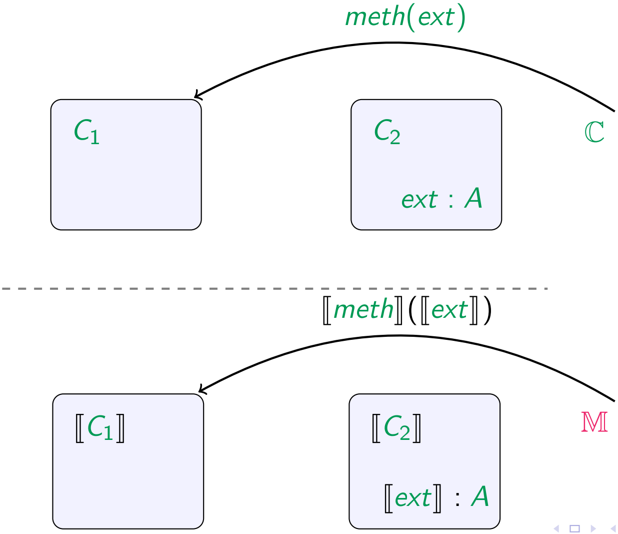

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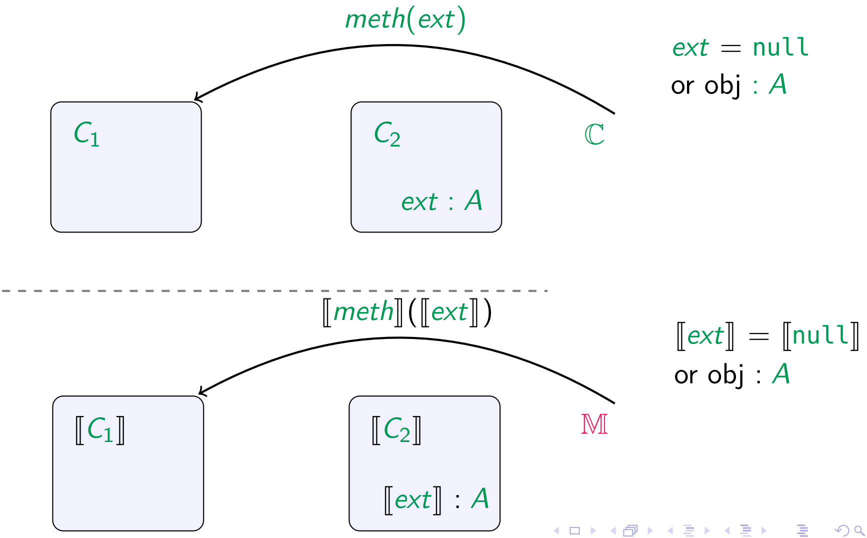

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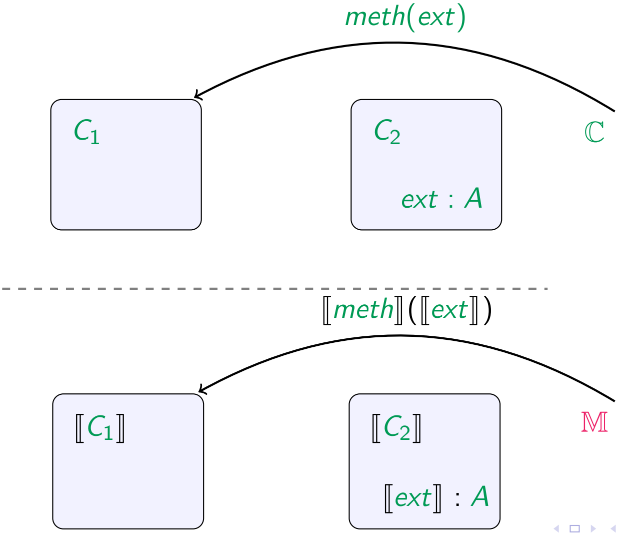

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$[\![ext]\!] = [\![\texttt{null}]\!]$
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or obj : $B \not\lessdot A$
or garbage

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  - non-feasible since trust is not transitive

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1. What is a PMA module?
2. How does this address the previous problems?

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- deep encapsulation at hardware level
- security building block of many security-relevant works
- readily available: Intel SGX

Untyped Assembly + PMA

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0x0001    call 0xb53
0x0002    movs r0 0x0b55
⋮
0x0b52    movs r0 0x0b55
0x0b53    call 0x0002
0x0b54    movs r0 0xeb54
0x0b55    ...
⋮
0xab00    jmp 0x0b53
⋮
0xeb52    movs r0 0xeb54
0xeb53    call 0xab02
0xeb54    ...
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0x0b53    call 0x0002
0x0b54    movs r0 0xeb54
0x0b55    ...
⋮
0xab00    jmp 0x0b53
⋮
--- ID 2 ---
0xeb52    movs r0 0xeb54
0xeb53    call 0xab02
0xeb54    ...
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-------------------------
0x0b55    ...
```

```
  ⋮
0xab00    jmp 0x0b53
  ⋮
```

ID 2

```
0xeb52    movs r0 0xeb54
0xeb53    call 0xab02
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0xeb54    ...
