State-Based Object Models Are More Abstract Than Trace-Based Models

Towards a Unified Specification Framework

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Background

- State-based specification techniques
  - Close to implementation
  - Examples: Eiffel, JML, Spec#

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- State-based specification techniques
  - Close to implementation
  - Examples: Eiffel, JML, Spec#
- Trace-based specification techniques
  - No need to think about states
  - Examples: Jass (trace assertions), Java Jr. (program equivalence)

This Talk is About ...

This talk is **not** about:

- Comparing specifications

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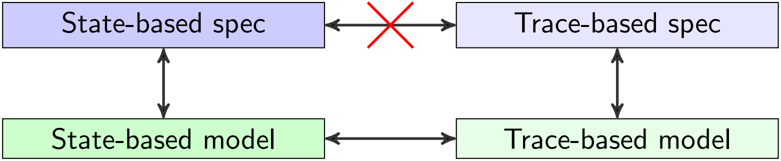

This talk is about:

- Comparing models via abstractions
- Applying simulation theory to this context

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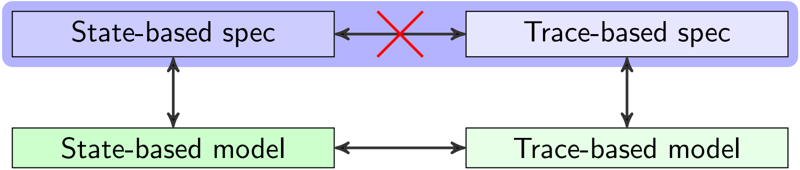

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Our settings

- Object-based component
  A set of runtime objects.
- Sequential
  All method calls must fulfill call stack property
- Deterministic
  Given a state and a particular call, a component will always produce the same behavior.

