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26-2-2024

Lecture 6: concurrency viewpoint

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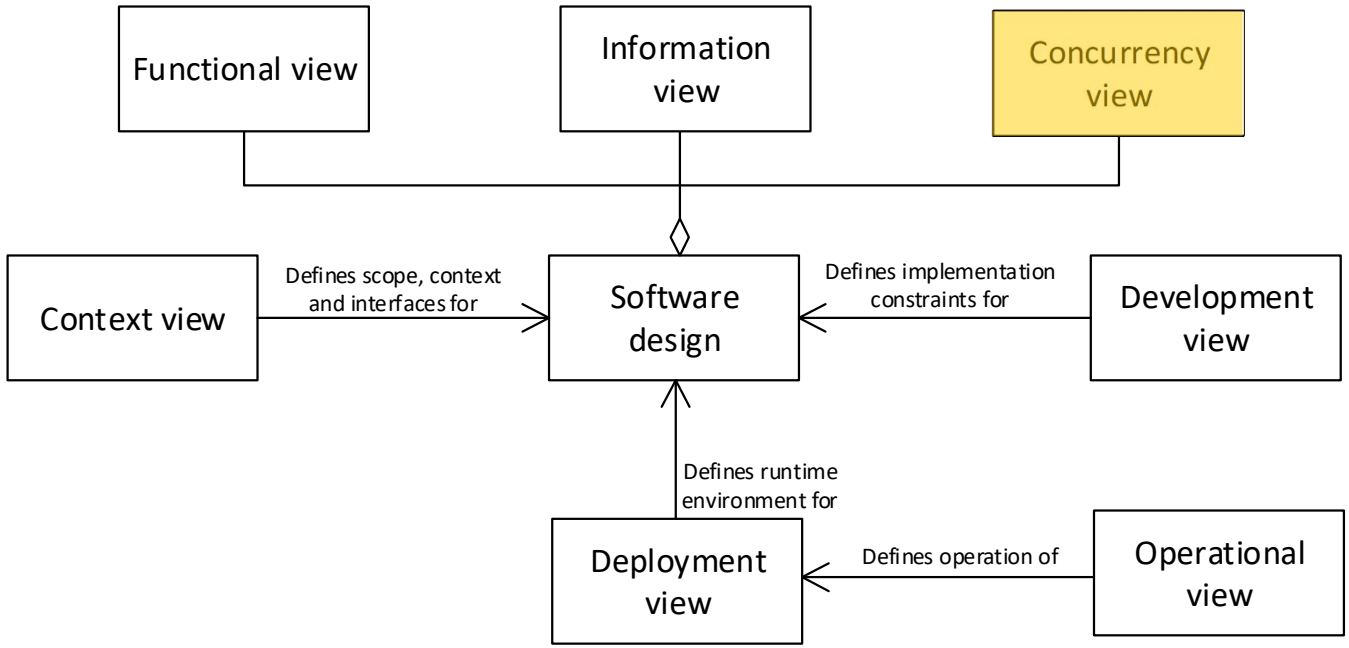
Viewpoint catalog



Viewpoint:

Collection of patterns, templates and conventions for constructing one type of view. It defines the stakeholders whose concerns are reflected in the viewpoint and the guidelines, principles, and template models for constructing its views

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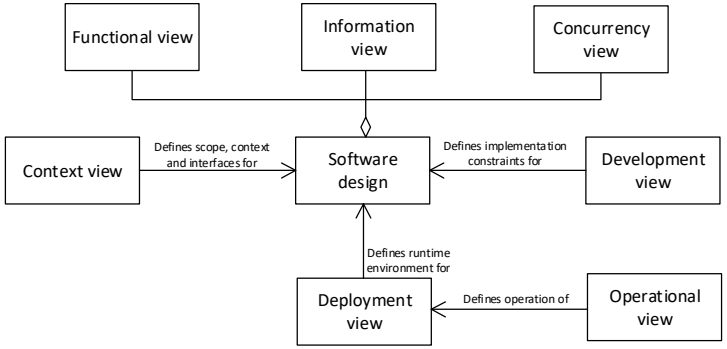
Concurrency view



- Concurrency view:
  - **Describes the concurrency structure of the system and maps functional elements to concurrency units to clearly identify the parts of the system that can execute concurrently and how this is coordinated and controlled**
- Concerns
  - **Task structure, mapping of functional elements to tasks,**
  - **Inter-process communication,**
  - **State management,**
  - **Synchronization and integrity,**
  - **Supporting scalability, task failure,**
  - **Startup and shutdown, re-entrancy**
- Models and views
  - **System level concurrency models**
  - **State models, protocol models**

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About today's papers...

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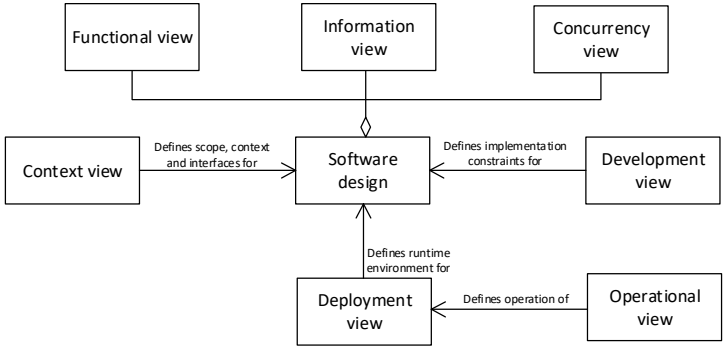
Concurrency view (2)

Relation with Shaw & Garlan (1995)?



- Problems and pitfalls
  - **Modelling the wrong concurrency**
  - **Modelling the concurrency wrongly**
  - **Excessive complexity**
  - **Resource contention,**
  - **Deadlocks, livelocks**
  - **Race conditions**
- Applicability
  - **Systems with a number of concurrent threads of execution**
  - **Component-based systems with loosely coupled elements**
  - **Interorganizational systems**

We tend to illogically reason over concurrency!
It is genuinely difficult to grasp how systems are intertwined and communicate!

My position: semiformal models are insufficient to understand concurrency!

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Models vs. pictures

What do you see?

Pictures: Everybody sees something different…

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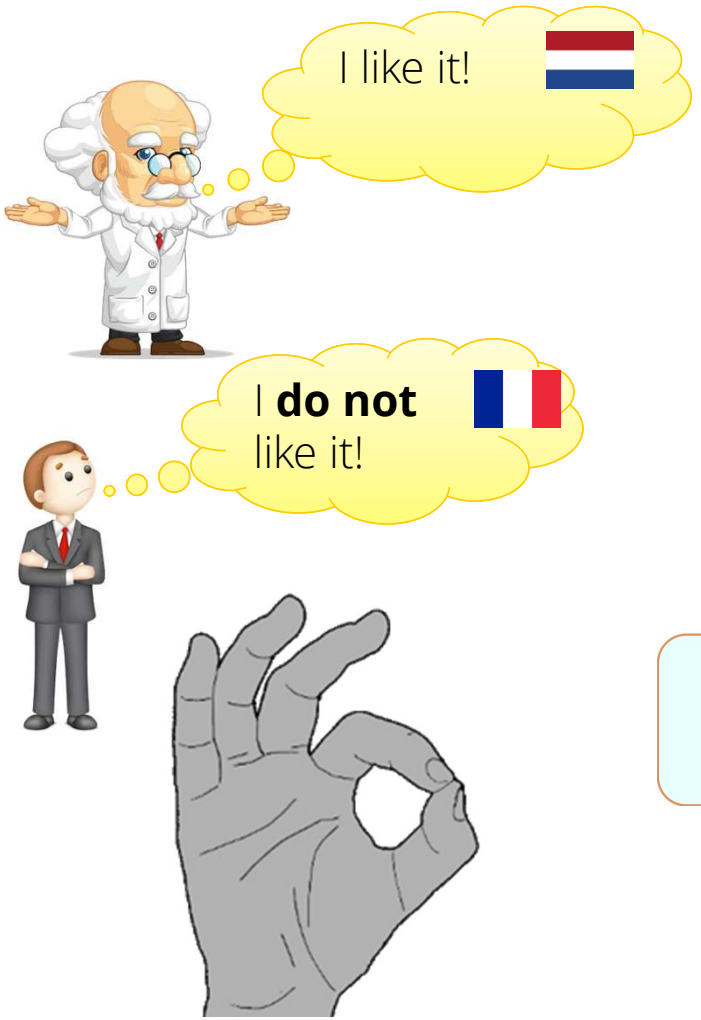
Models



- Syntax:
  - **What elements are there?**
  - **How are the elements related to each other?**
- Notation:
  - **How do you denote the different elements?**
- Semantics
  - **What is the (mathematical) meaning of the model?**
- Pragmatics
  - **How do you use and create the models?**

- Intention
  - **What does the modeler want to express with their model?**

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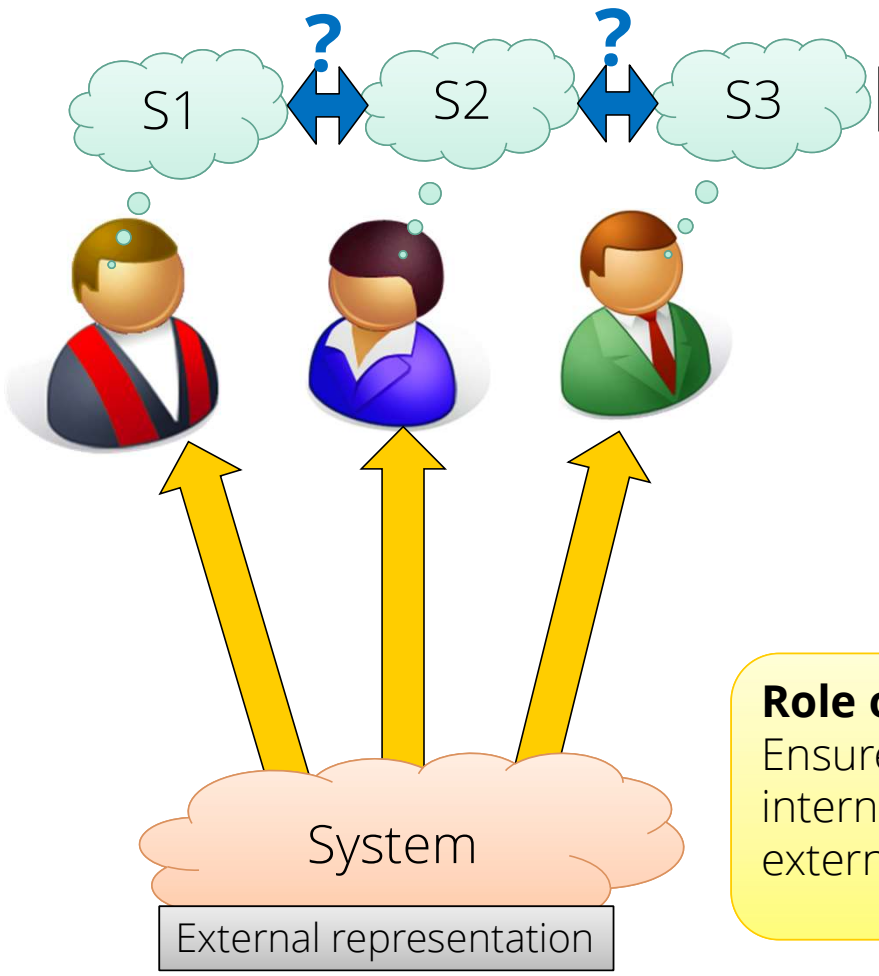
Intention: ensure the right internal representation!