  ⋮
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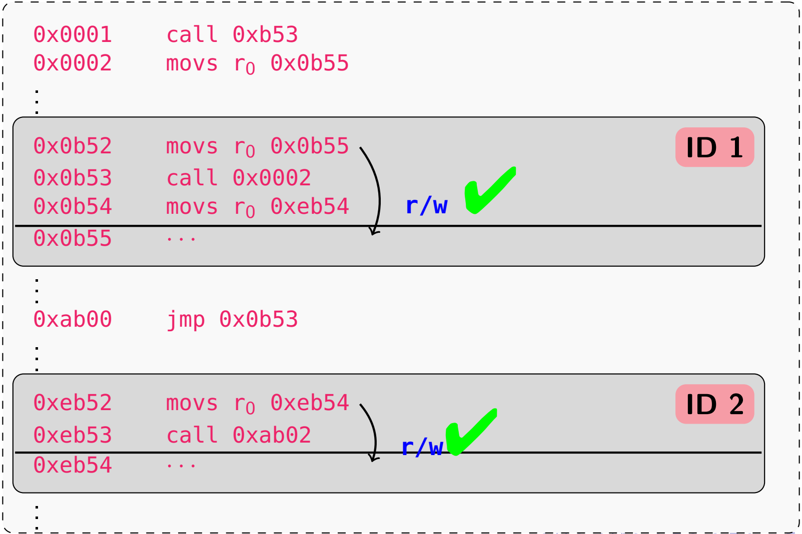

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  ⋮
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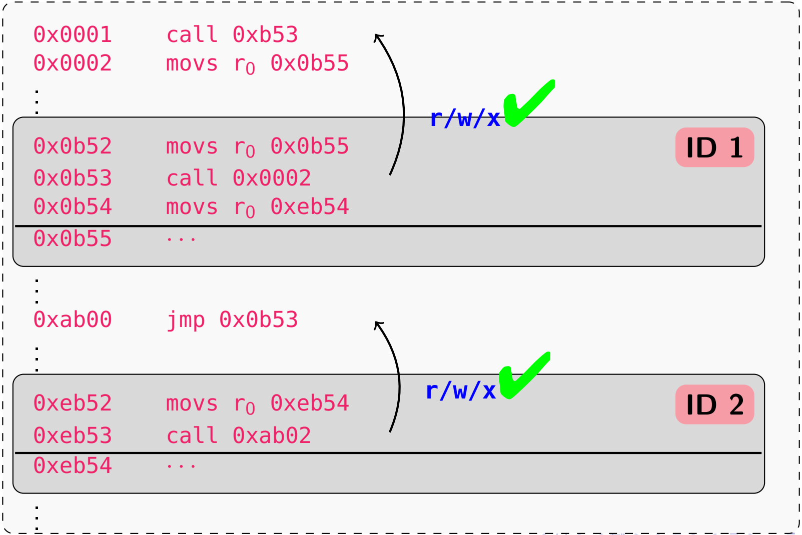
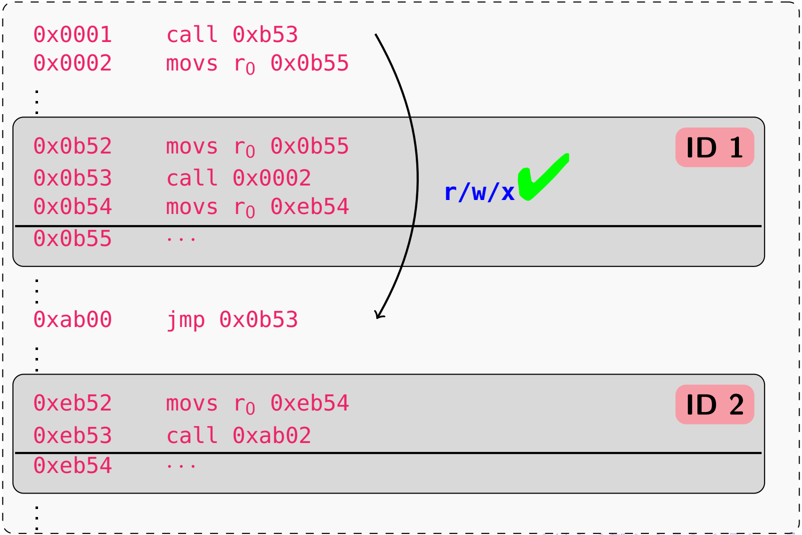
------------------------------
0x0b55    ...
  ⋮
0xab00    jmp 0x0b53
  ⋮
ID 2
0xeb52    movs r0 0xeb54
0xeb53    call 0xab02
------------------------------
0xeb54    ...
  ⋮
```

Untyped Assembly + PMA



Untyped Assembly + PMA



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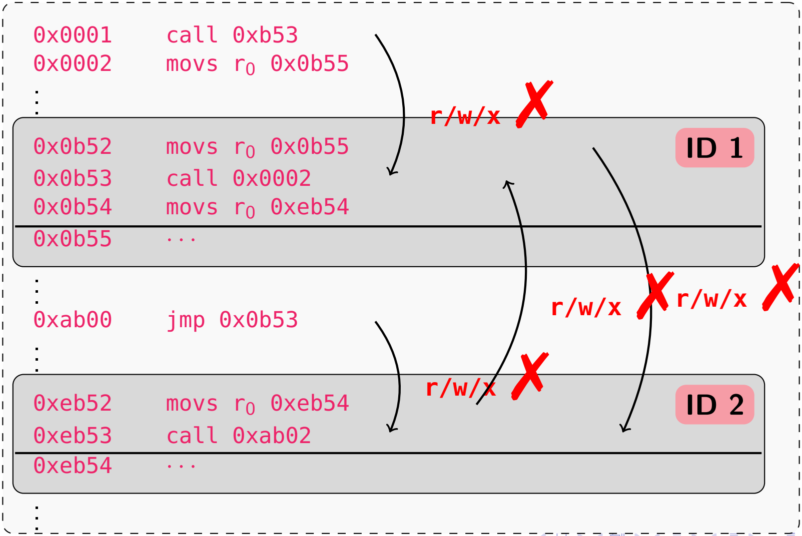
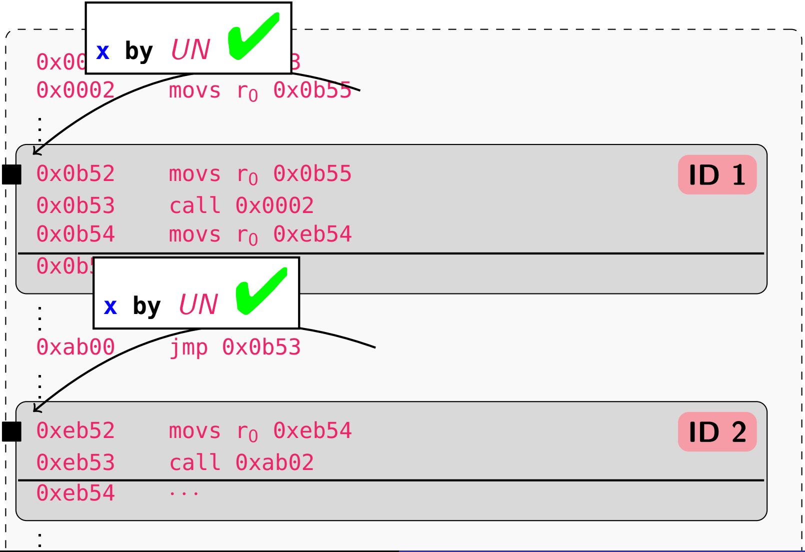