Subject-Observer Pattern [GOF]

```
interface Observer {
  void notify(State s);
}

class Subject {
  Observer o1, o2;

  Subject(Observer o1, Observer o2) {
    this.o1 = o1; this.o2 = o2;
  }

  void update(State s) {
    o1.notify(s);
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$o1 \neq o2 \neq$ **null**

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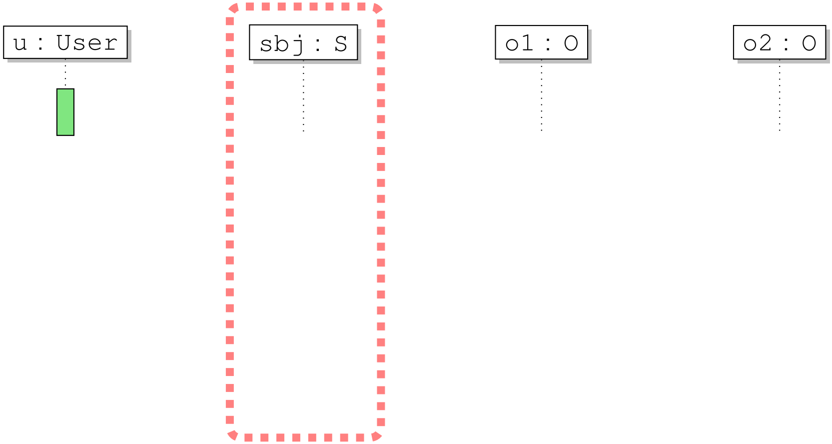
Subject Component Behavior



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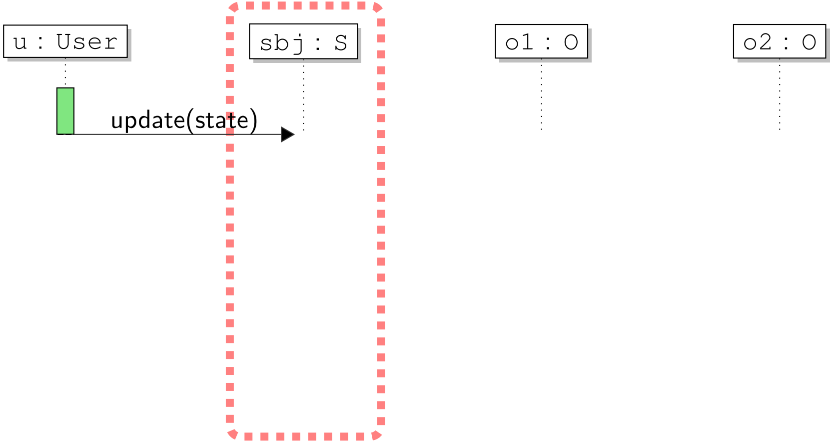

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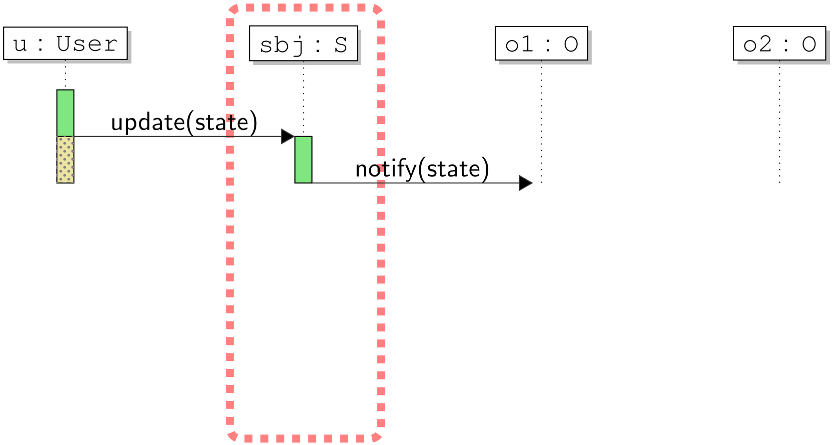

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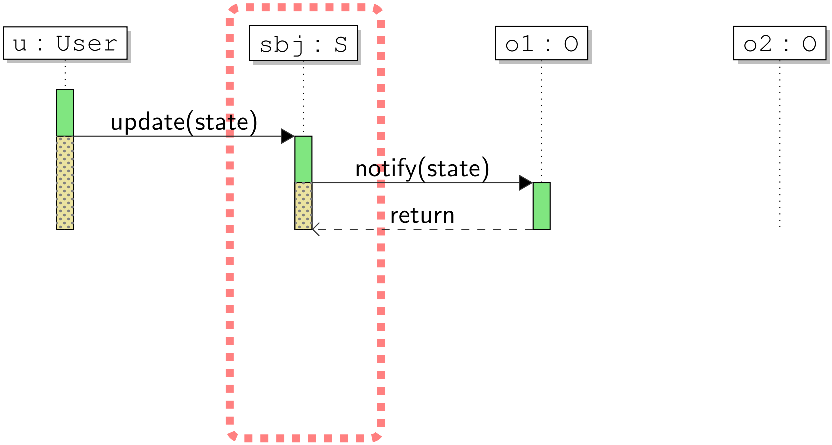

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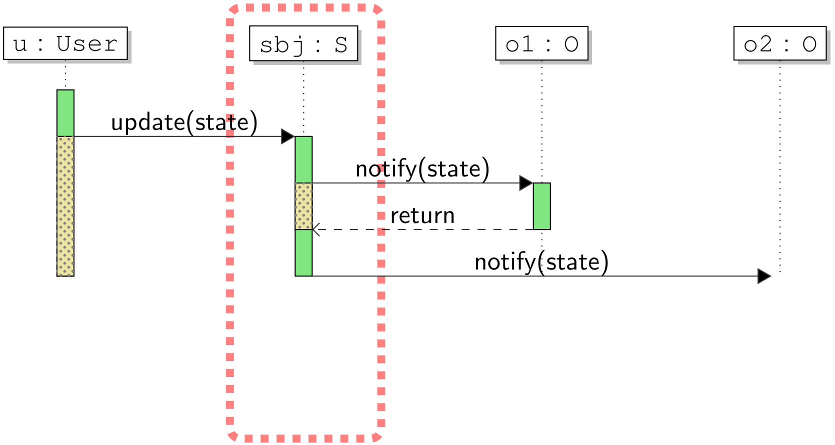

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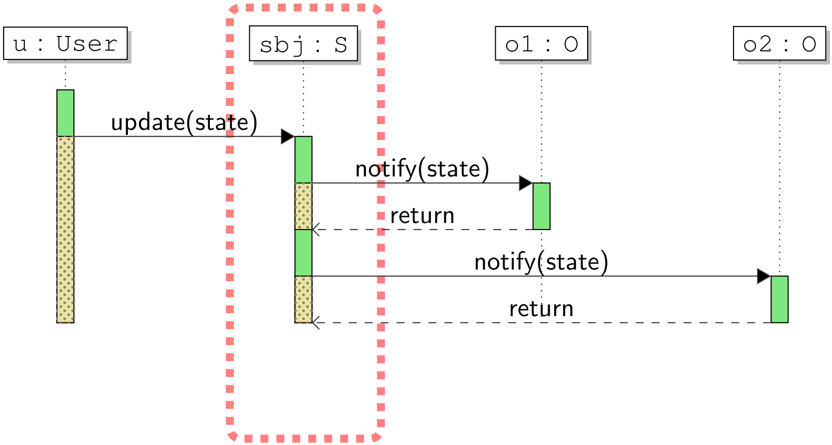

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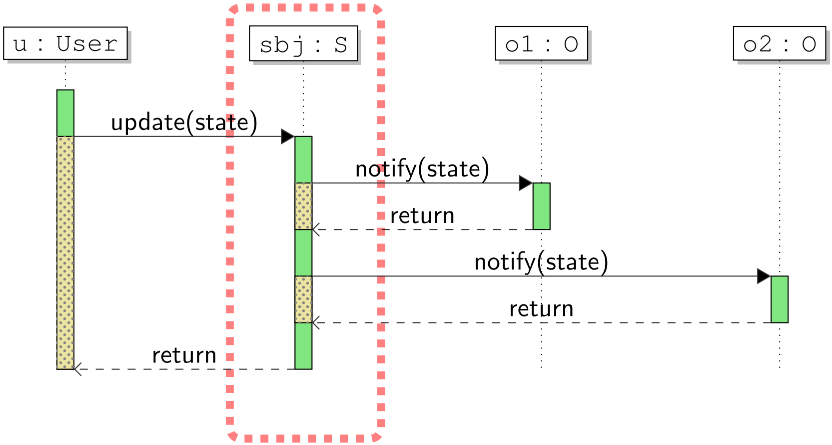

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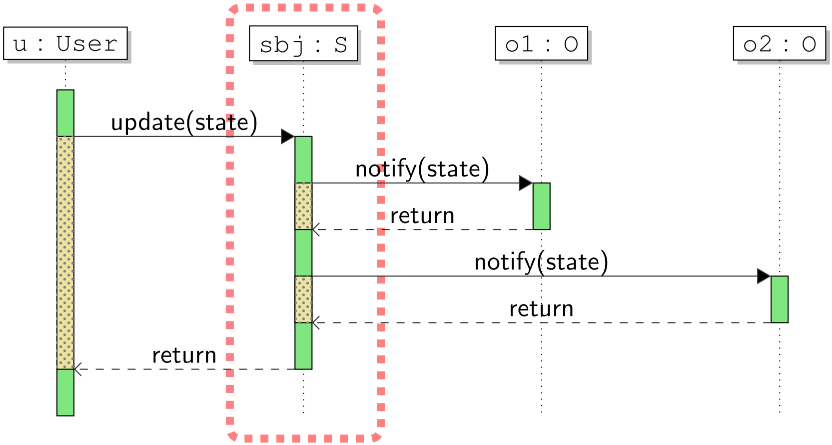

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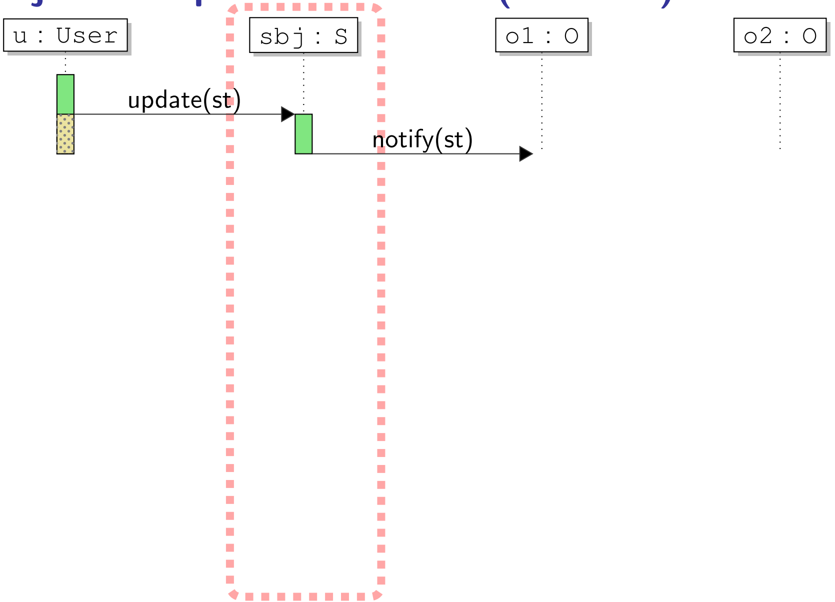

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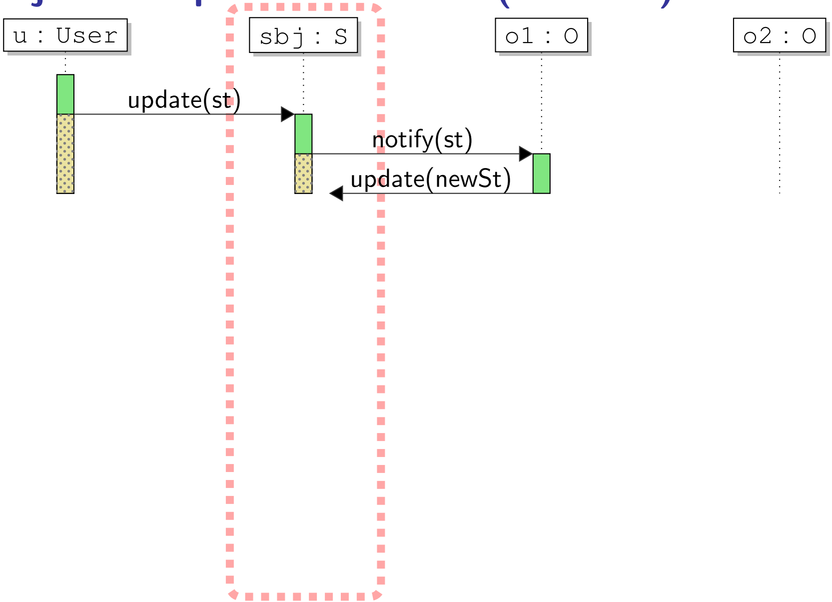

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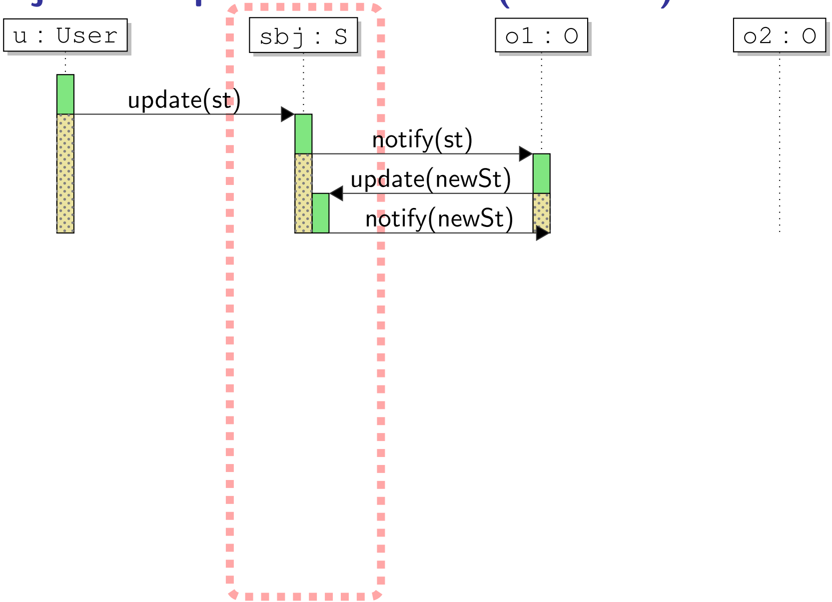

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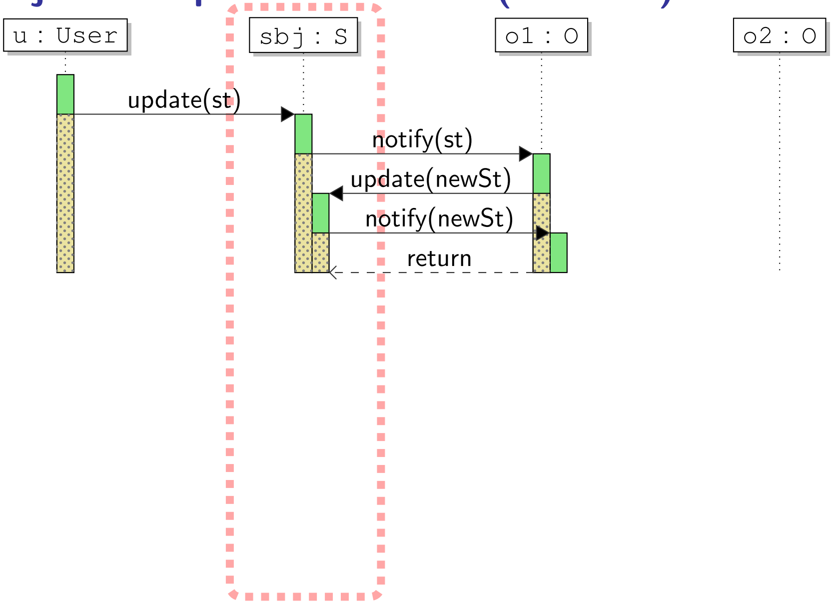

