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Formal Methods (FM), 7 March 2023

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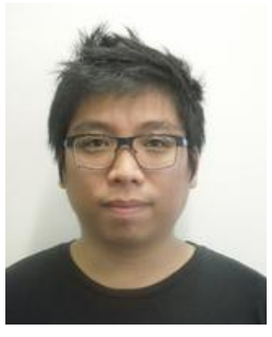

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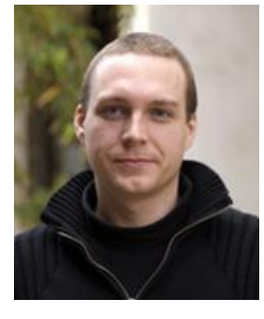

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# Threat scenario: *Trojan* and *spy*


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Covert channels


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## *Victim/~~Trojan~~* and *spy?*

Covert channels
+
Side channels



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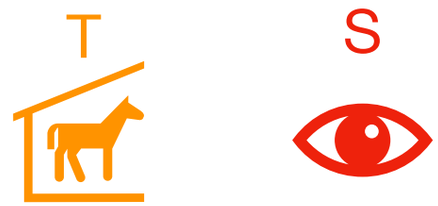


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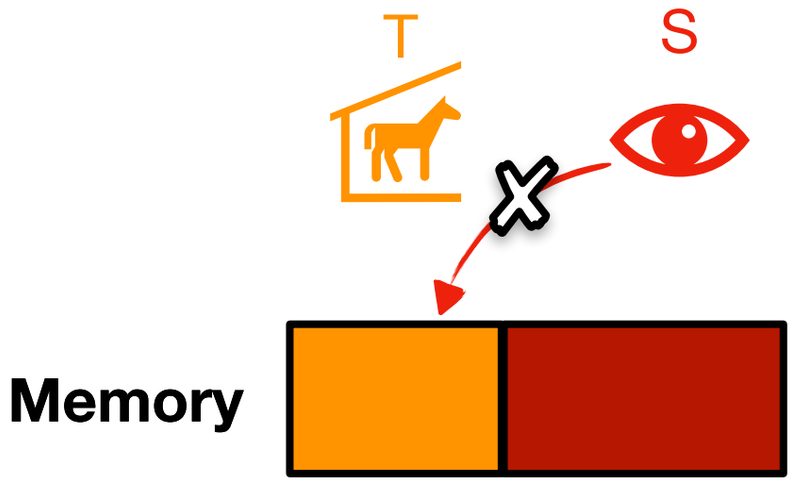

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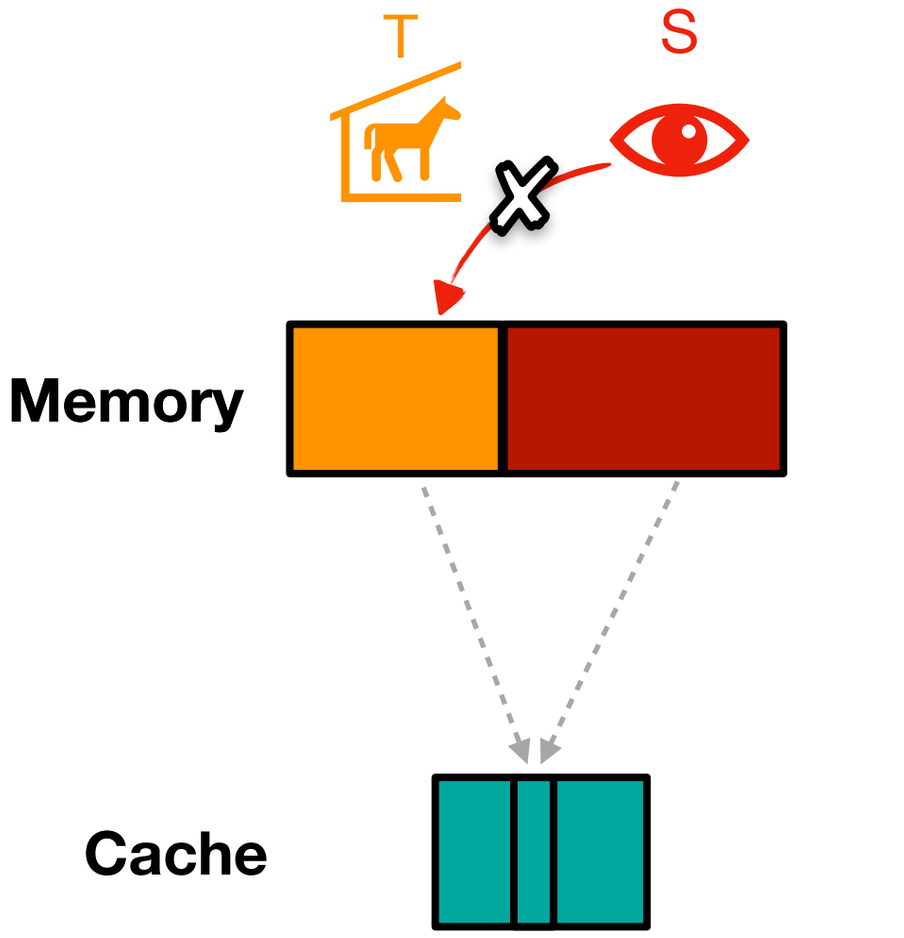

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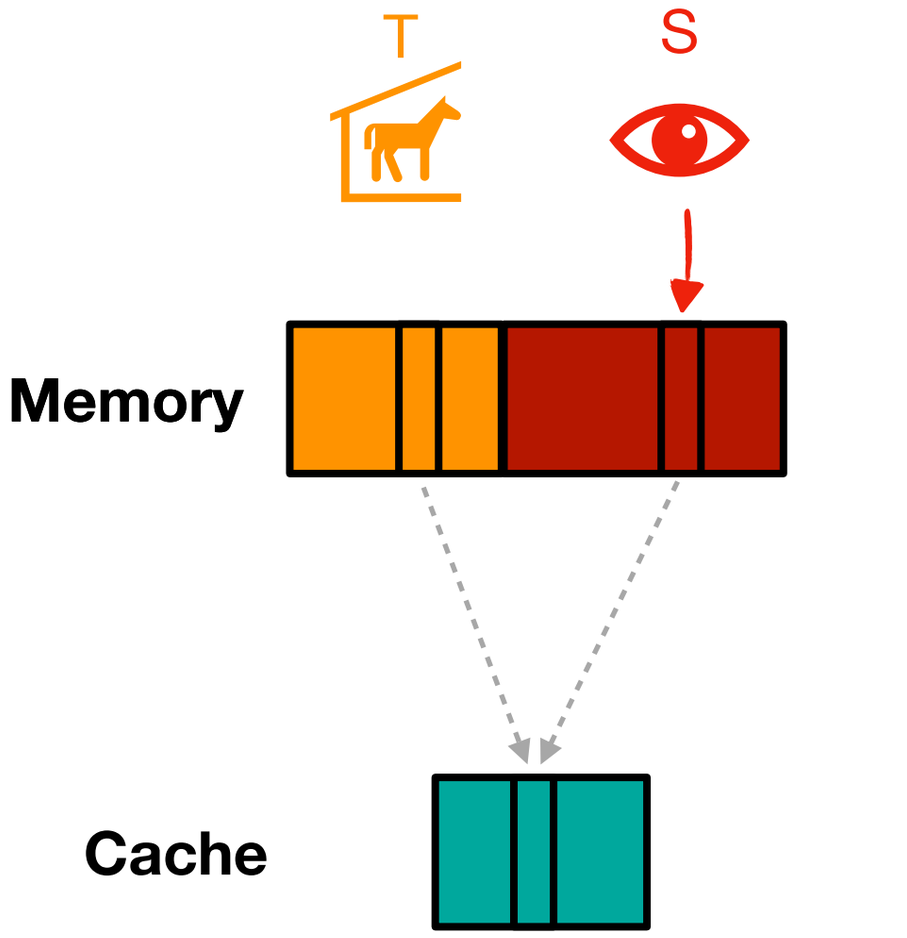

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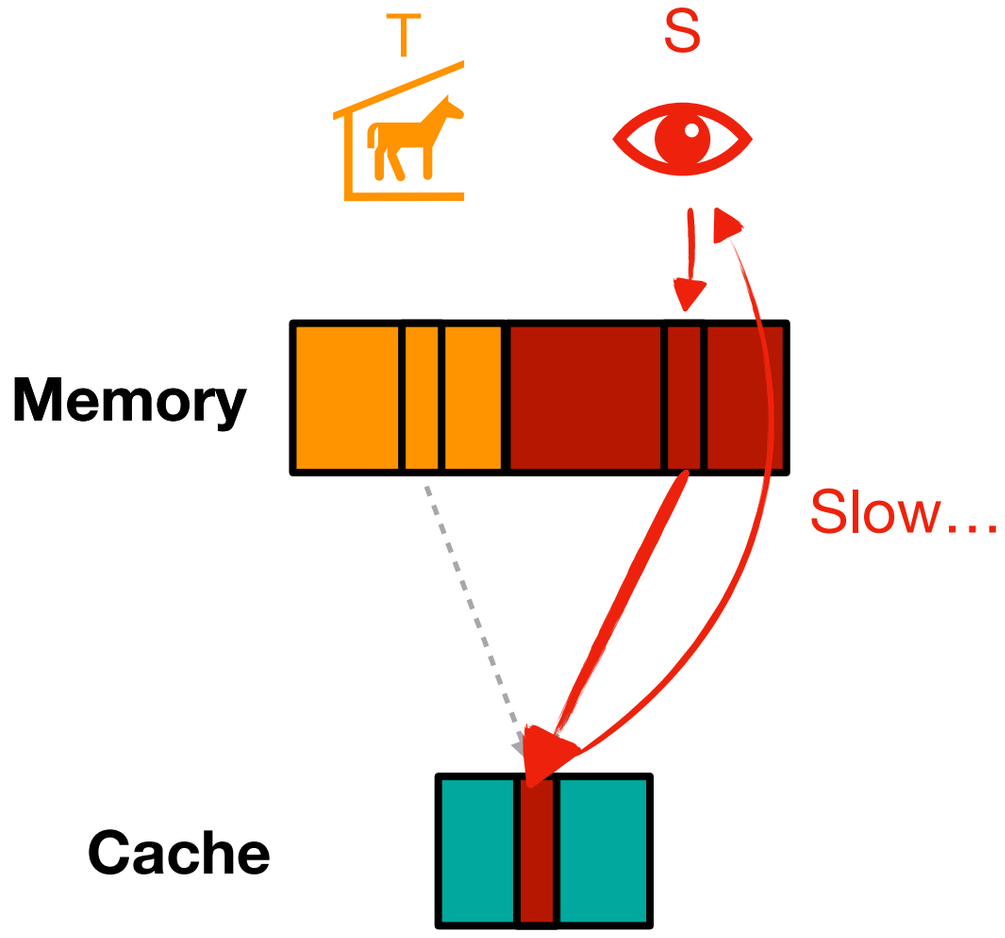

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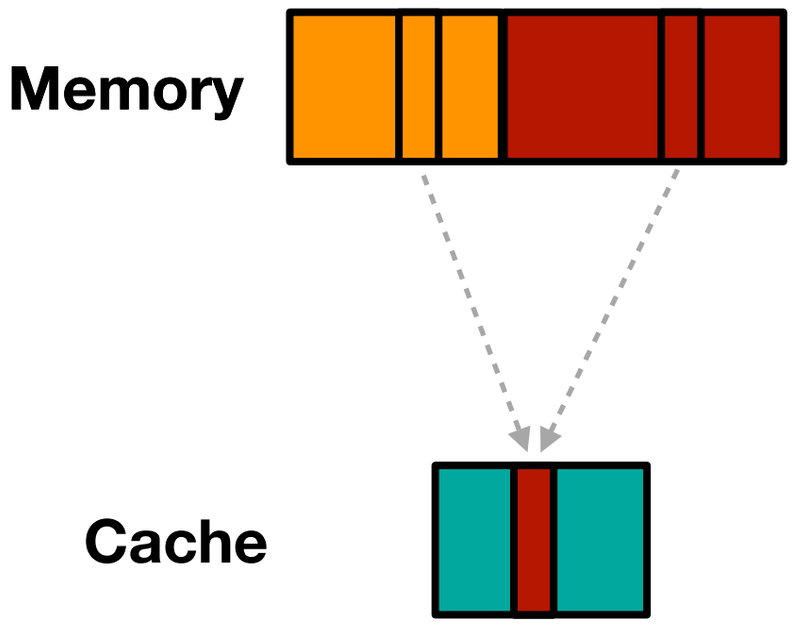

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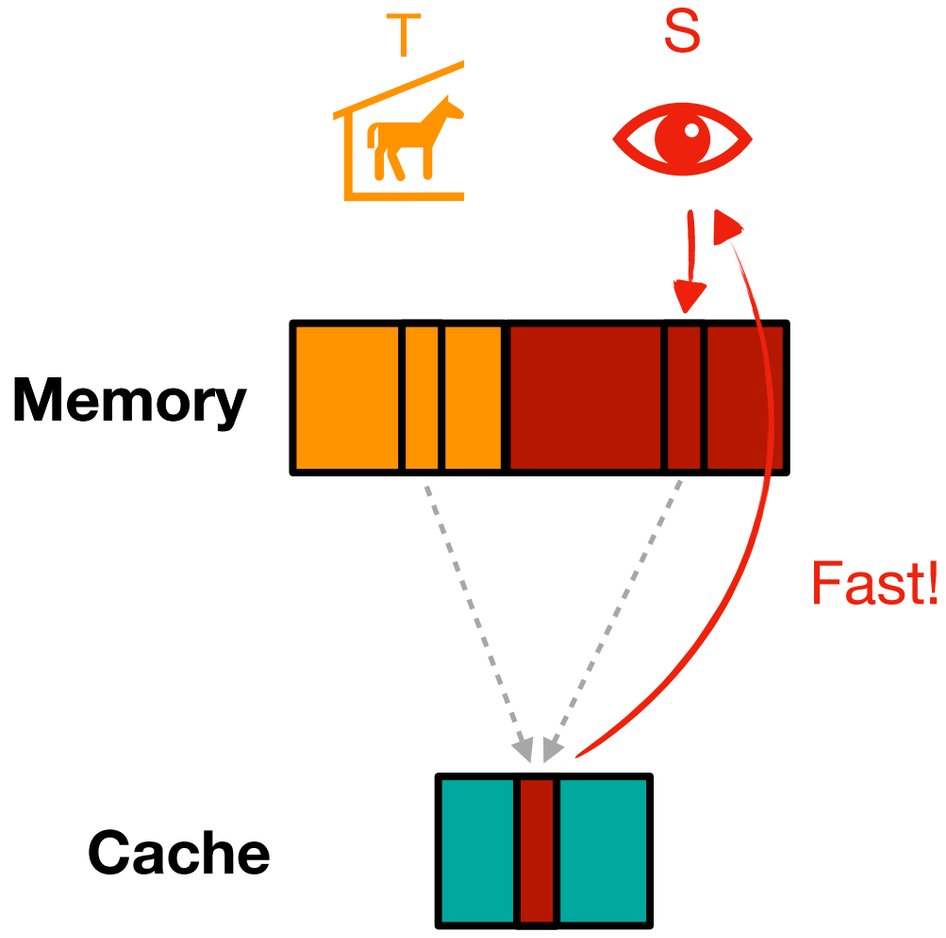

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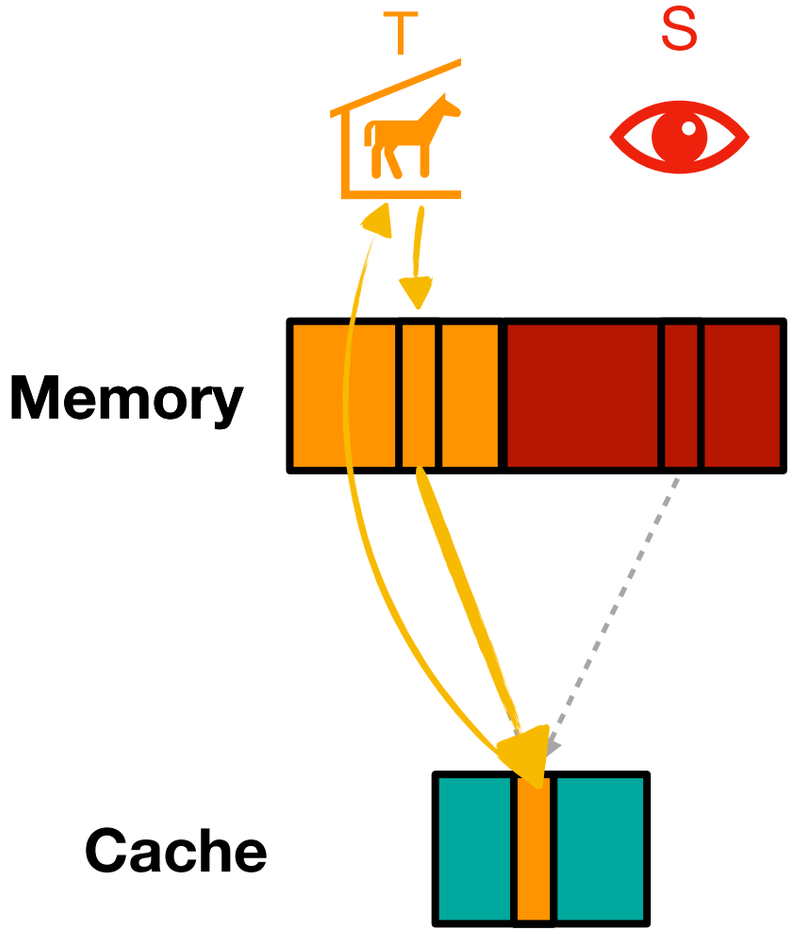

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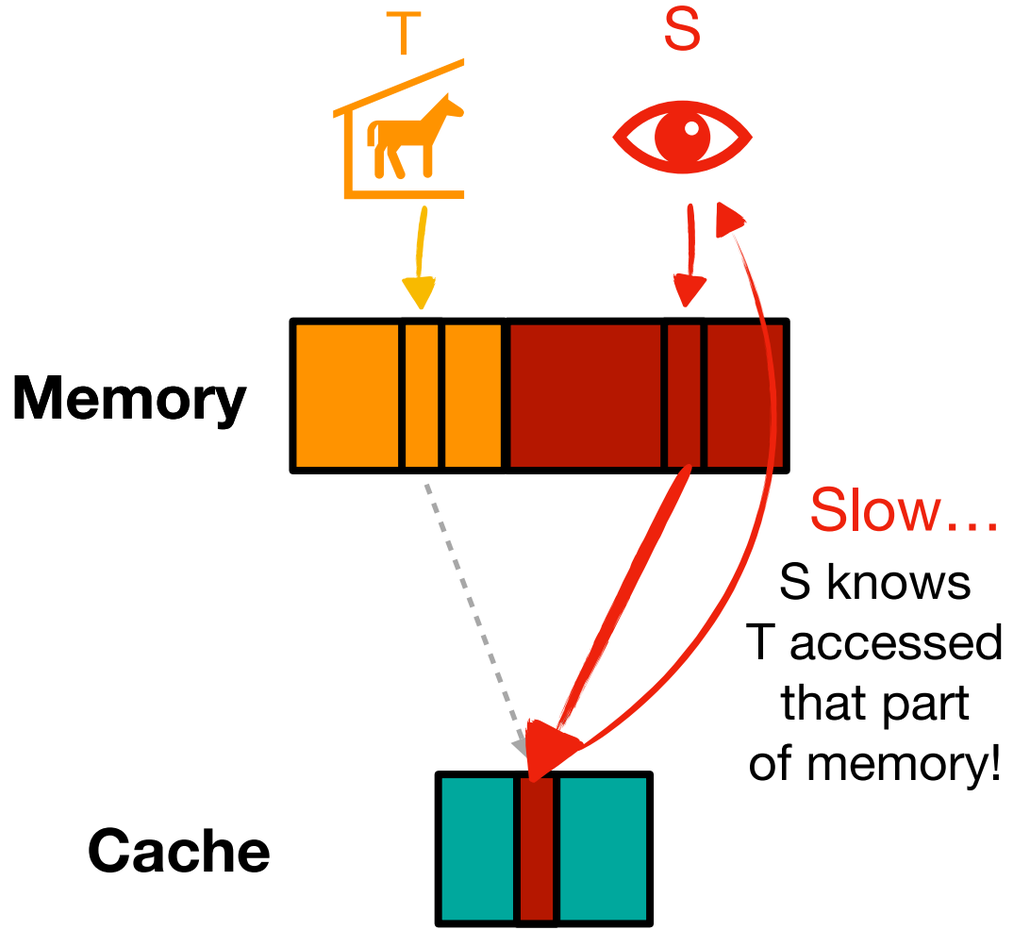

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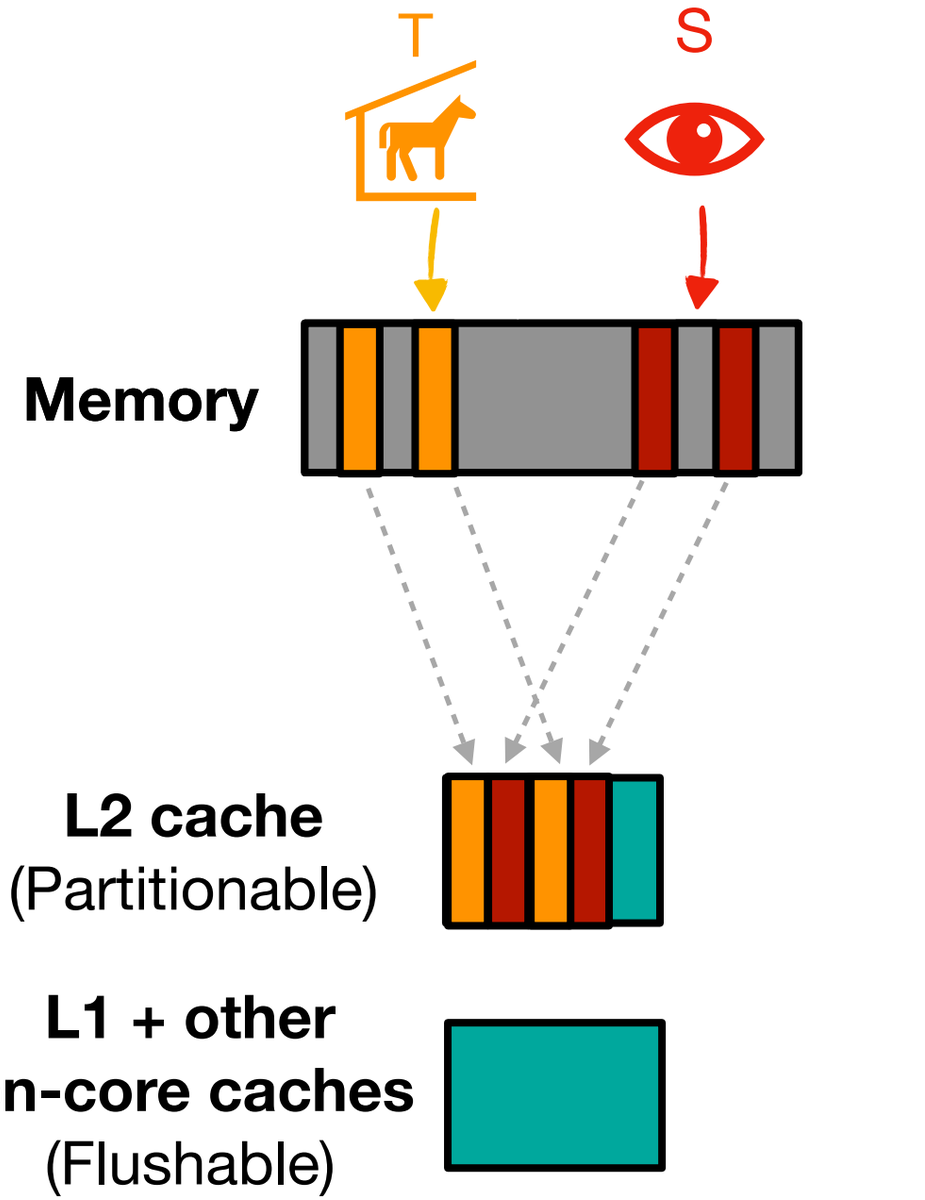

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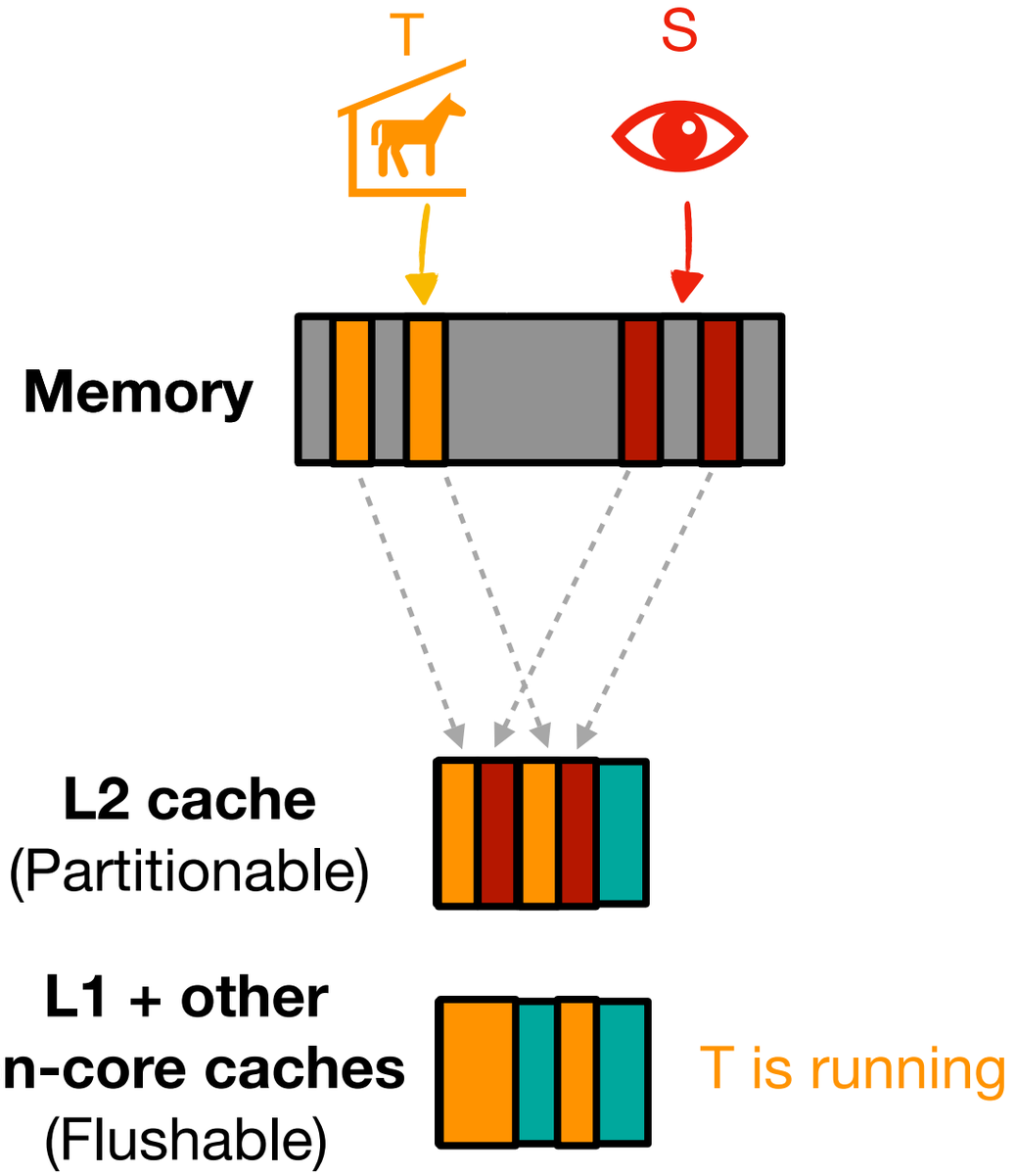

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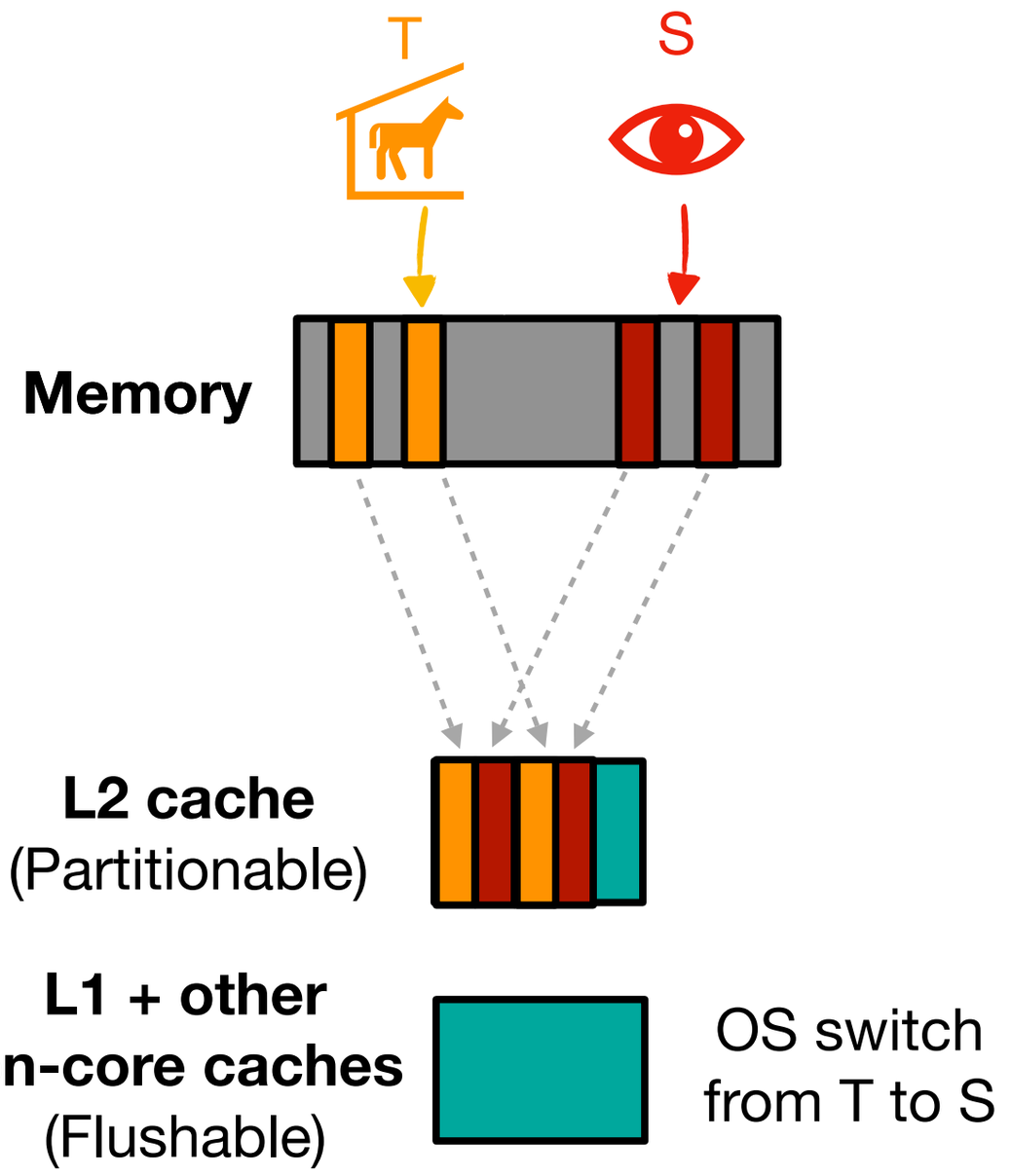