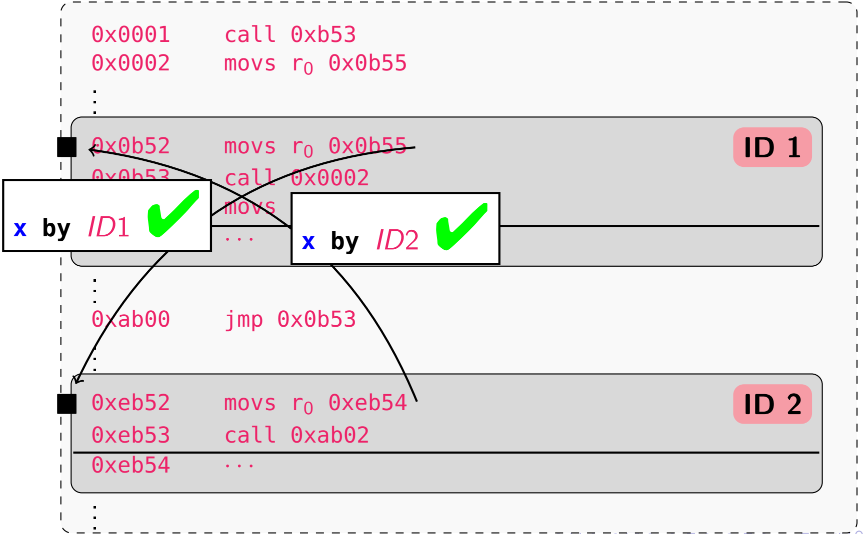
Untyped Assembly + PMA

```
0x0001    call 0xb53
0x0002    movs r0 0x0b55
  ⋮
0x0b52    movs r0 0x0b55      ID 1
0x0b53    call 0x0002
0x0b54    movs r0 0xeb54
---------------------------------
0x0b55    ...
  ⋮
0xab00    jmp 0x0b53
  ⋮
0xeb52    movs r0 0xeb54      ID 2
0xeb53    call 0xab02
---------------------------------
0xeb54    ...
  ⋮
```

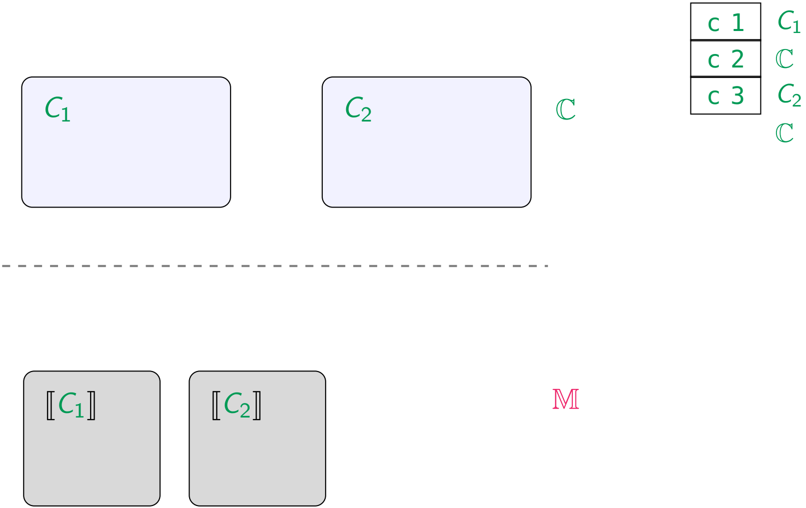
Untyped Assembly + PMA



Untyped Assembly + PMA



Addressing Call Stack Shortcutting



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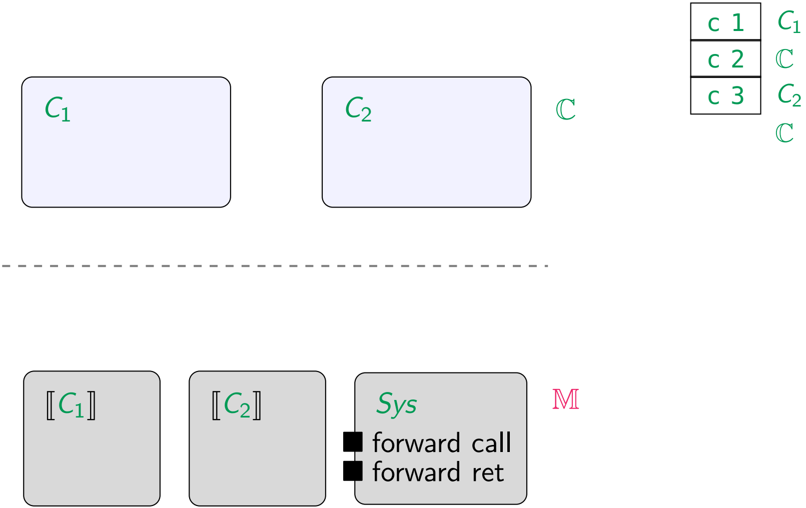

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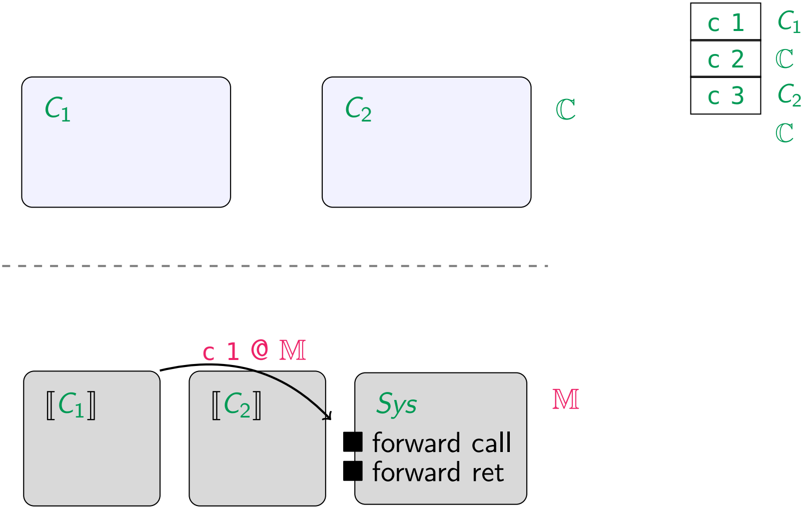