Internal representation

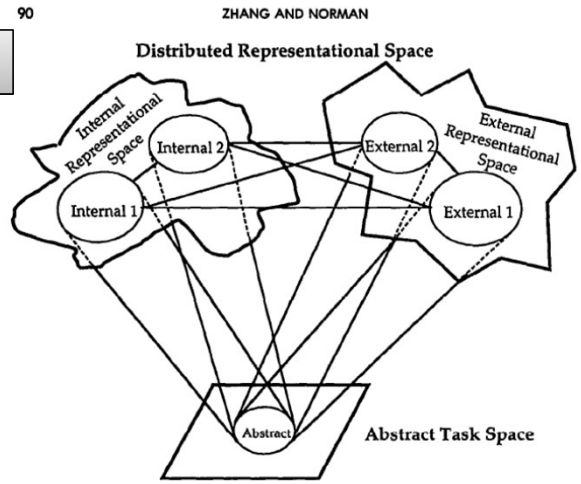
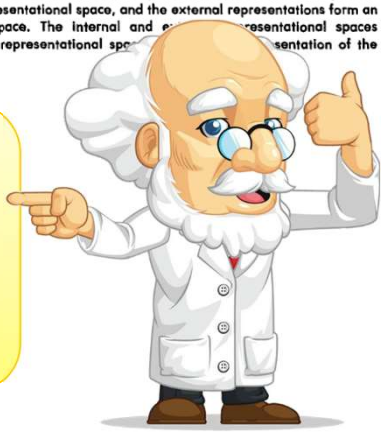


Figure 1. The theoretical framework of distributed representations. The internal representations form an internal representational space, and the external representations form an external representational space. The internal and e... resentational spaces together form a distributed representational spa... sentation of the abstract task space.

Role of Mathematics:
Ensures that everyone has the same internal representation of some external representation



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Back to software architecture...

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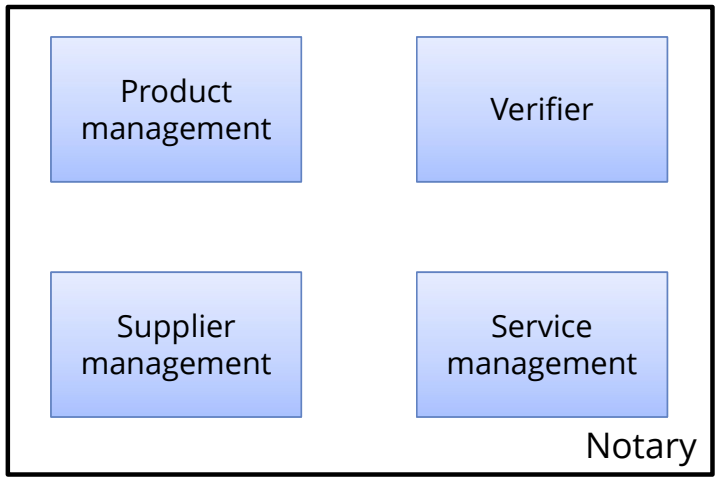
Create a functional architecture for this context:



- Notary is a platform with providers and clients.
- Providers deliver services to clients.
- Clients directly approach a provider.
- The notary is a trusted party.
- Clients need to be checked by the Notary
- Clients send their approval to a preferred provider
- Payment is only done once the client signed the bill
- Multiple payments per service possible
- Payment is done by the notary
- The notary can use several agencies to get more info upon a client's request

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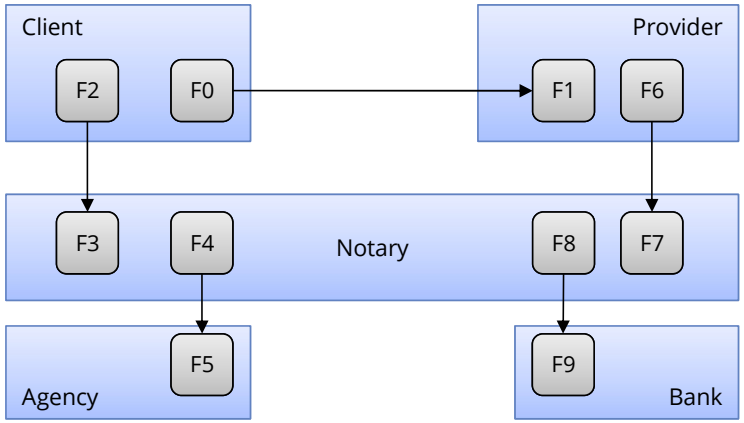
Create a functional architecture for this context:



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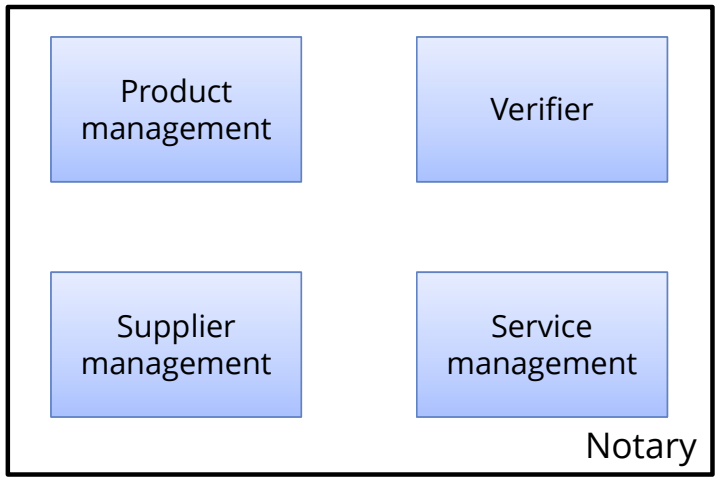
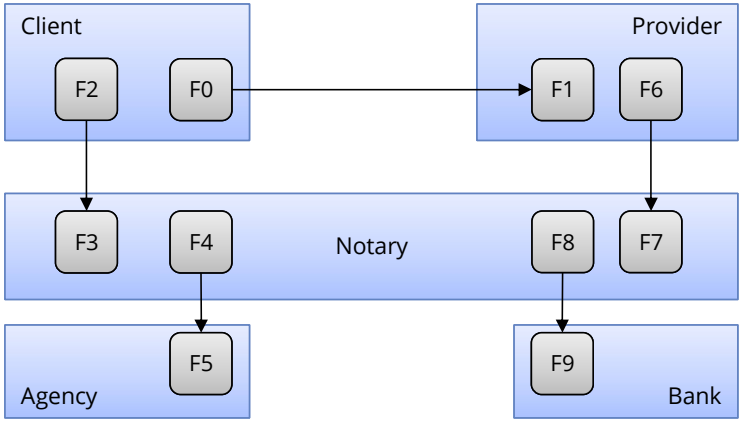
Create a functional architecture for this context:

Functional architecture



mapping

Logical architecture



From a “usage” perspective

From a “resource” perspective

Here, you already see the envisioned “services”!

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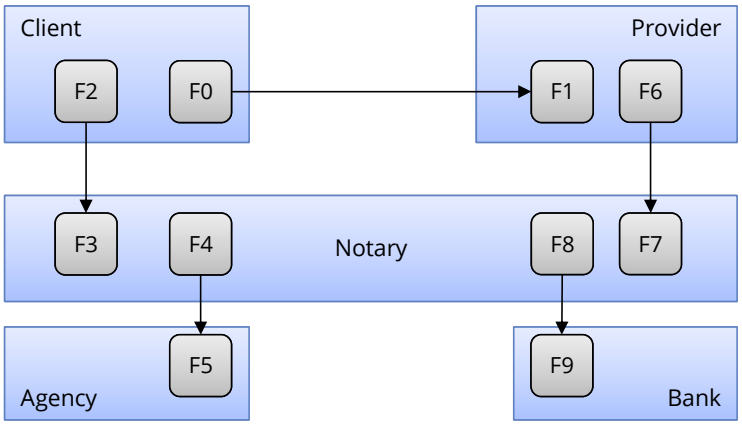
Logical architecture model



- Hierarchical structure:
  Atomic and composite containers
- Atomic Container
  Groups a coherent set of functions
- Composite Containter
  Only contains containers
- Function calls:
  Always between functions
  Arrow: function "converses" with another function

Remember: "just" a lines-and-boxes diagram

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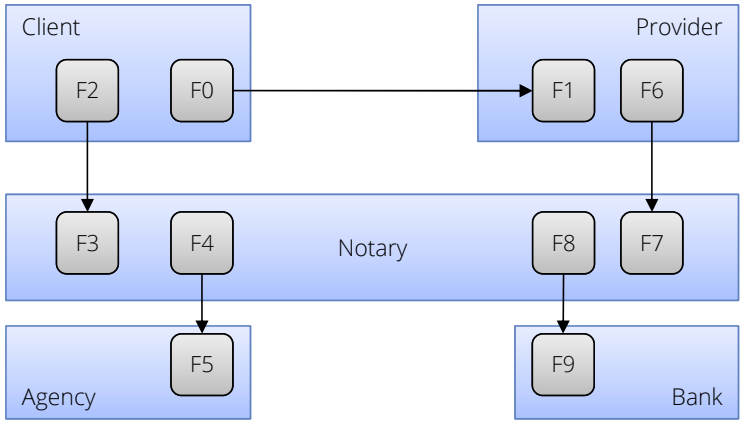
From logical model to concurrency…



Each system is running concurrently with all the other systems!