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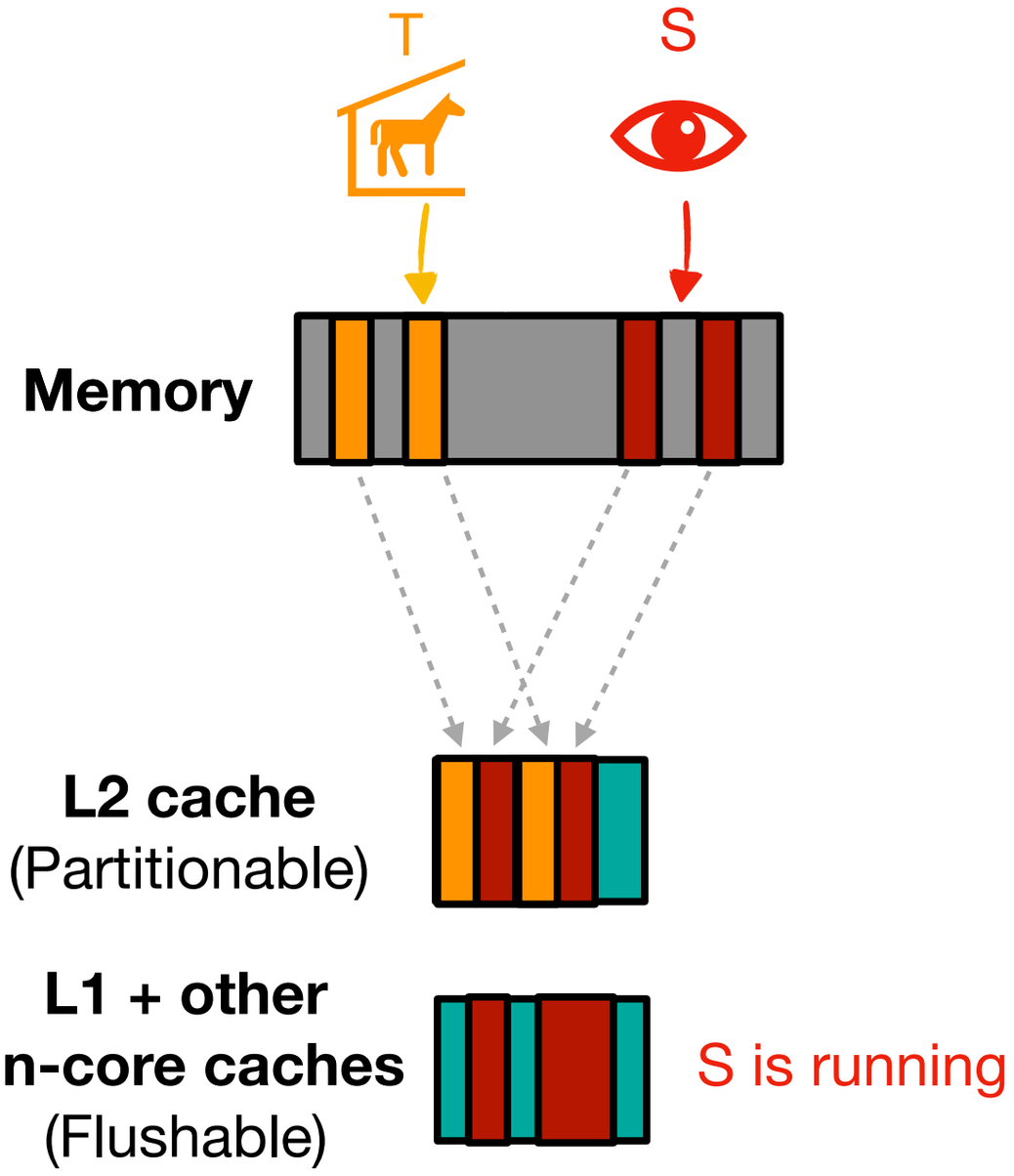


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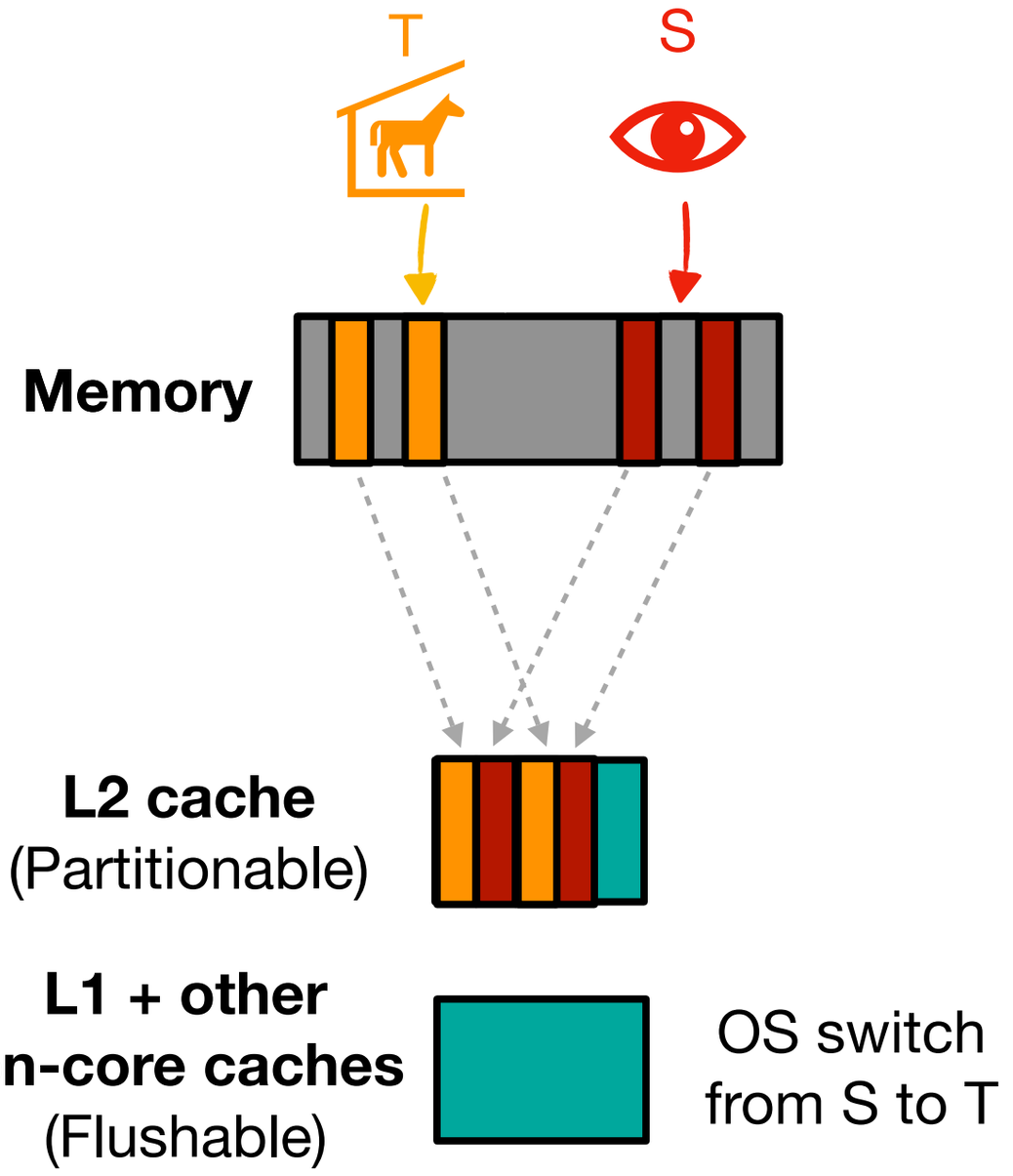


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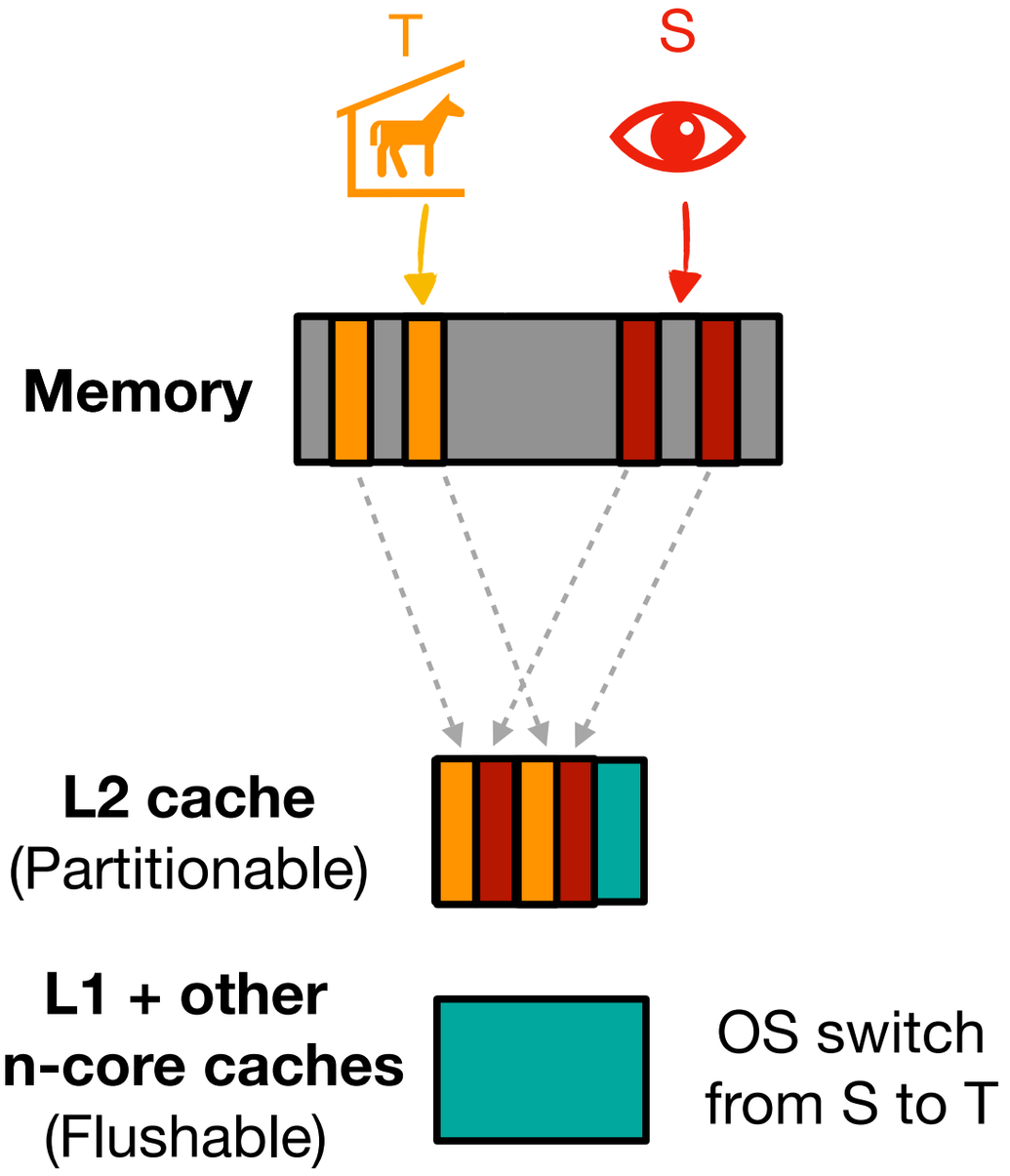


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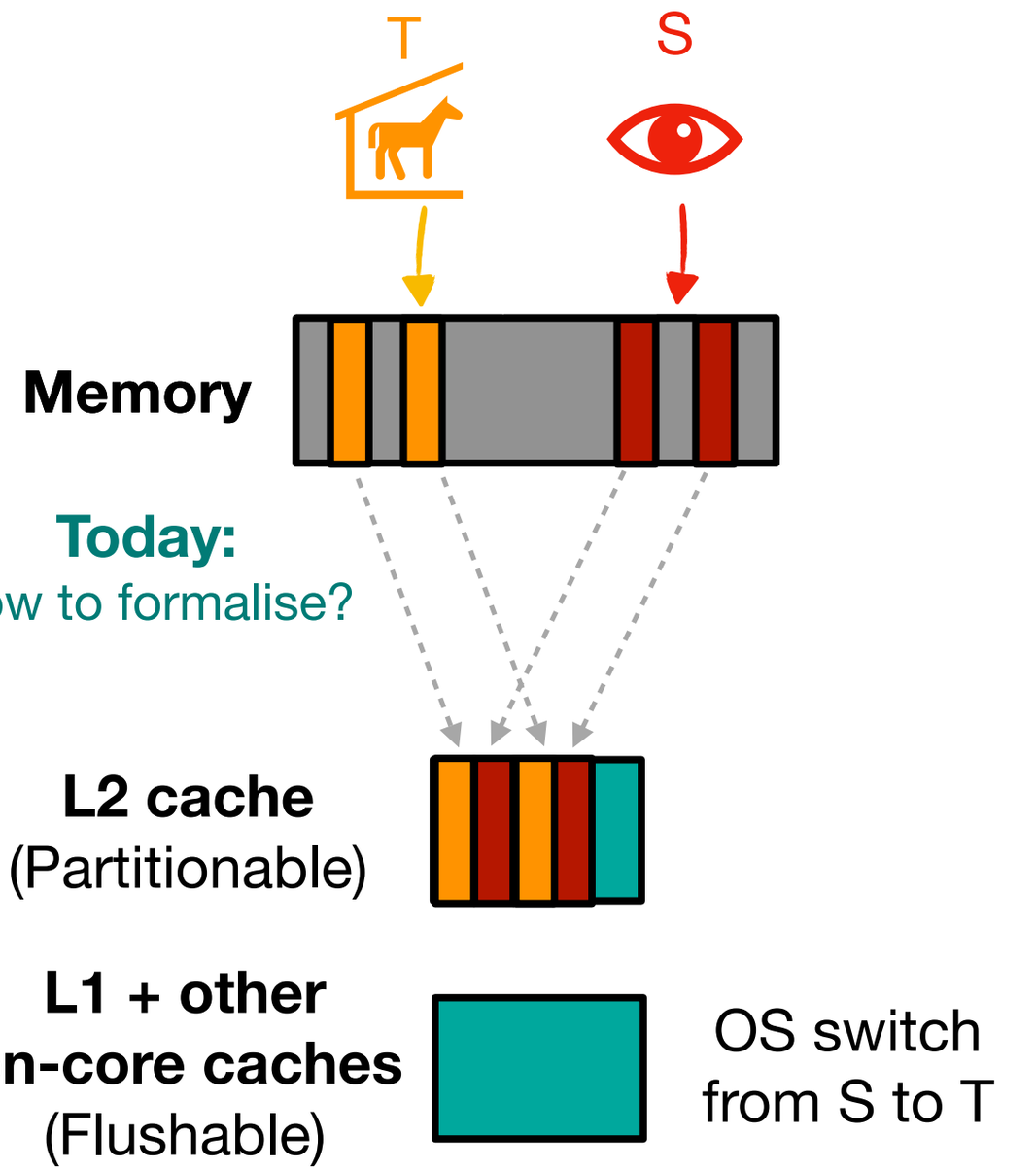


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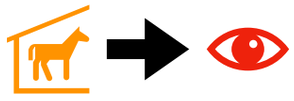

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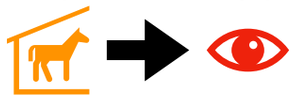


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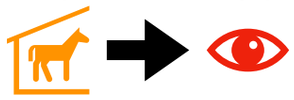


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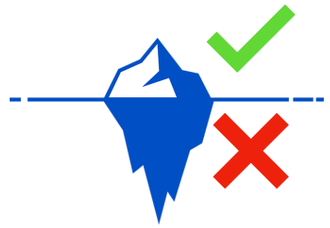

Make security property precise enough to exclude flows from covert state.

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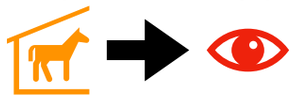


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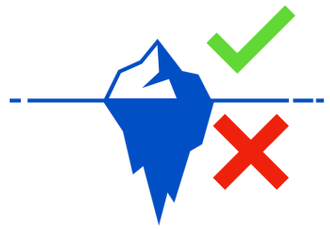

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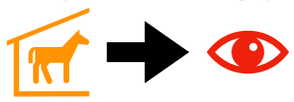


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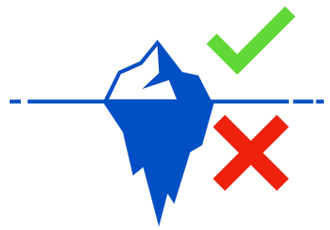

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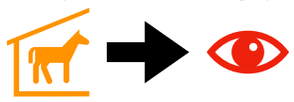


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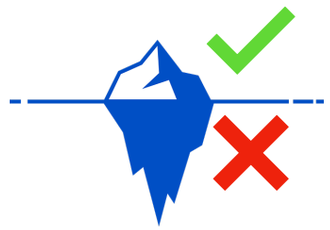

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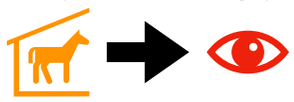


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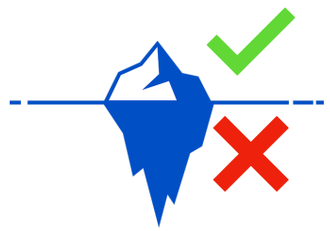

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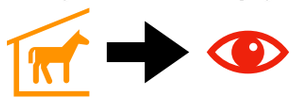


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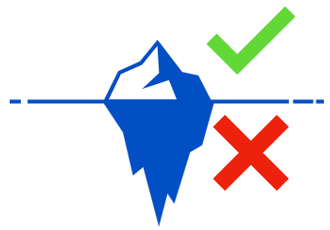

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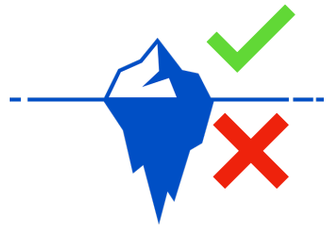

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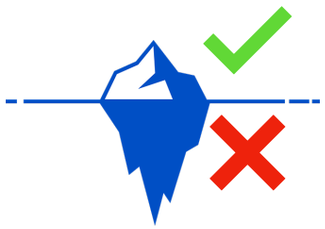

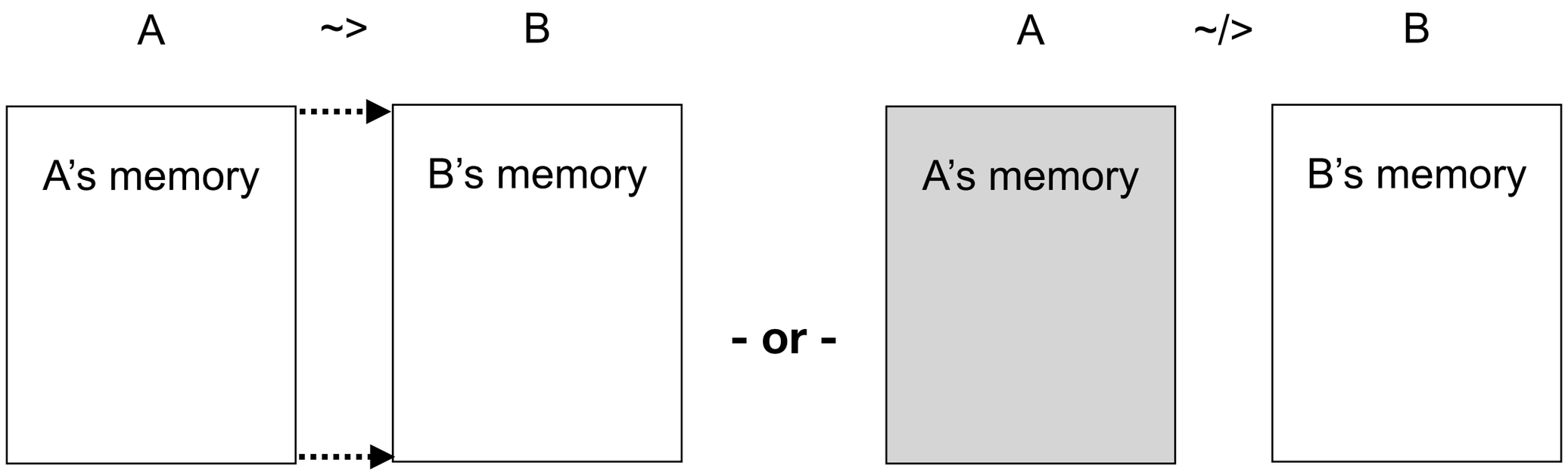


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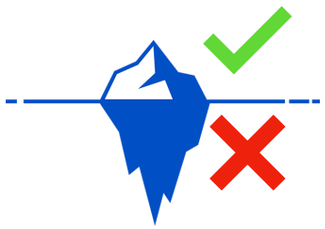

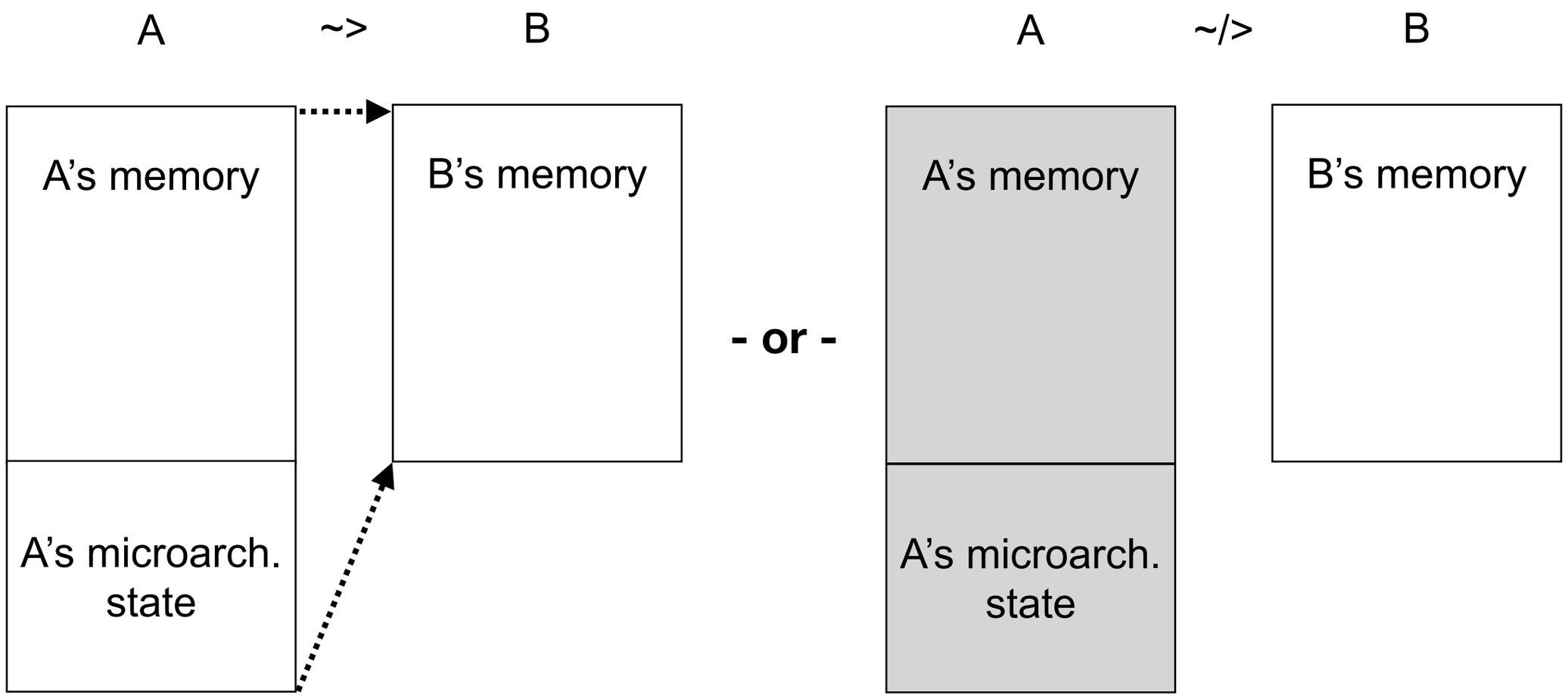


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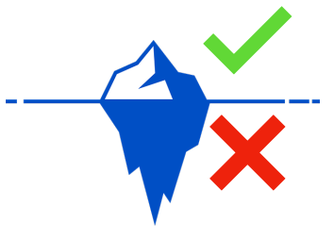

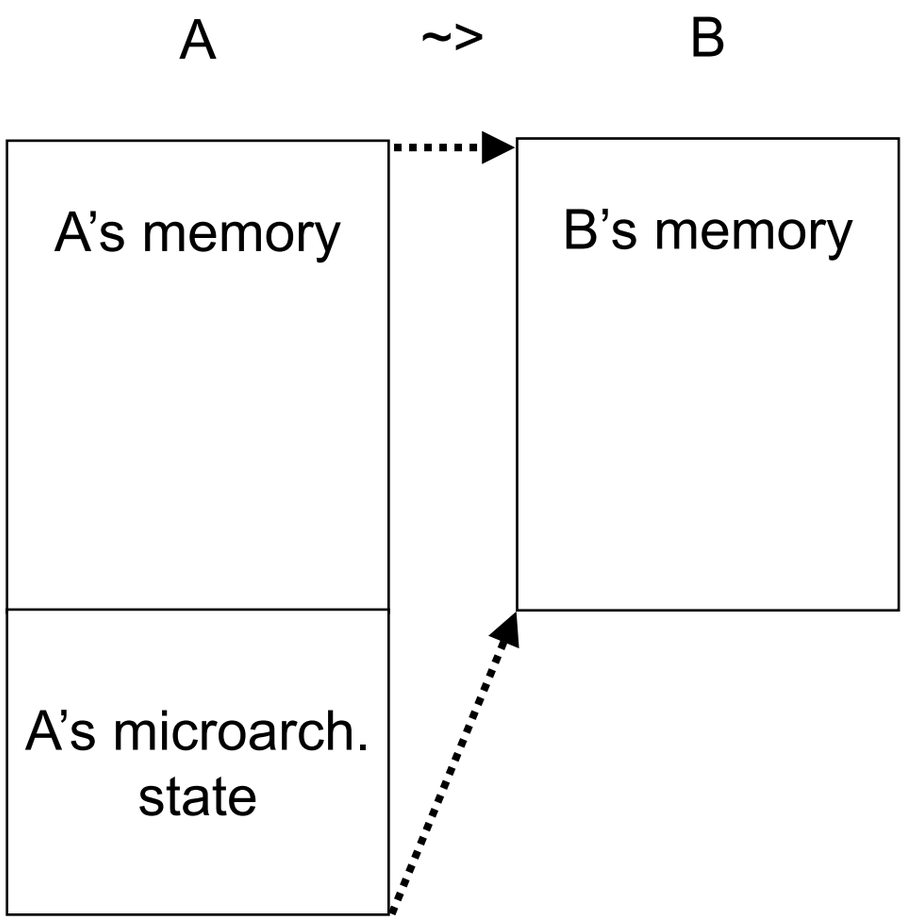


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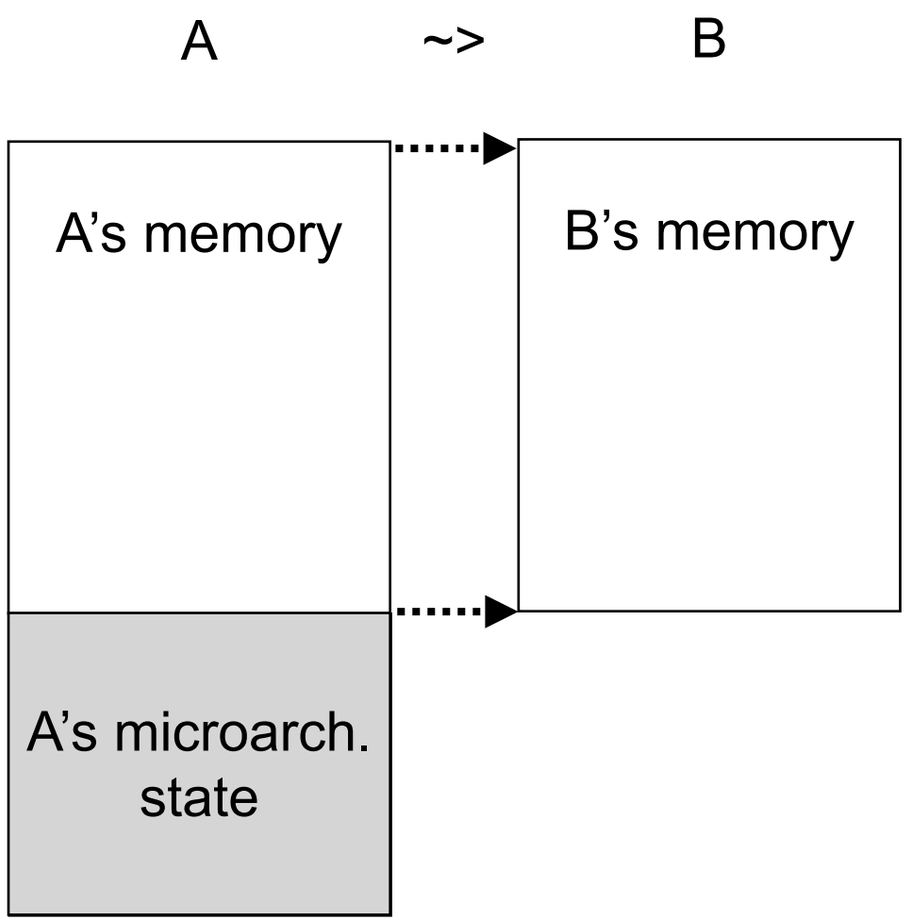


**Principle: Need policies to allow some (*overt*) flows while excluding other (*covert*) ones**

# Covert state: Partitionable vs flushable


**<u>Principle</u>:**
**Model channels as *state elements***
**by their *elimination strategy***
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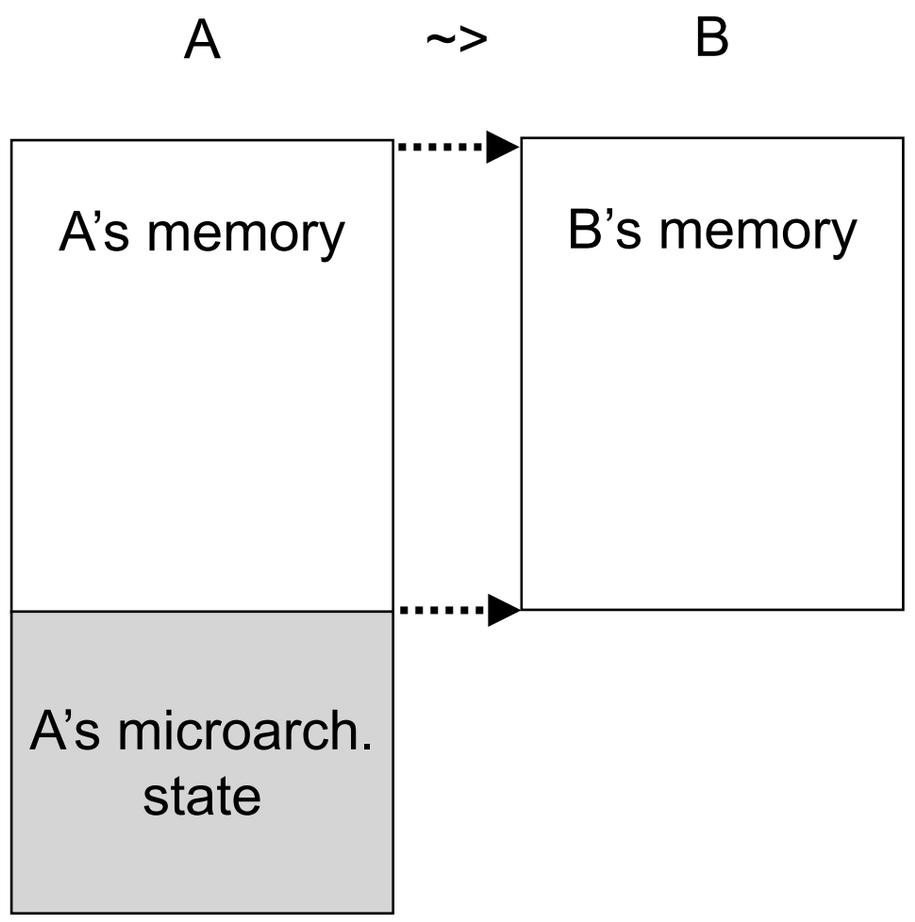