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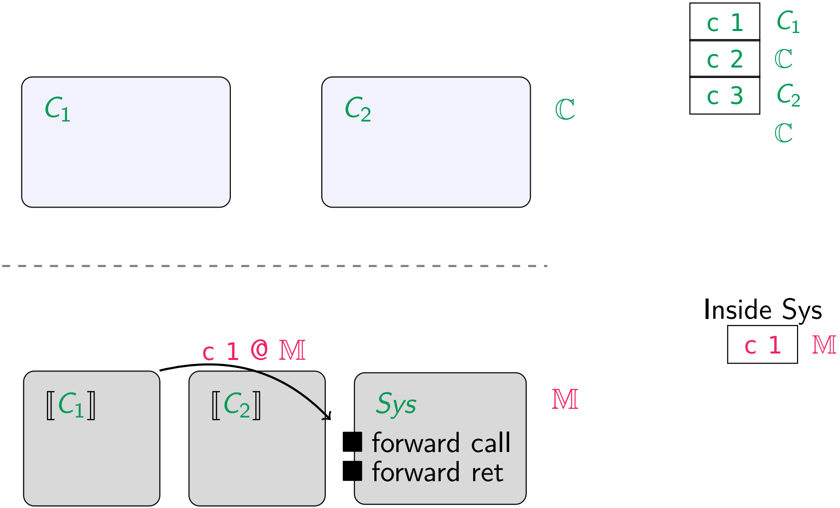

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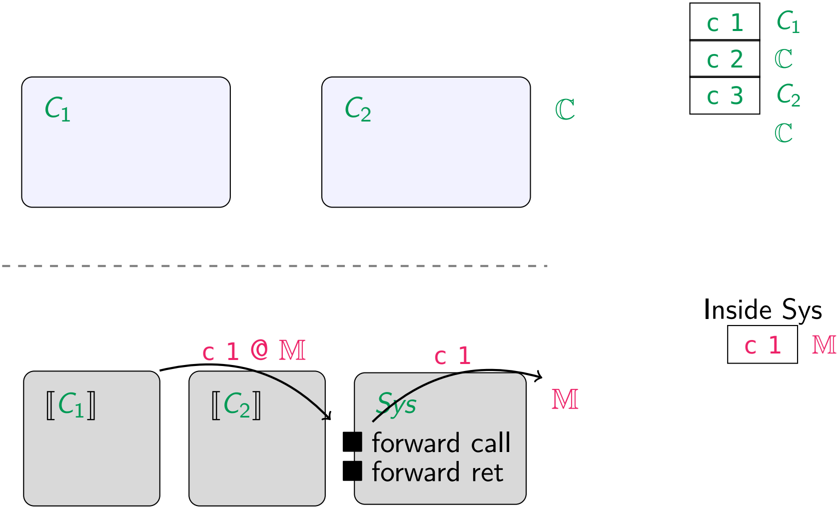

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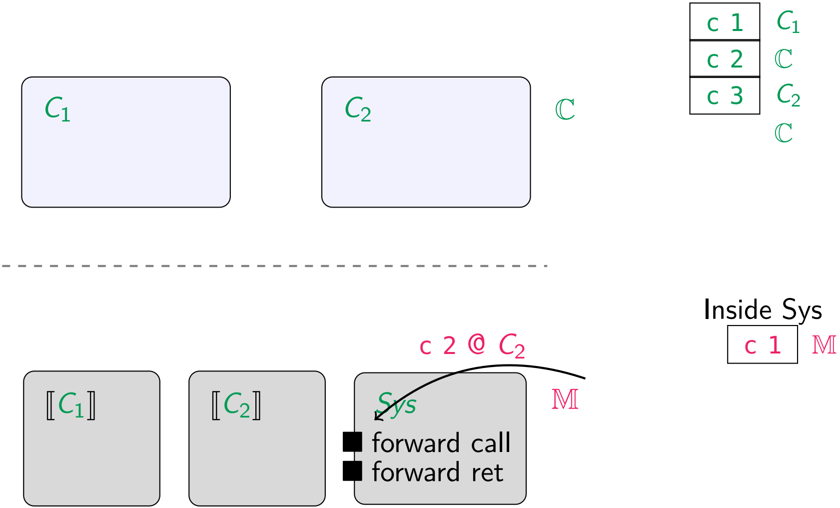

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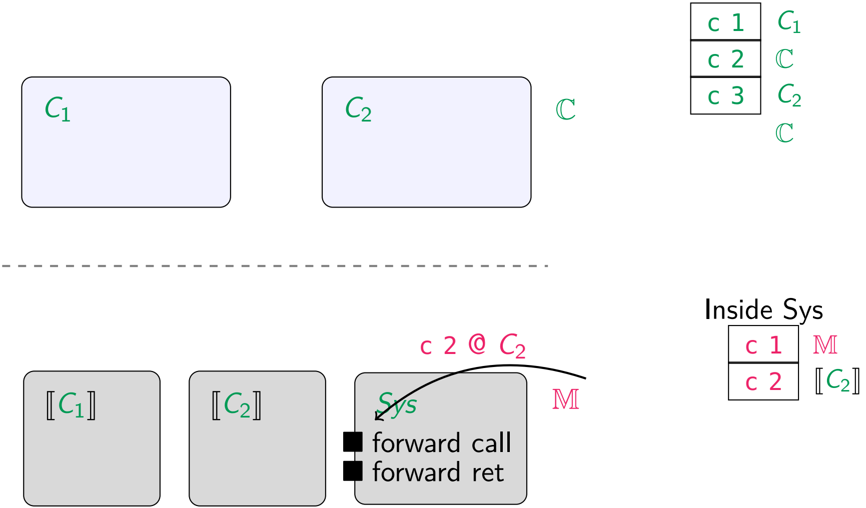

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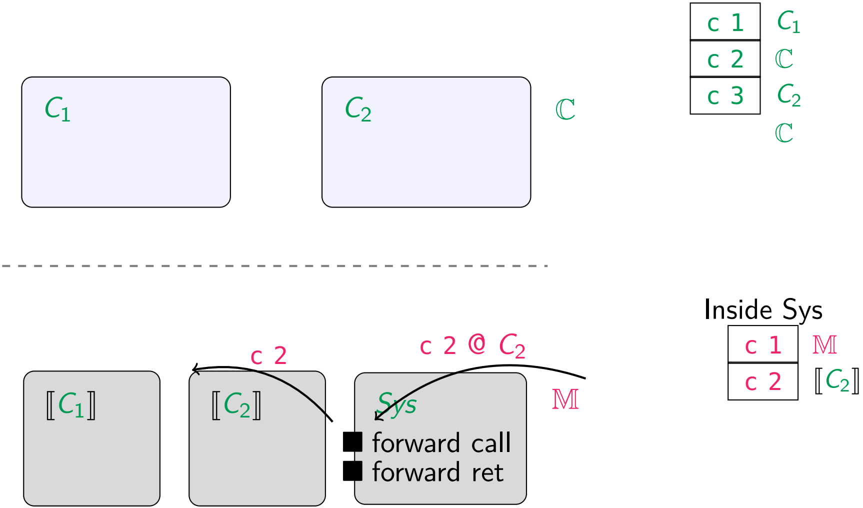

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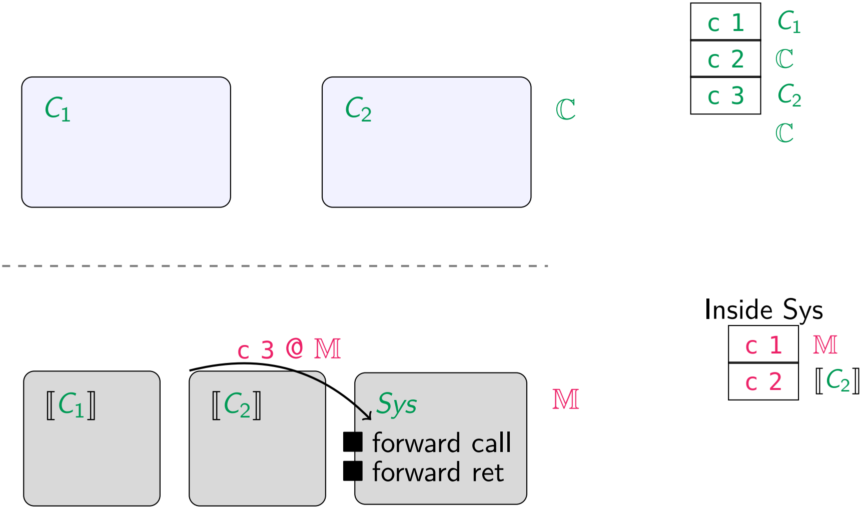

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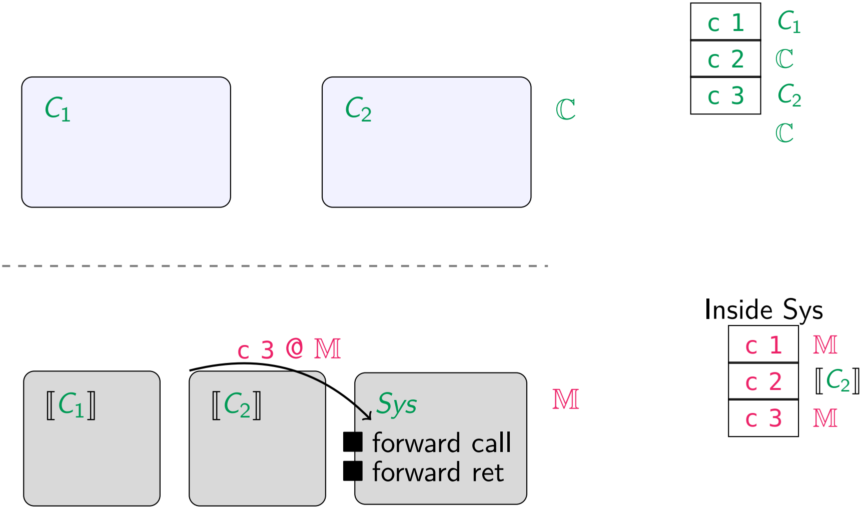