- Notary is a platform with providers and clients.
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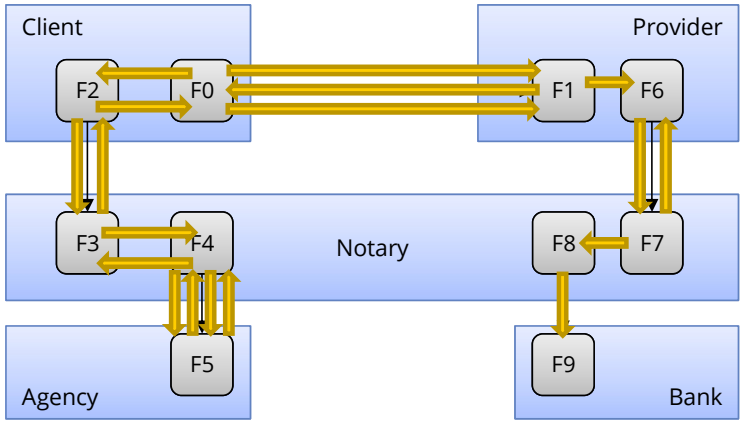
Logical model and scenarios



- Scenario is a sequence of function calls
- Formal definition:

  Given a logical model $(C, F, h, \rightarrow)$**,**
  a scenario is a partial order over the function calls,
  i.e., $\sigma \in (\rightarrow)^*$ **such that:**

  Functions can only start if being called before:

  $$\forall 1 < i < |\sigma| : \left(\exists 1 < j < i : \pi_3(\sigma(j)) = \pi_1(\sigma(i))\right)$$

Key:
F0: Request service
F1: Handle service request
F2: Request approval
F3: Receive approval request
F4: Validate client
F5: Do credibility check
F6: Request payment
F7: Check payment request
F8: Send payment
F9: Make payment

Given a set A, a sequence of length $n \in \mathbb{N}$ is a function $\sigma : \{1..n\} \rightarrow A$

- We write $\sigma = \langle a_1, \ldots, a_n \rangle$ if $\sigma(i) = a_i$ for all $1 \leq i \leq n$.
- We denote its length by $|\sigma|$
- If $n = 0$, we call it the empty sequence, and denote it with ϵ
- The set of all finite sequences over A is denoted by A^*

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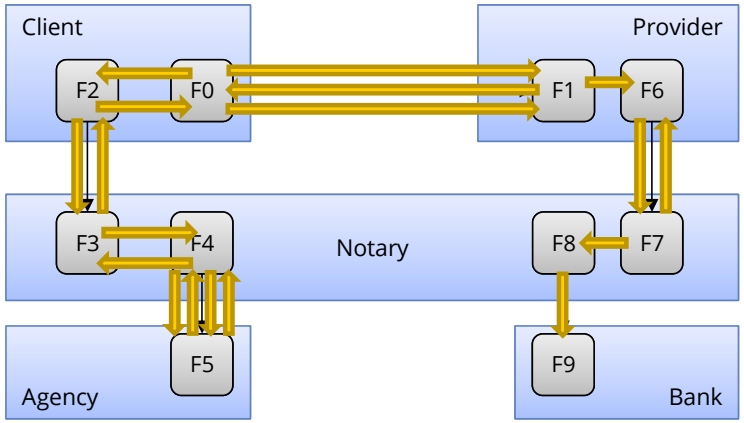
Logical model and scenarios



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  Functions can only start if being called before:

  $$\forall 1 < i < |\sigma| : \left(\exists 1 < j < i : \pi_3(\sigma(j)) = \pi_1(\sigma(i))\right)$$

Problem: scenarios can be conflicting!

Key:
F0: Request service
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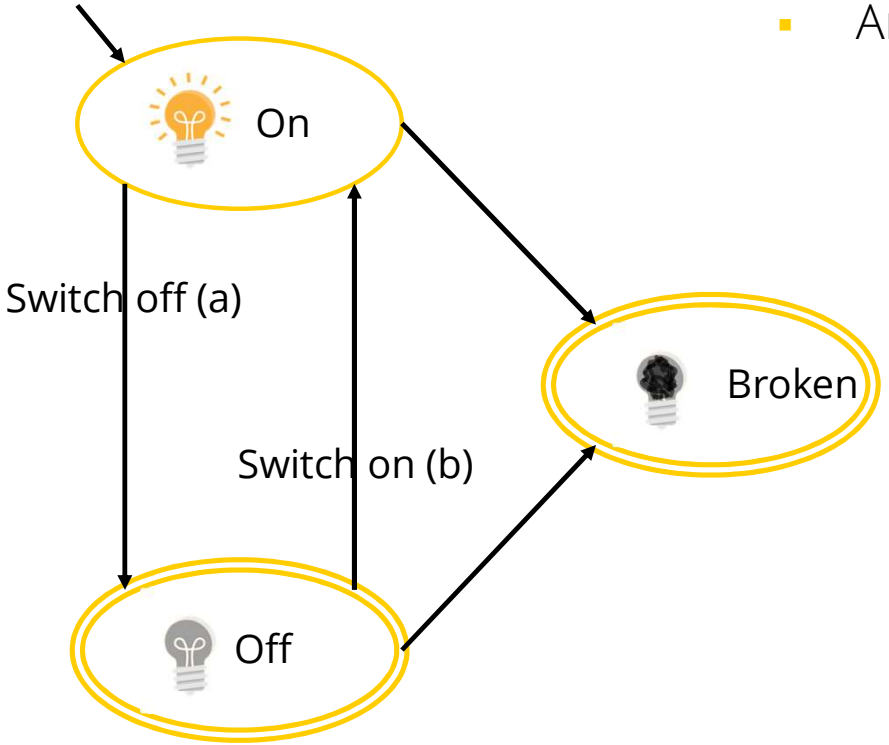
Generalizing scenarios: Labeled transition systems



- An automaton is a 5-tuple $(Q, A, \rightarrow, s_0, \Omega)$
  - Q **is a set of states**
  - A **is a set of observable action labels**
  - **Flow relation** $\rightarrow \subseteq Q \times (A \cup \{\tau\}) \times Q$ **with**
    - τ **the unobservable action, so** $\tau \notin A$
  - $s_0 \in Q$ **is the *initial state***
  - $\Omega \subseteq Q$ **is the set of *final (accepting) states***

Q = { On, Off, Broken }
A = { a, b },
$\rightarrow$ = { (On, a, Off), (Off, b, On),
(Off, τ, Broken), (On, τ, Broken) }
s_0 = On
Ω = { Off, Broken }

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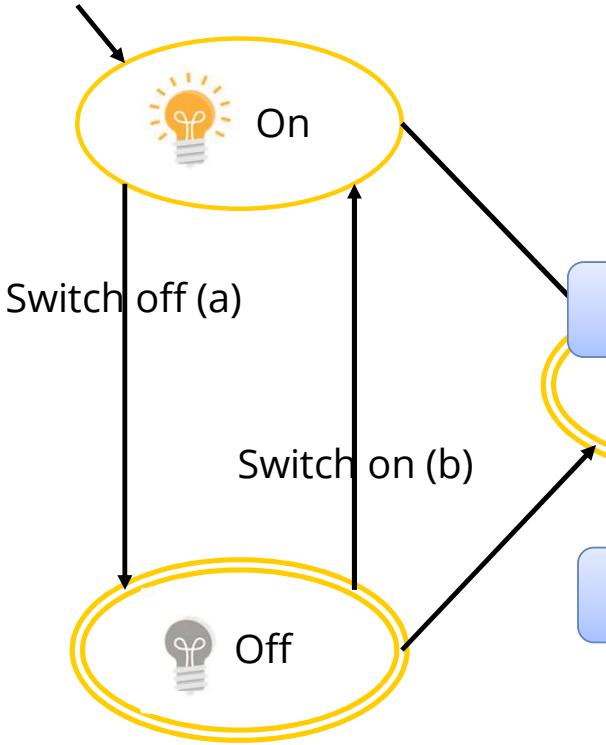
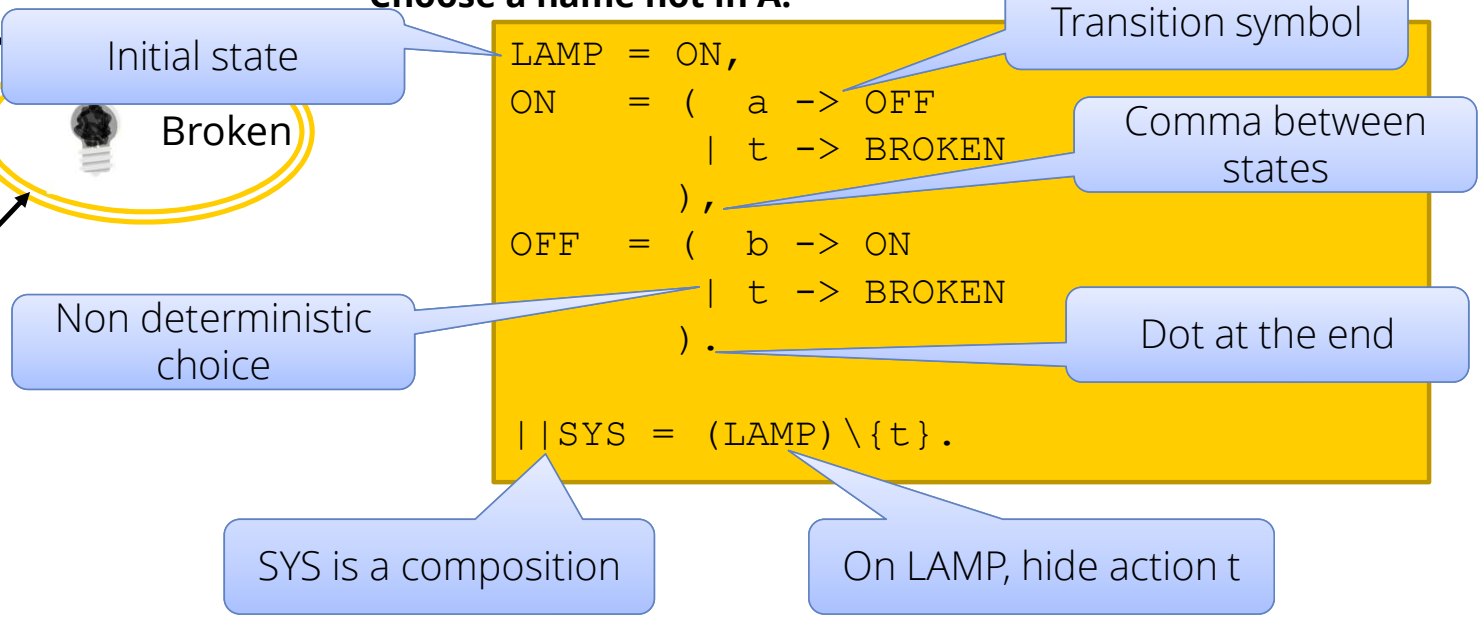
Modeling Label Transition Systems in LTSA



- States in capital
- Actions in small letters
- List all transitions per state:

Note: silent action cannot be implemented directly!
Choose a name not in A.




```
LAMP = ON,
ON   = (  a -> OFF
        | t -> BROKEN
       ),
OFF  = (  b -> ON
        | t -> BROKEN
       ).

||SYS = (LAMP)\{t}.
```

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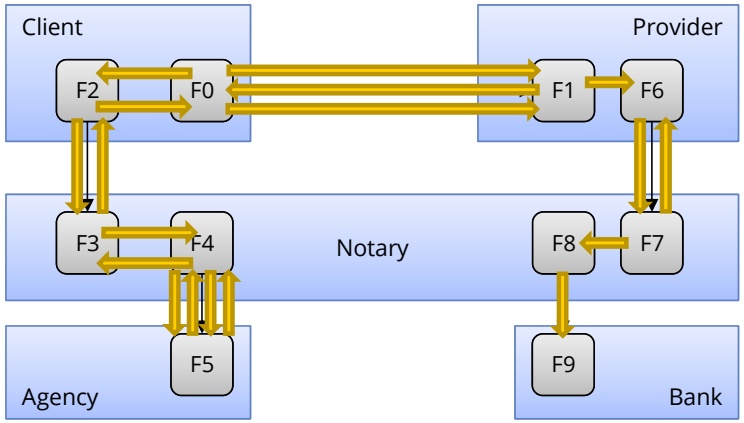
Define an LTS for F0 in LTSA



- The client asks for permission. Upon receiving the permission, (s)he asks for a service of the provider, and either accepts or denies the offer received by the provider. Upon accepting, the provider offers the service, and regularly sends an invoice, which needs to be signed and returned by the client. Once denied, either (s)he stops, or (s)he asks for a better offer.
  In case the client does not receive permission, (s)he tries again.