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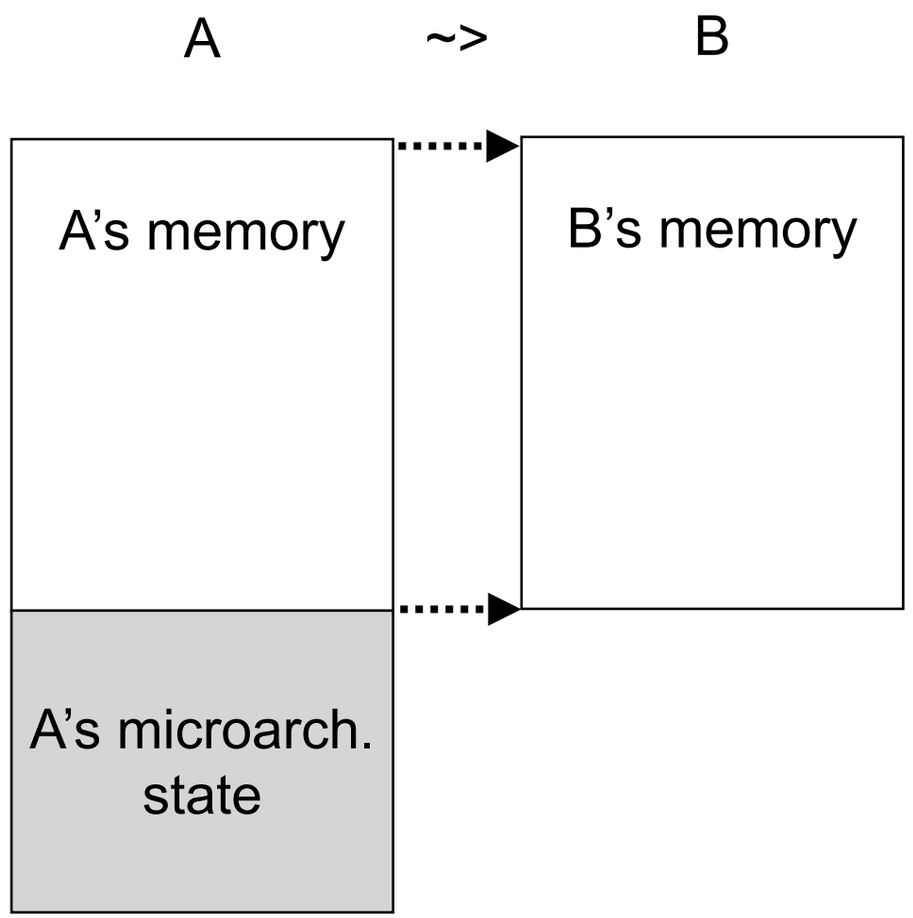

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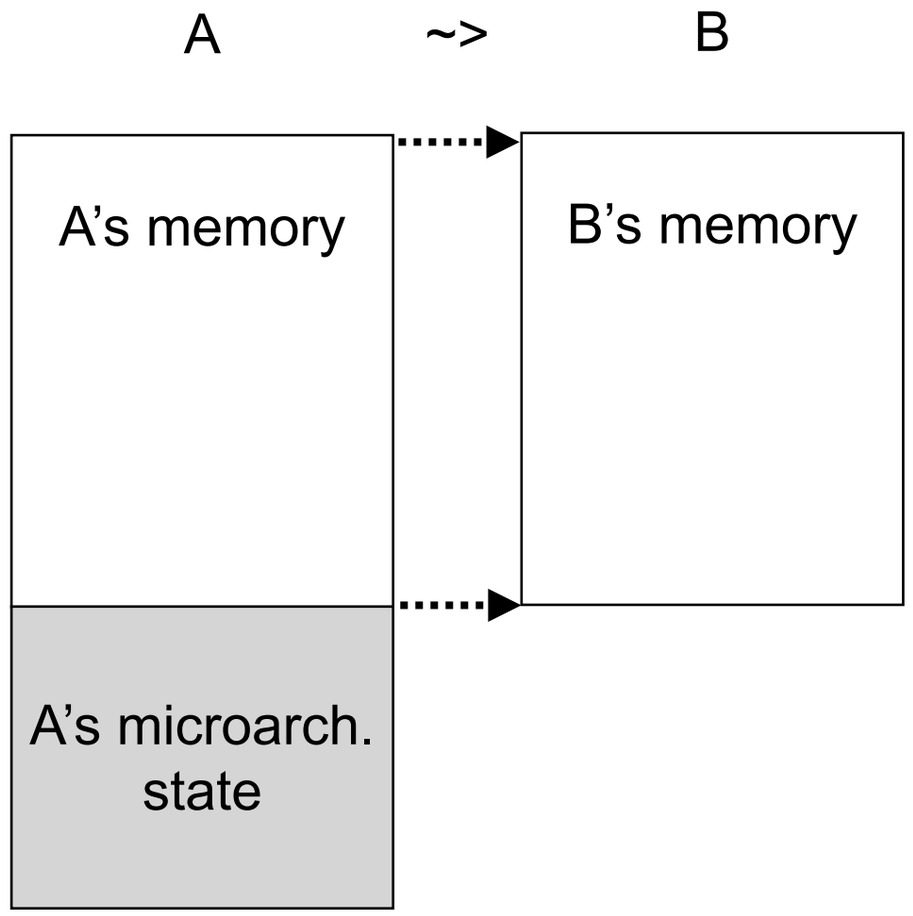

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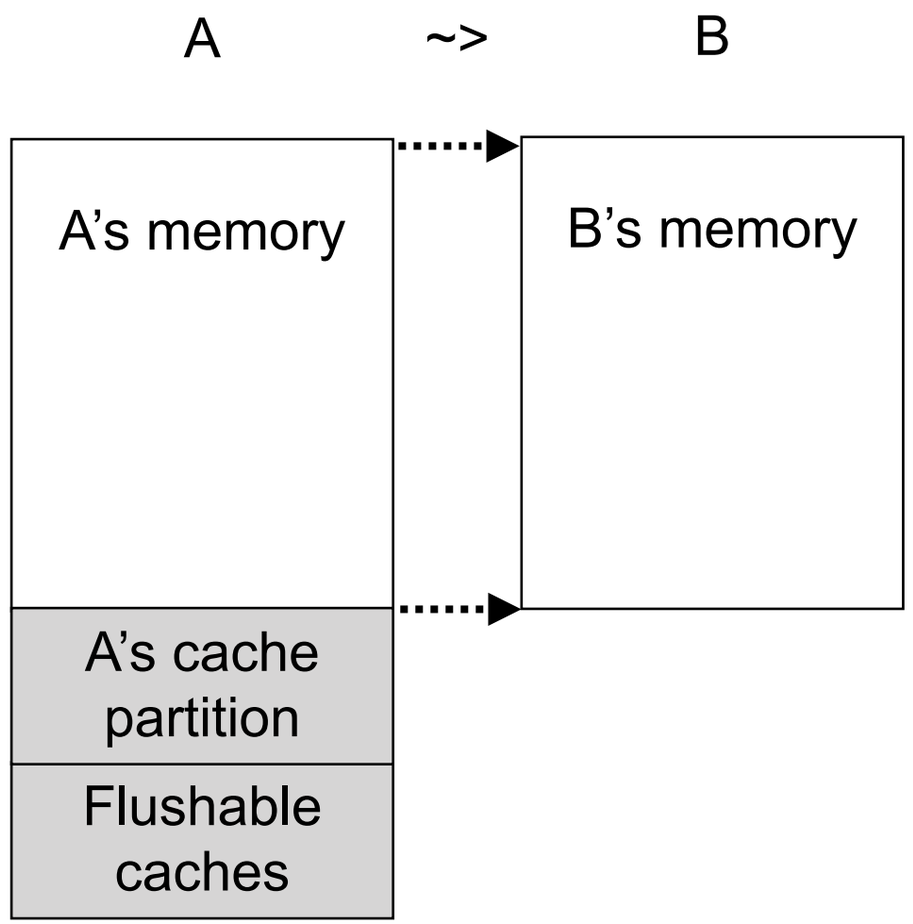

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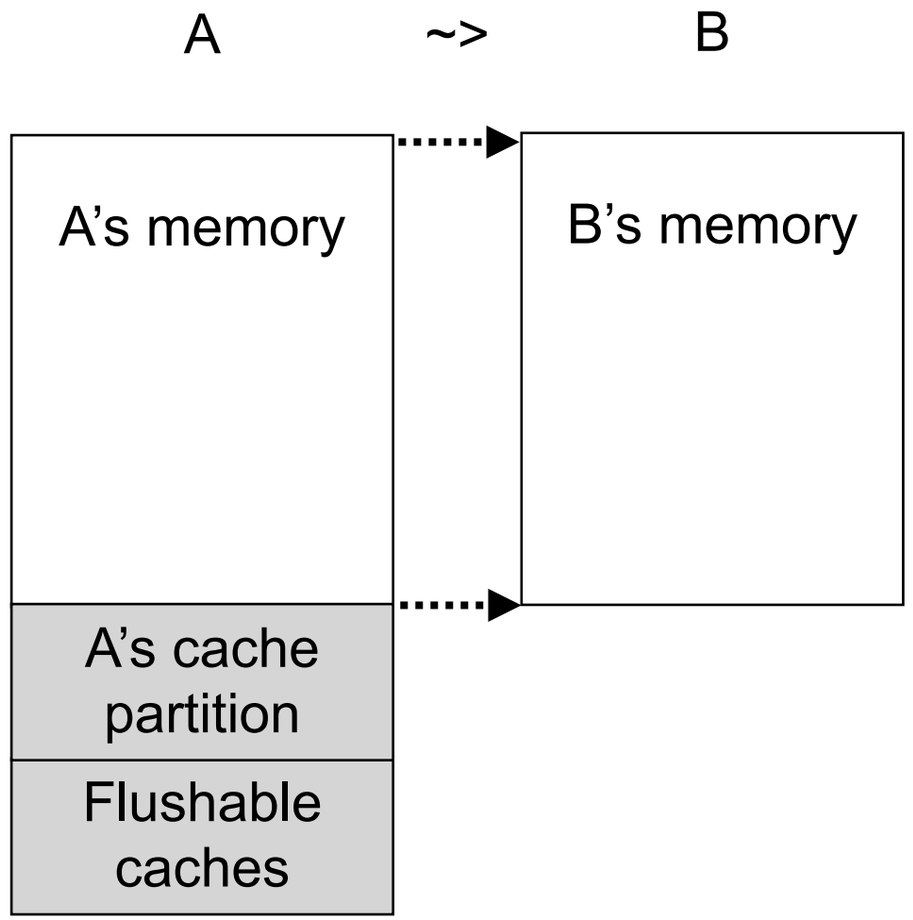

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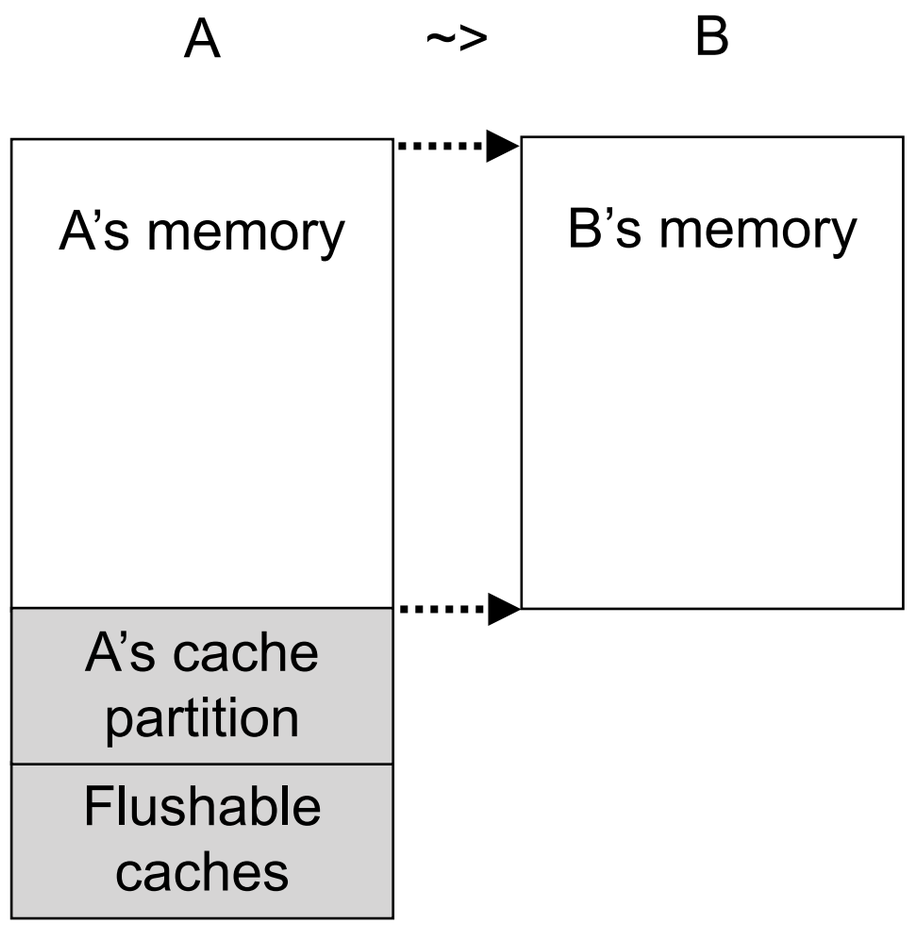

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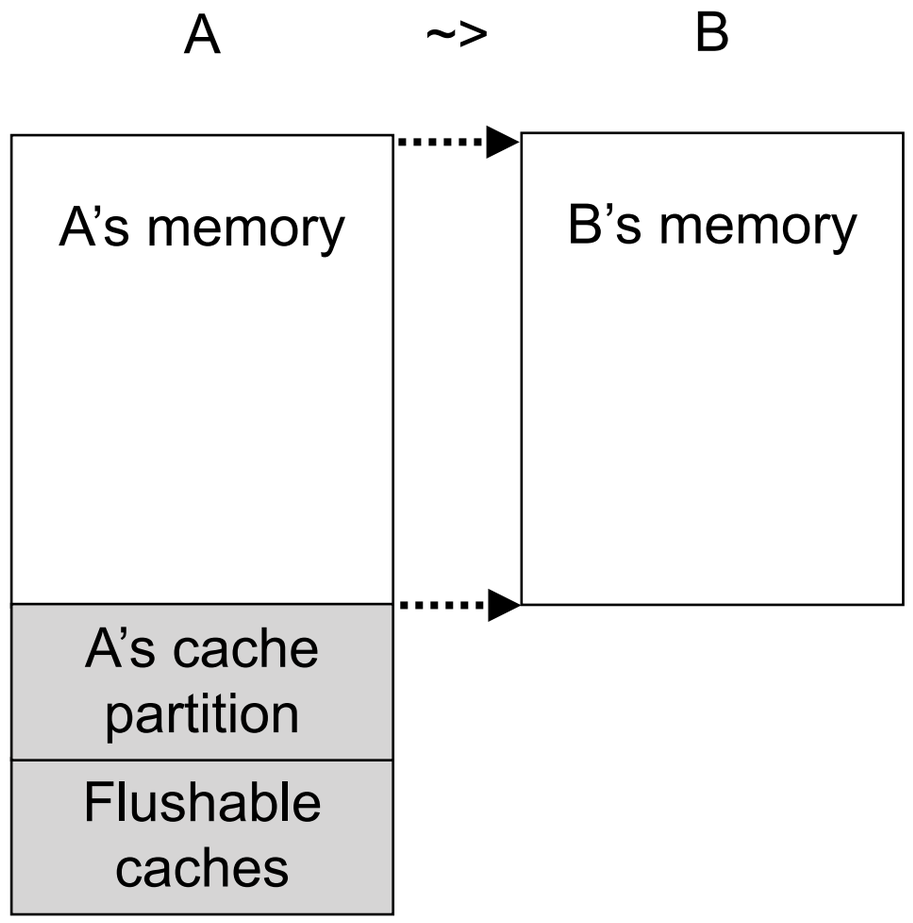

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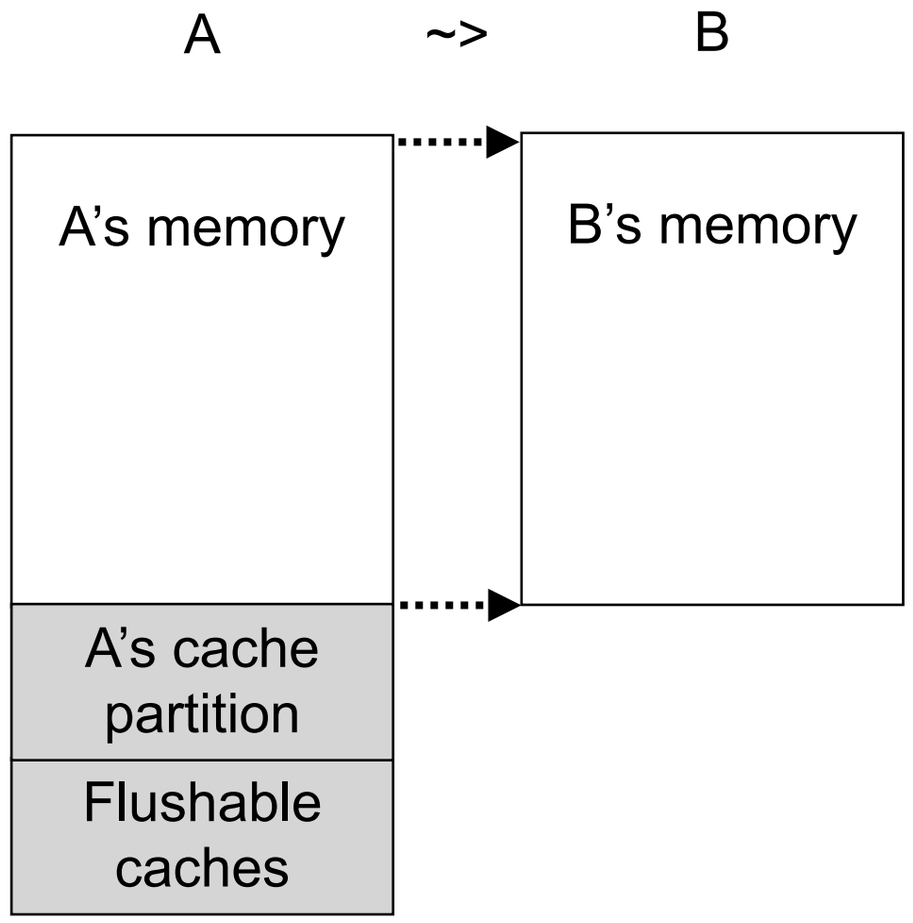

# How to formalise an OS enforces *time protection*?

Versus threat scenario:
trojan and spy


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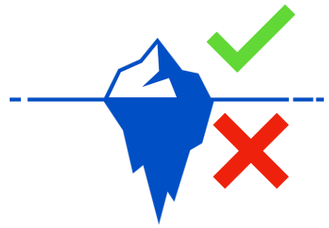

Make security property precise enough to exclude flows from covert state.


Demonstrating these principles,
we formalised in Isabelle/HOL:

1. OS security model imposing requirements on relevant parts of OS.
(Intended for seL4, but *generic*)

2. OS security property that is dynamic; this makes it observer relative.
(Improving on seL4's of [Murray et al. 2012])

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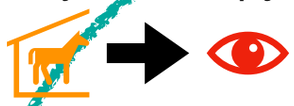


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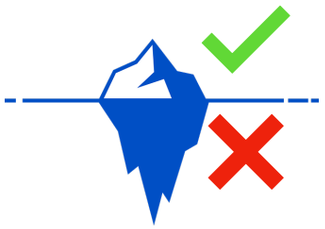

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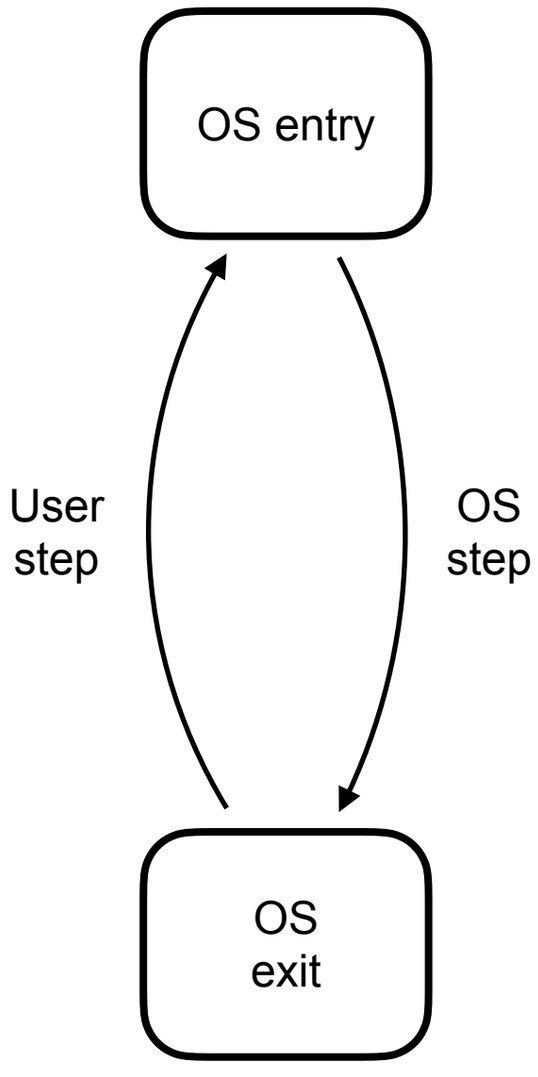
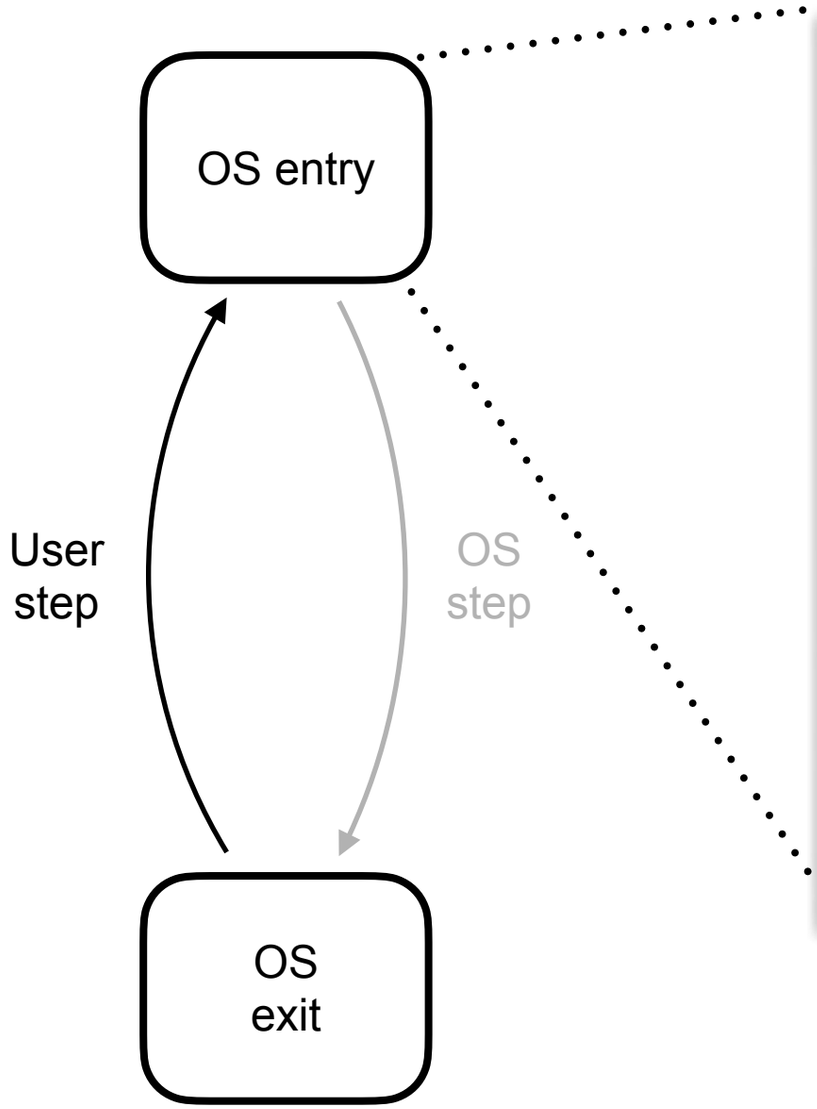
# OS security model


## Transition system



# OS security model


## Transition system




### State fields

mem :: *addr* ⇒ *int*

flst :: *addr* ⇒ bool /* Flushable microarch. */

pst :: *addr* ⇒ bool /* Partitionable microarch. */

tm :: *nat* /* Time */

dom :: *domain* /* Current domain */

devs :: *device* set /* Interrupt-generating devices */

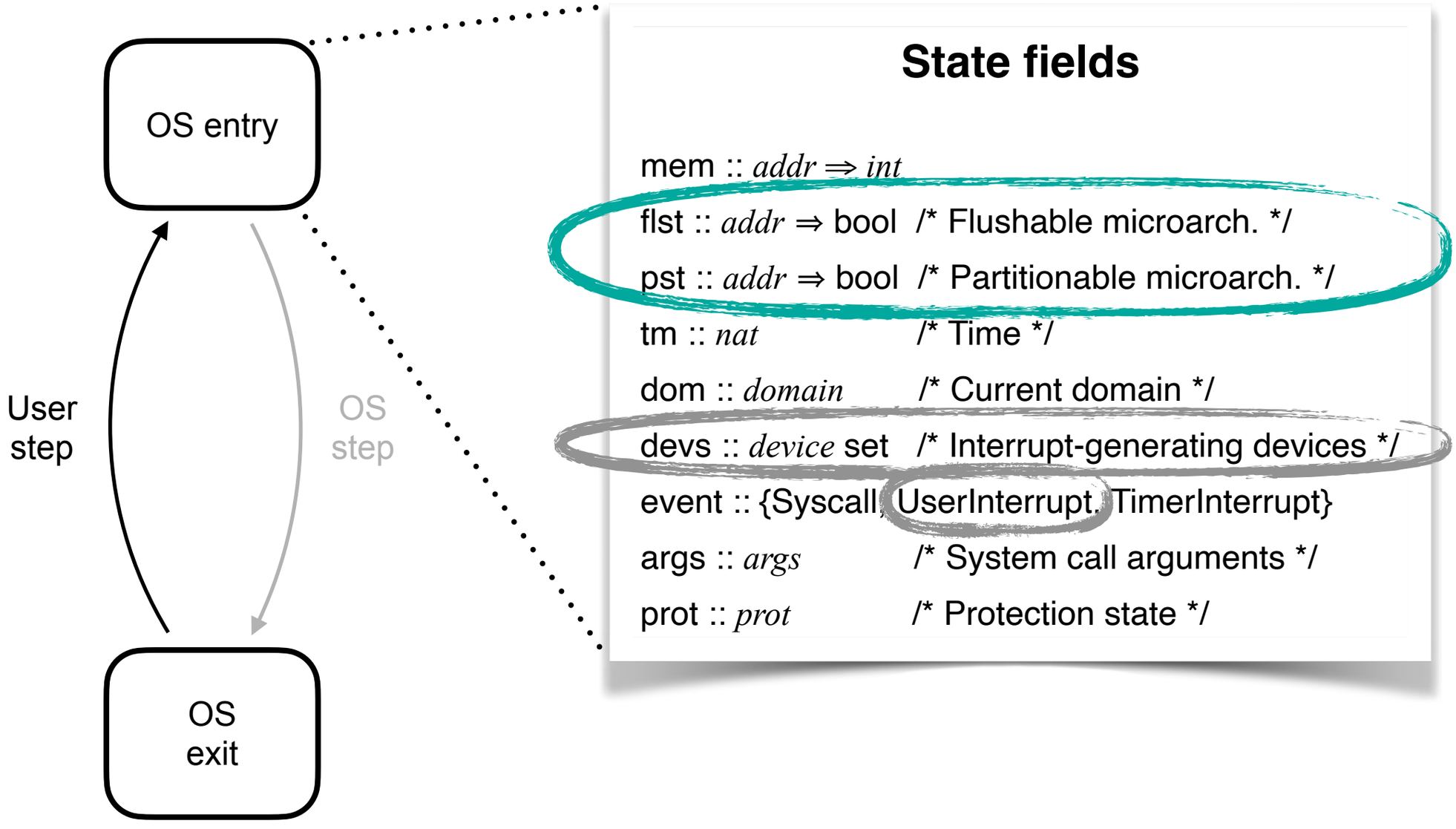
event :: {Syscall, UserInterrupt, TimerInterrupt}

args :: *args* /* System call arguments */

prot :: *prot* /* Protection state */

# OS security model


## Transition system




Microarchitecture
Devices

# OS security model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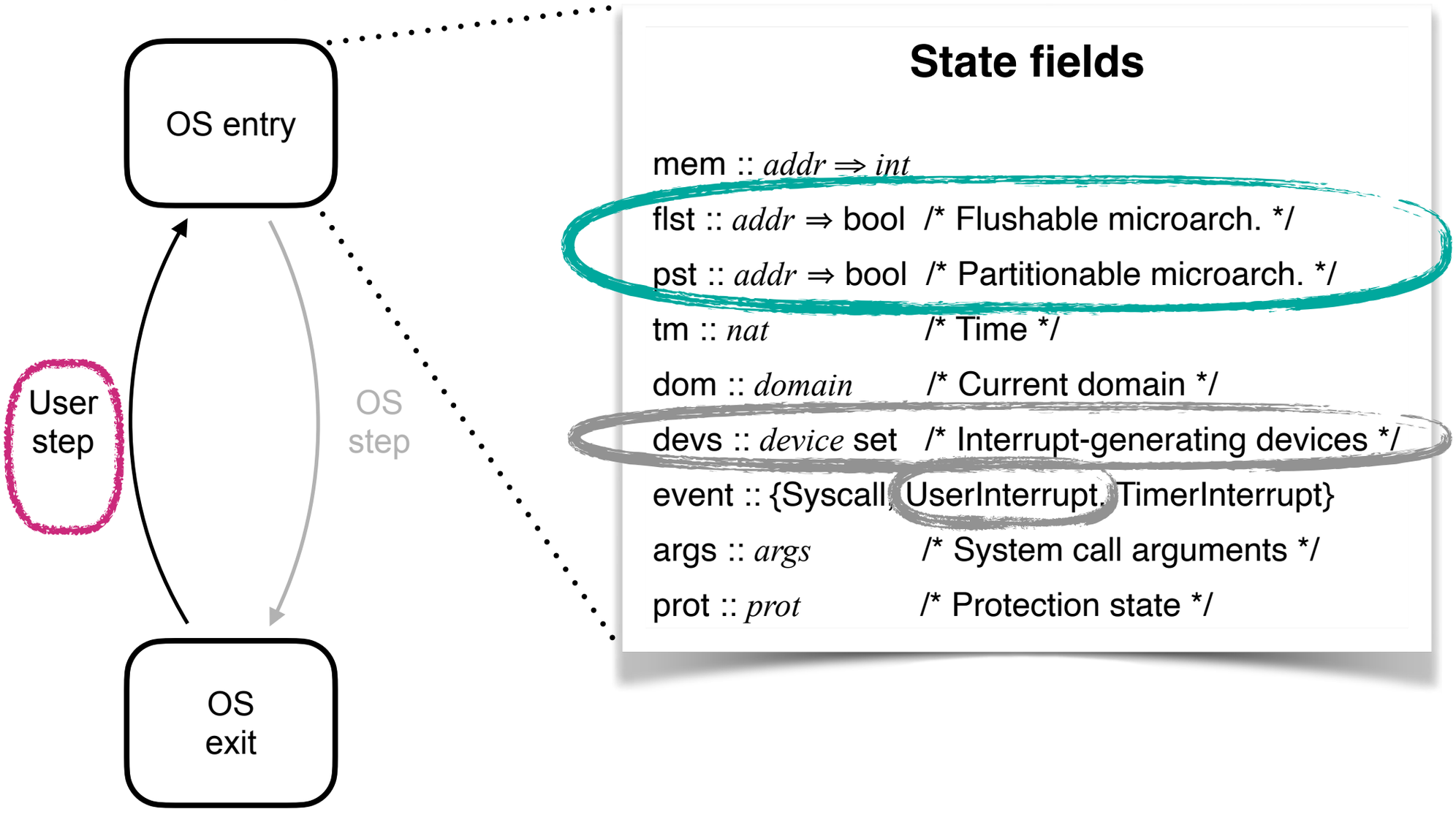


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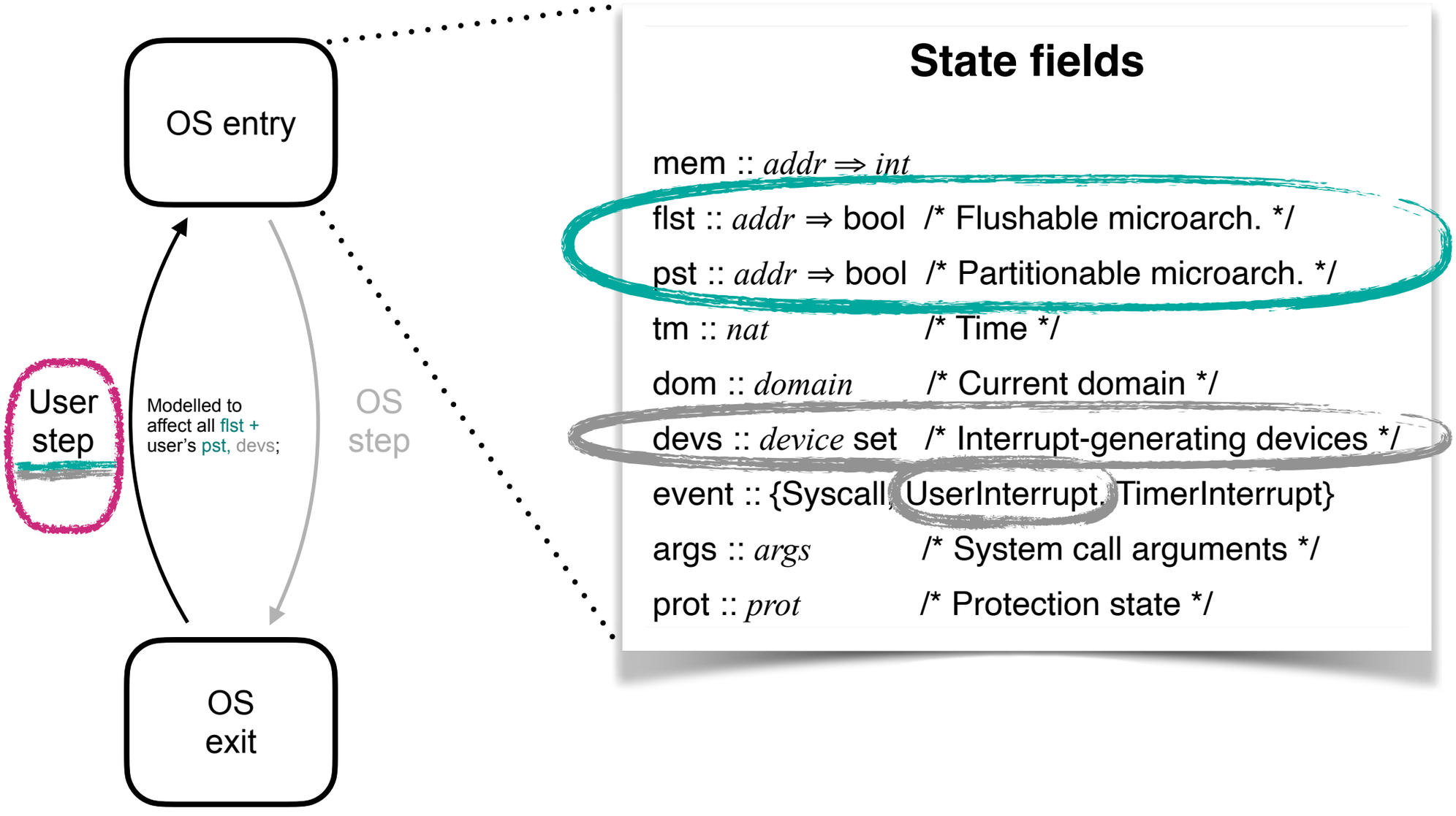