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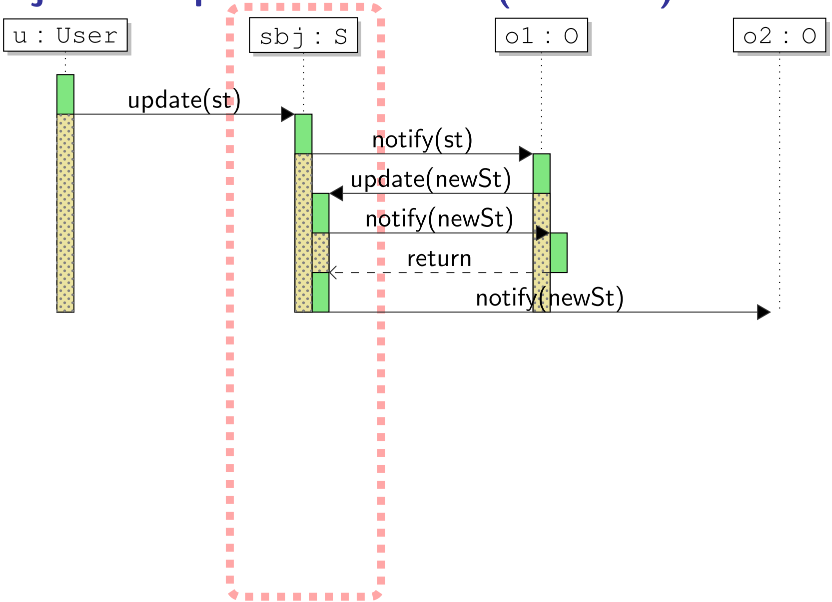

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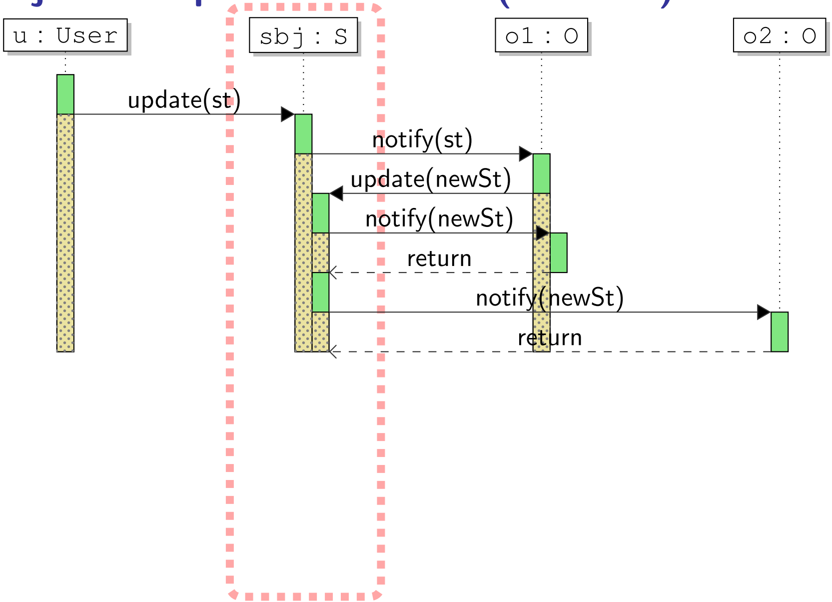

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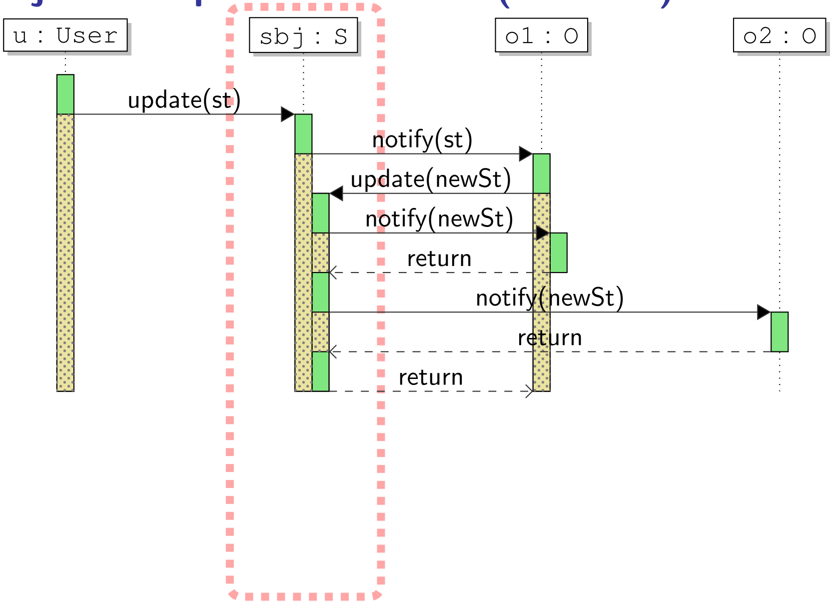

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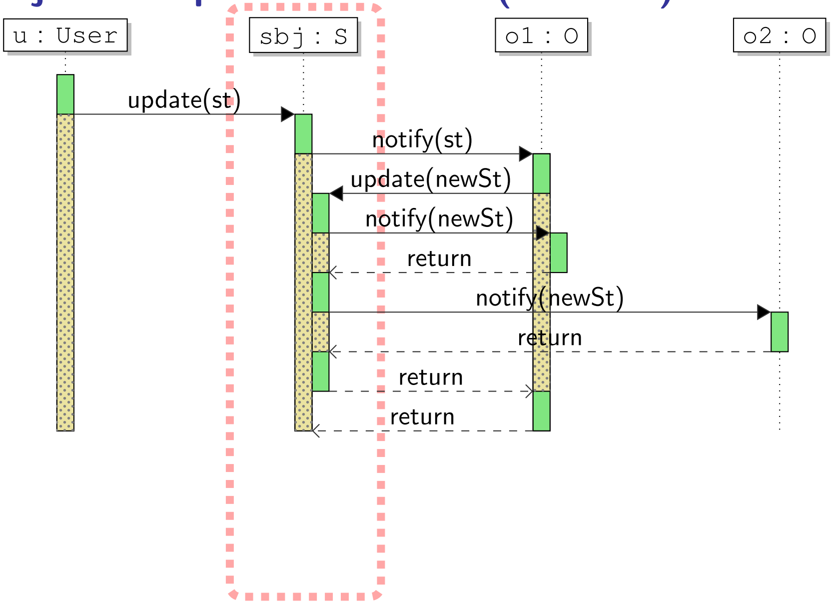

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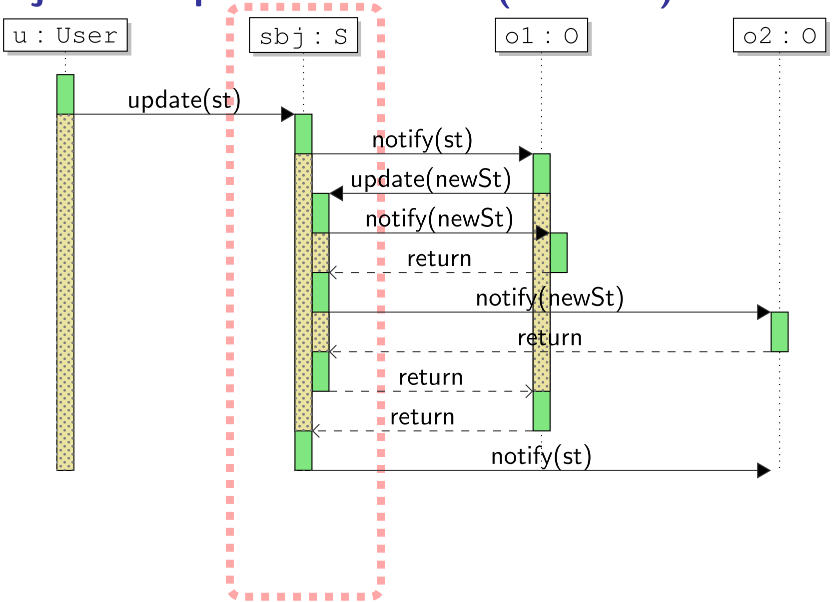

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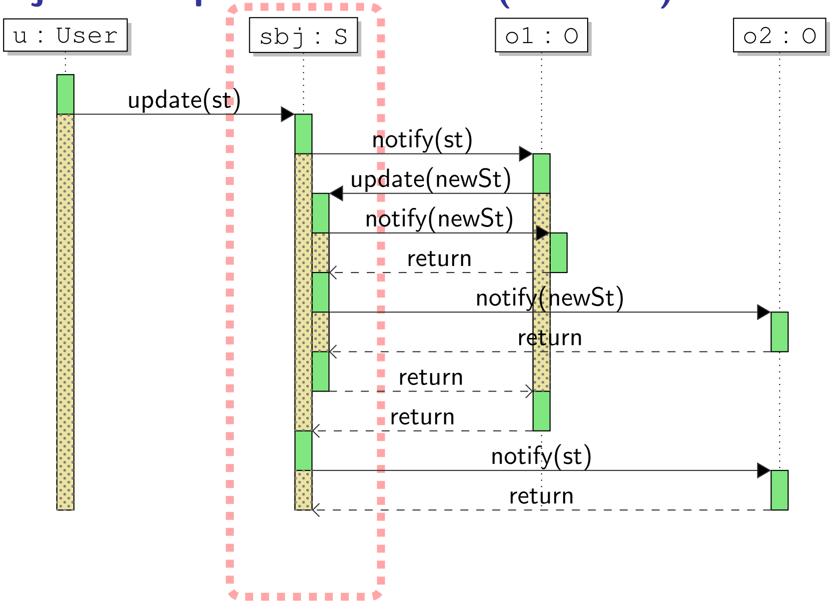

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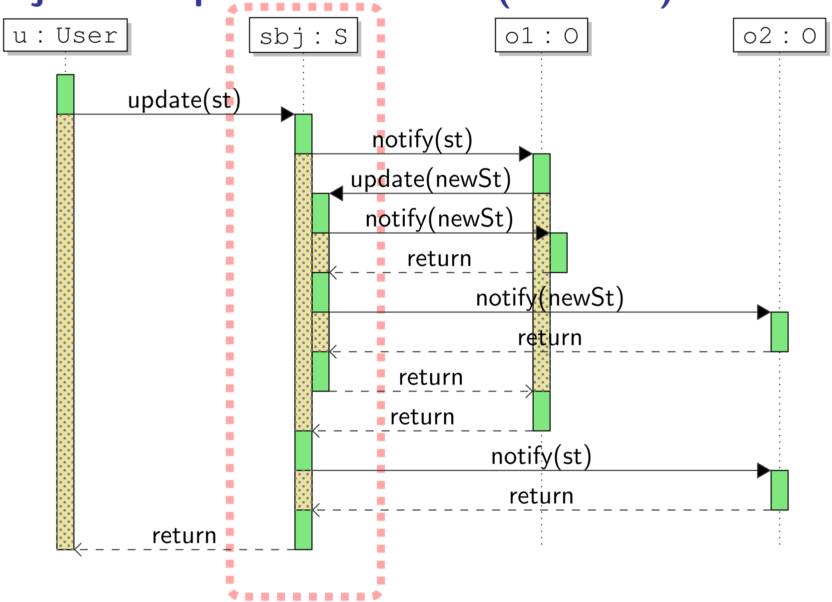

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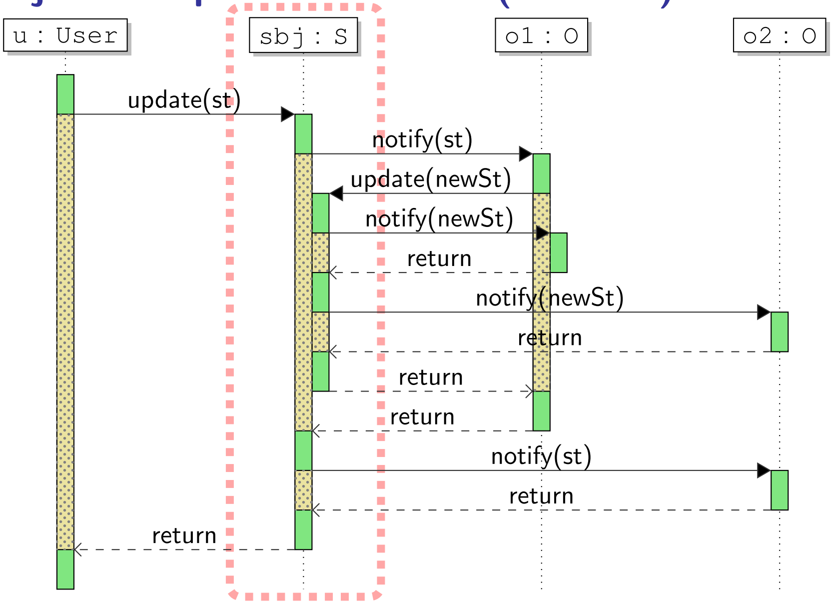

Model ingredients

- Object universe:

$$O = \{sbj, o_1, o_2, st_1, st_2, st_3, \ldots\}$$

- A component = a set of objects (subset of O)

$$C = \{sbj\}$$

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- A set of messages.

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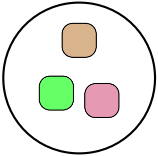

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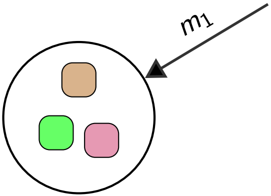

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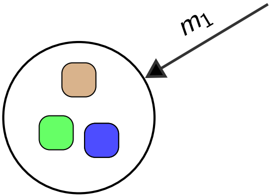

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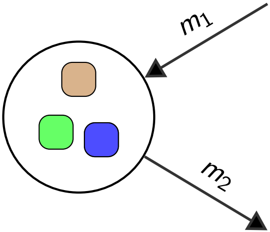

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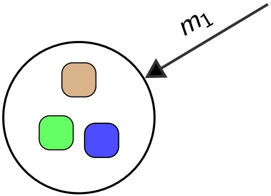