Key:
F0: Request service
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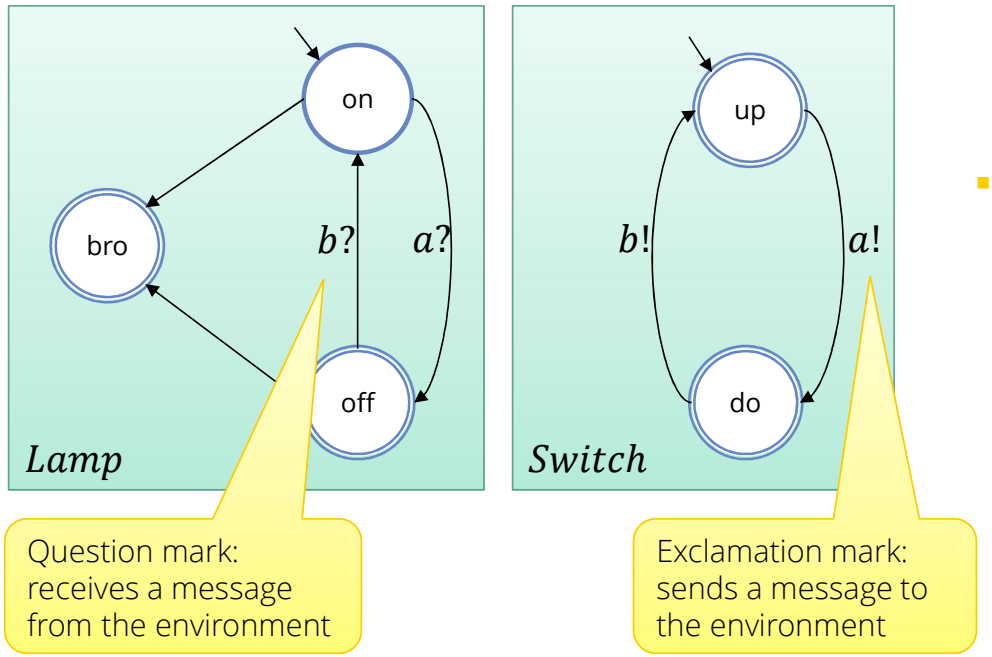
Interface automata
(Also referred to as Finite State Processes)



- Actions of LTS divided in three sets:
  - **Internal action**
  - **Sending action: denoted with an exclamation mark**
  - **Receiving action: denoted with a question mark**
- Synchronization:
  - **Sync is a function: if a! and a? are both enabled in the two LTSs, they synchronize in action a**

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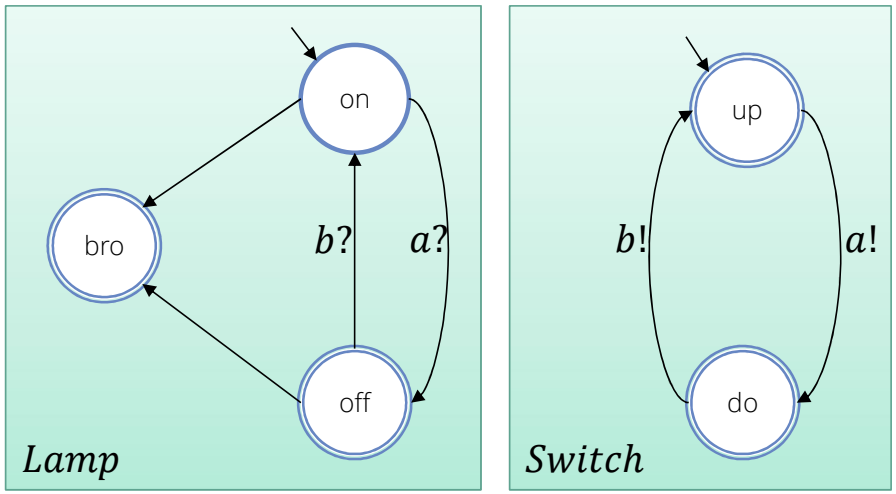
Composing interface automata

Composition of interface automata



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Composing interface automata

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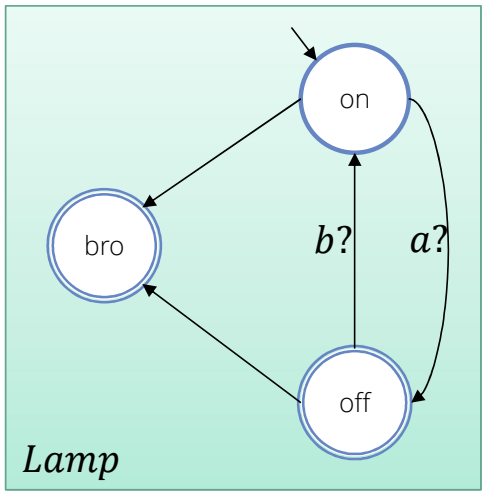

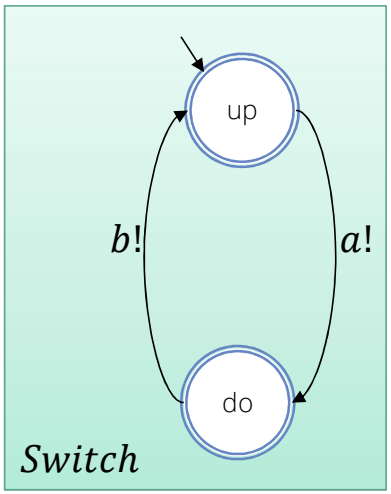

Let $L_1 = (S_1, A_1, \rightarrow_1, s_0^1, \Omega_1)$ **and** $L_2 = (S_2, A_2, \rightarrow_2, s_0^2, \Omega_2)$**,**
Let $R \subseteq A$ **be a set of actions to synchronize on**
i.e. $\forall a \in R: (a? \in S_1 \wedge a? \in S_2) \vee (a! \in S_1 \wedge a? \in S_2)$
Define $R^+ = \bigcup_{a \in R} \{a!, a?\}$

Then: $L_1 \otimes_R L_2 = (\mathrm{S}, \mathrm{A}, \rightarrow, \mathrm{s}_0, \Omega)$ **with**

$$S = S_1 \times S_2$$

$$A = (R \cup A_1 \cup A_2) \setminus \mathrm{R}^+$$

$$\rightarrow = \left\{ \left((s_1, s_2), a, (s_1', s_2)\right) \middle| (s_1, a, s_1') \in \rightarrow_1 \wedge\, a \in A_1 \setminus R^+ \right\}$$
$$\cup \left\{ \left((s_1, s_2), a, (s_1, s_2')\right) \middle| (s_2, a, s_2') \in \rightarrow_2 \wedge\, a \in A_2 \backslash \mathrm{R}^+ \right\}$$
$$\cup \left\{ \left((s_1, s_2), a, (s_1', s'_2)\right) \middle| (s_1, a?, s_2) \in \rightarrow_1, (s_2, a!, s_2') \in \rightarrow_2, a \in \mathrm{R} \right\}$$
$$\cup \left\{ \left((s_1, s_2), a, (s_1', s_2')\right) \middle| (s_1, a!, s_2) \in \rightarrow_1, (s_2, a?, s_2') \in \rightarrow_2, a \in R \right\}$$

$$s_0 = (s_0^1, s_0^2)$$

$$\Omega = \Omega_1 \times \Omega_2$$

Notice: this is interleaving semantics!

ReqEng: In FSP: $(a \rightarrow S) \parallel (b \rightarrow T) \equiv \left(a \rightarrow \left(S' \parallel (b \rightarrow T)\right) \middle| b \rightarrow \left((a \rightarrow S) \parallel T\right)\right)$

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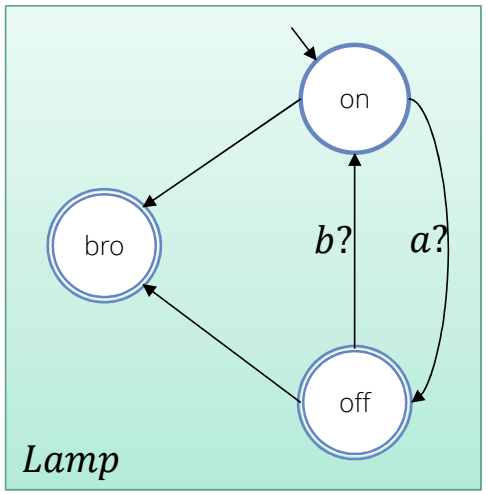
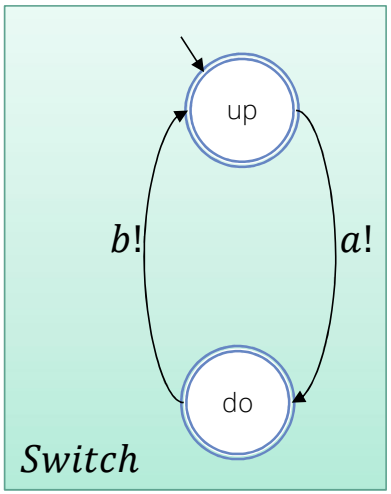
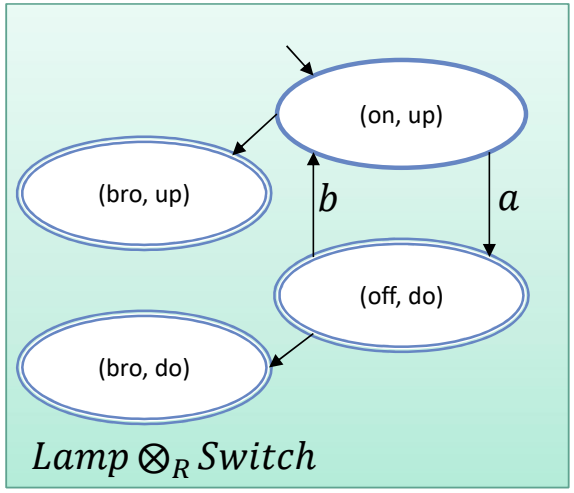
Composing interface automata