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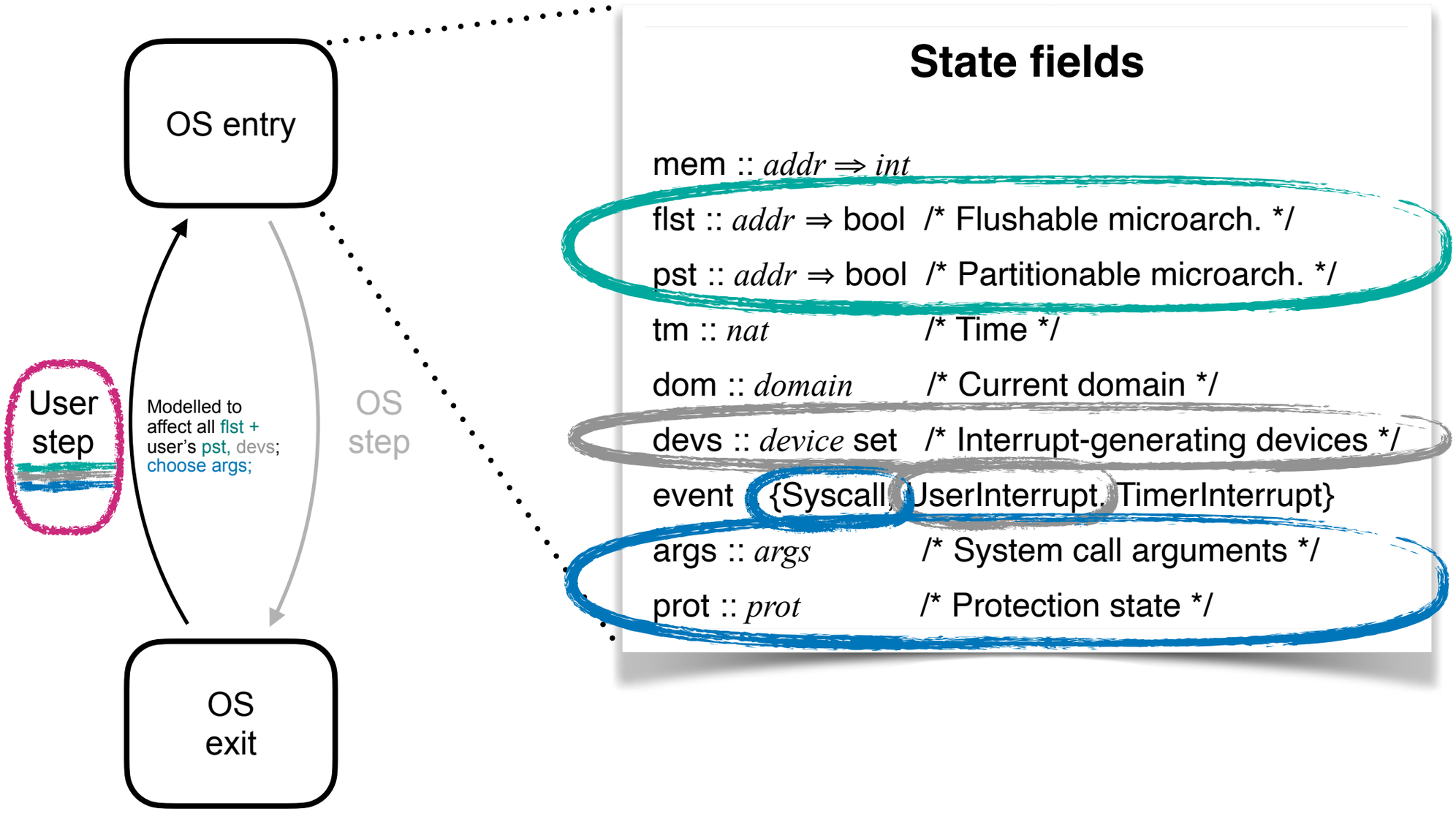

# OS security model


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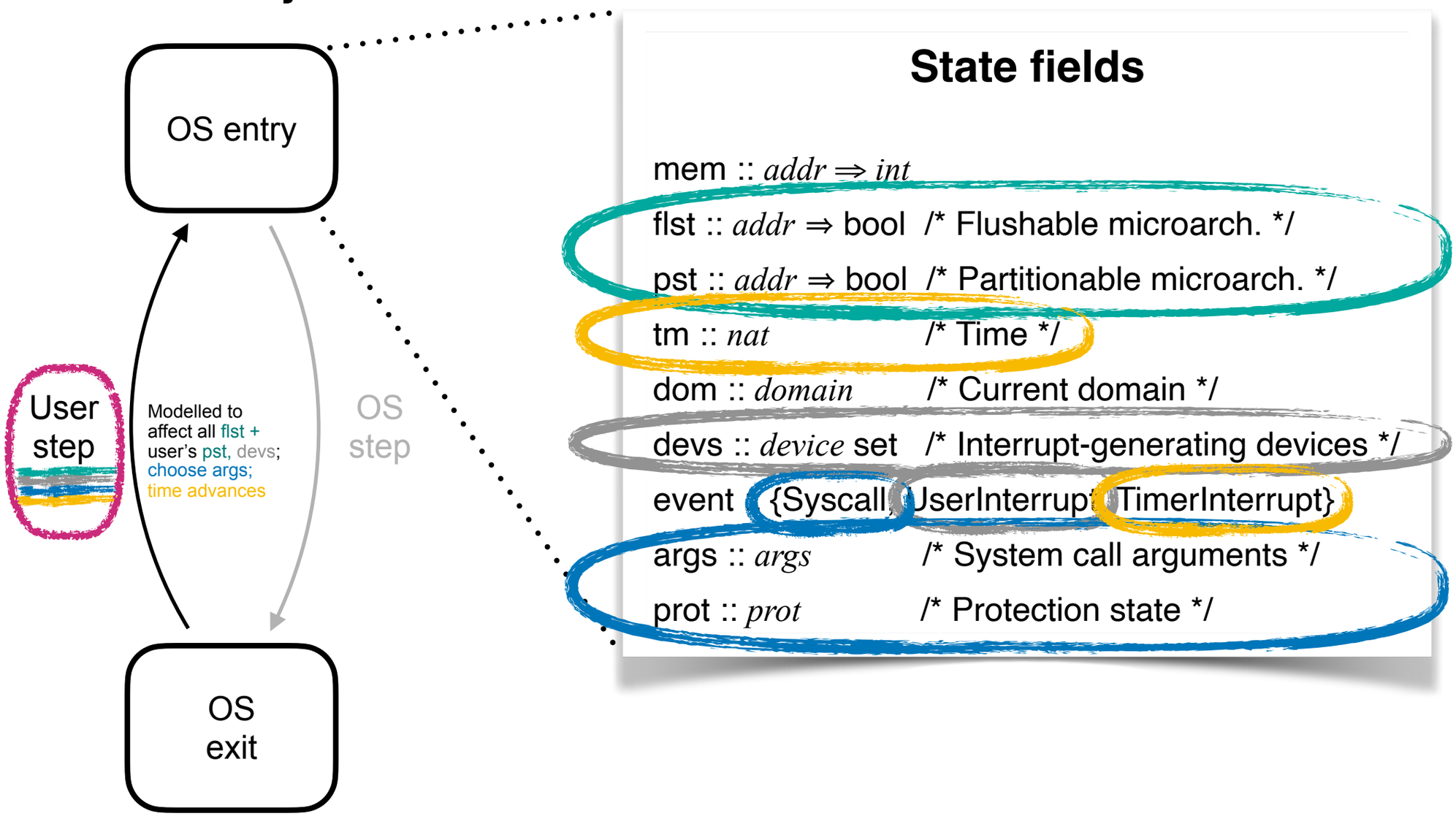

# OS security model


Microarchitecture
Devices
Policy-determining state
Time

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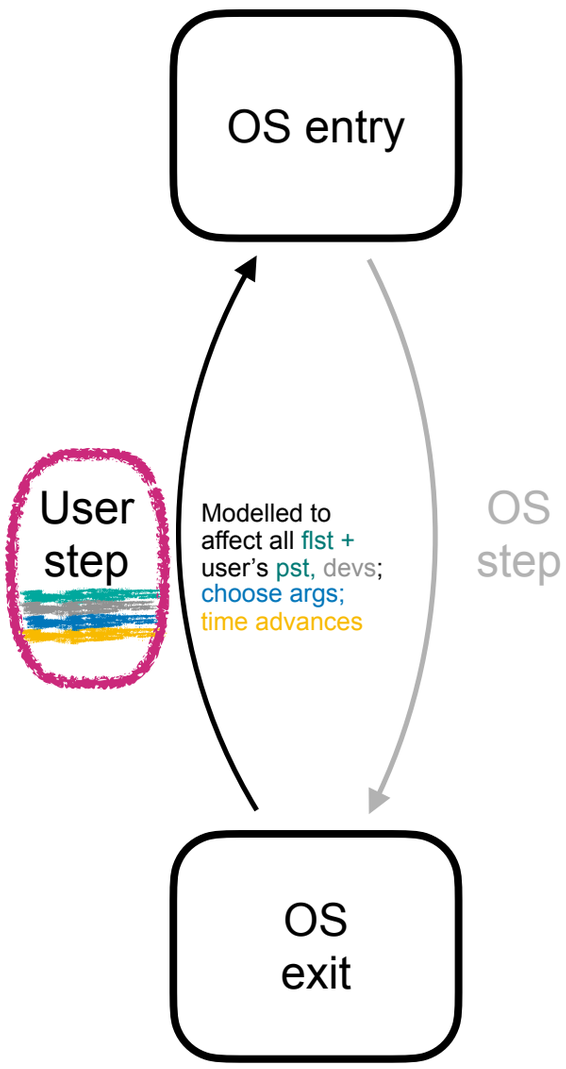

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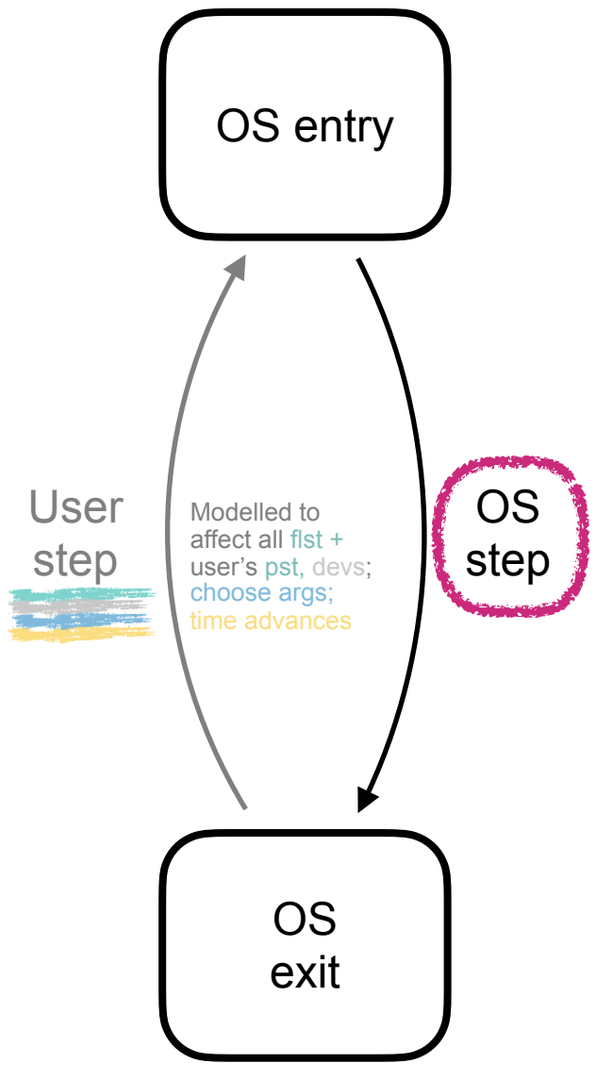

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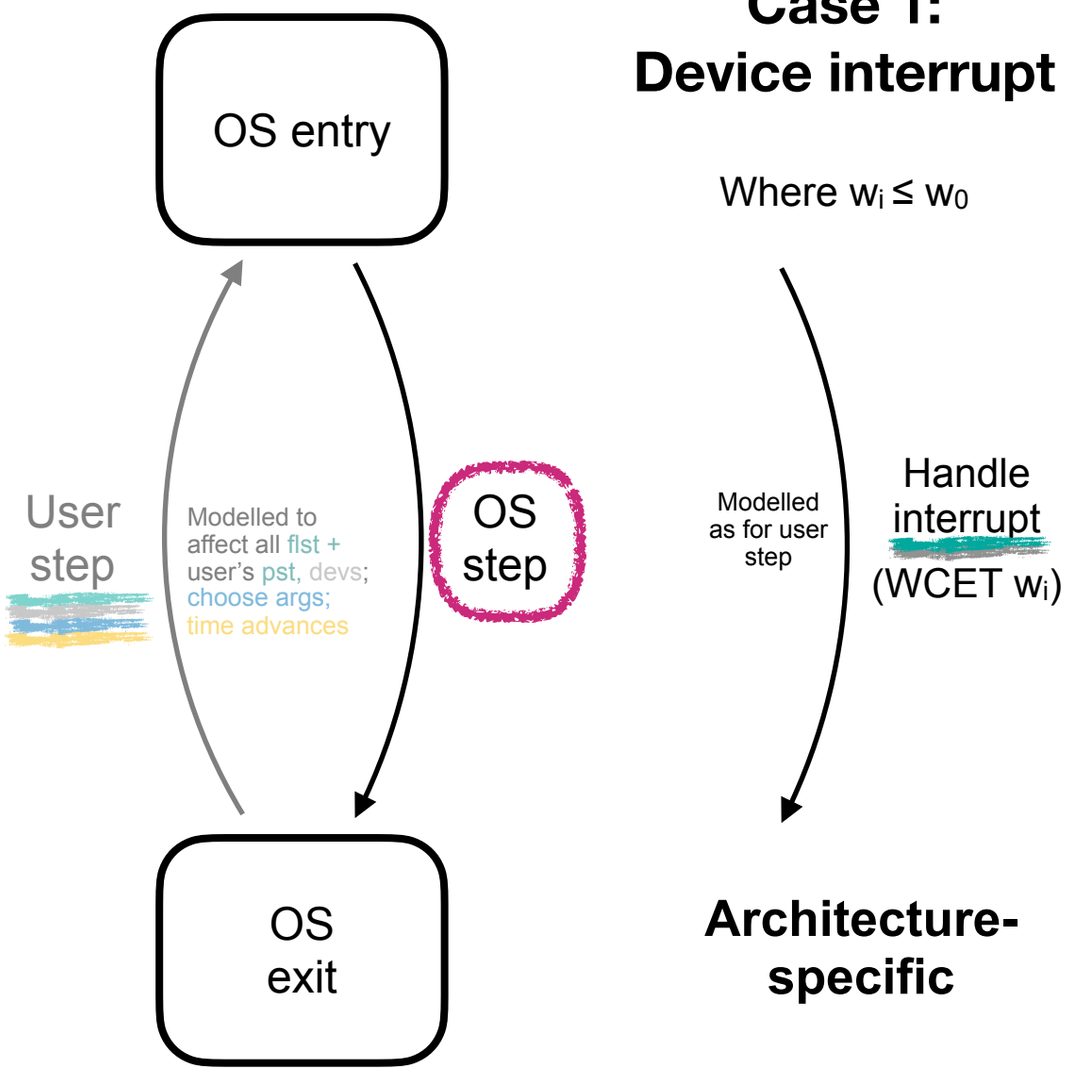

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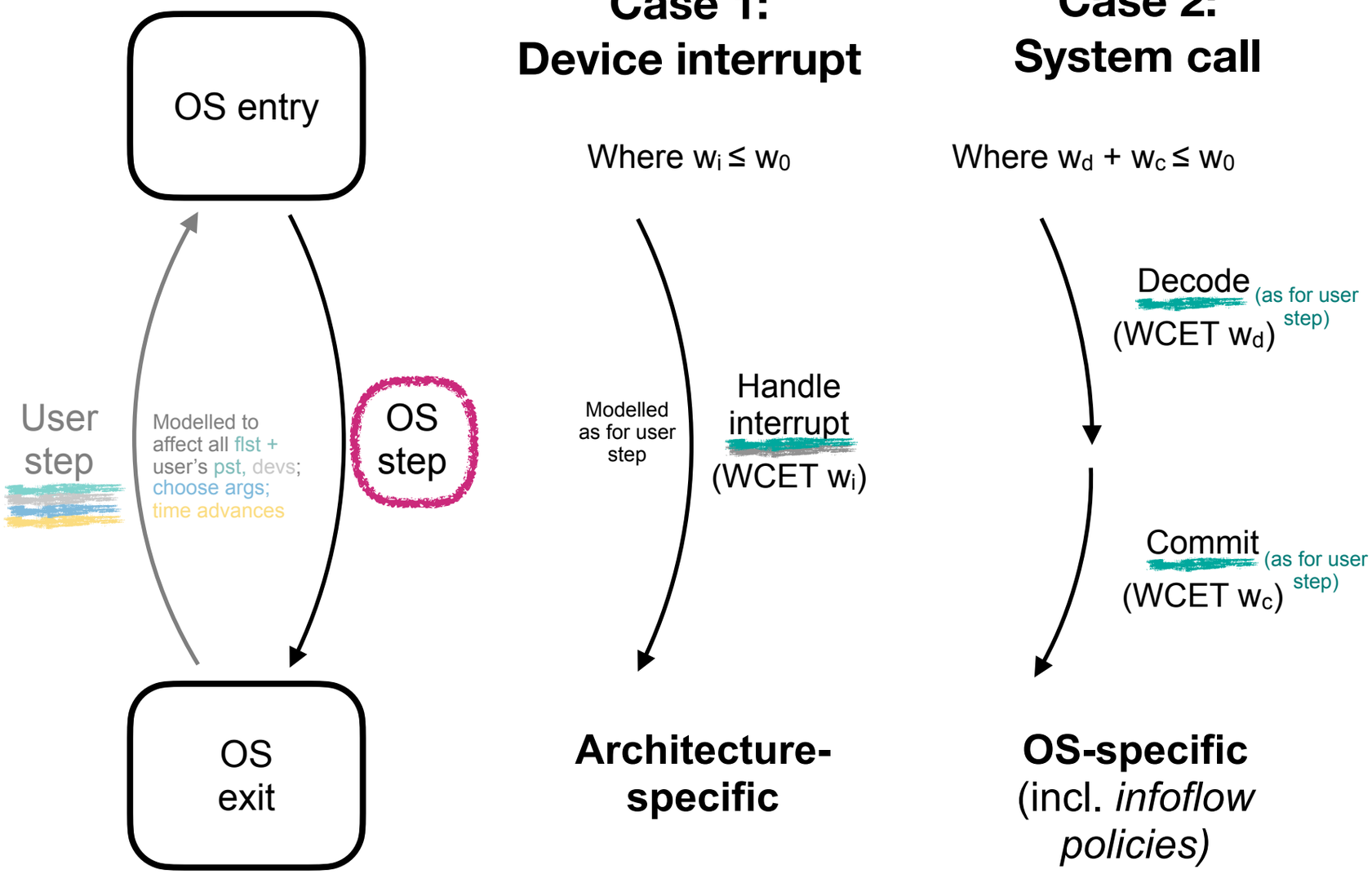

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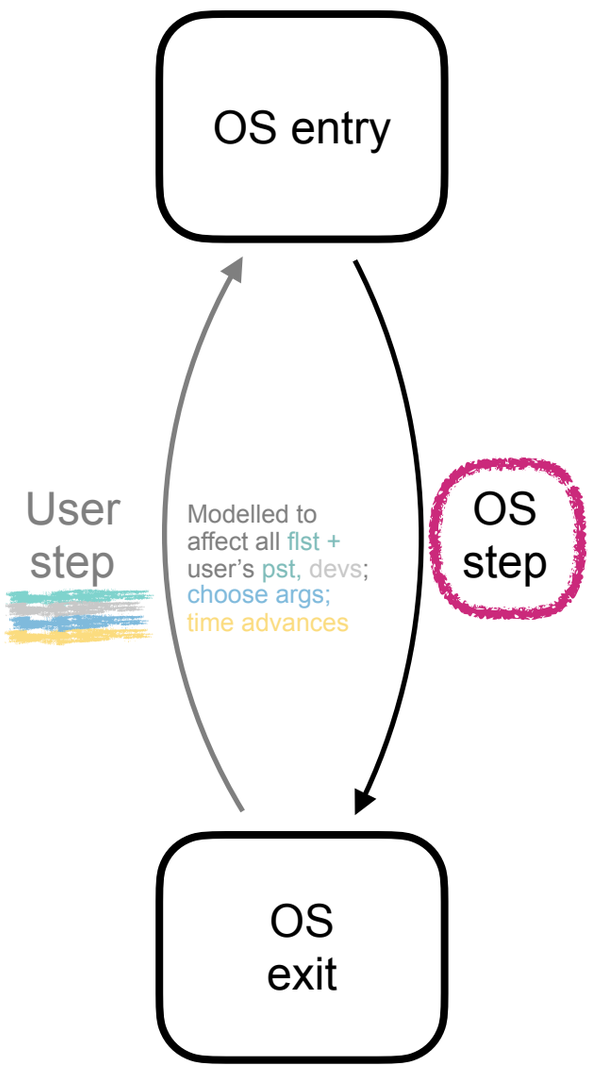
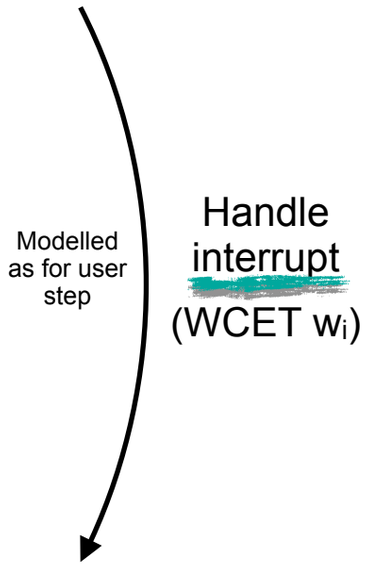



## Case 1: Device interrupt

Where $w_i \leq w_0$




**Architecture-specific**

## Case 2: System call

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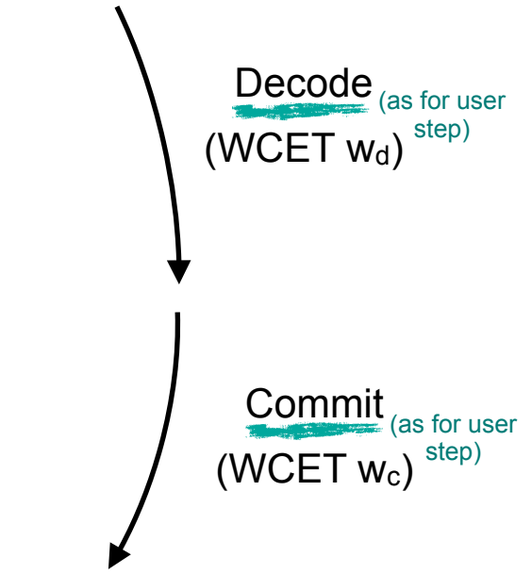


**OS-specific** (incl. *infoflow policies)*

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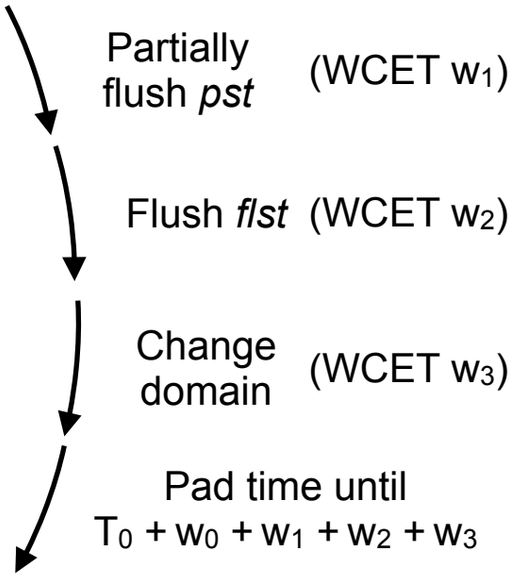
Timer interrupt delivered at (worst-case) $T_0 + w_0$

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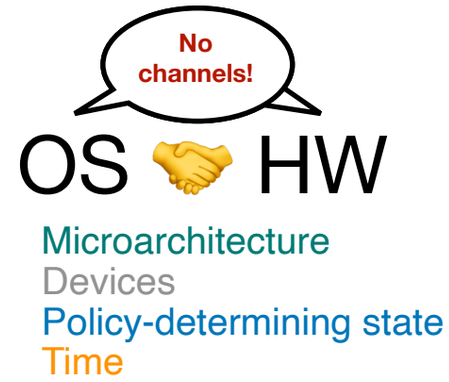


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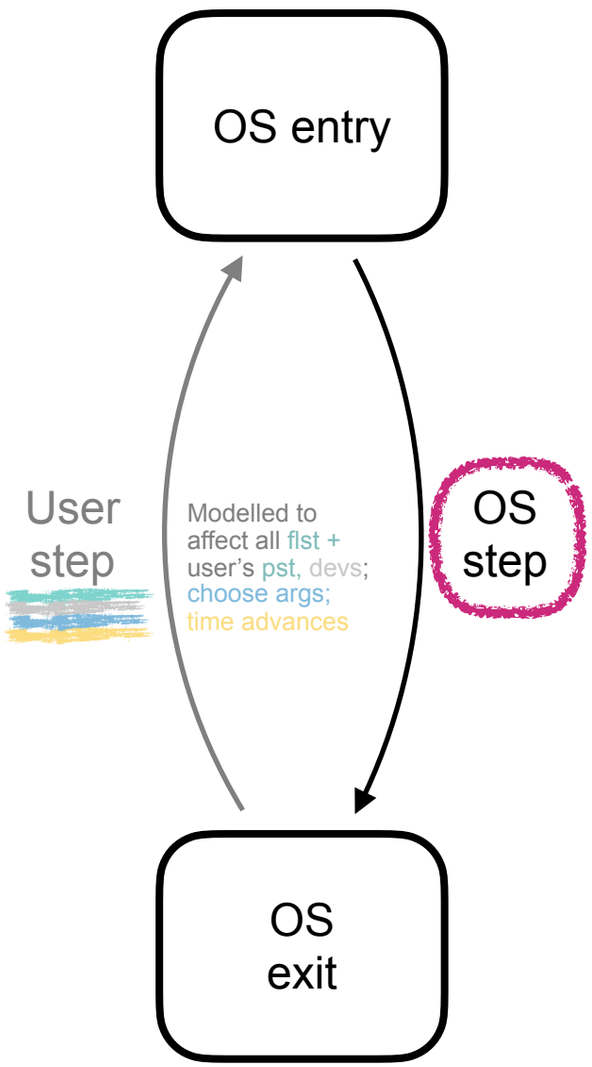


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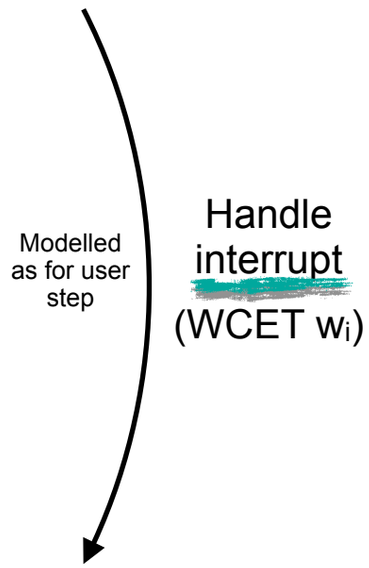