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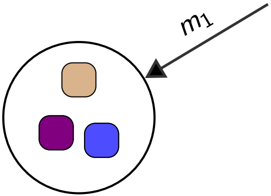

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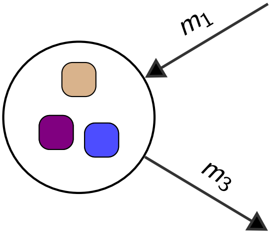

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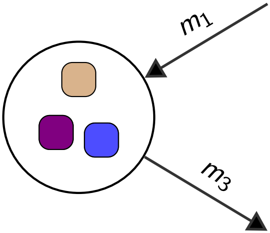
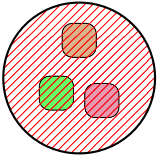


State-Based Models

Transition system of (abstract) states

$$\mathcal{M}(Msg, O) = \langle S, \Theta, s_0 \rangle$$

Model Representation



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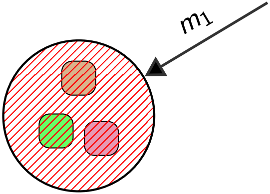
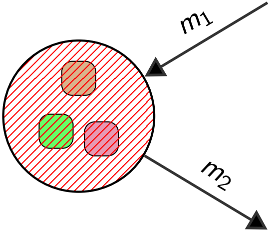


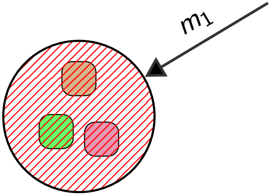
$t =$

Model Representation



$$t = (m_1, m_2)$$

Model Representation



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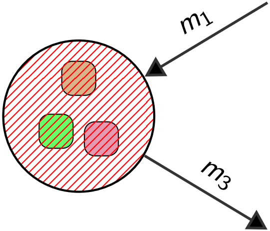

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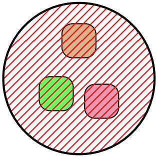

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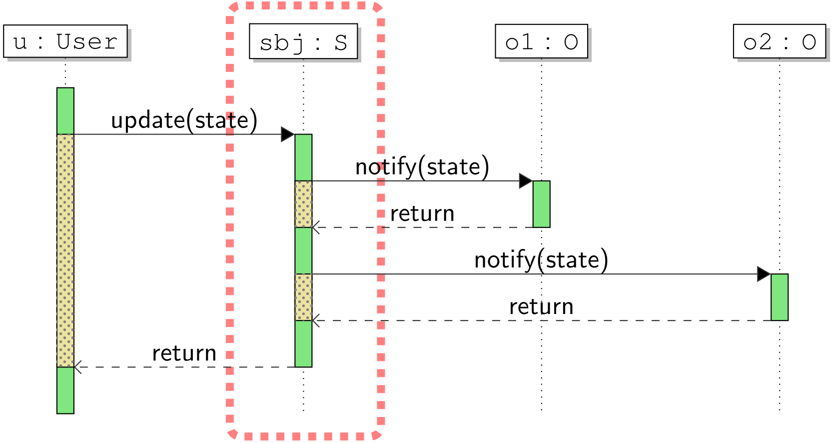
Trace-Based Models

A trace-based model = a set of traces

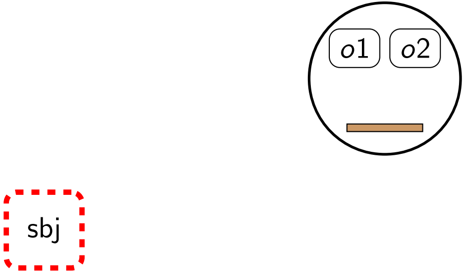
$$\mathcal{T}(Msg, O) = Traces(O)$$

A trace is a sequence of pairs of messages

Subject Component Behavior



Subject Component State-Based Model



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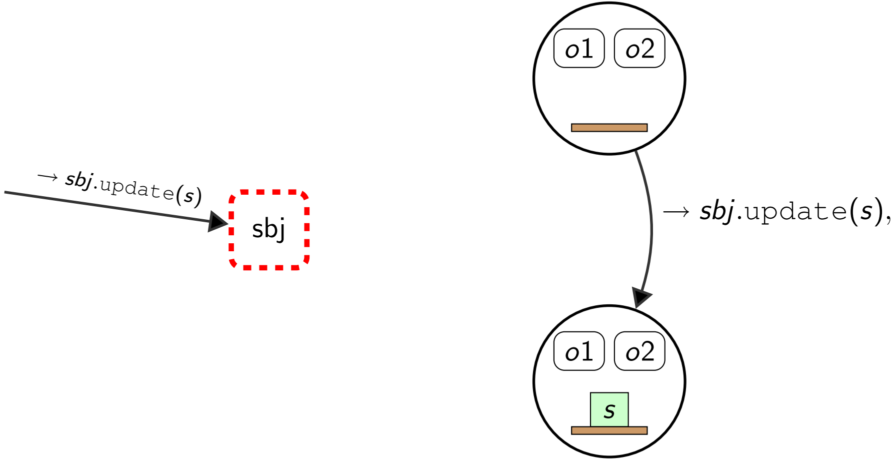

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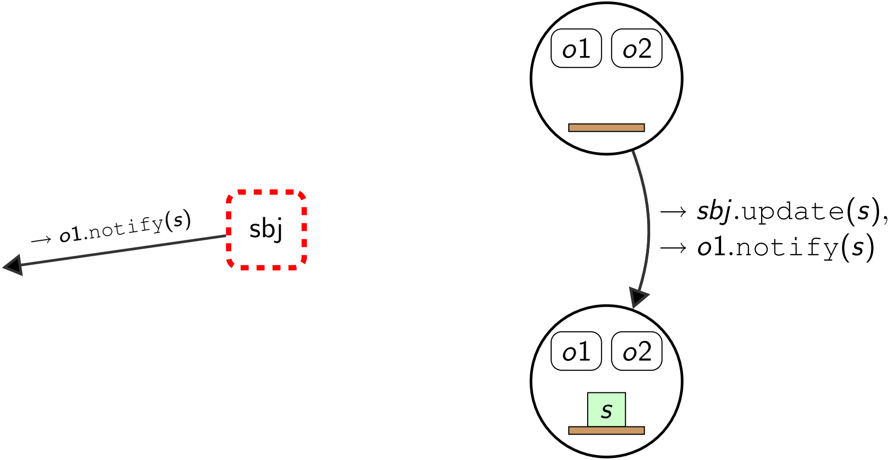