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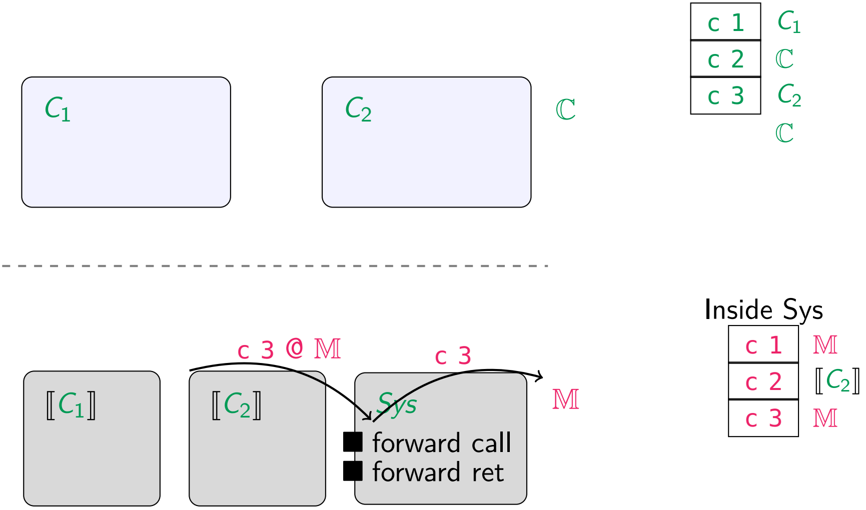

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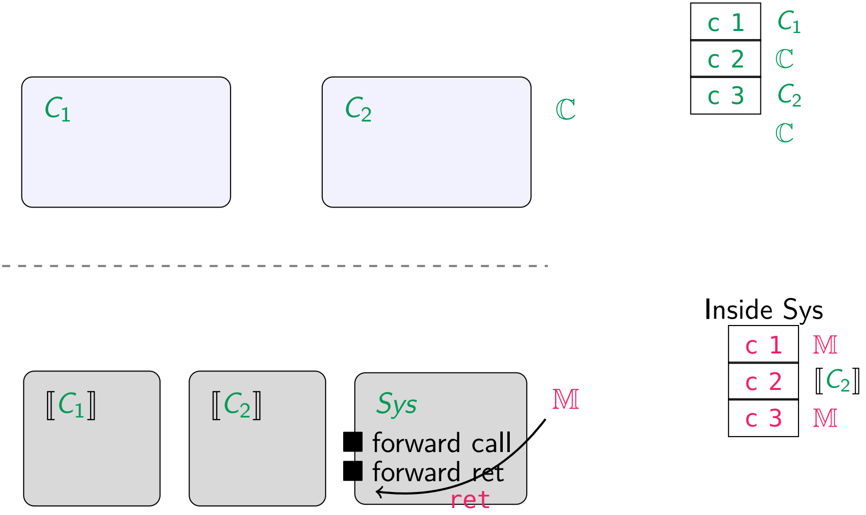
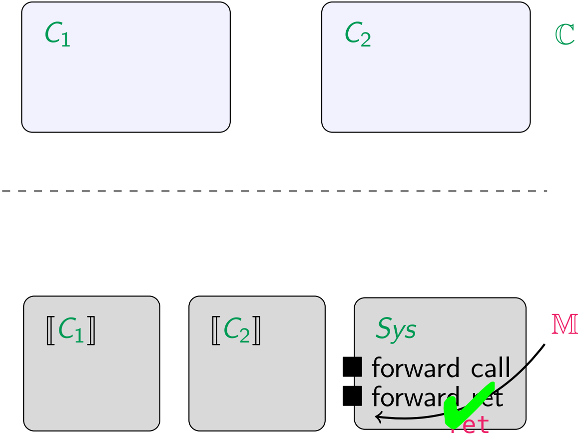


Addressing Call Stack Shortcutting

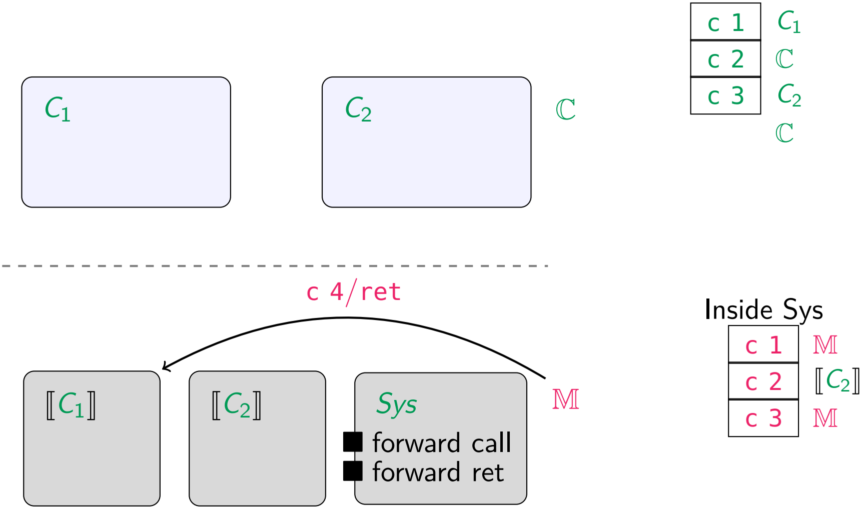
c 1	C_1
c 2	$\mathbb{C}$
c 3	C_2
	$\mathbb{C}$



Inside Sys

c 1	$\mathbb{M}$
c 2	$[\![C_2]\!]$
c 3	$\mathbb{M}$

Addressing Call Stack Shortcutting



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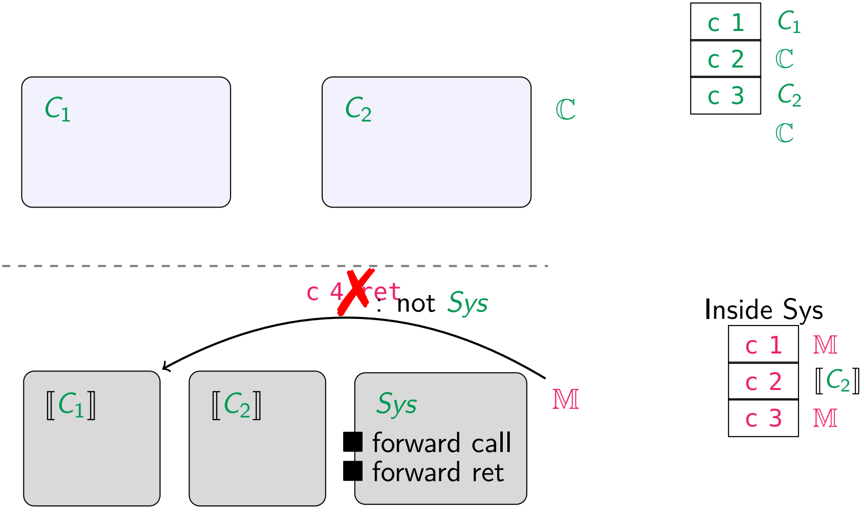
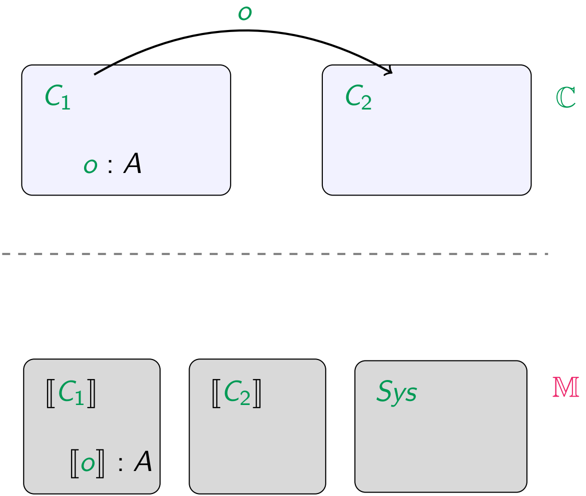


Addressing Object Guessing & Faking