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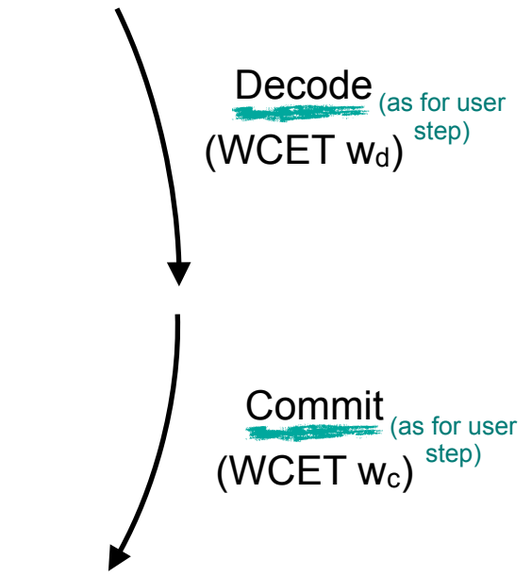


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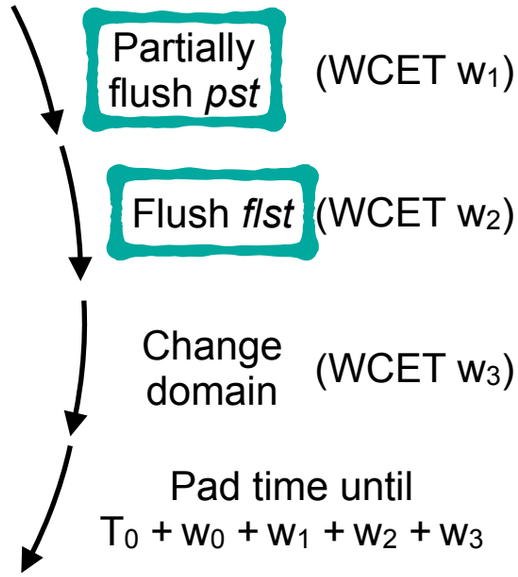


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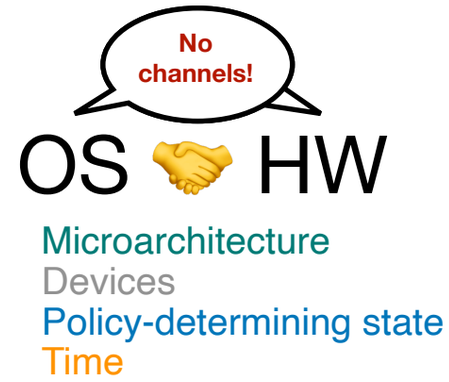


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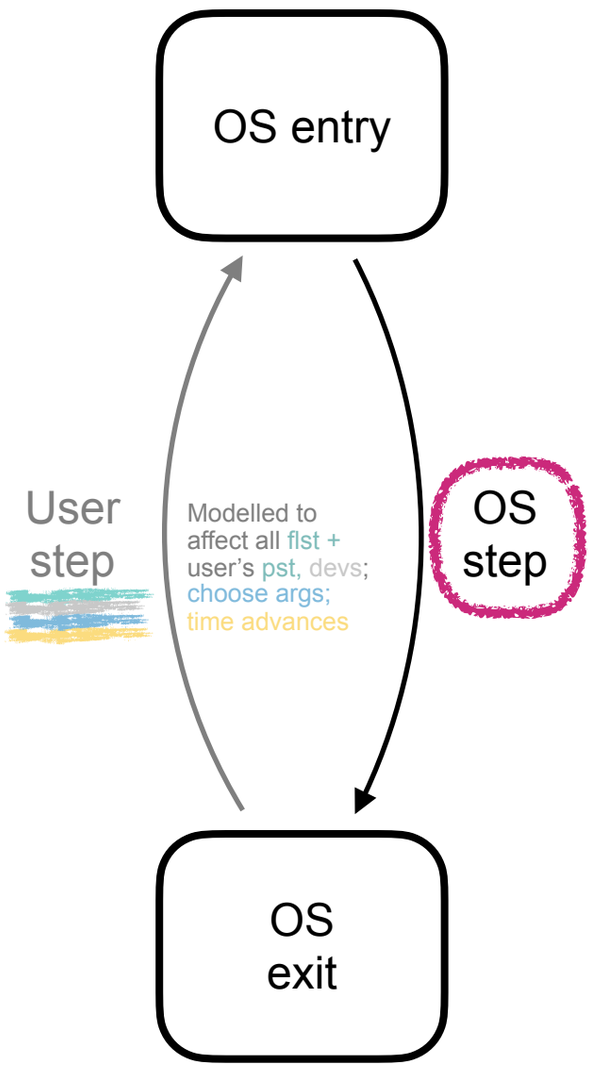


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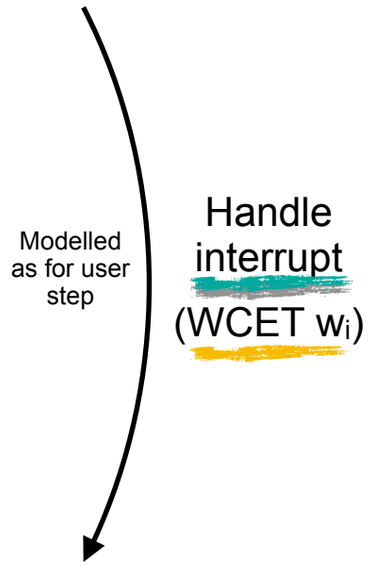


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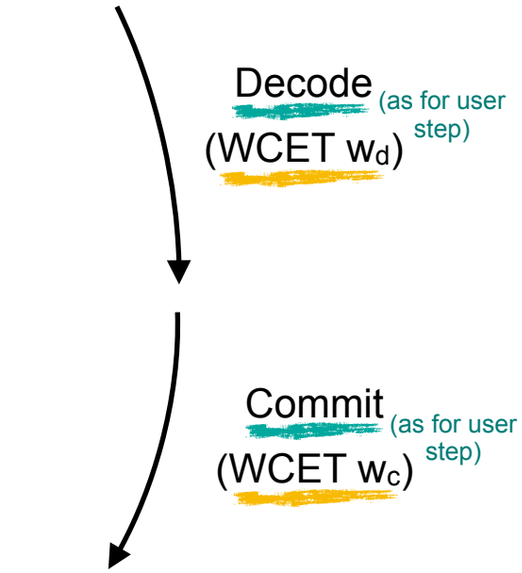


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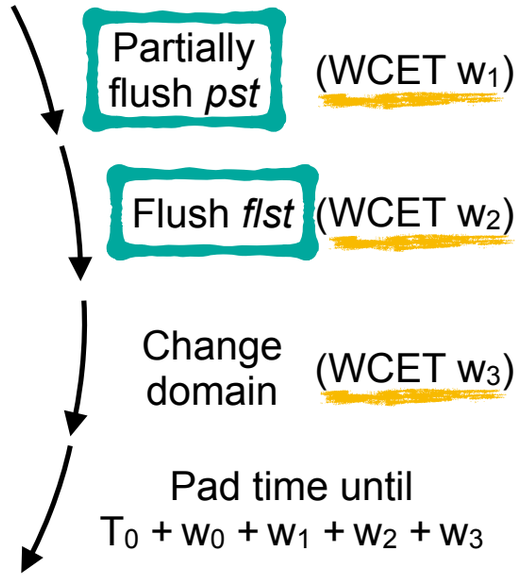


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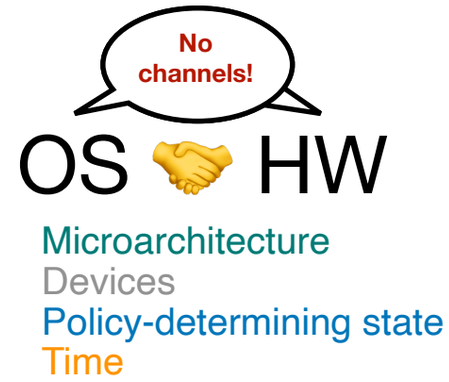


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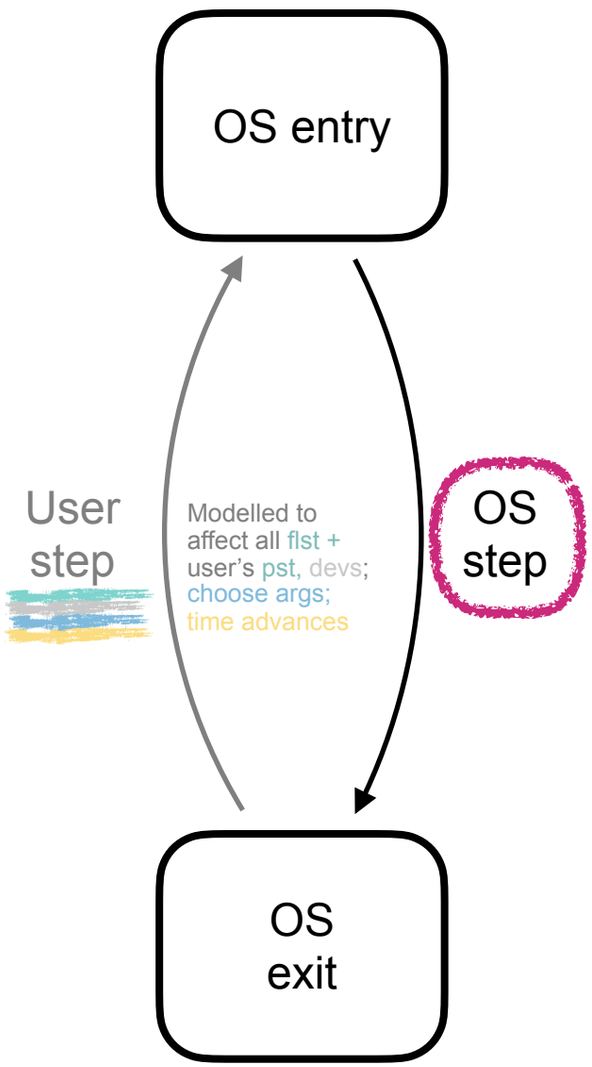


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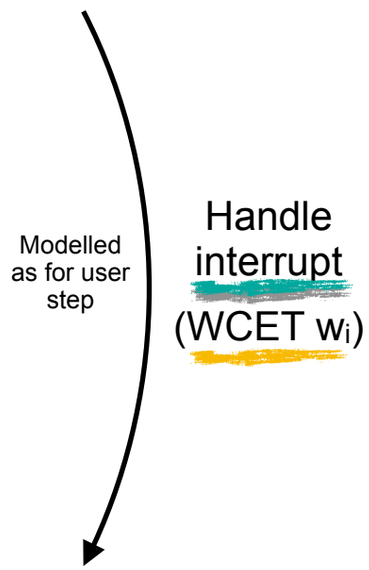


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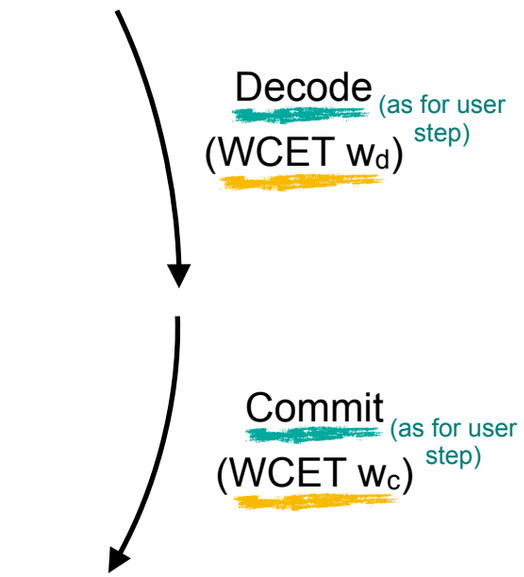


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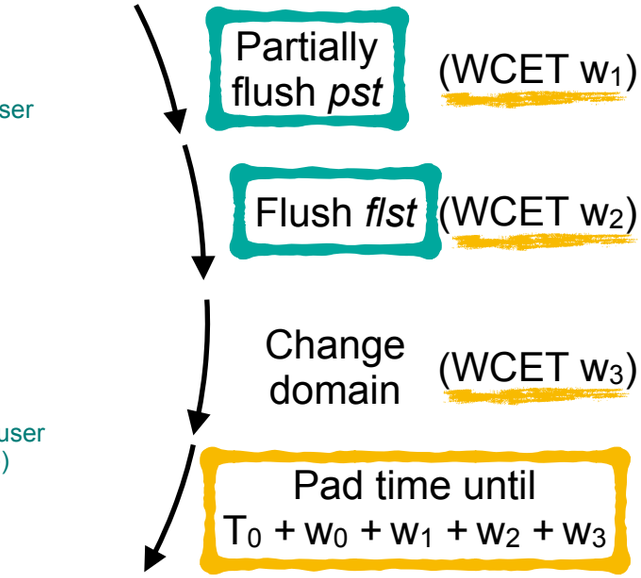


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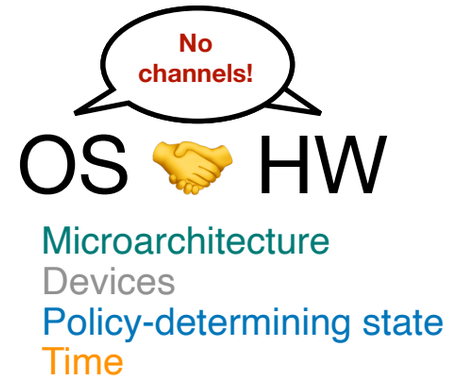


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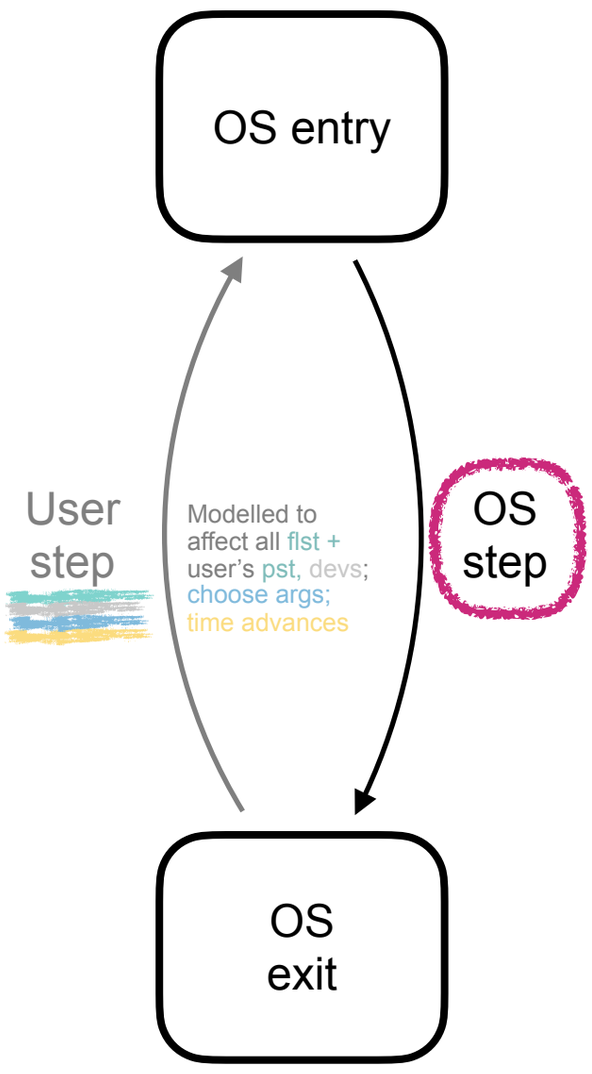


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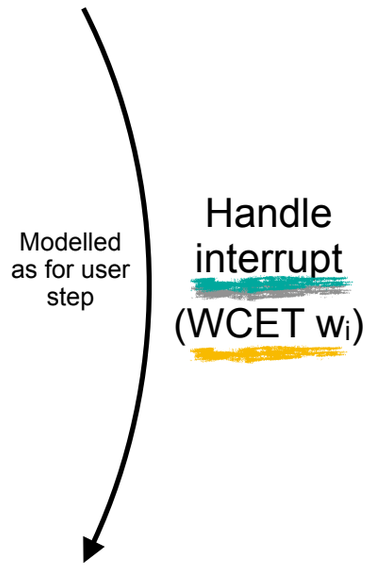


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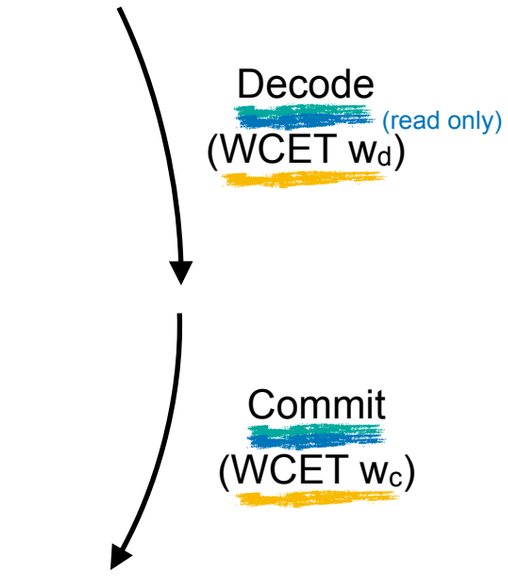


**OS-specific** (incl. *infoflow policies)*

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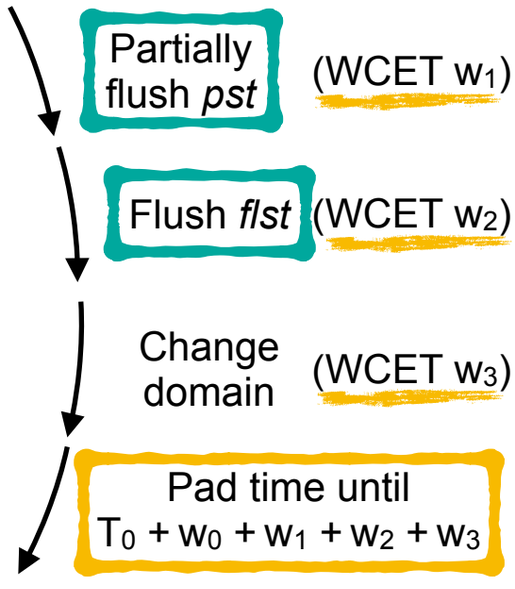
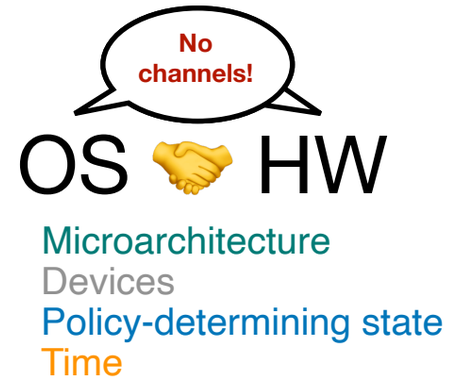
Timer interrupt delivered at (worst-case) $T_0 + w_0$




**Architecture-specific**

# Security proof approach

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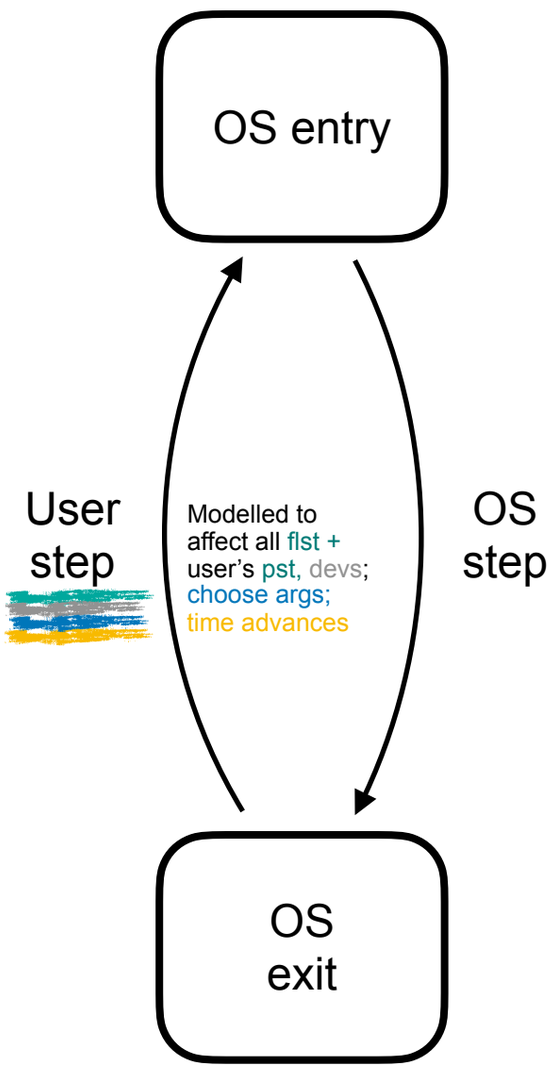


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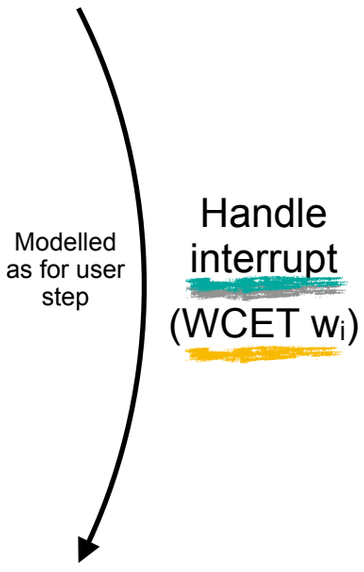


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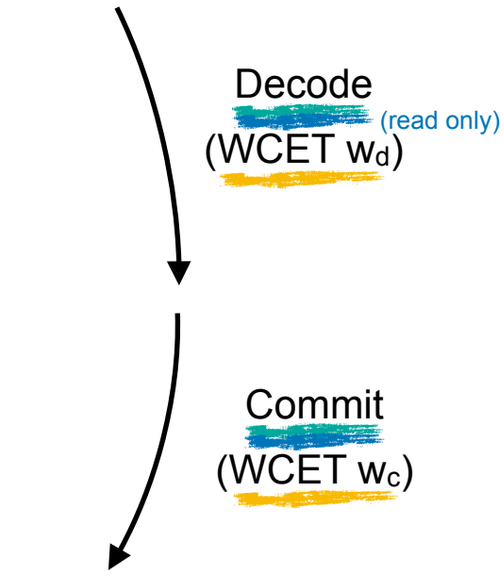


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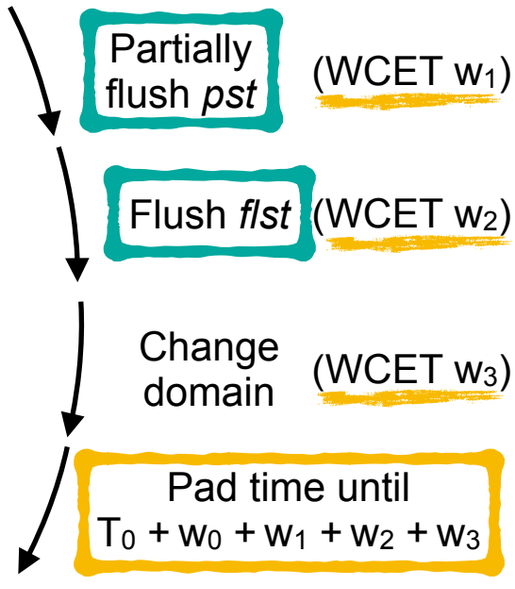


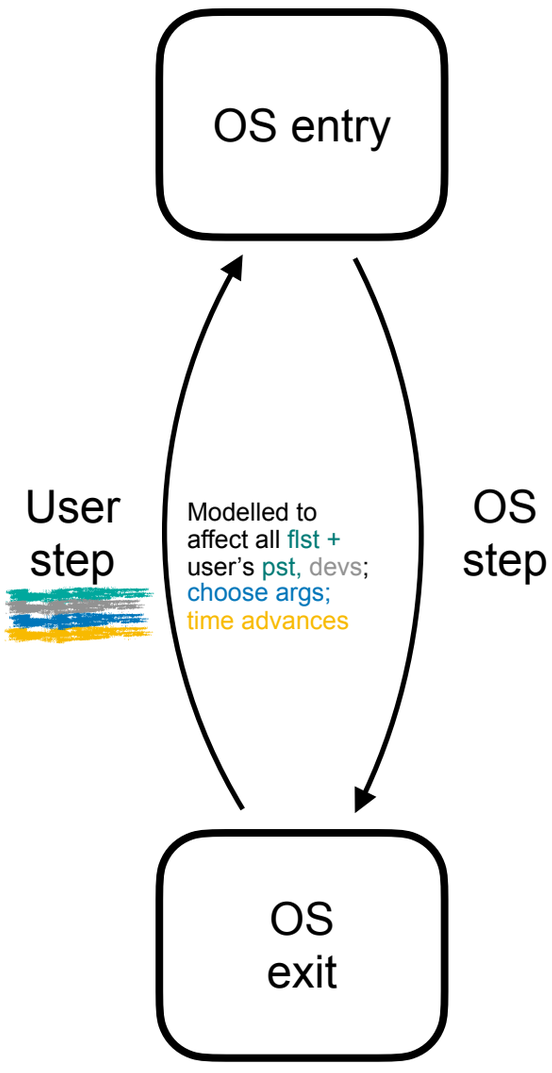

**Architecture-specific**

# Security proof approach


Microarchitecture
Devices
Policy-determining state
Time

**Requirements**
(In addition to WCETs)

## Transition system

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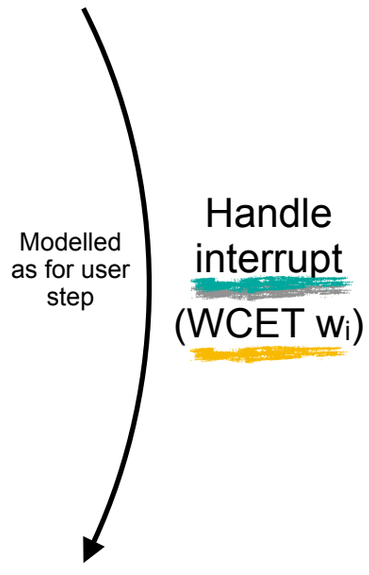


**Architecture-specific**

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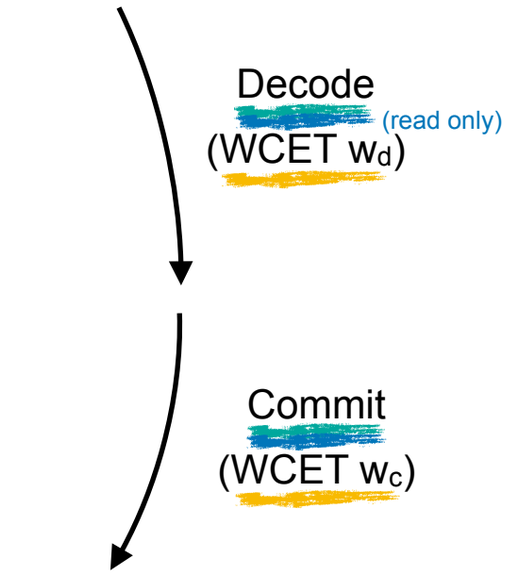


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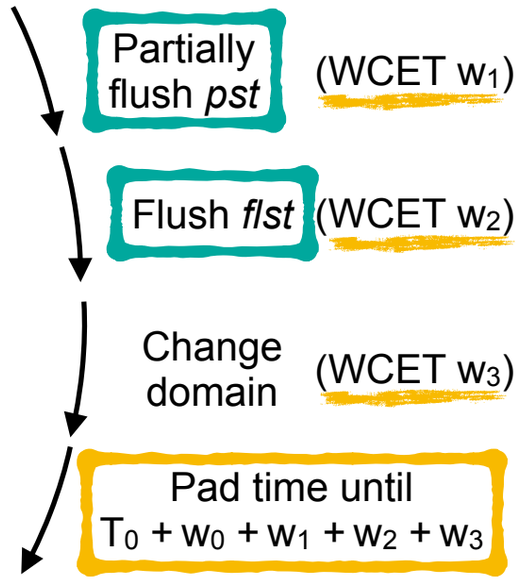


**Architecture-specific**

# Security proof approach


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Devices
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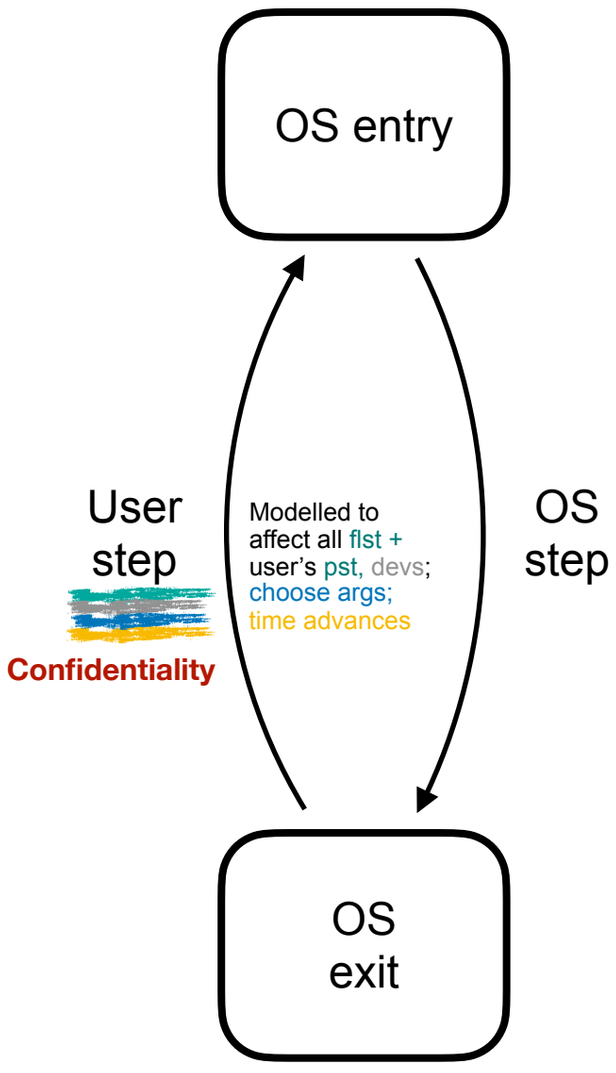


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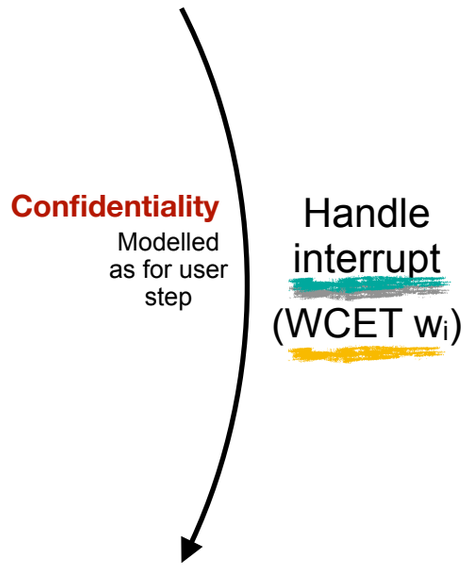


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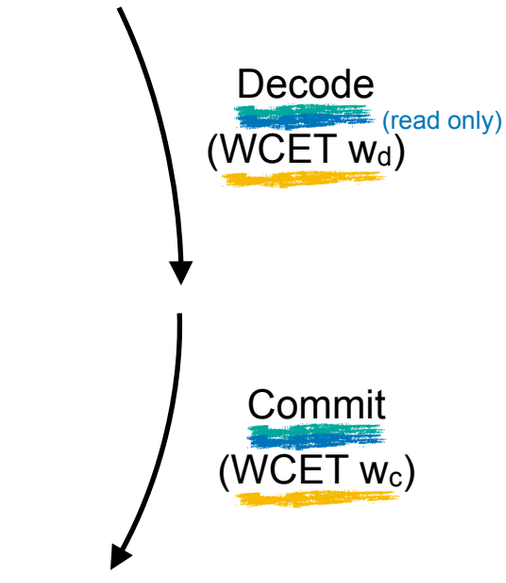