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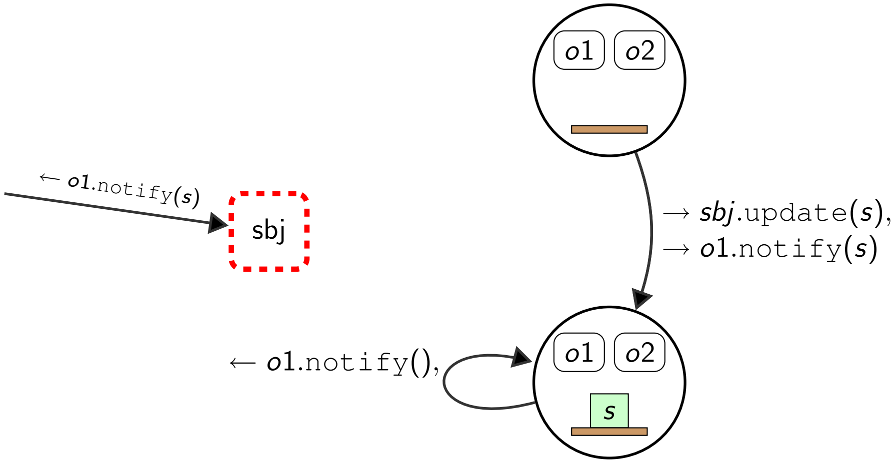

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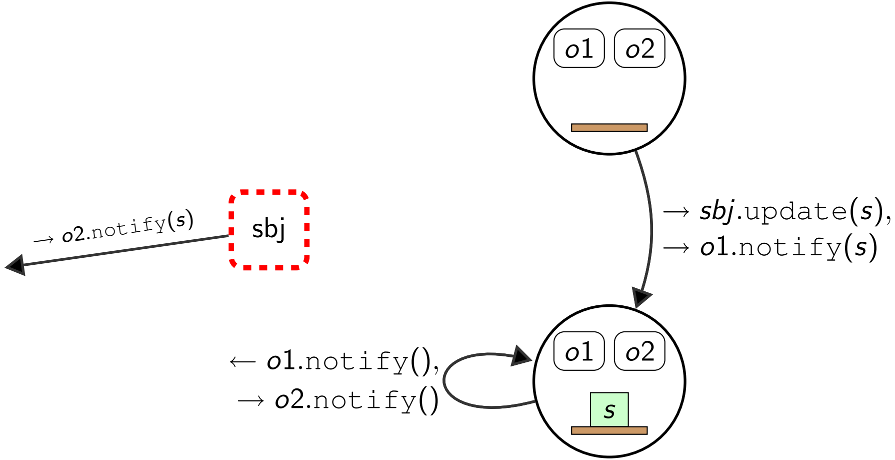

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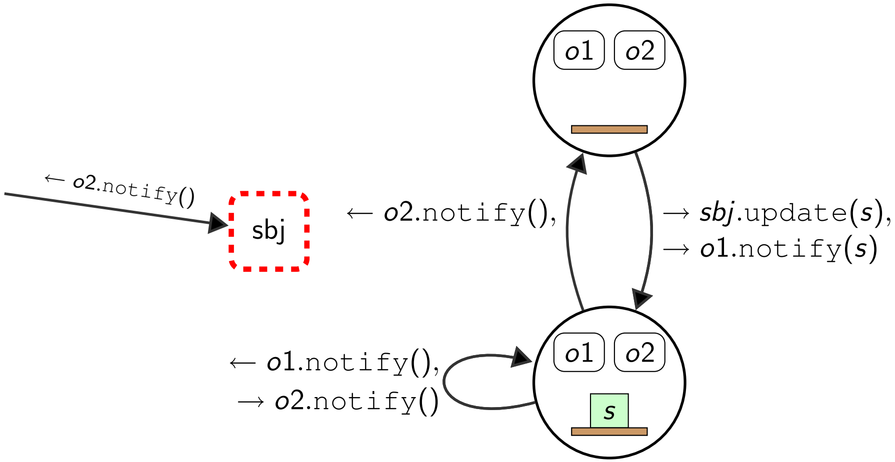

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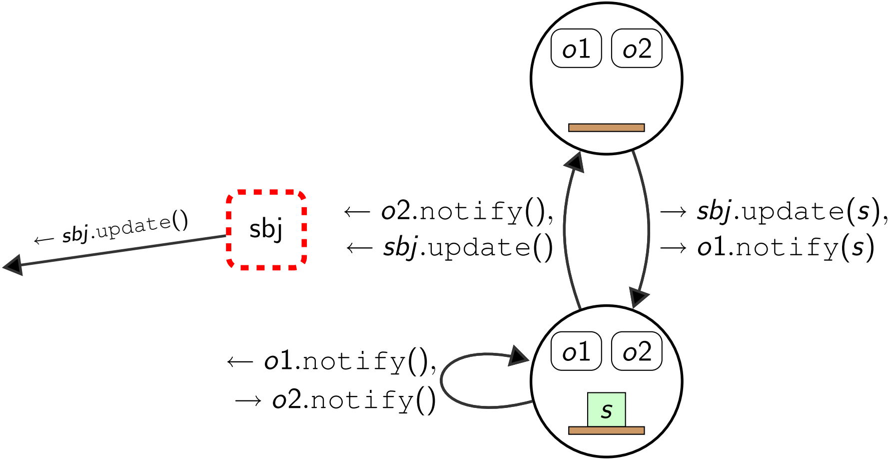

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&\quad (\leftarrow o2.\texttt{notify}(), \leftarrow \mathit{sbj}.\texttt{update}())],\\
&\ldots\}
\end{aligned}
$$

Well-Formedness Condition

All traces must follow the call stack property.

e.g. $t = \ldots, \rightarrow sbj.\texttt{update}(s), \rightarrow o1.\texttt{notify}(s), \leftarrow o2.\texttt{notify}()$
is disallowed.

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Trace-based models

Description: mutually recursive functions, *match* and *partition*.

$$t = \rightarrow a.m, \rightarrow b.n, \rightarrow c.o, \rightarrow d.p, \leftarrow d.p, \rightarrow e.q, \leftarrow e.q, \leftarrow c.o$$

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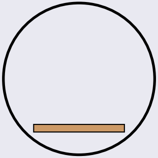
e.g. $t = \ldots, \rightarrow sbj.\texttt{update}(s), \rightarrow o1.\texttt{notify}(s), \leftarrow o2.\texttt{notify}()$ is disallowed.

State-based models

Create a call stack restrictor model.



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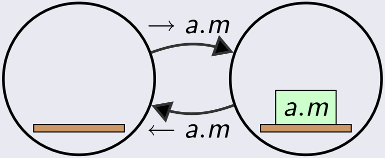

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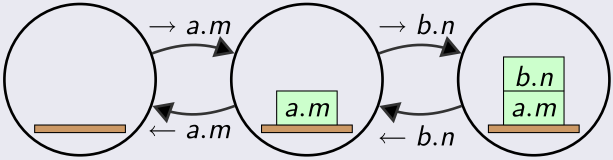