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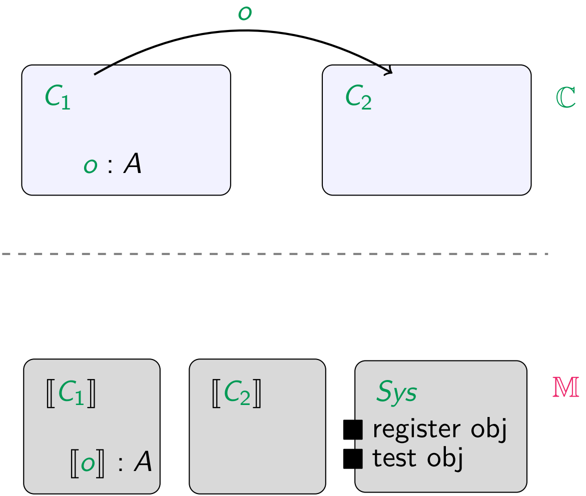

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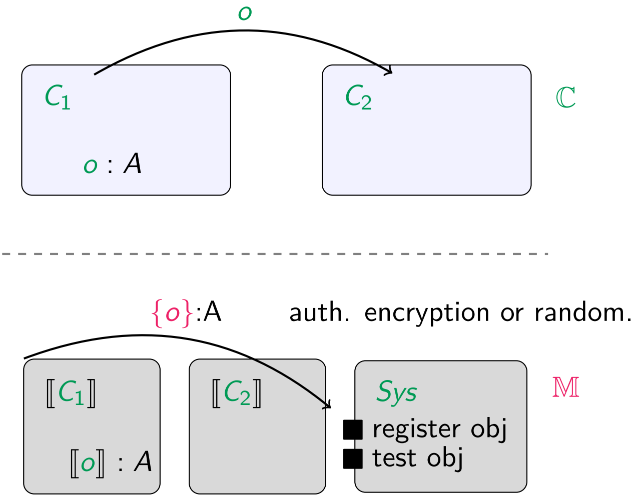

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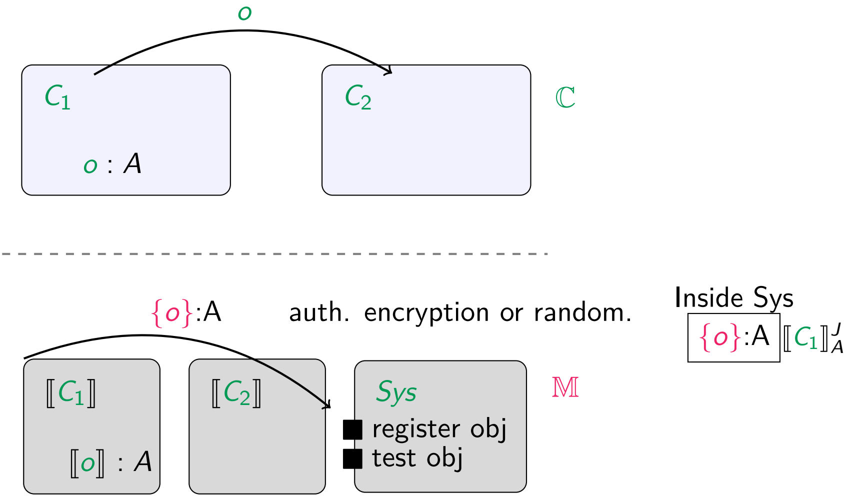

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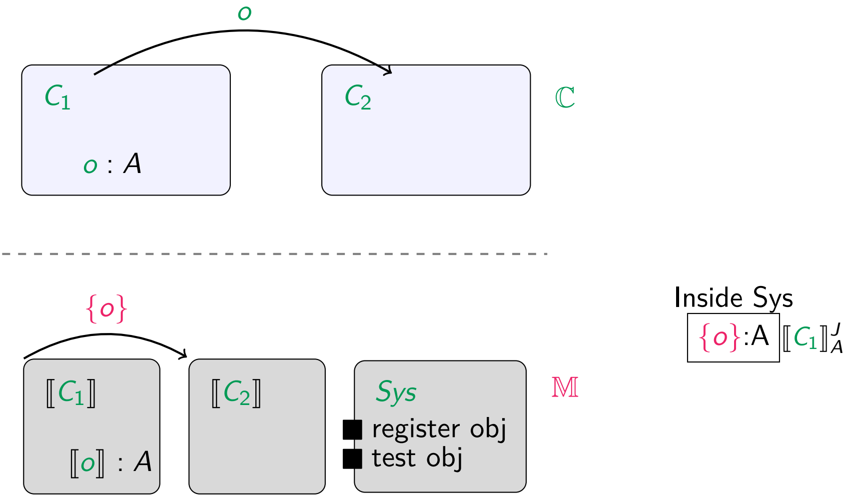

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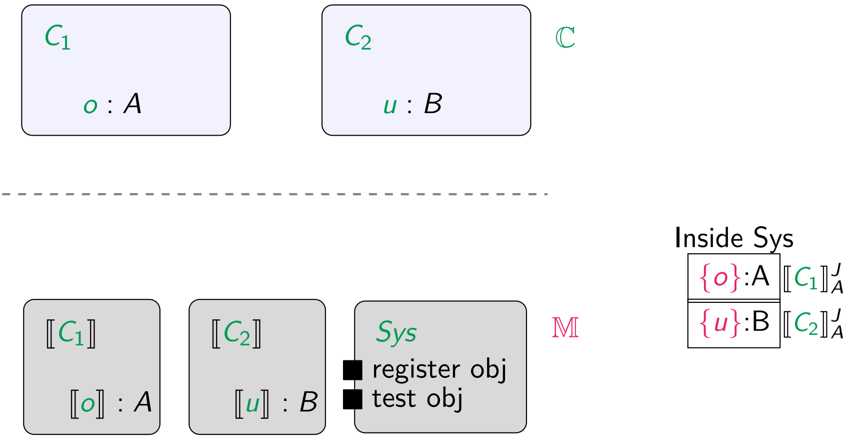

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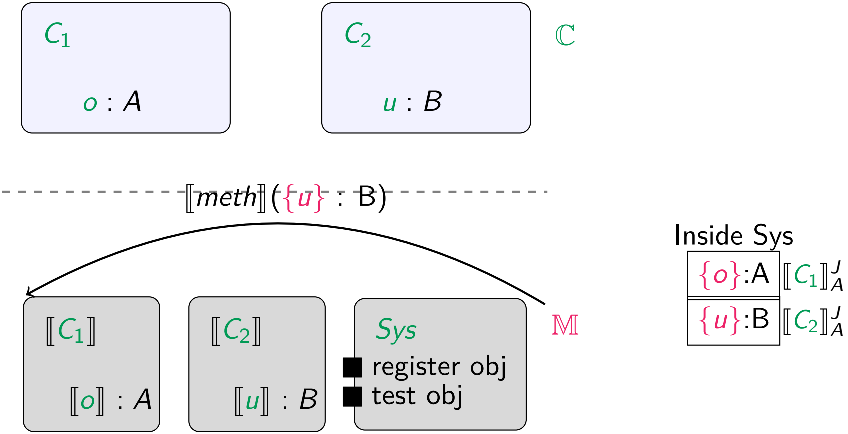

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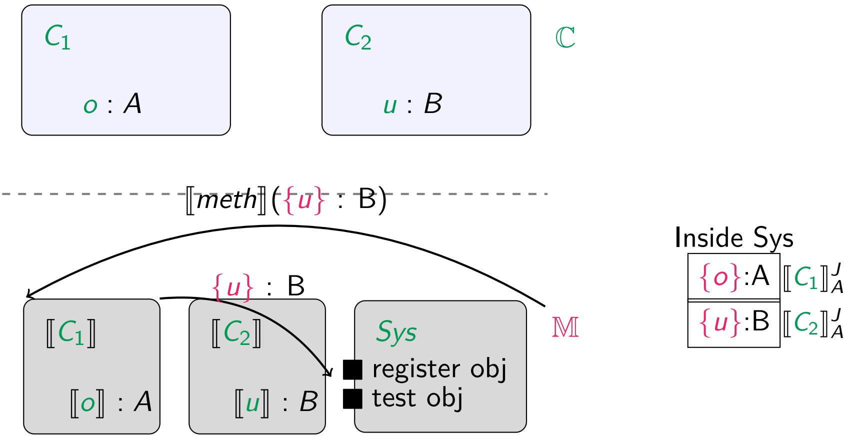

More Solutions