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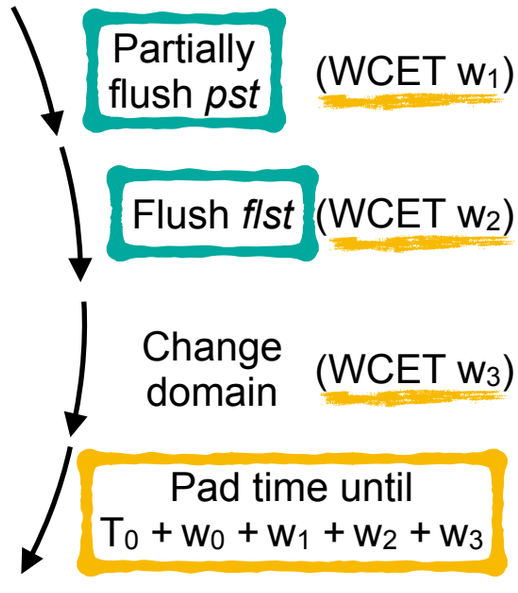


**Architecture-specific**

# Security proof approach


Microarchitecture
Devices
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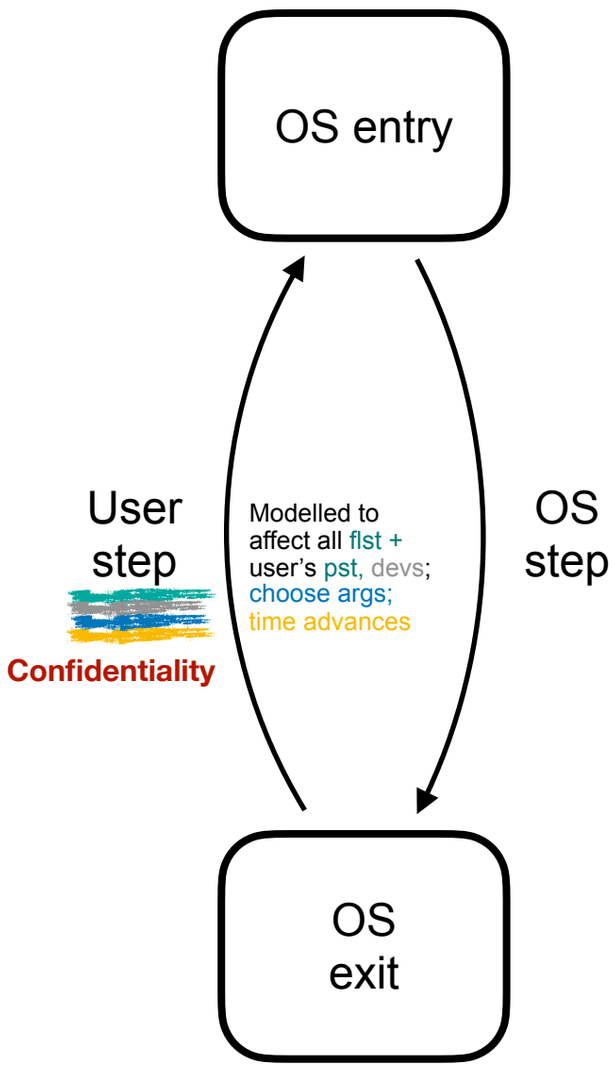


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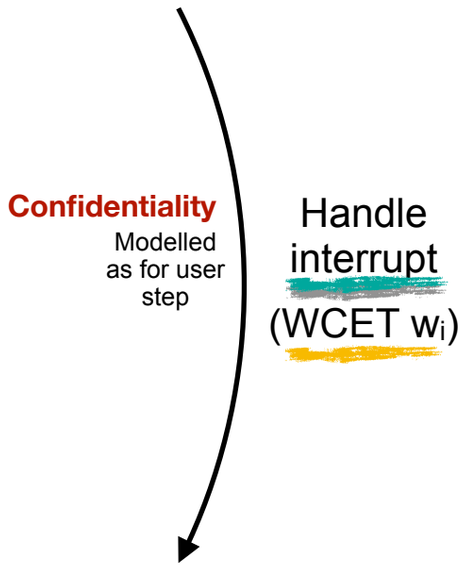


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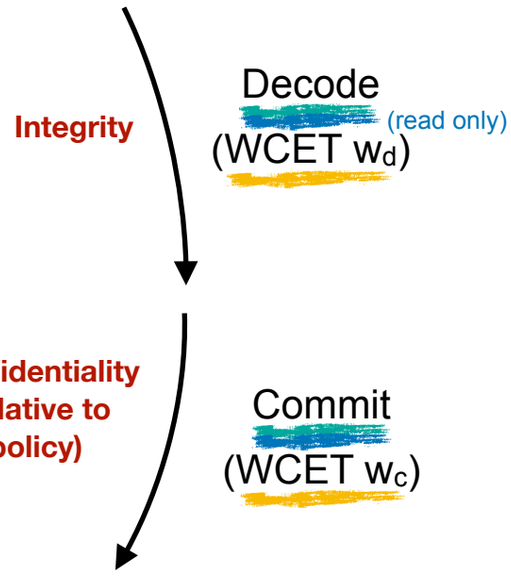


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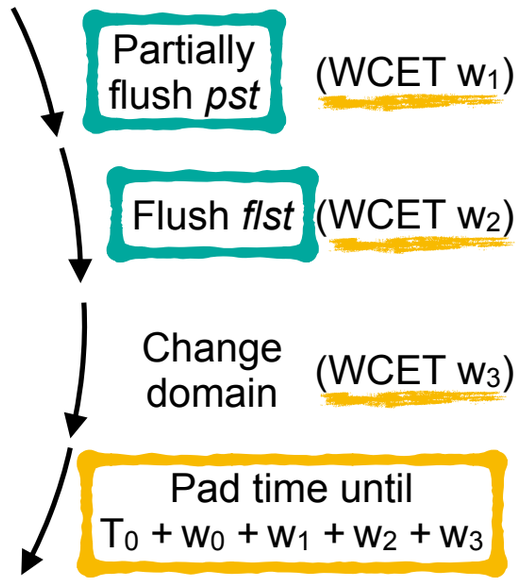


**Architecture-specific**

# Security proof approach


Microarchitecture
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Time

**Requirements**
(In addition to WCETs)

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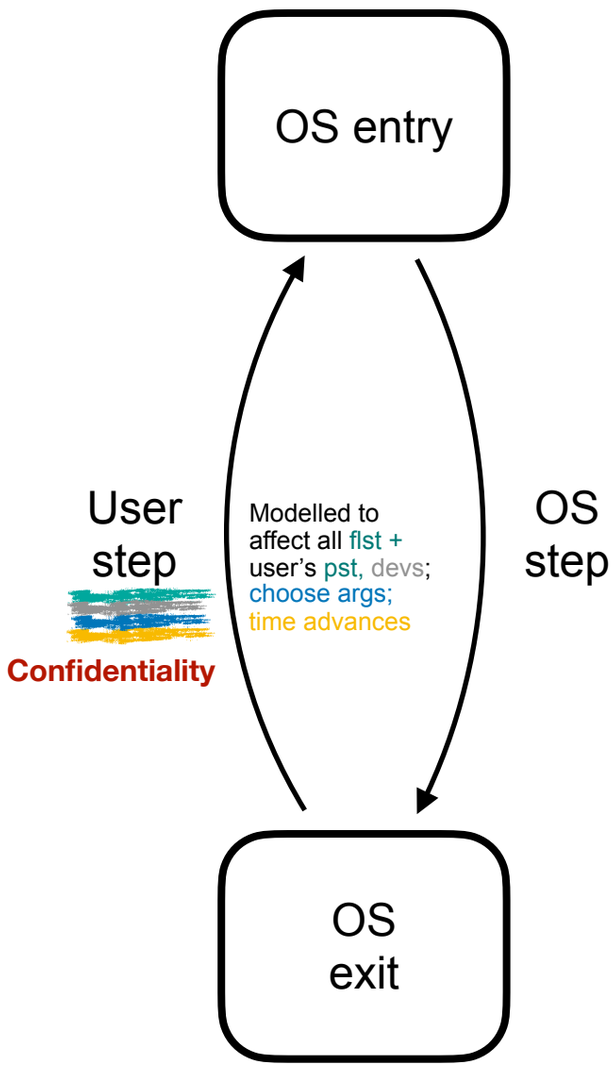


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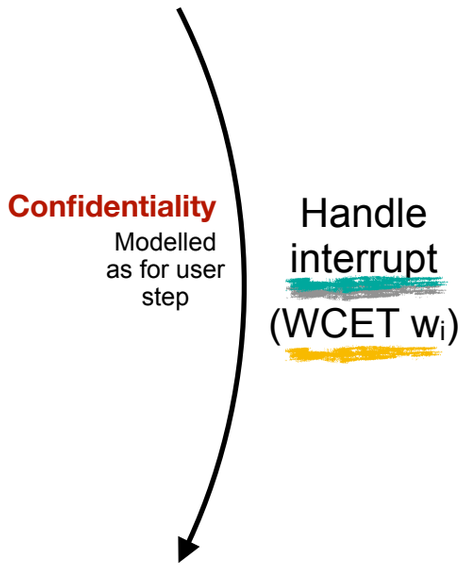


**Architecture-specific**

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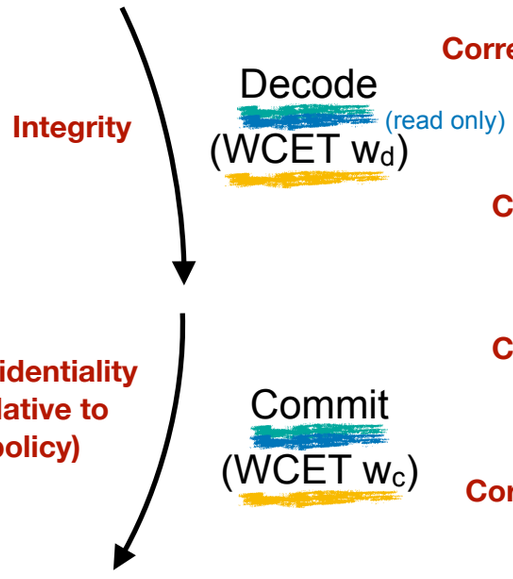


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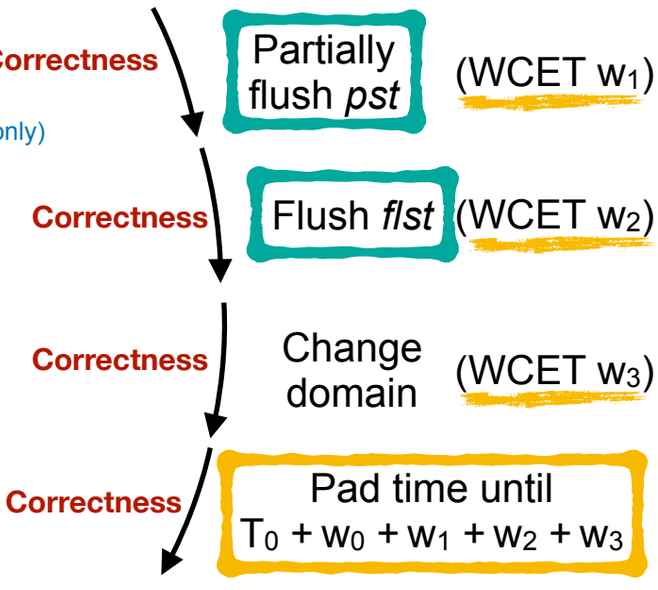


**Architecture-specific**

# Security proof approach


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**Requirements**
(In addition to WCETs)

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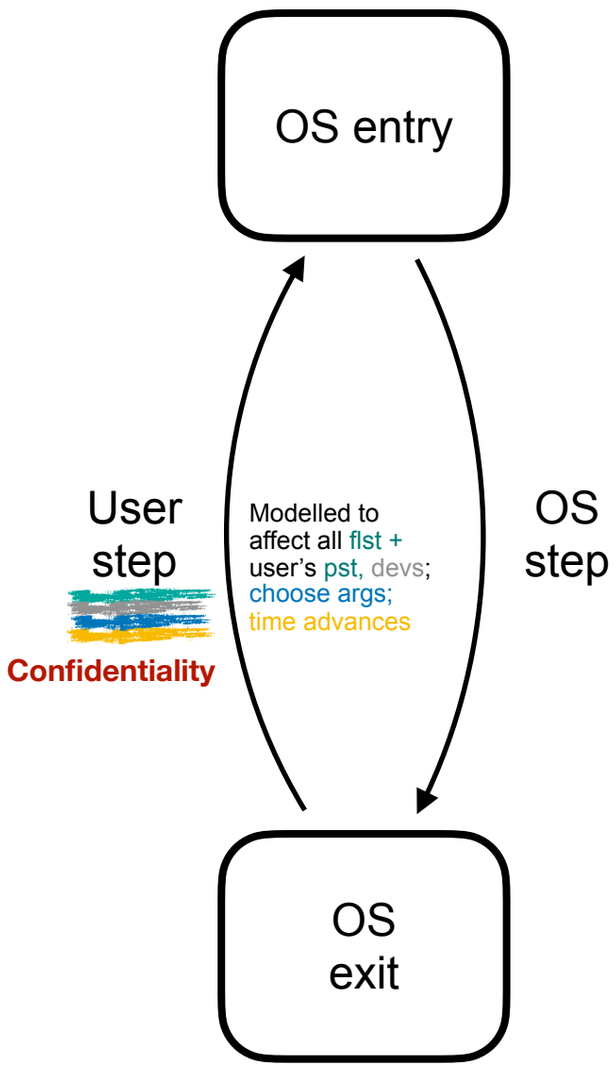


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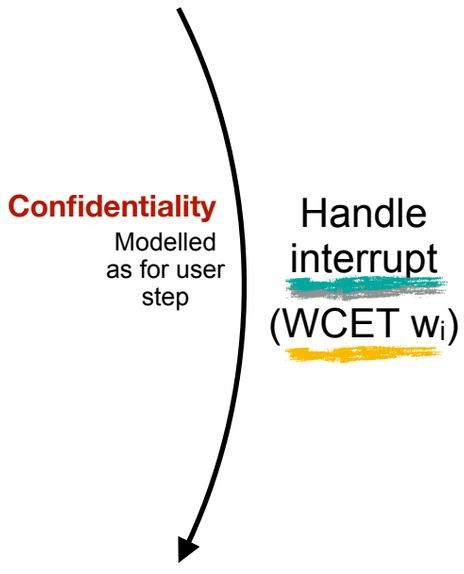


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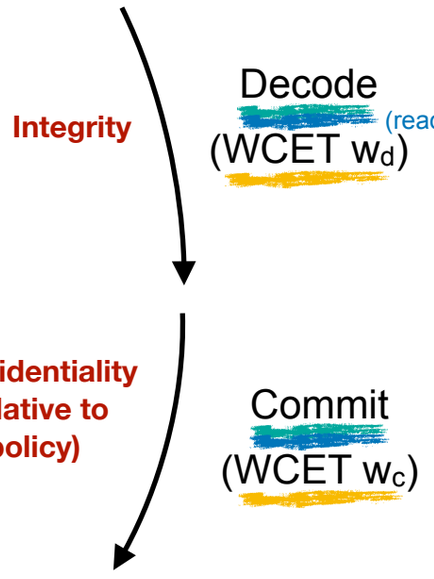


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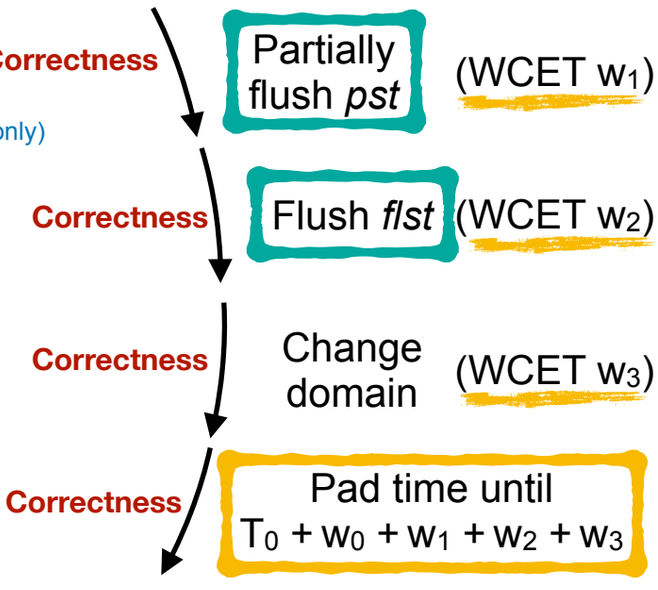


**Architecture-specific**

We prove: **Confidentiality property (bisimulation) step lemmas**

# Security proof approach


Microarchitecture
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Time

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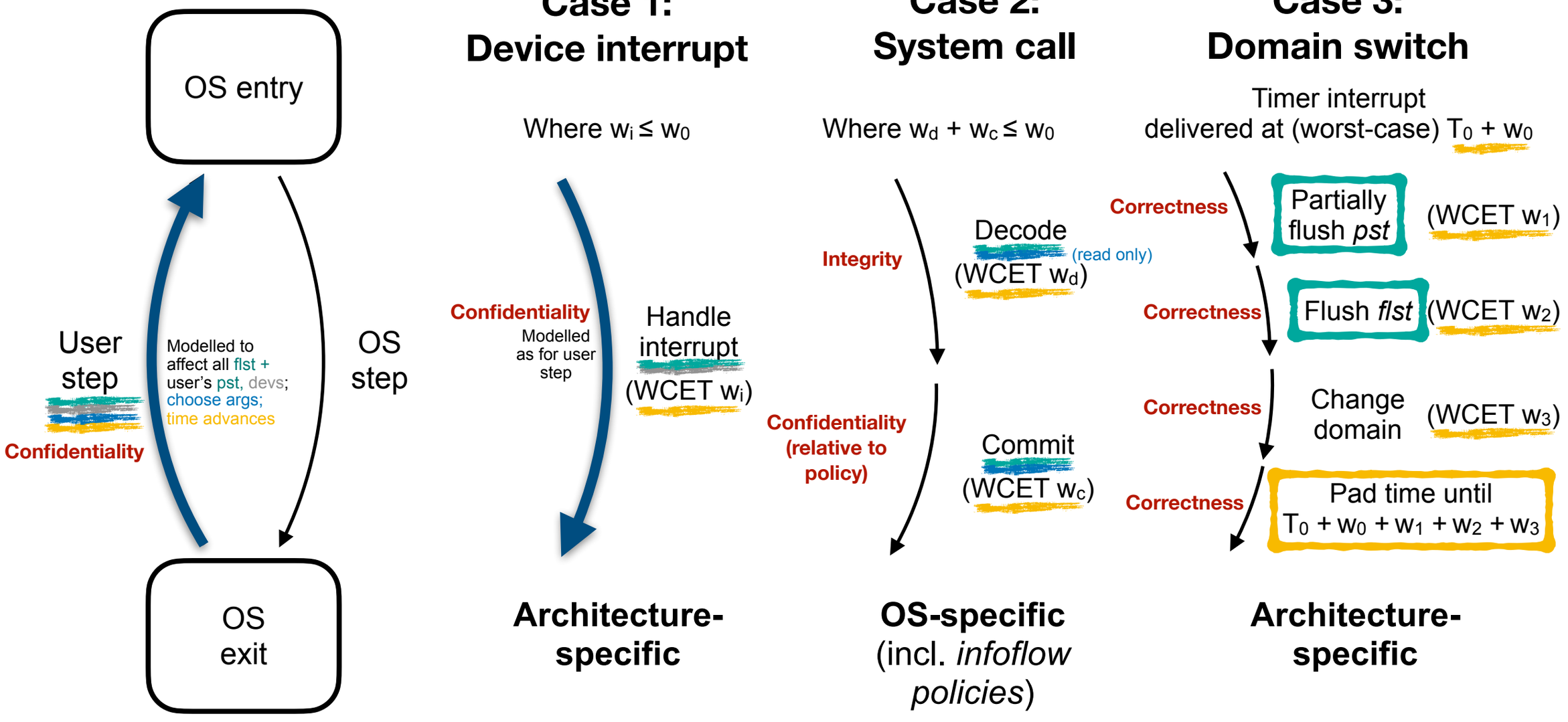
## Transition system

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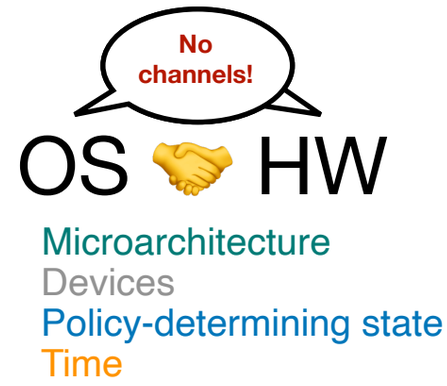


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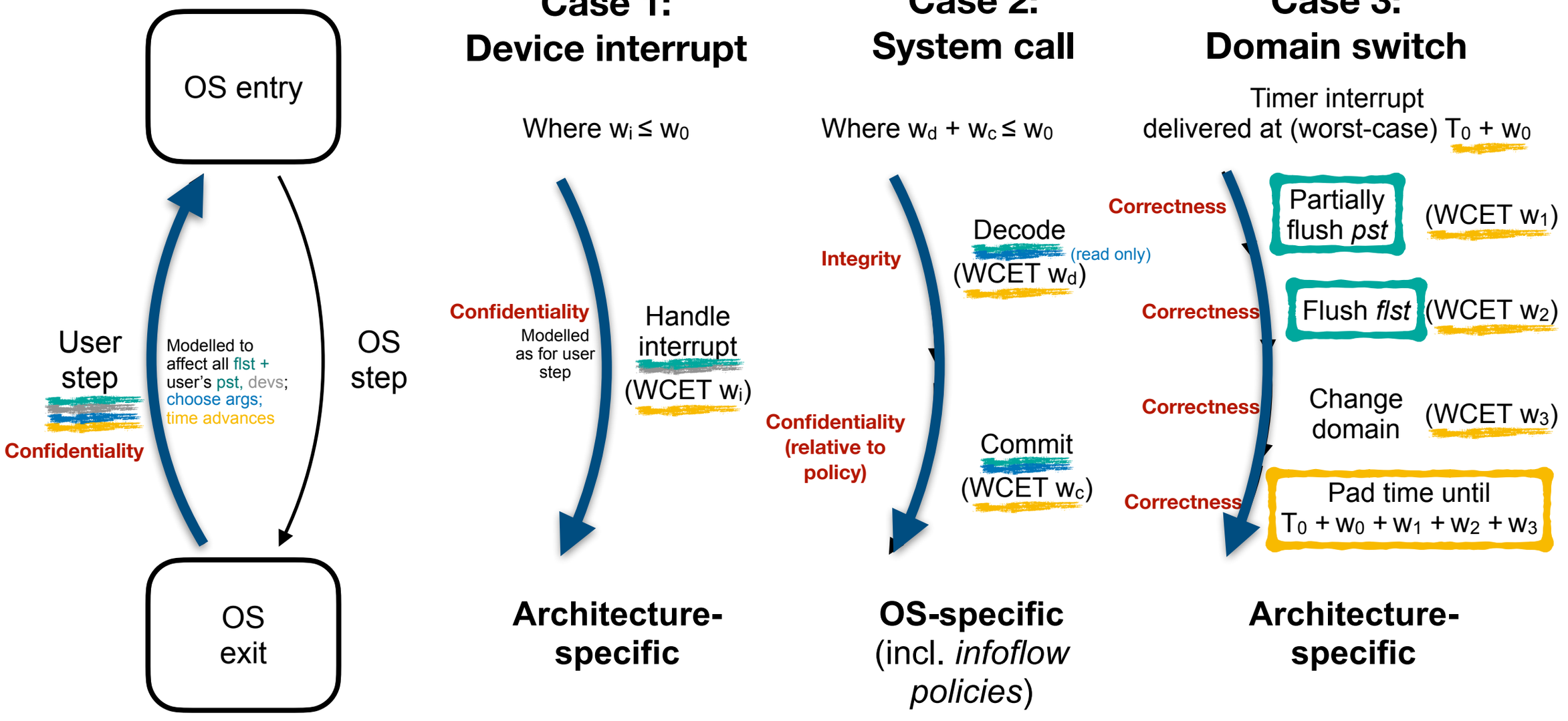


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Microarchitecture
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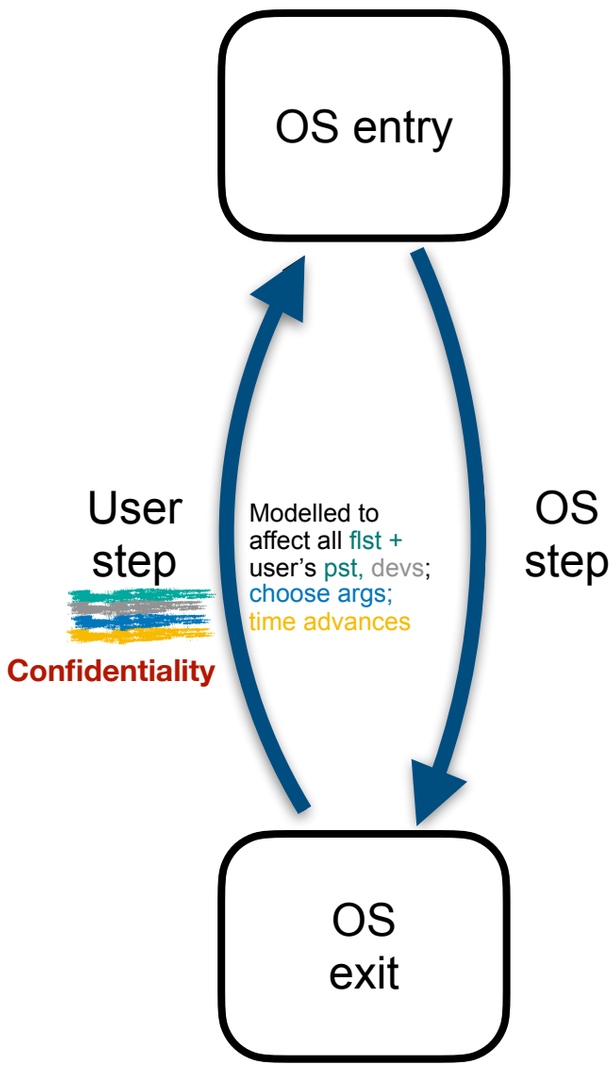


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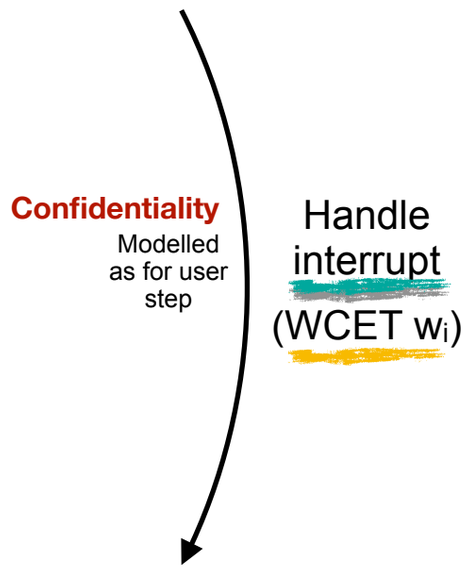


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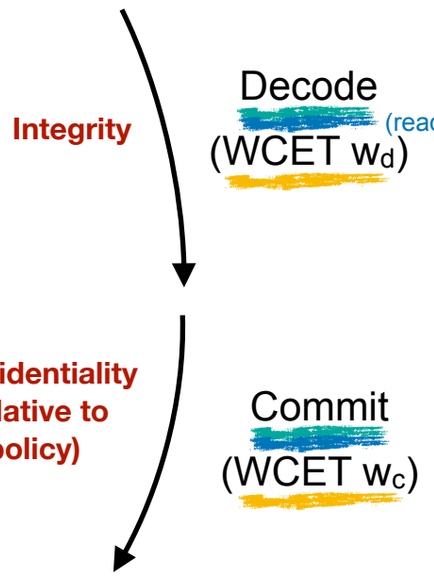


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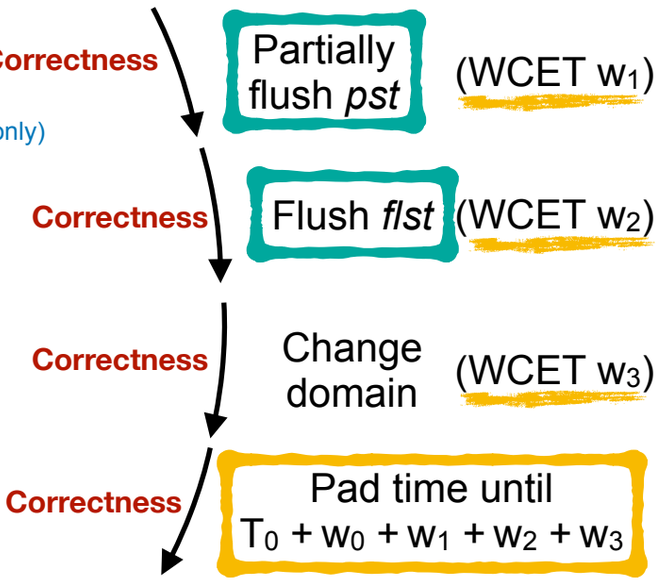


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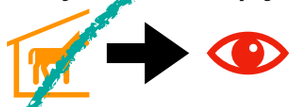
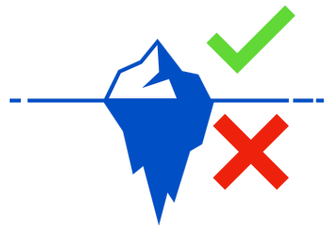
# How to formalise an OS enforces *time protection*?

Versus threat scenario:
trojan and spy




OS 🤝 HW

Abstract *covert state* + *time* to reflect strategies enabled by HW:
Partition or flush state; pad time.



Make security property precise enough to exclude flows from covert state.