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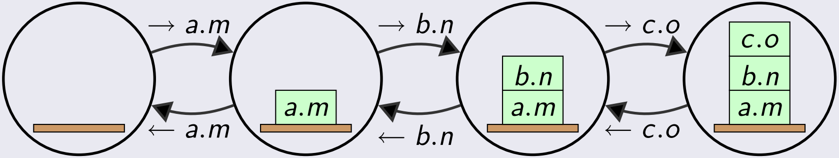

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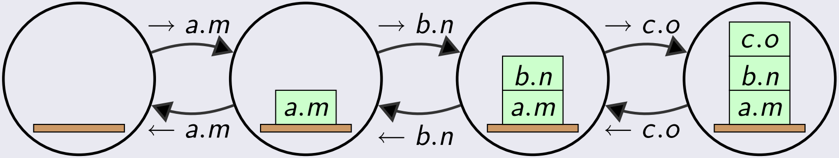

- extend this to pairs of messages
- take the synchronous product

Trace-Based Models as State-Based Models

Lemma

Every trace-based model $\mathcal{T}$ can be canonically represented as a state-based model $\mathcal{M} = \langle S, \Theta, s_0 \rangle$.

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$$t = (m_1, m_2), (m_3, m_4), \ldots$$

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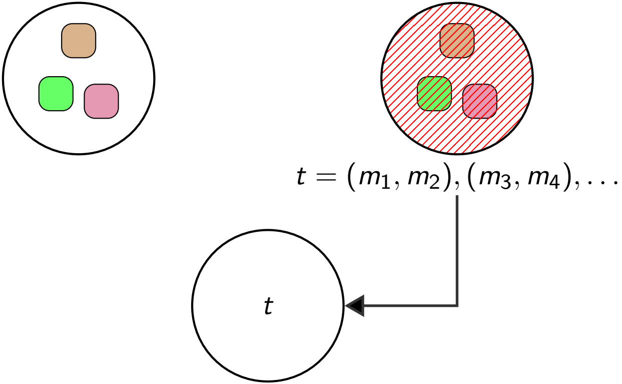

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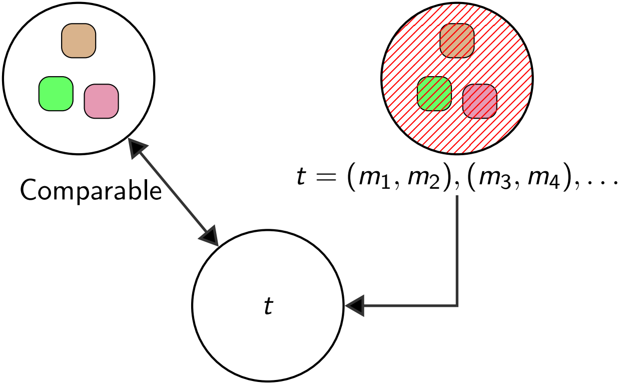


Model Abstraction

Given: $\mathcal{M}_1 = \langle S_1, \Theta_1, s_{0,1} \rangle$ and $\mathcal{M}_2 = \langle S_2, \Theta_2, s_{0,2} \rangle$

$\mathcal{M}_2$ is *more abstract* than $\mathcal{M}_1$

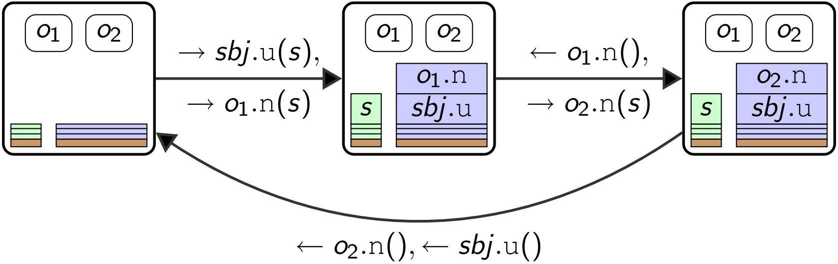
iff

there is $\alpha : S_1 \rightarrow S_2$ such that

- $s_{0,2} = \alpha(s_{0,1})$, and
- if $s_1 \xrightarrow{m_a, m_b}_1 s_1'$, then $\alpha(s_1) \xrightarrow{m_a, m_b}_2 \alpha(s_1')$.

Abstraction Example

$$t = t', \rightarrow sbj.\mathtt{u}(s), \rightarrow o_1.\mathtt{n}(s), \leftarrow o_1.\mathtt{n}(), \rightarrow o_2.\mathtt{n}(s), \leftarrow o_2.\mathtt{n}(), \leftarrow sbj.\mathtt{u}()$$



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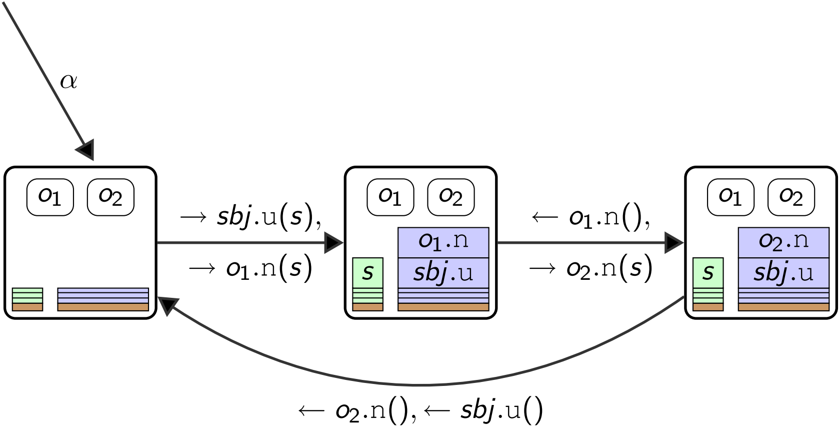