$R = \{a, b\}$

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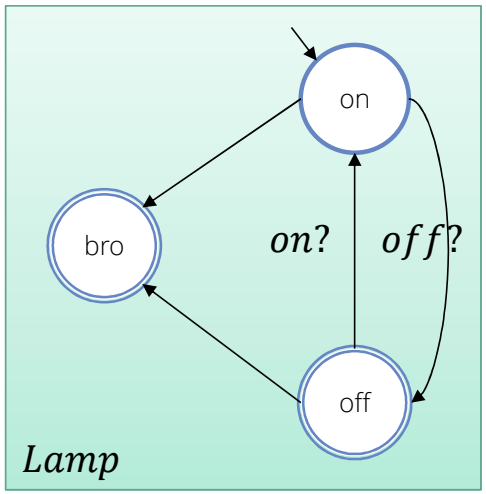
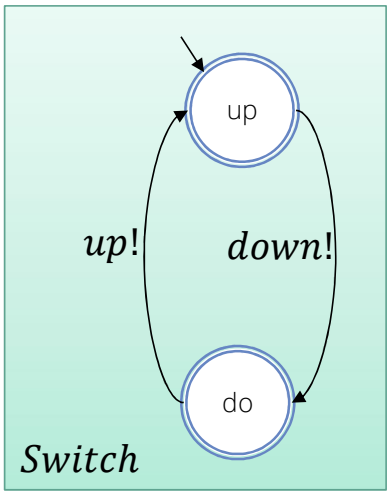
Composing interface automata in LTSA





- Define each system separately
  - **Prefix a send action with an s**
  - **Prefix a receive action with an r**

```
LAMP = ON,
ON   = (  rOff -> OFF | t -> BROKEN),
OFF  = (  rOn -> ON   | t -> BROKEN).

SWITCH = UP,
UP     = (sDown -> DOWN),
DOWN   = (sUp   -> UP).
```

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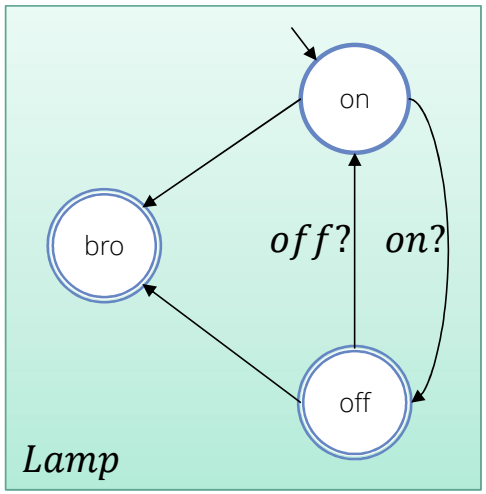
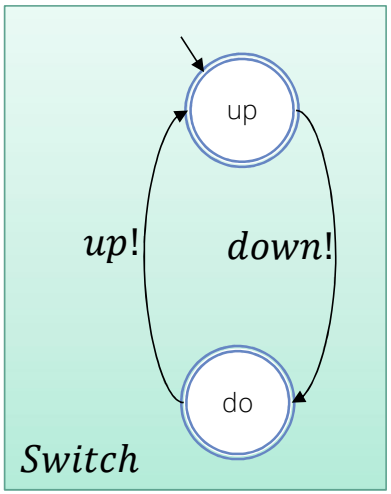
Composing interface automata in LTSA





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  - **Prefix a send action with an s**
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- Compose the systems (||)

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LAMP = ON,
ON   = (  rOff -> OFF | t -> BROKEN),
OFF  = (  rOn -> ON   | t -> BROKEN).

SWITCH = UP,
UP     = (sDown -> DOWN),
DOWN   = (sUp   -> UP).

||SYS = ( LAMP || SWITCH ).
```

SYS is a composition of lamp with switch

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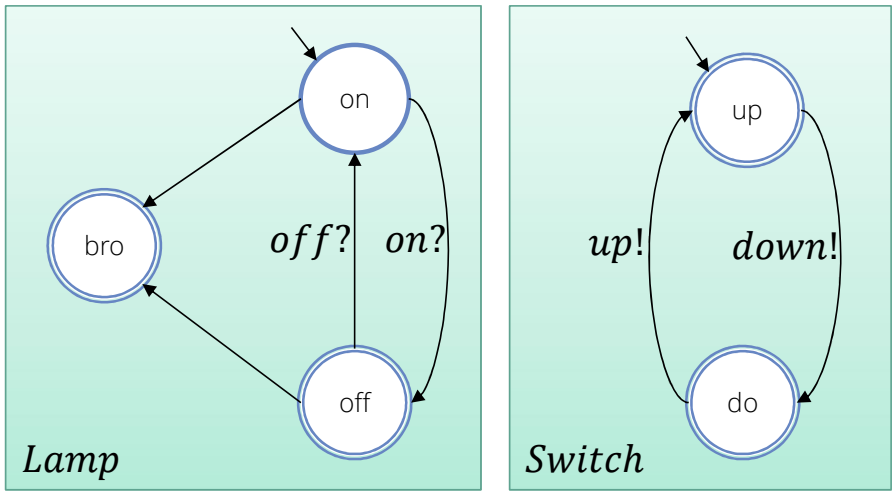
Composing interface automata in LTSA



- Define each system separately
  - **Prefix a send action with an s**
  - **Prefix a receive action with an r**
- Compose the systems (||)
- Specify synchronization relation with relabelling:
  - **rename the actions to create the synchronization: /{sSendAction/rReceiveAction}**

```
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ON   = (  rOff -> OFF | t -> BROKEN),
OFF  = (  rOn -> ON   | t -> BROKEN).

SWITCH = UP,
UP     = (sDown -> DOWN),
DOWN   = (sUp   -> UP).