Demonstrating these principles,
we formalised in Isabelle/HOL:

1. OS security model imposing requirements on relevant parts of OS.
(Intended for seL4, but *generic*)

2. OS security property that is dynamic; this makes it observer relative.
(Improving on seL4's of [Murray et al. 2012])

3. Proof our security property holds if OS model's requirements hold.

4. Basic instantiation of OS model exercising dynamic policy.

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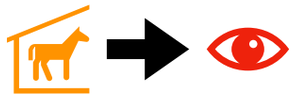


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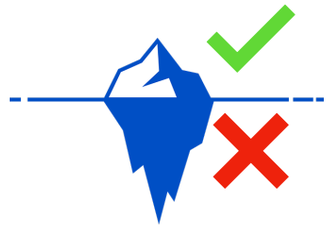

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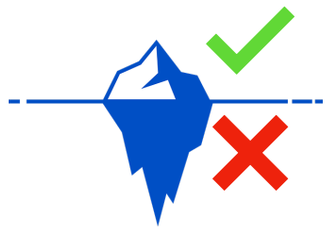
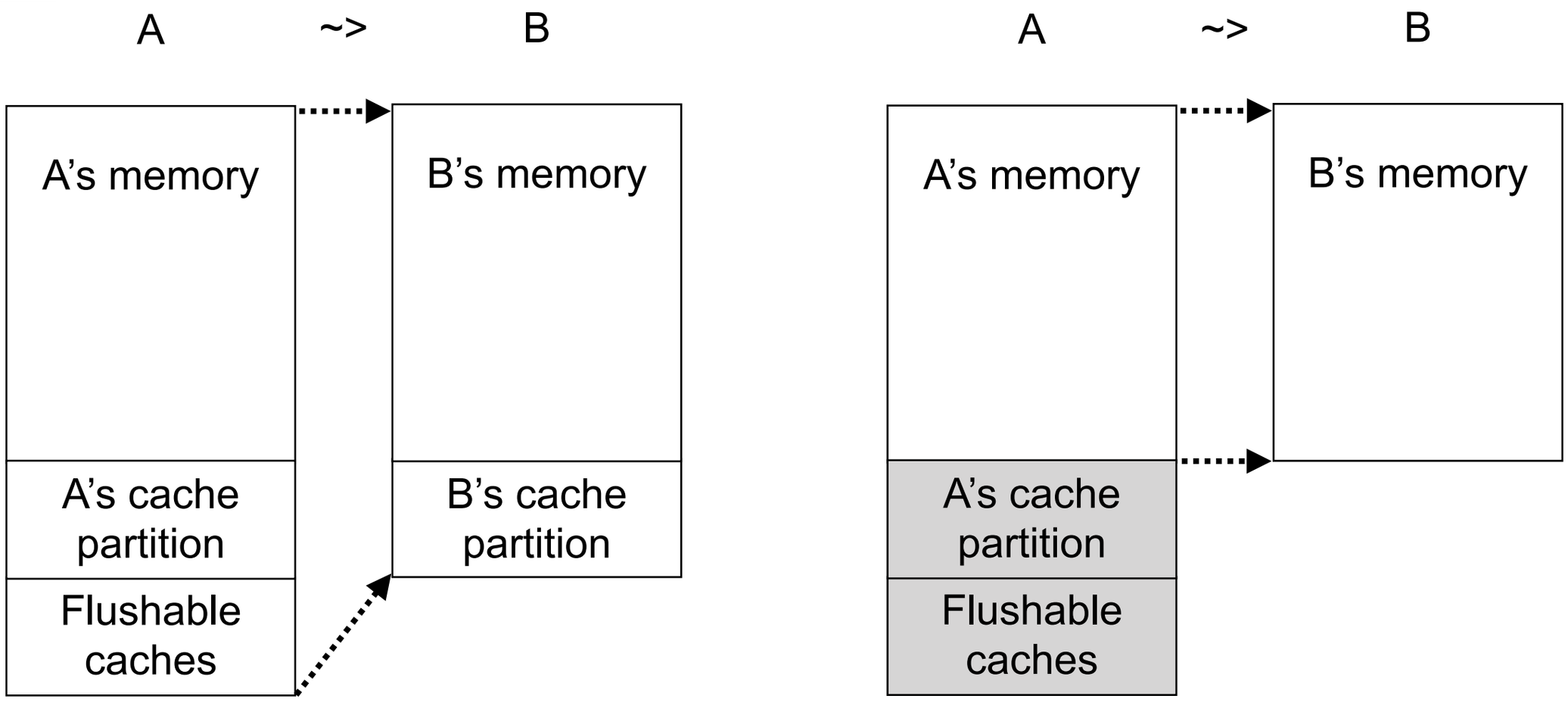
# OS security property



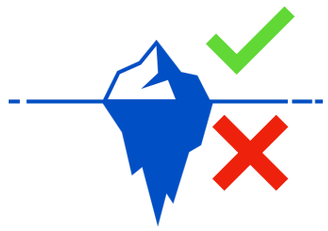
Recall:



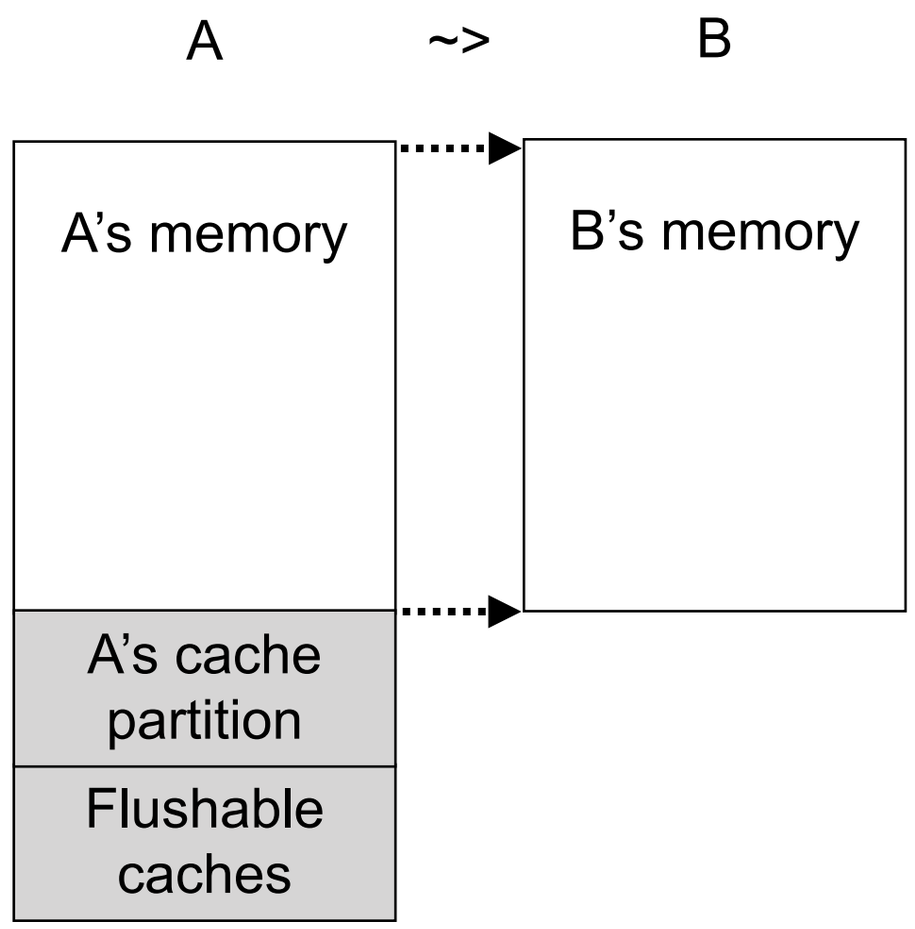

From prior seL4 infoflow proofs [Murray et al. 2012, 2013]:
*"all or nothing" policies*

**For time protection, need *spatial precision* to *allow some flows* but *exclude others***

# OS security property



Our infoflow policies:

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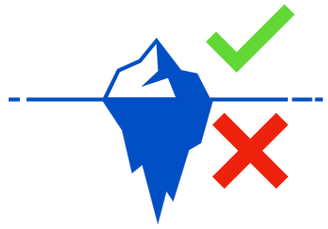
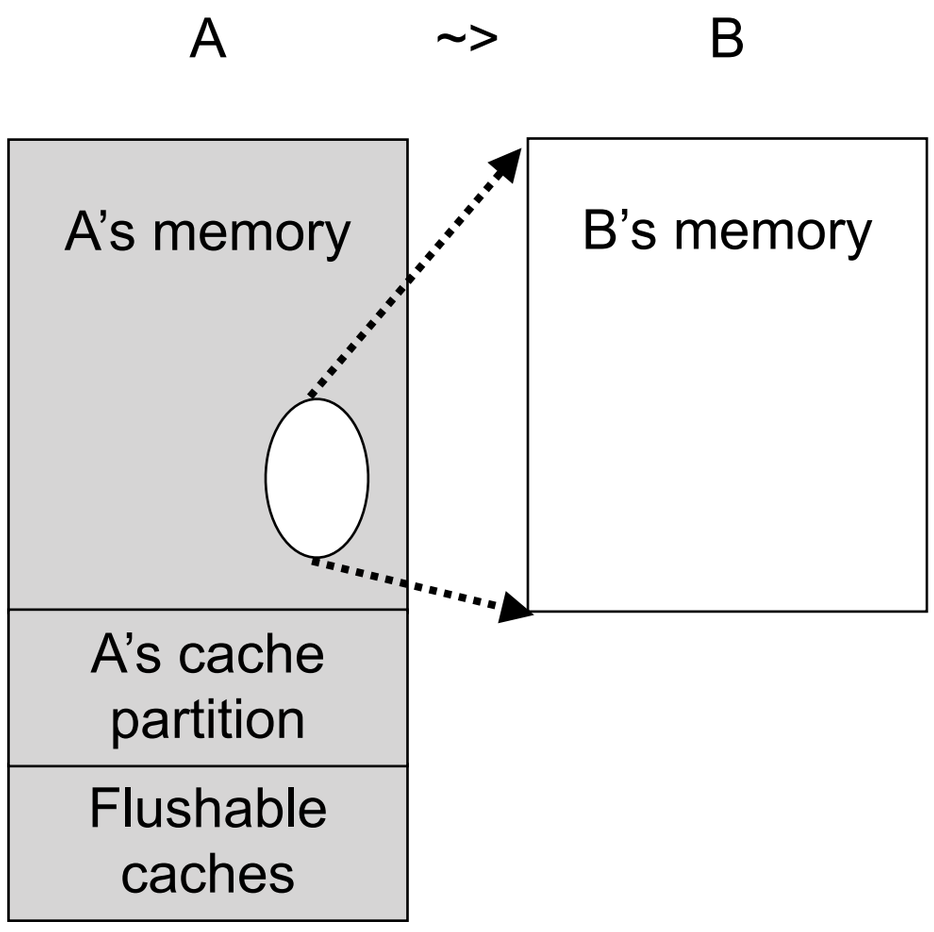
# OS security property



Our infoflow policies:

- *Arbitrary* spatial precision

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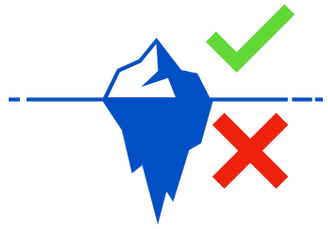
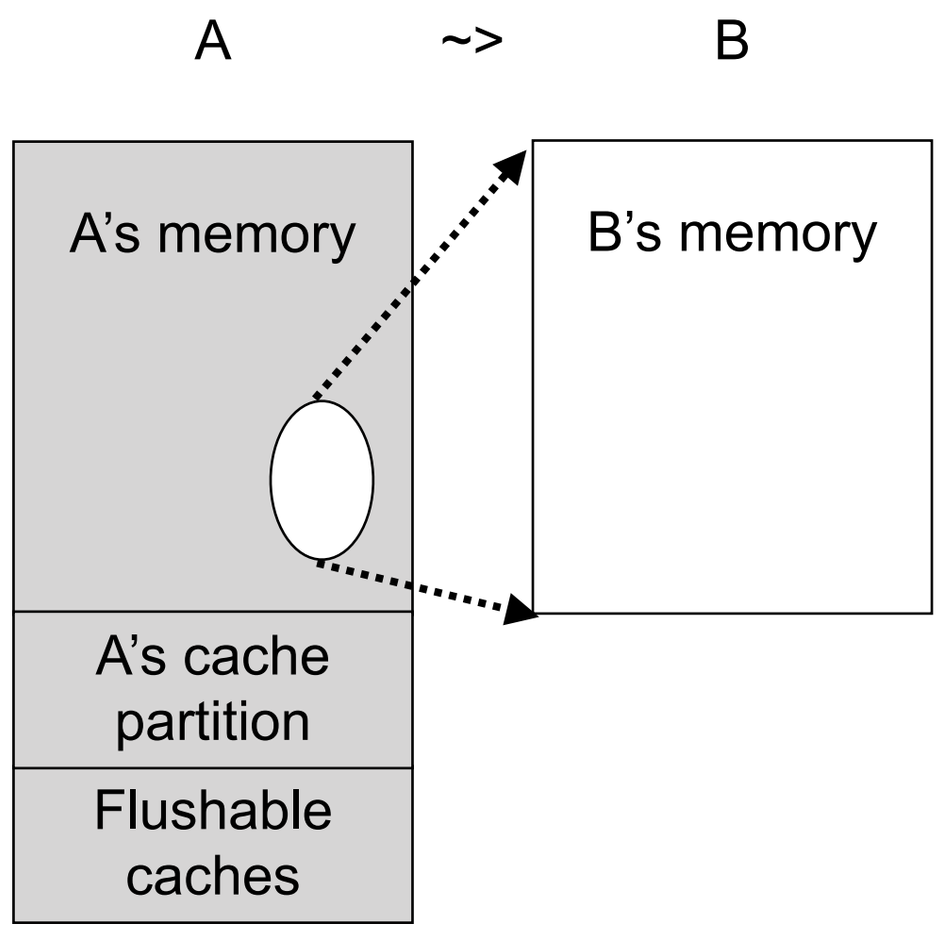


Our infoflow policies:

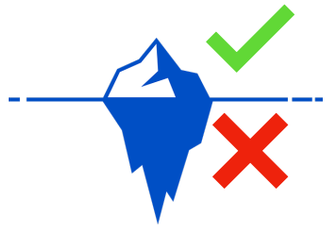
- *Arbitrary* spatial precision
- *Policy channels* specified as *state relations*: $_s\ ^{|A \underset{\sim}{\rightsquigarrow} B|}\ _t$

  If $^{|A \underset{\sim}{\rightsquigarrow} B|}$ equates part of A, then info flow is allowed from there to B.




**For time protection, need *spatial precision* to *allow some flows* but *exclude others***

# OS security property



Our infoflow policies:

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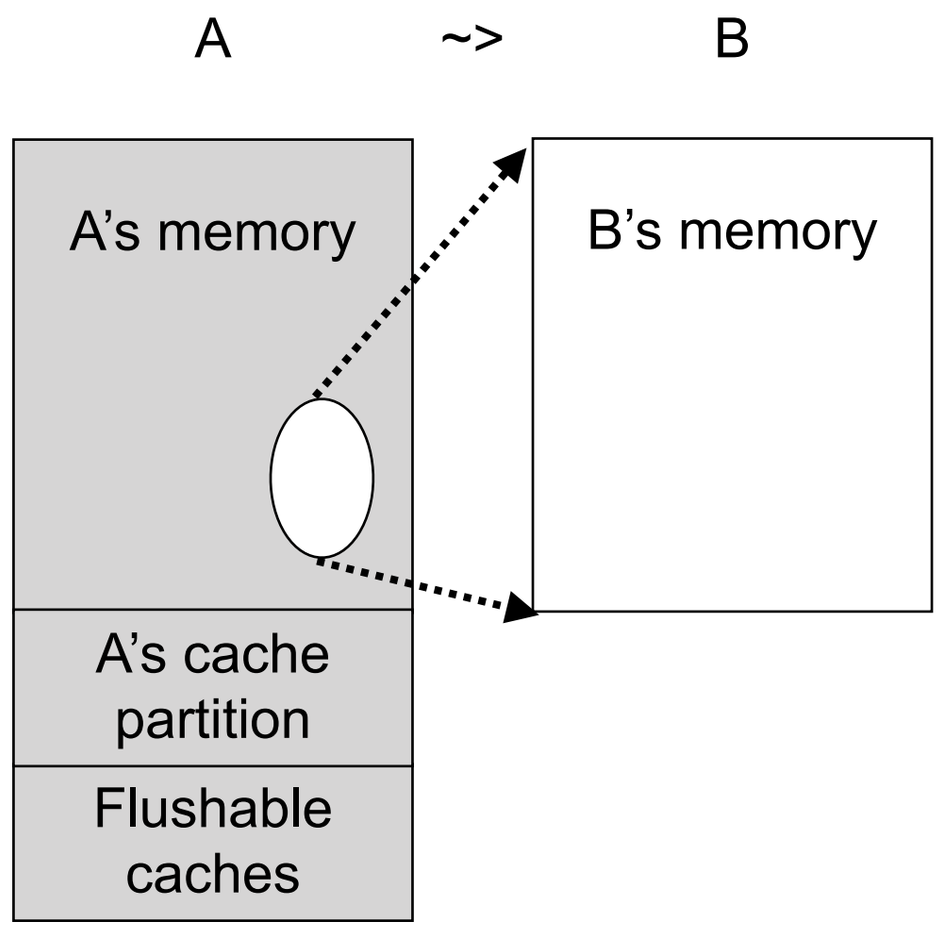
- Also arbitrary *temporal precision*

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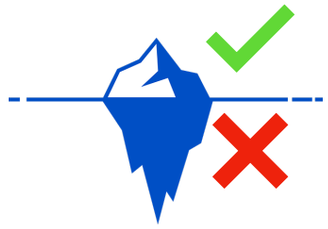

Our infoflow policies:

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- *Policy channels* specified as *state relations*: $_s\ ^{|A \underset{\sim}{\rightsquigarrow} B|}\ _t$

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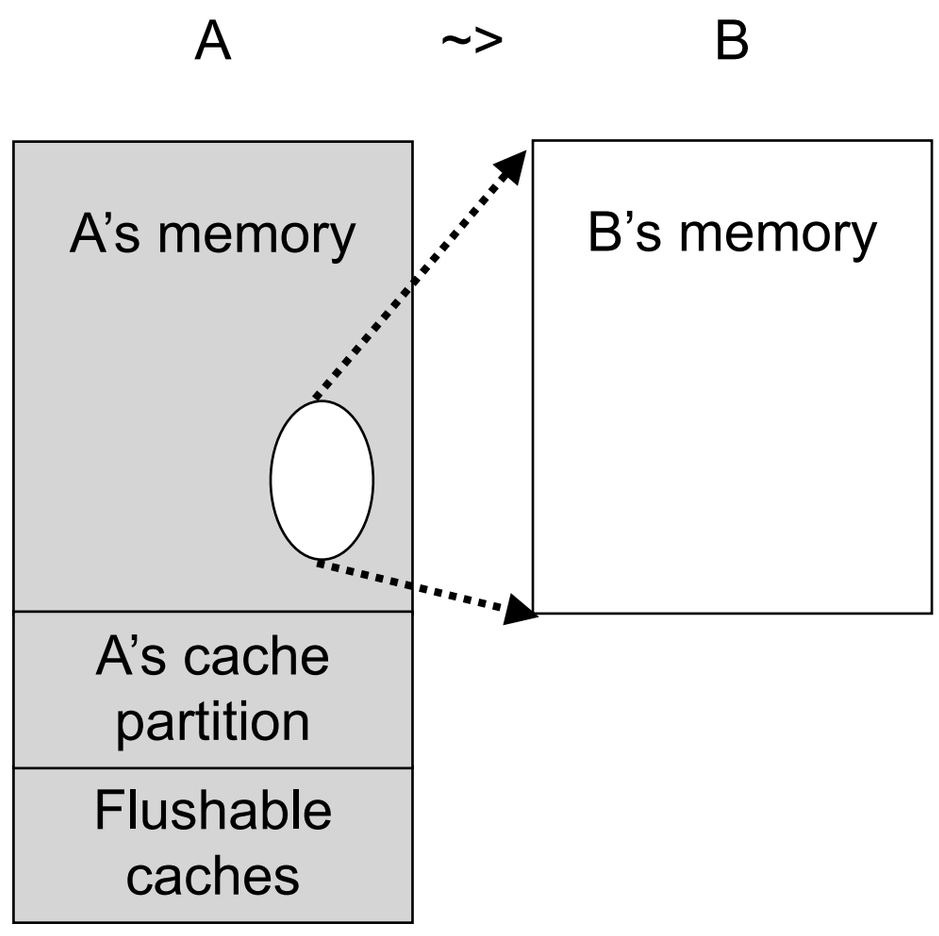


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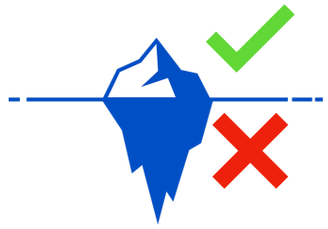

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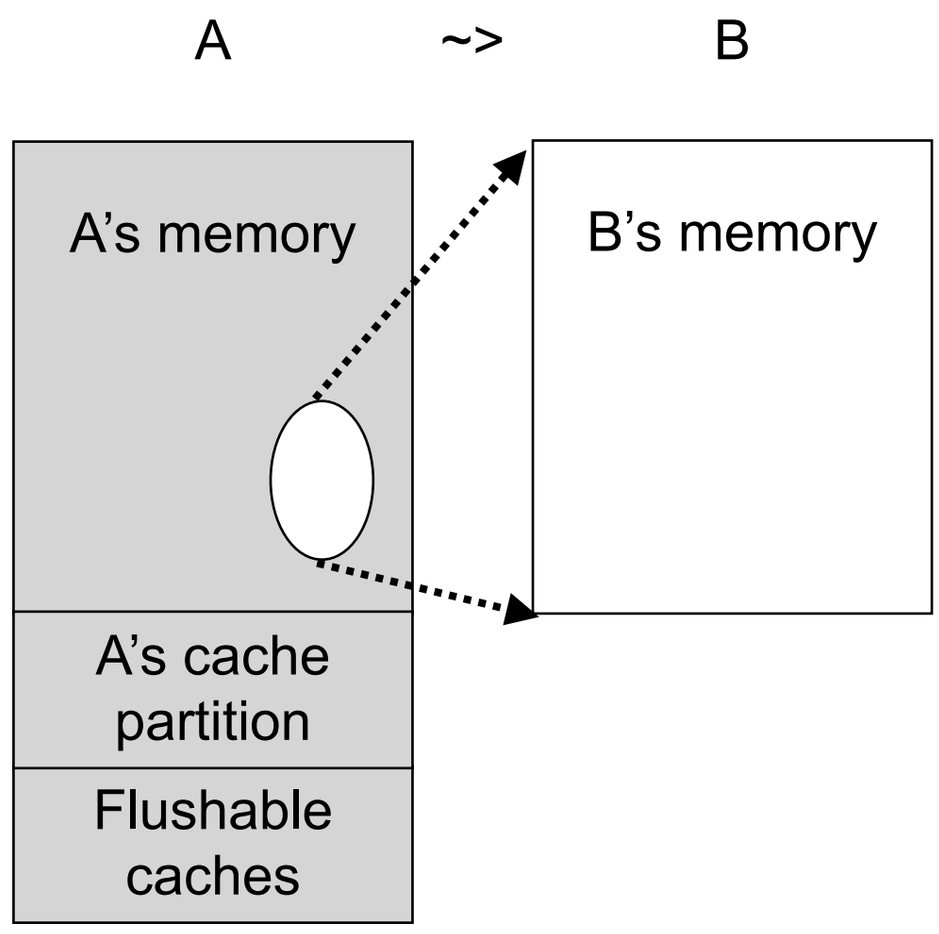


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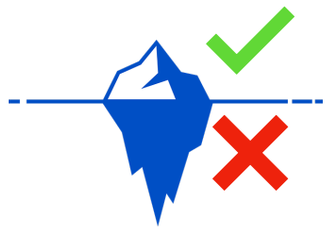

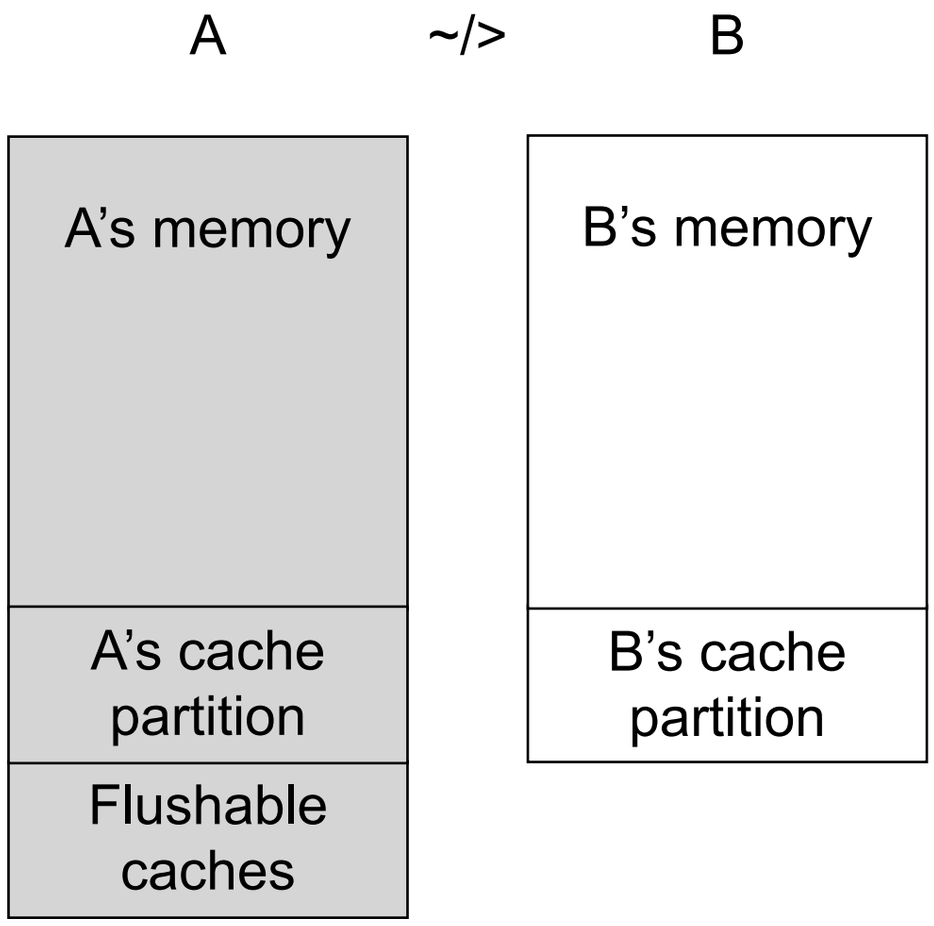

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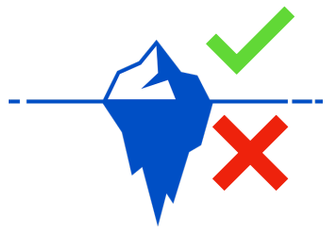

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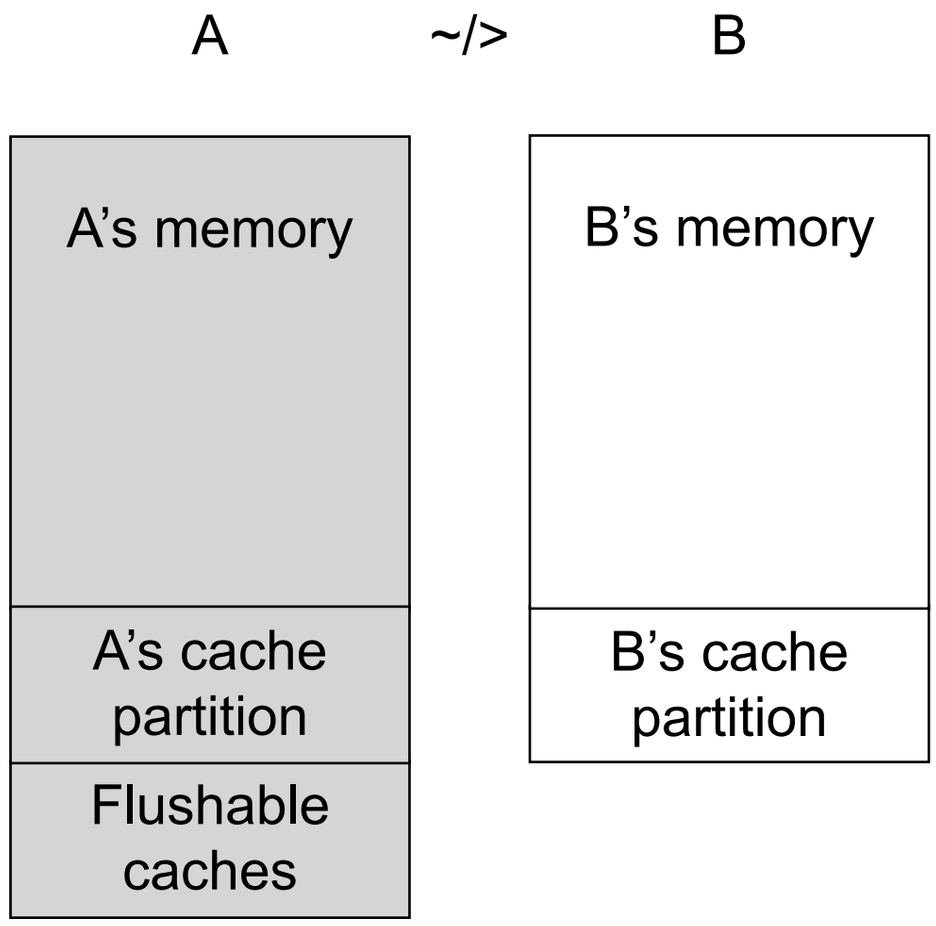

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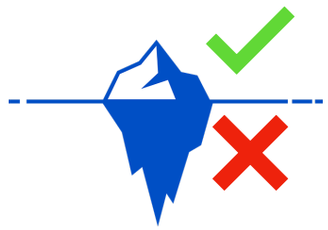

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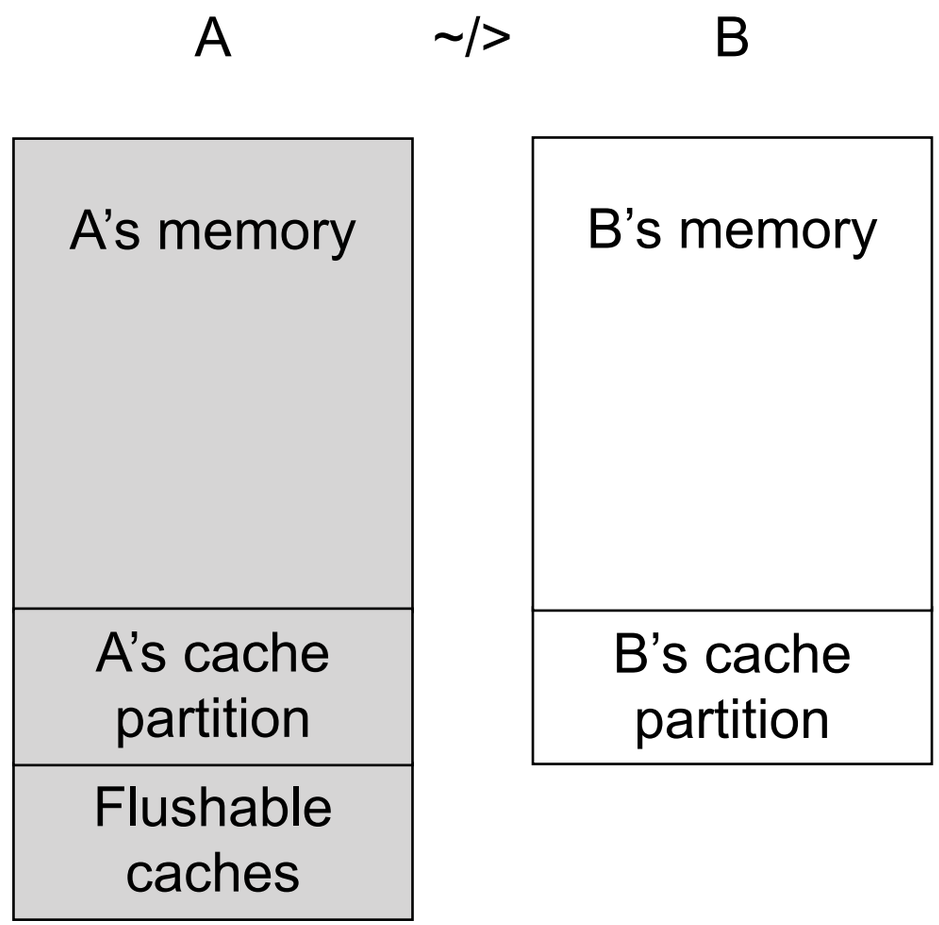

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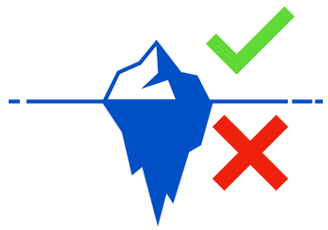

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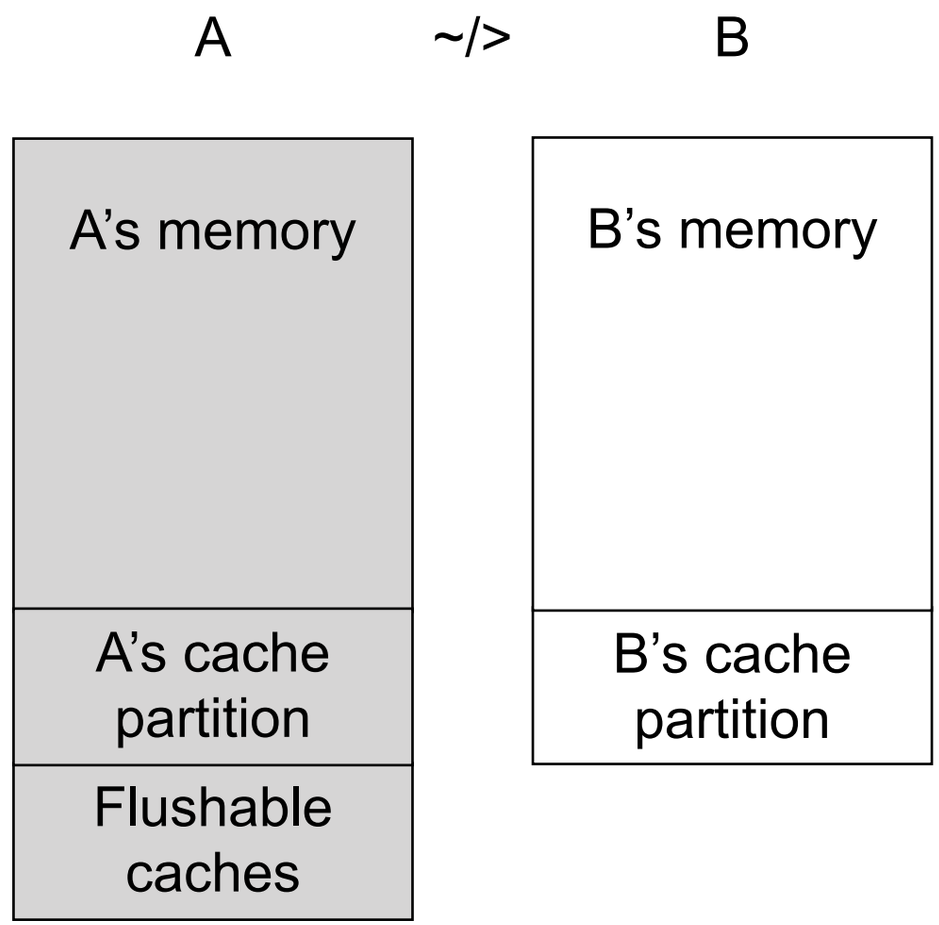