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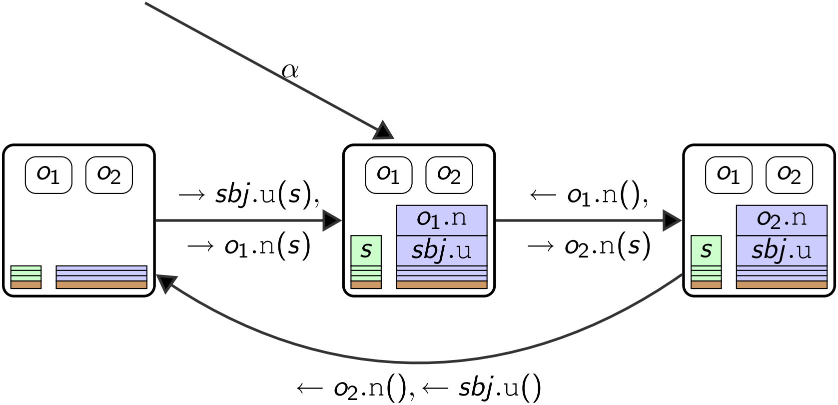

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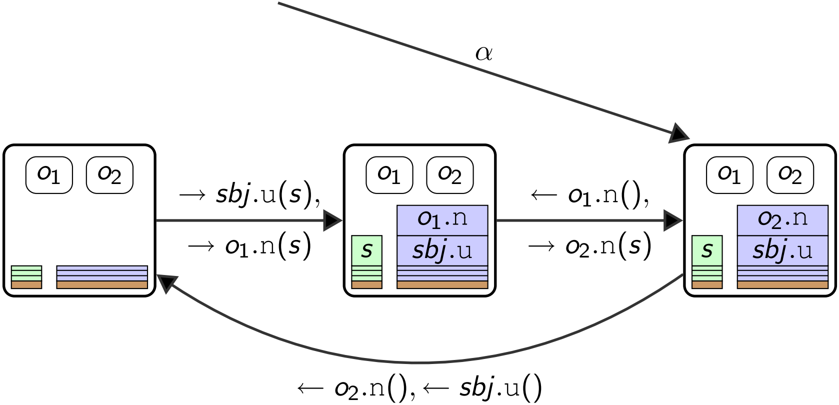

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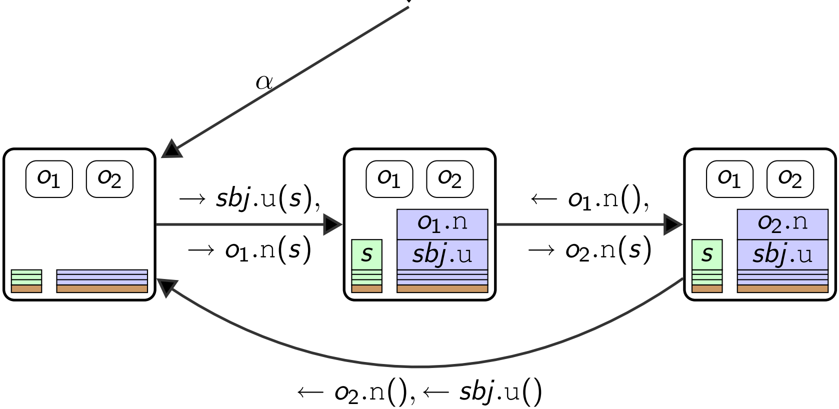


Model Comparison

Theorem

For any trace-based model $\mathcal{T}$, there is state-based model $\mathcal{M}$ which is more abstract than $\mathcal{T}$. The converse does not hold.

Intuition:

$\Rightarrow$ Use previous lemma and take α as the identity function.

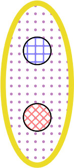
$\Leftarrow$ Counter example: subject component.

Main cause: sequential setting

Simulation [Milner 1971]

Given: $\mathcal{M}_1 = \langle S_1, \Theta_1, s_{0,1} \rangle$ and $\mathcal{M}_2 = \langle S_2, \Theta_2, s_{0,2} \rangle$

A *simulation* for $(\mathcal{M}_1, \mathcal{M}_2)$ is a binary relation $\mathcal{R} \subseteq S_1 \times S_2$ such that

1. $(s_{0,1}, s_{0,2}) \in \mathcal{R}$,
2.  $\in \mathcal{R}$

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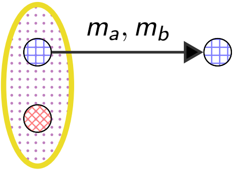
2. 

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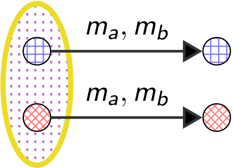
2. 

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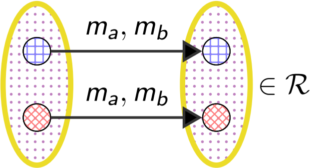
2. 

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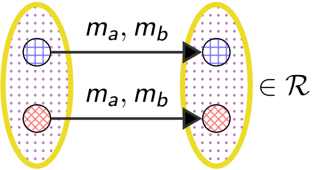
2. 