||SYS = ( LAMP || SWITCH )/{sDown/rOn, sUp/rOff}.
```

/ denotes a renaming action!
s/r renames an r into s

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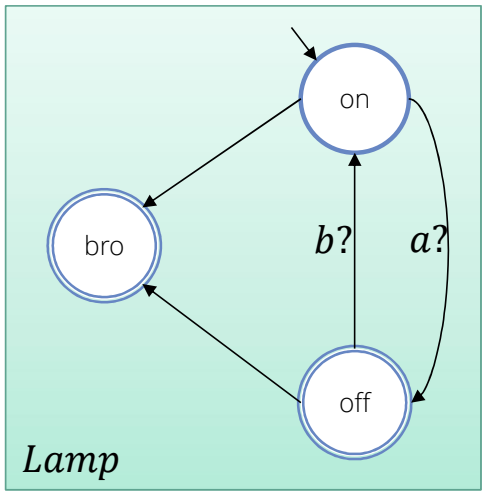
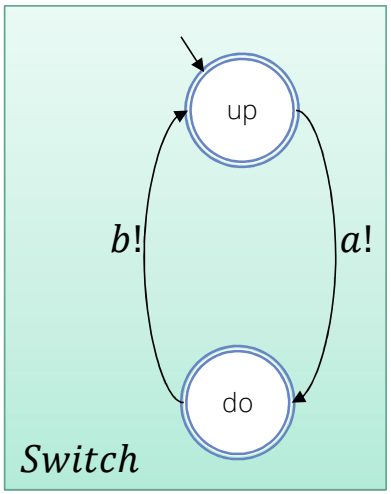
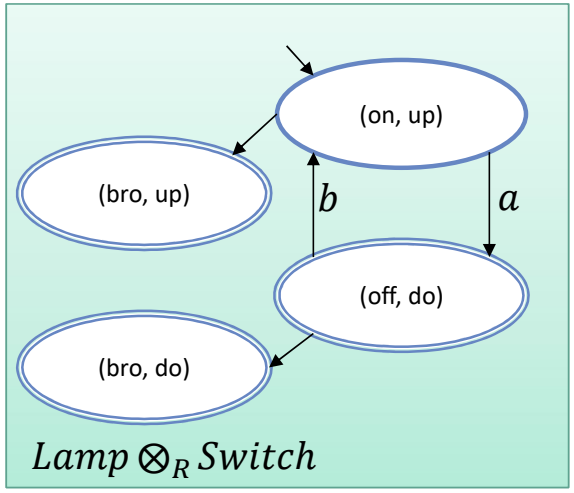
Composing interface automata







$R = \{a, b\}$

Notice: once the lamp is broken, it is not possible to use the switch anymore! This is due to the fact that the actions of the switch need to be synchronized with the lamp. As it does not react on any messages anymore, the system is in deadlock.

Deadlock: a state with no outgoing actions. Possible repair: add a "self-loop" on state "bro" labeled $a?$ and $b?$

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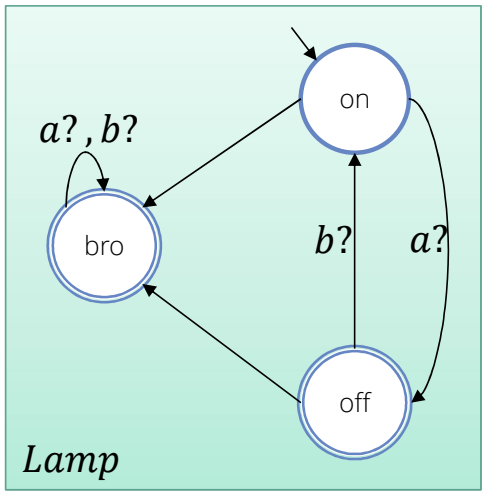
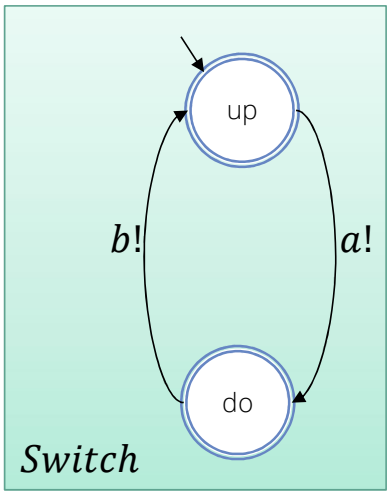
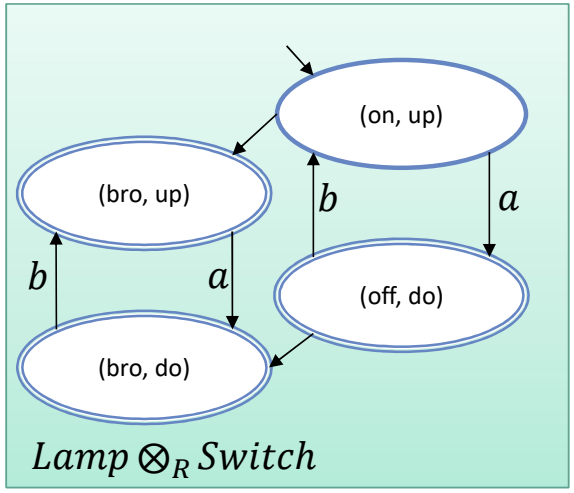
Composing interface automata







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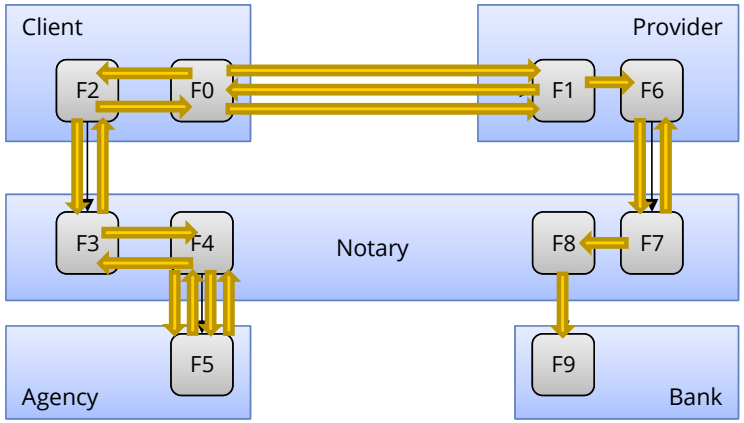
Define the following LTS for F1 in LTSA, and compose it with F0



- Upon receiving a request for an offer from a client, the provider creates and sends an offer. If the offer is rejected, the provider will create a new offer, and send it.
- Once the offer is accepted, the service is provided, and on a regular basis an invoice is sent, which is signed and returned by the client. This signed bill is then passed to the administration.

Key:
F0: Request service
F1: Handle service request
F2: Request approval
F3: Receive approval request
F4: Validate client
F5: Do credibility check
F6: Request payment
F7: Check payment request
F8: Send payment
F9: Make payment

What are your observations?

Designing the individual systems is “easy”. Their composition is exponentially more difficult!

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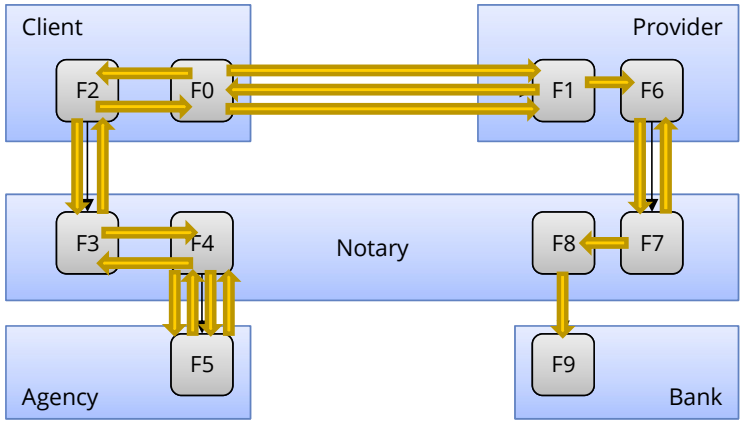
Communication mechanisms



- Synchronous communication
  You have to know in which state the other is!
- Asynchronous communication
  Send messages to the other, the state of the other is unknown!

FSP, Interface automata only allow for synchronous communication!

Key:
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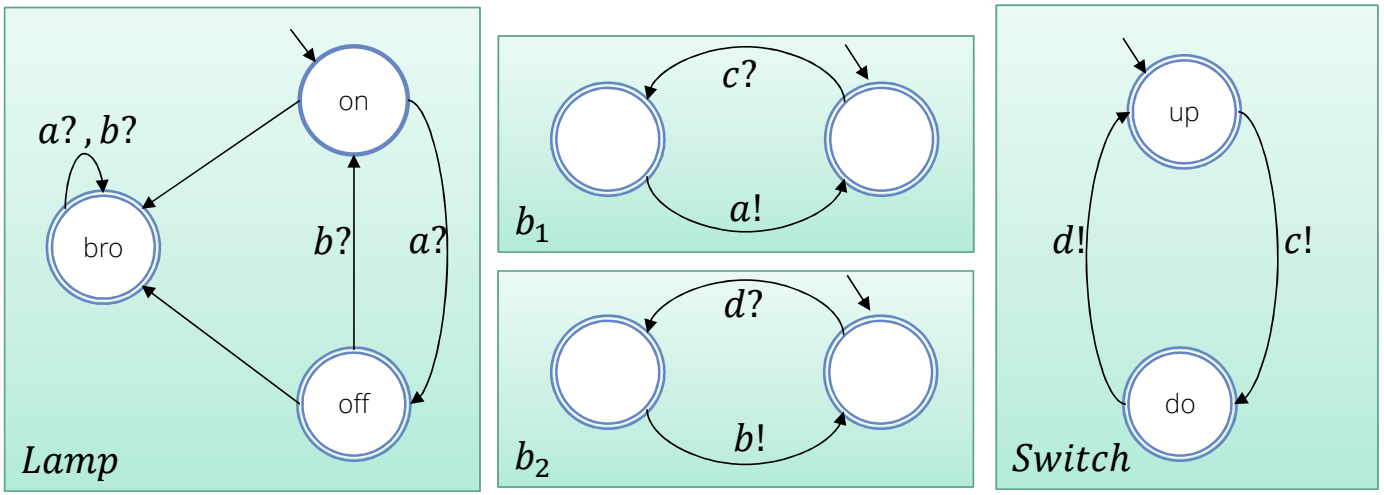
Simulating asynchronous behavior with buffers



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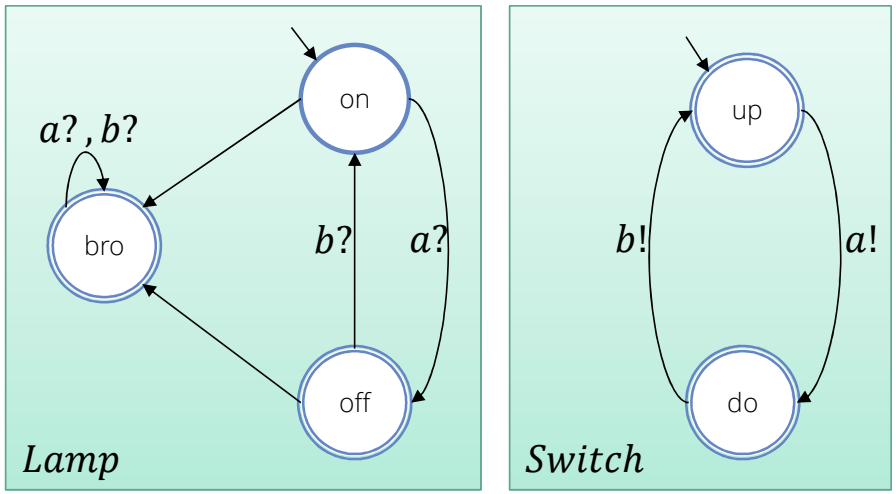
I/O automata



- Message queue to delay messages
  - **Queue per automaton / global queue**
  - **Messages are handled in order.**
  - **Capacity of the queue?**

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Petri nets

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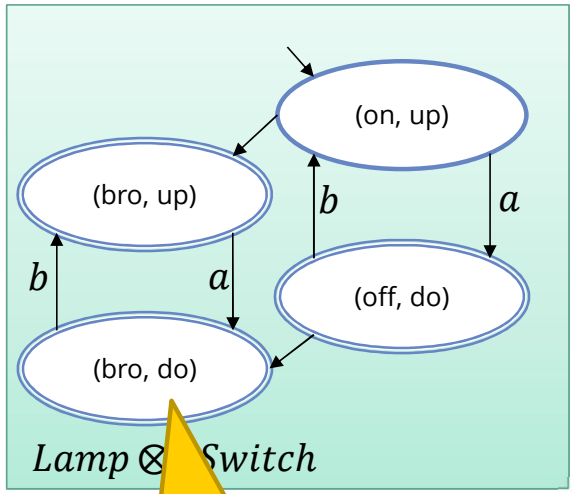
Labeled Transition Systems have global states!



- Instead of global states: distributed states!

- Transitions: state changes are local
  check locally if a transition can fire:
  transition firing changes the state locally

State resembles:
- State of switch
- State of light

How can we make advantage of this split state?

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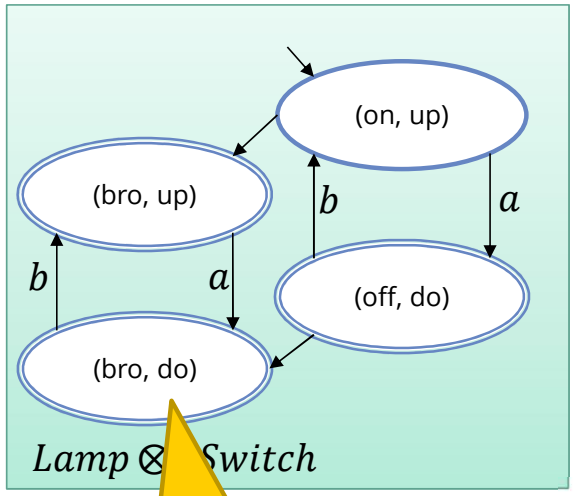
Labeled Transition Systems have global states!



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Petri nets: an informal introduction

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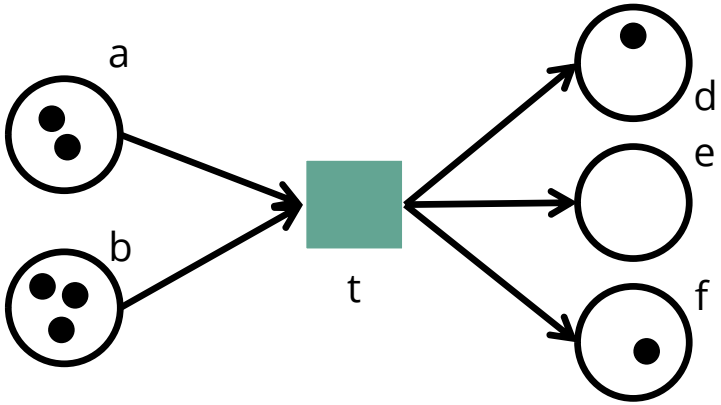
Petri nets: an informal introduction



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Arcs are always from a place to a transition, or
From a transition to a place

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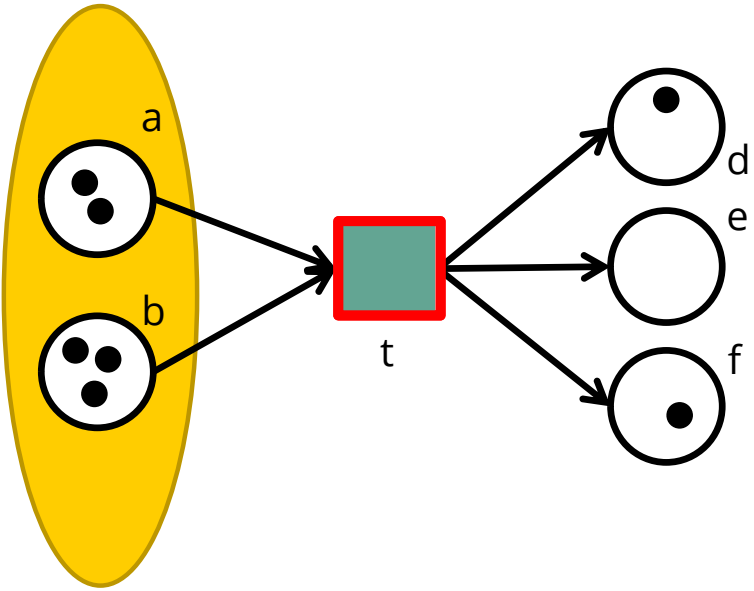

Input places of transition t

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- Transition enabled:

all input places have at least 1 token

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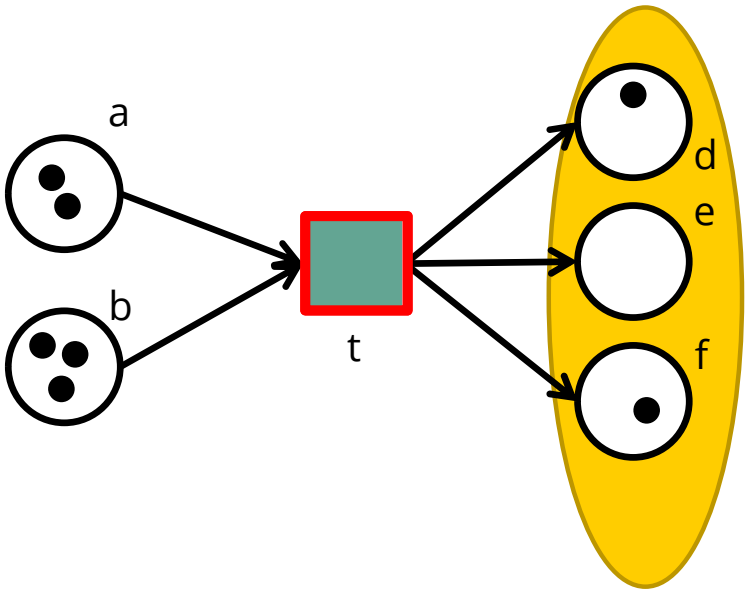
Petri nets: an informal introduction



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Consumes 1 token from each input place
Produces 1 token in each output place

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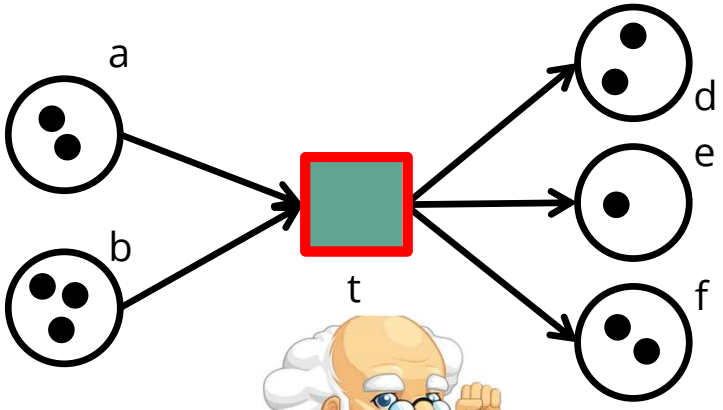

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There is no law of token preservation!

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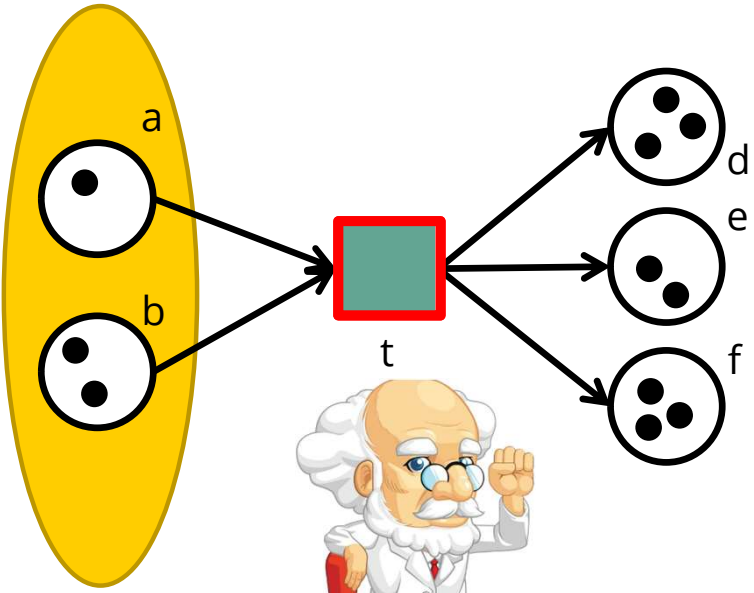
Petri nets: an informal introduction