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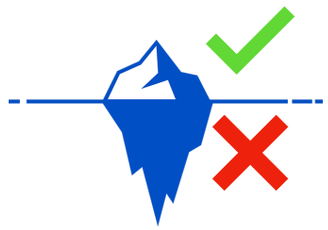

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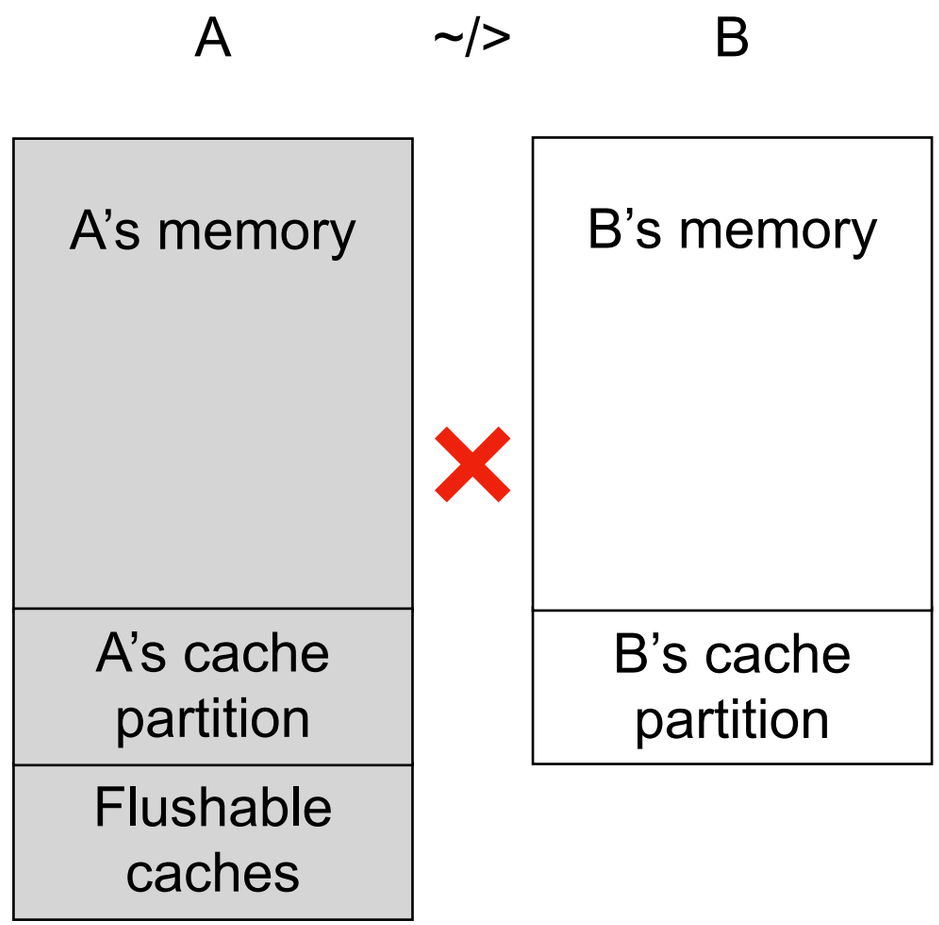

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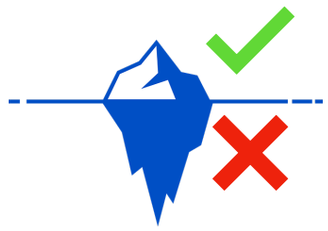

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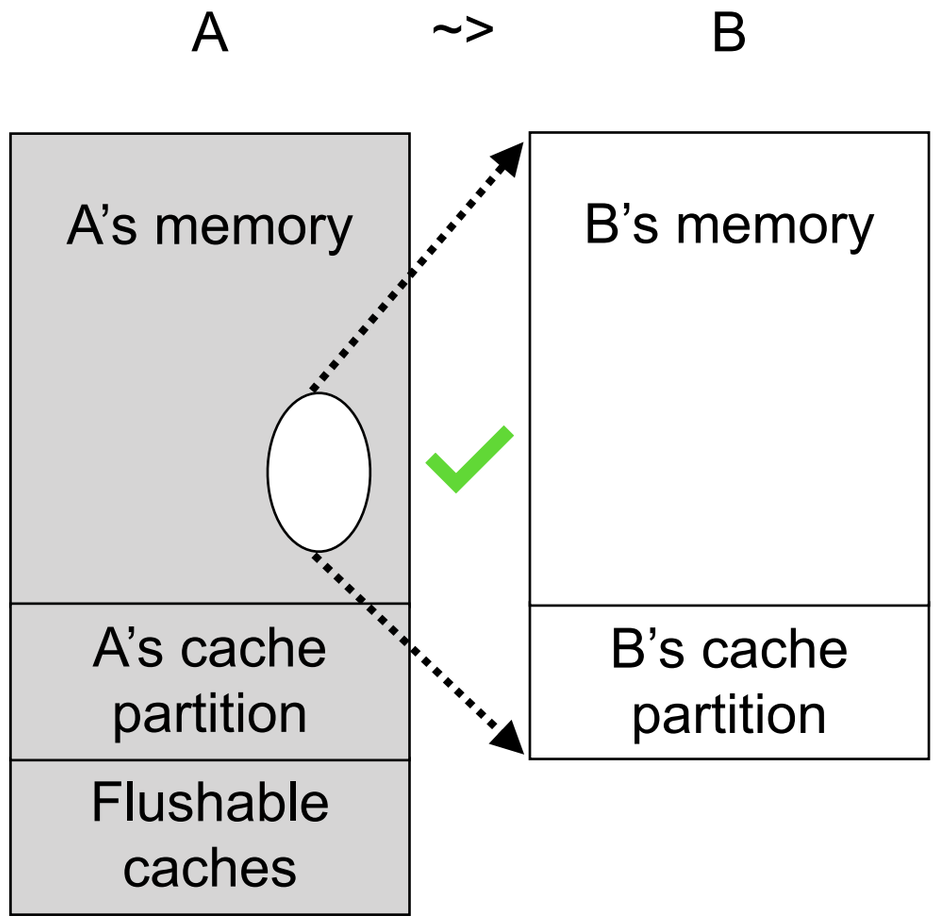

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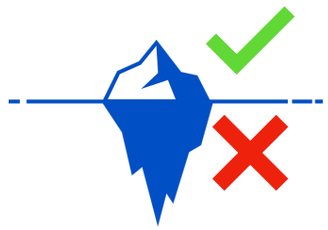

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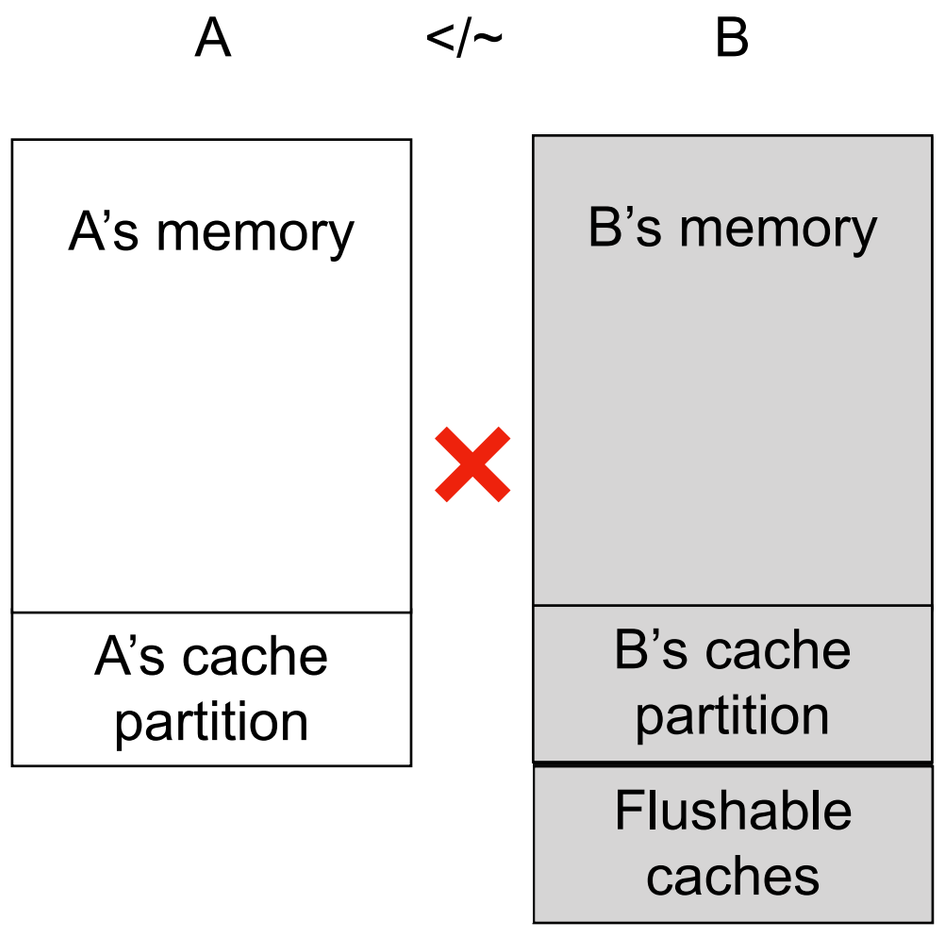


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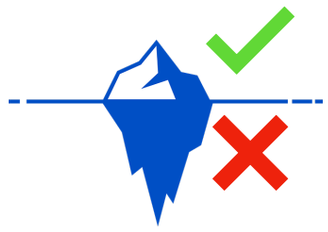

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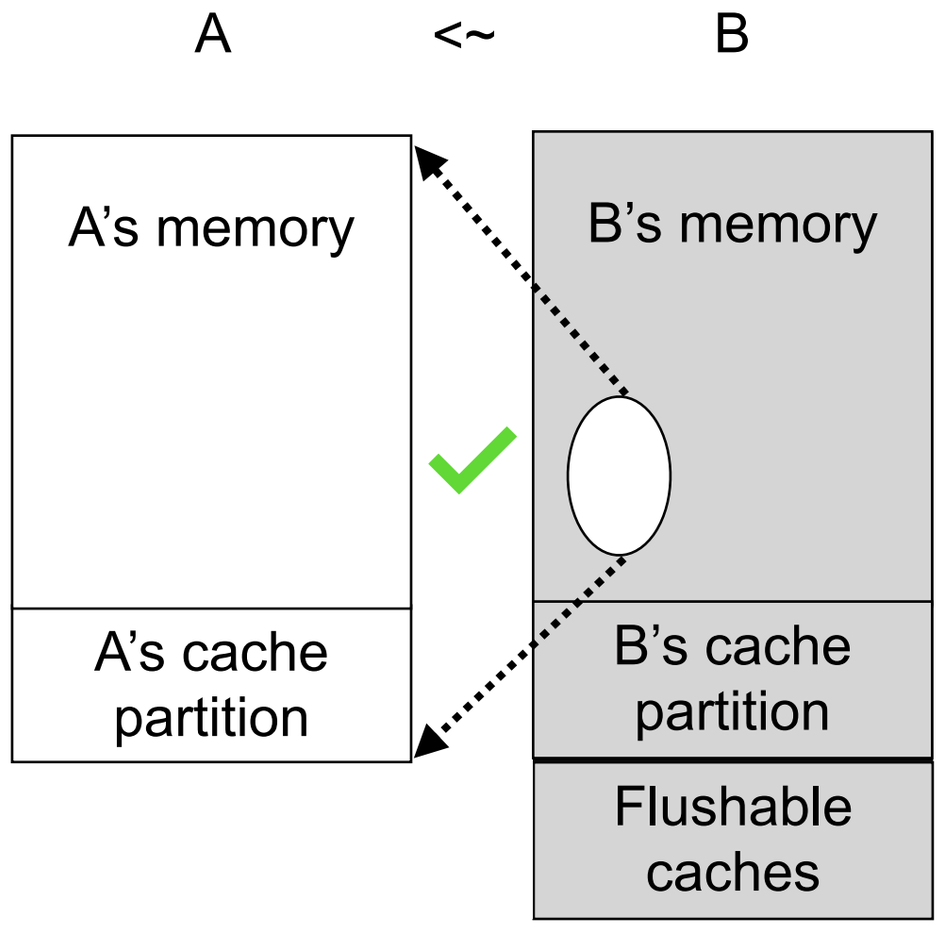


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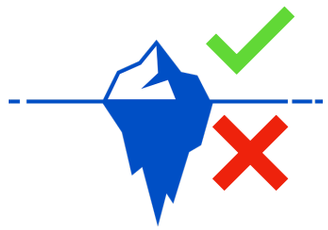

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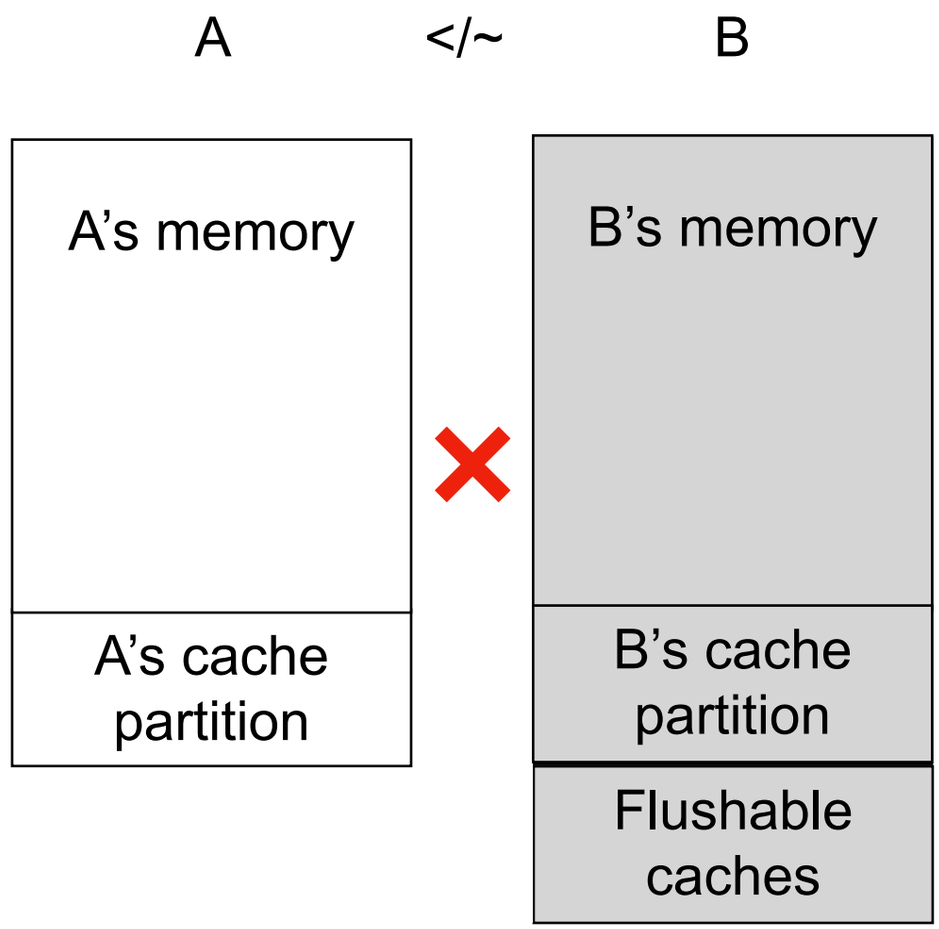


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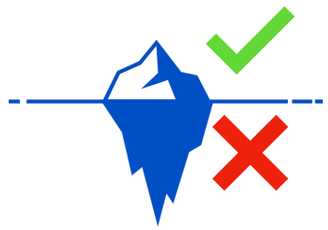

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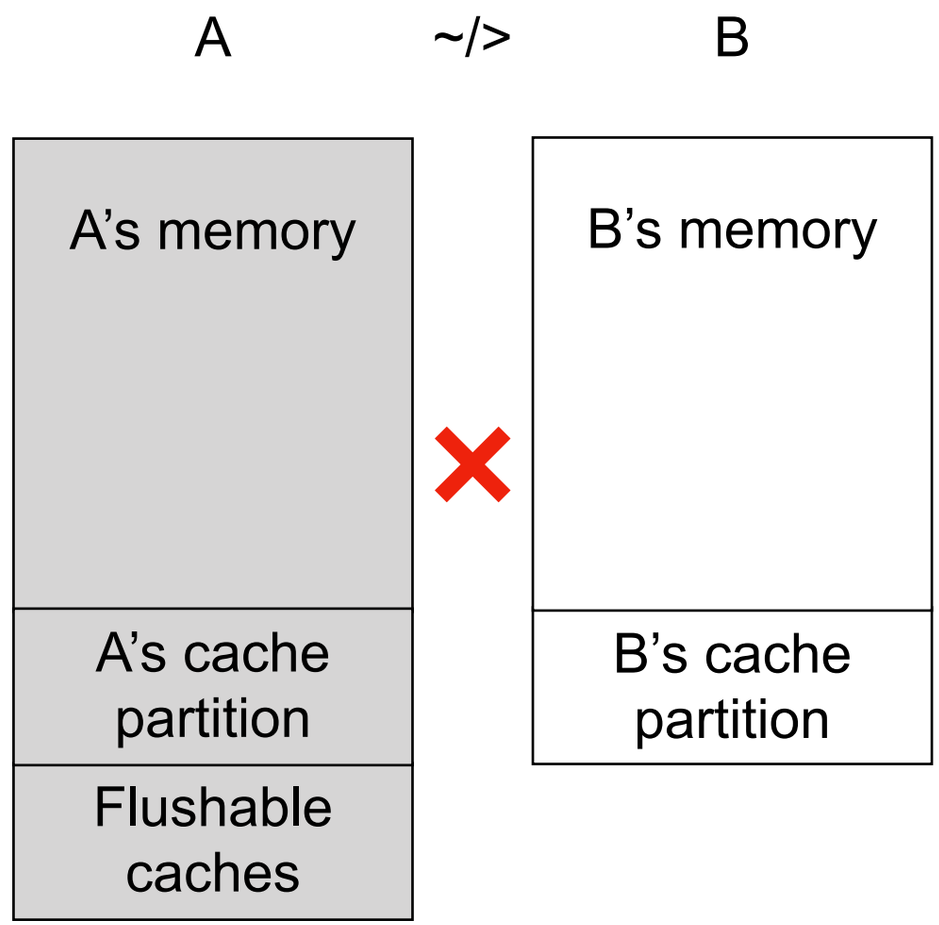


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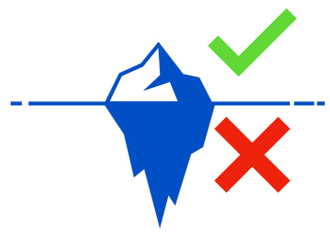

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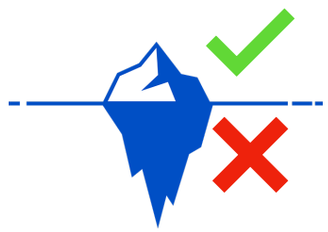

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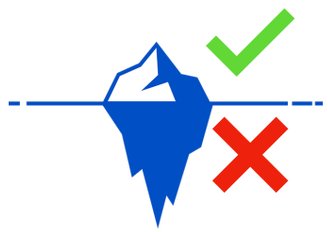

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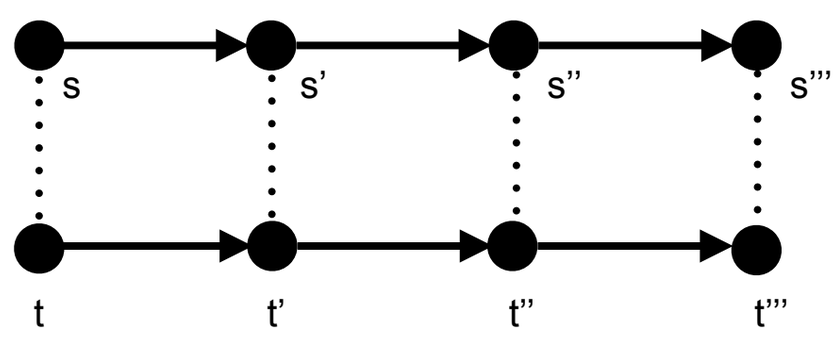


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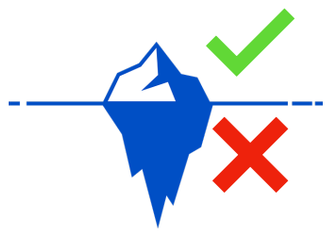

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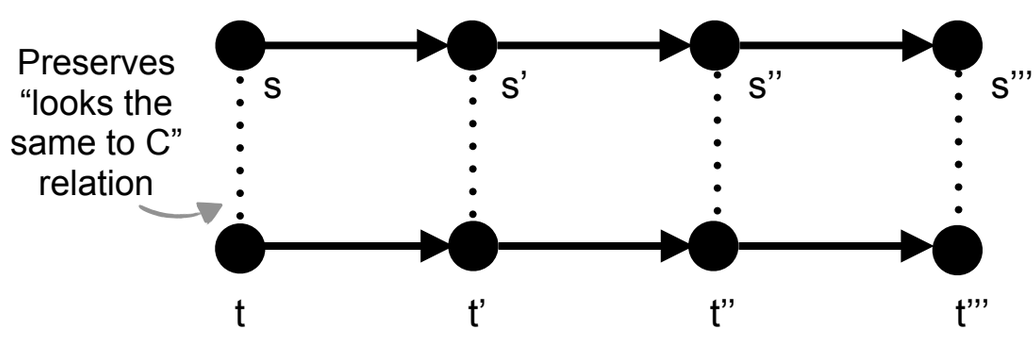


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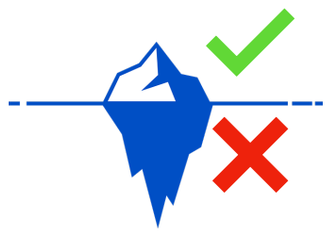

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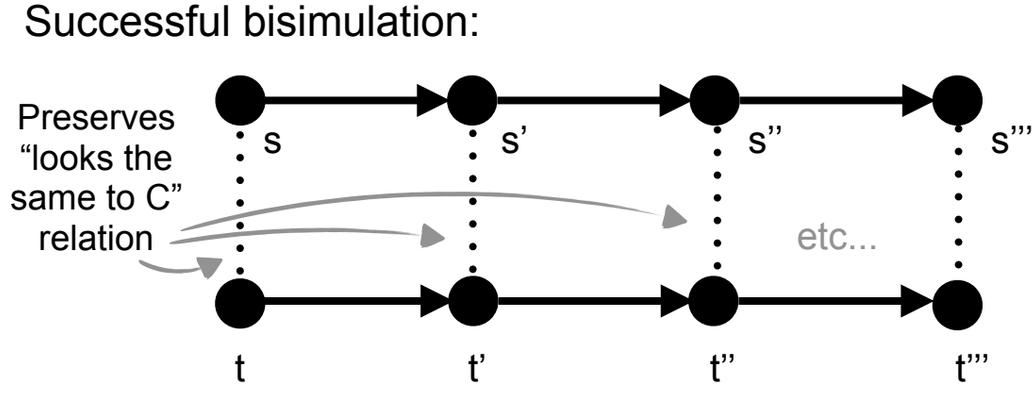


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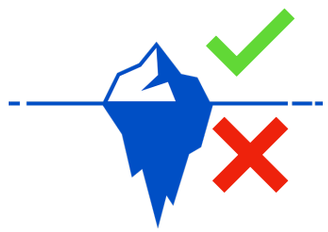

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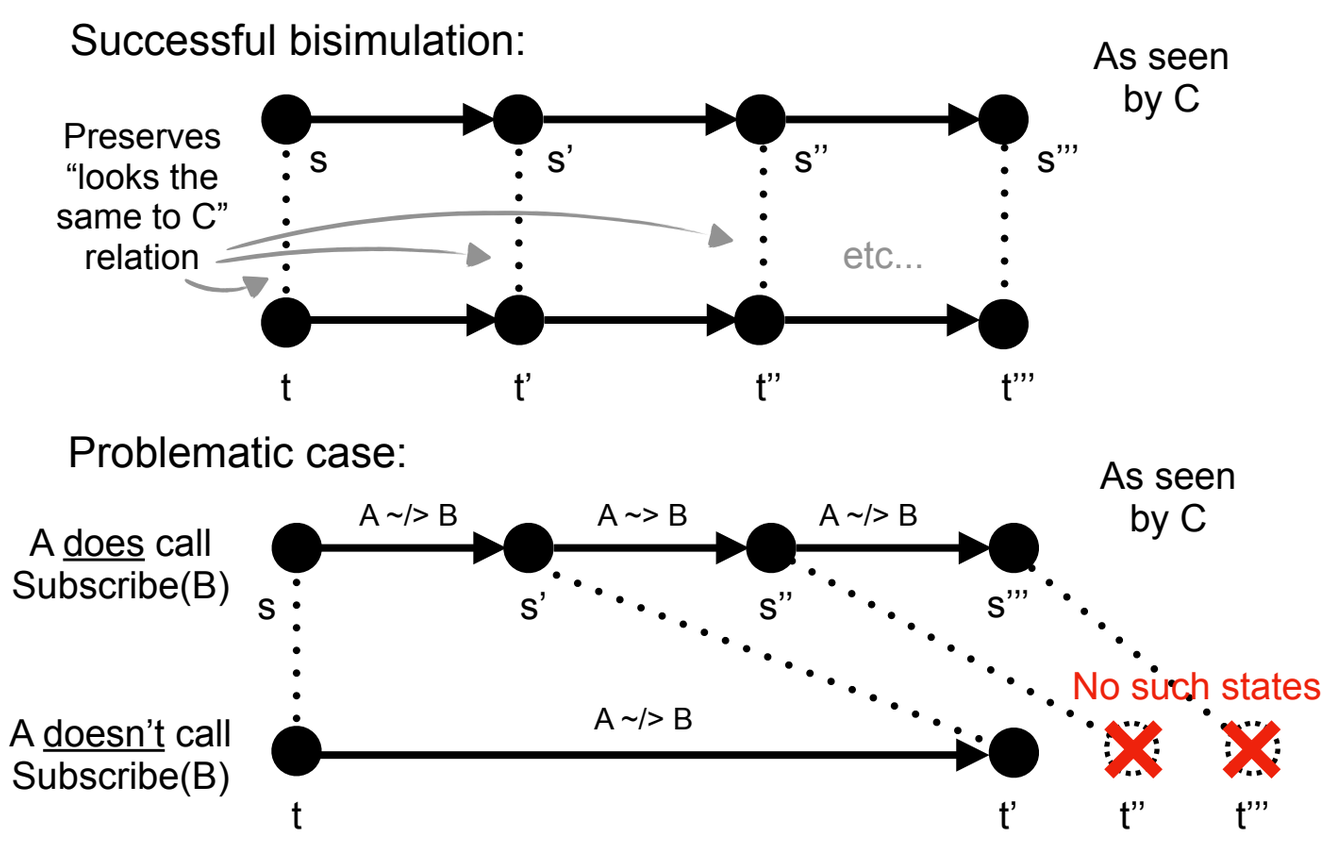

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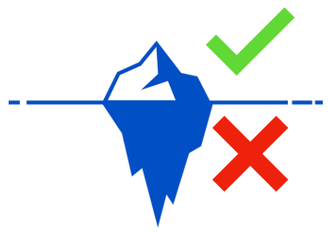

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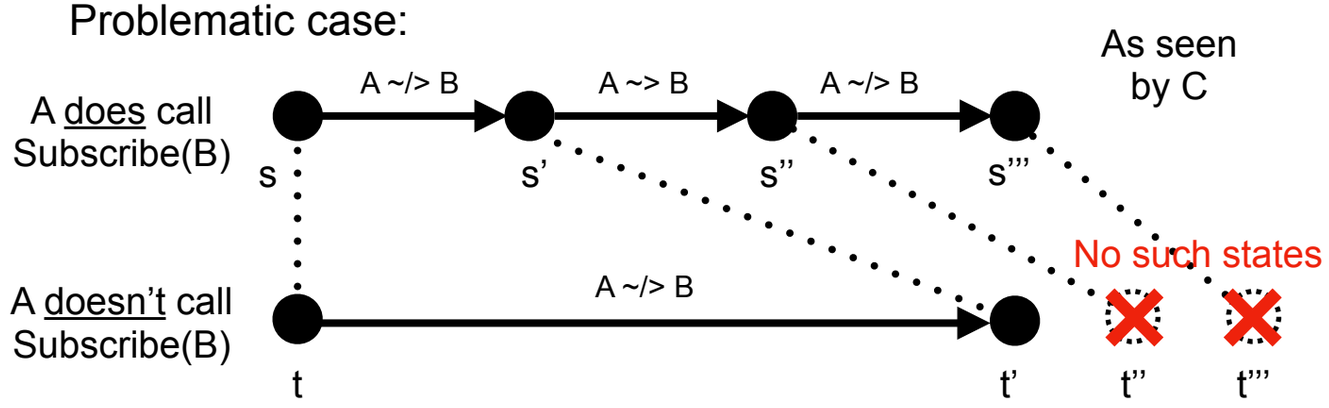
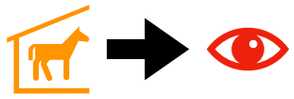



- *Solution*: C's property must treat *states* (in the state machine) as observable only whenever
  - C is running, or
  - When *d* is running, *d* ~> C.

# How to formalise an OS enforces *time protection*?

Versus threat scenario:
trojan and spy

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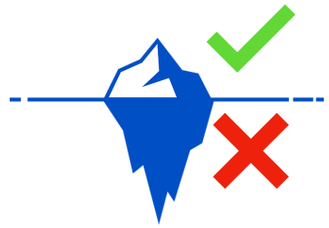
Partition or flush state; pad time.



Make security property precise enough to exclude flows from covert state.


Demonstrating these principles,
we formalised in Isabelle/HOL:

1. OS security model imposing requirements on relevant parts of OS.
(Intended for seL4, but *generic*)

2. OS security property that is dynamic; this makes it observer relative.
(Improving on seL4's of [Murray et al. 2012])

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4. Basic instantiation of OS model exercising dynamic policy.

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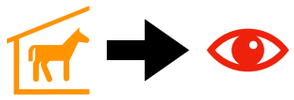


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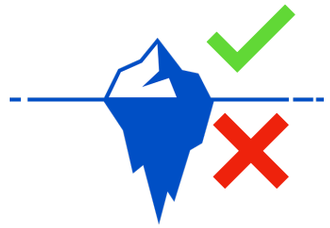

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**Thank you!**
**Q & A**


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**Paper:** https://doi.org/jzwj
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2. OS security property that is dynamic; this makes it observer relative.
(Improving on seL4's of [Murray et al. 2012])

3. Proof our security property holds if OS model's requirements hold.

4. Basic instantiation of OS model exercising dynamic policy.