- the paper describes more problems
- and how to address them

Formal Guarantees

- what tells us that $[\![\cdot]\!]^J_A$ is secure?

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Formal Guarantees

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- $[\![\cdot]\!]^{J}_{A}$ is fully abstract (like others)
- $[\![\cdot]\!]^{J}_{A}$ **also** has *modular full-abstraction*
- no new machinery but the following is needed:
  - compiler modularity
  - compiler full-abstraction

Compiler Modular Full-Abstraction

$$\forall \mathcal{C}_1, \mathcal{C}_2, \mathcal{C}_3, \mathcal{C}_4.$$
$$\forall \mathcal{P}. [\![\mathcal{C}_2]\!]^J_A \simeq^{\mathcal{T}} \mathcal{P}$$
$$\forall \mathcal{P}'. [\![\mathcal{C}_4]\!]^J_A \simeq^{\mathcal{T}} \mathcal{P}'$$

$$\mathcal{C}_1 + \mathcal{C}_2 \simeq^{\mathcal{S}} \mathcal{C}_3 + \mathcal{C}_4$$
$$\Updownarrow$$
$$[\![\mathcal{C}_1]\!]^J_A + \mathcal{P} \simeq^{\mathcal{T}} [\![\mathcal{C}_3]\!]^J_A + \mathcal{P}'$$

Compiler Modular Full-Abstraction

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$$[\![\mathcal{C}_1]\!]^J_A + \mathcal{P} \simeq^{\mathcal{T}} [\![\mathcal{C}_3]\!]^J_A + \mathcal{P}'$$

- $\mathcal{P}$ and $\mathcal{P}'$ can even be hand-optimized
- as long as they behave like $[\![\mathcal{C}_2]\!]^J_A$ and $[\![\mathcal{C}_4]\!]^J_A$

Questions

Thank you!

Qs ?