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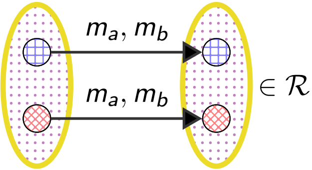
2. 

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Simulation retains the same behavior in our settings [KučeraMayr02]

Most Abstract Model [Grumberg and Bustan 2003]

Simulation equivalence: $\mathcal{M}_1 \simeq \mathcal{M}_2 \equiv \mathcal{M}_1 \preceq \mathcal{M}_2$ and $\mathcal{M}_2 \preceq \mathcal{M}_1$

Purpose:

- build equivalence classes of states of $\mathcal{M}$
- build quotient models

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Theorem

Let $\mathcal{M}/\simeq$ be the quotient of $\mathcal{M}$ under $\simeq$, then $\mathcal{M}/\simeq$ is the most abstract model.

Conclusion and Future work

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- State-based object models are more abstract than trace-based models
- Most abstract models can be built using simulation quotient.

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Future Work

- Generalize settings (trace restriction as precondition, full OO, nondeterminism, concurrency).
- Compare specifications and build common framework.

Generalized State-Based Subject Specification

```
state spec Subject {
  Subject sbj;
  Observer o1, o2;
  Stack<State> st;

  in → sbj.update(s) out → o1.notify(s)
    ensures st = old(st).push(s);

  in ← o.notify() out → o2.notify(s)
    requires o = o1;
    ensures s = old(st).top();

  in ← o.notify() out ← sbj.update()
    requires o = o2;
    ensures st = old(st).pop();
}
```