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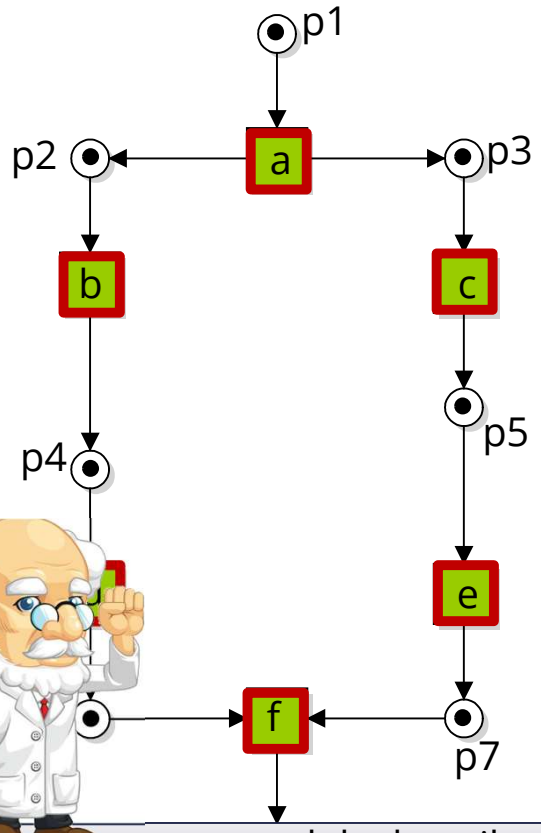
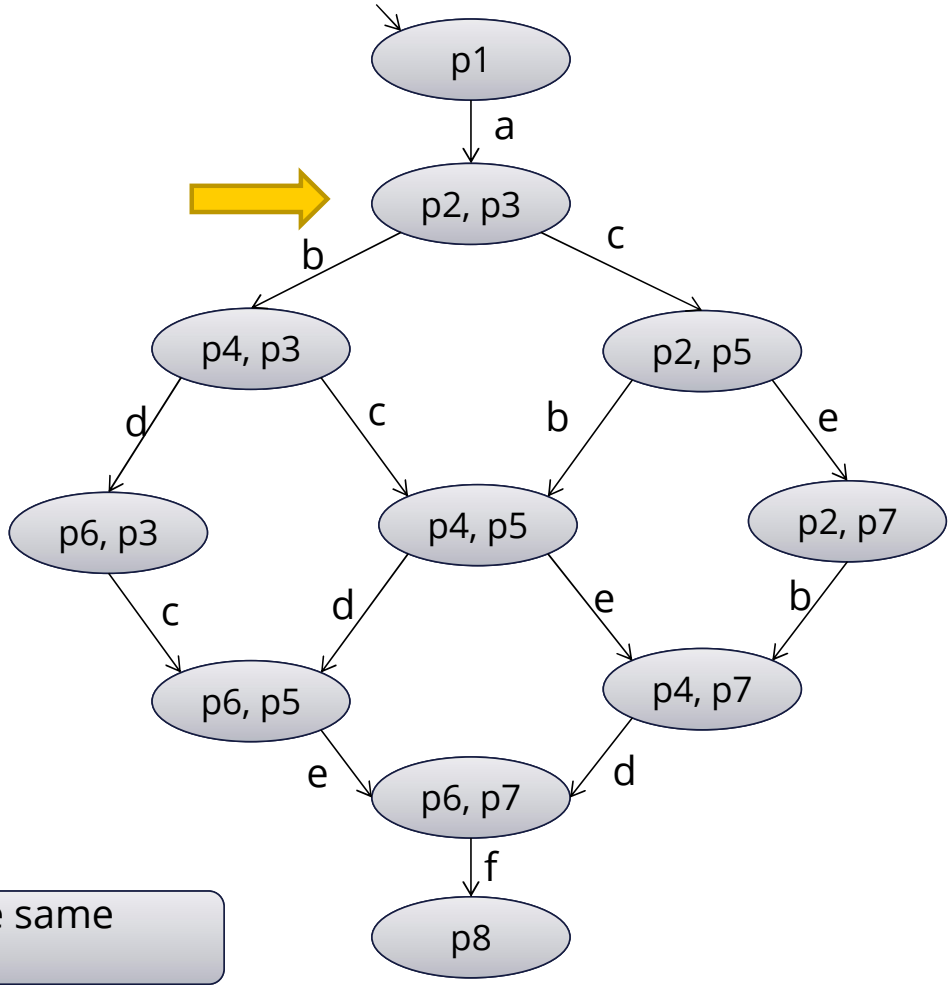
Petri nets: behavior in terms of LTSs



These two models describe the same behavior!



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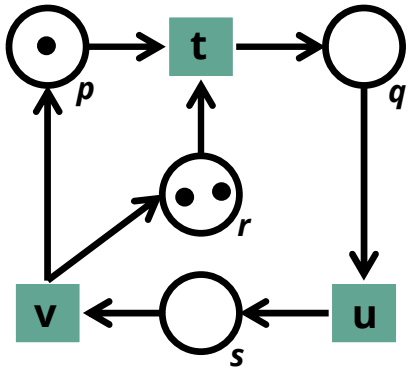
Petri nets: formal definition



$N = ((P, T, F), m_0)$ with:

$P = \{p, q, r, s\}$

$T = \{t, u, v\}$

$F = \{(p,t), (r,t), (t,q), (q,u)$
$(u,s), (s,v), (v,r), (v,p)\}$

$m_0 = [\, p,\ r^2 \,]$

(reads as: $[\, p^1,\ r^2, q^0, s^0]$)

- A Petri net is a 4-tuple N = $((P, T, F), m_0)$ with:

- P: a (finite) set of places
- T: a (finite) set of transitions
- P and T are disjoint ($P \cap T = \emptyset$)
- F is the flow relation that defines the arcs

$$F \subseteq (P \times T) \cup (T \times P)$$

- m_0 is the initial marking, gives the tokens per place

$$m_0 : P \rightarrow \mathbb{N}$$

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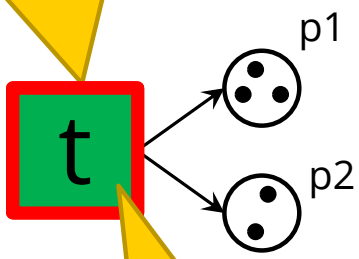
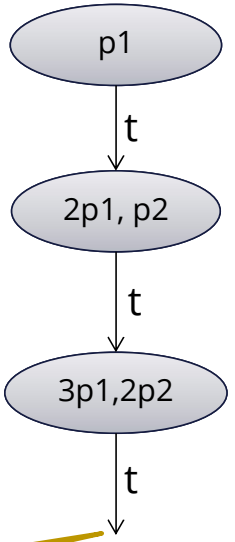
Petri nets vs. LTSs

All input places always have a token
(empty set, so always true!)



Always enabled!



Infinite sequence

Infinite Automata!

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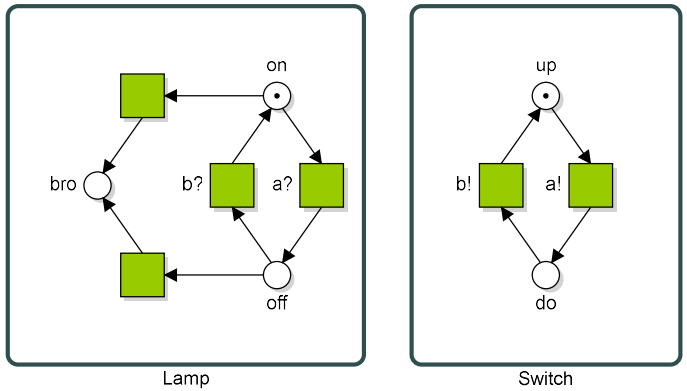
Back to our lamps: now as Petri nets



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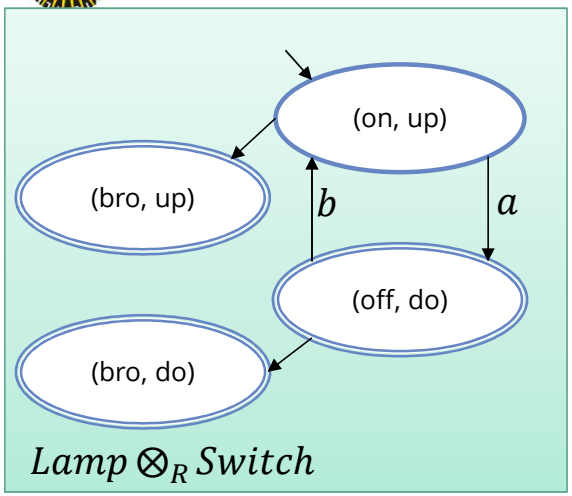
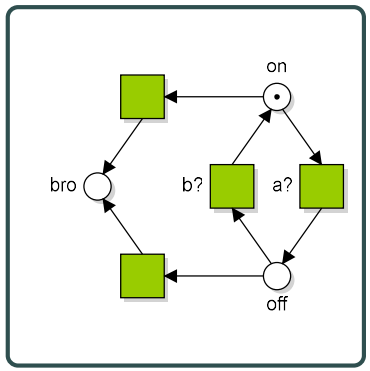
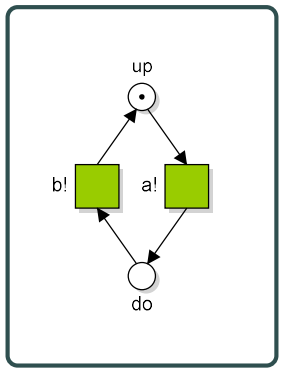
Back to our lamps: now as Petri nets

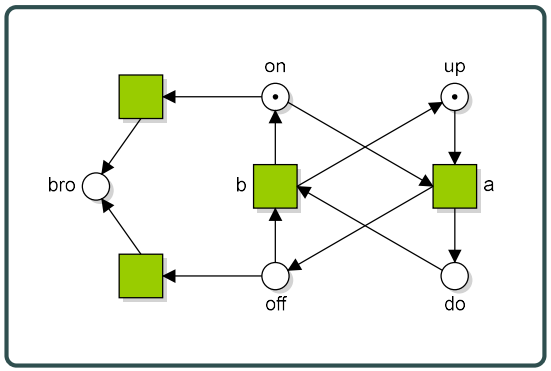




Lamp



Switch



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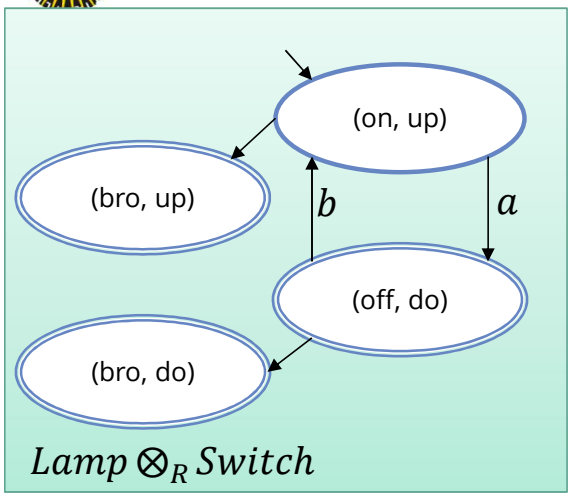
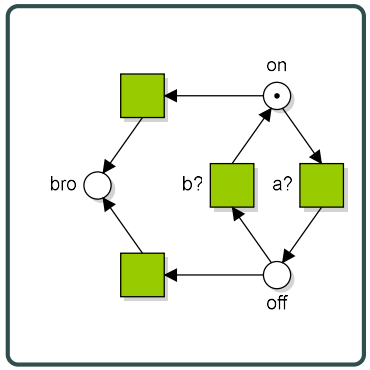
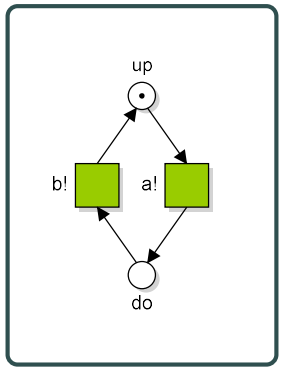
Back to our lamps: now as Petri nets

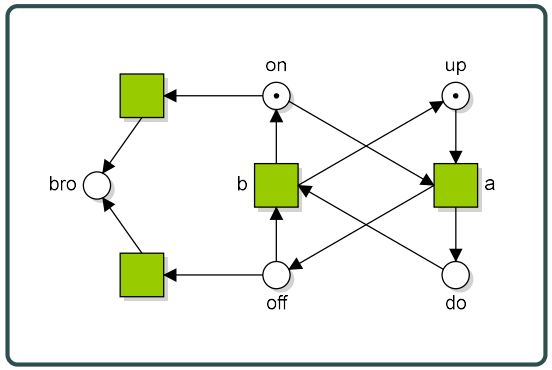


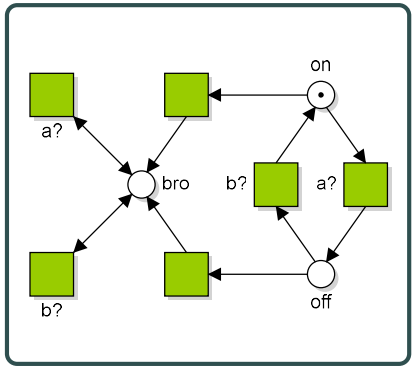


Lamp



Switch





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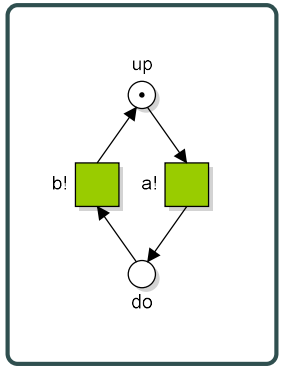

Switch

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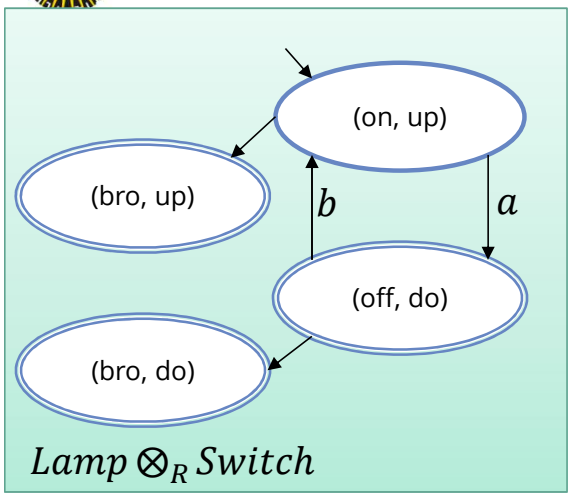
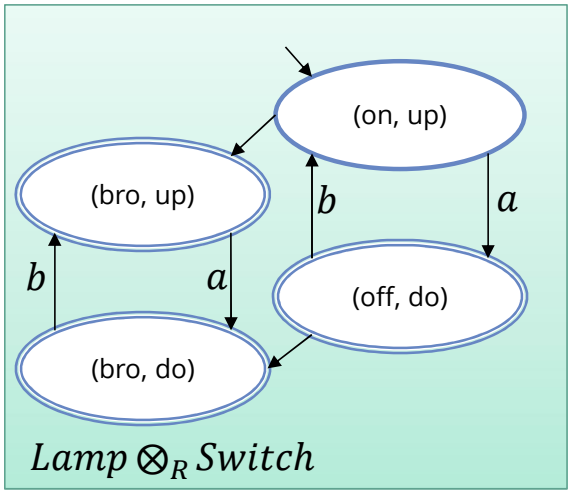
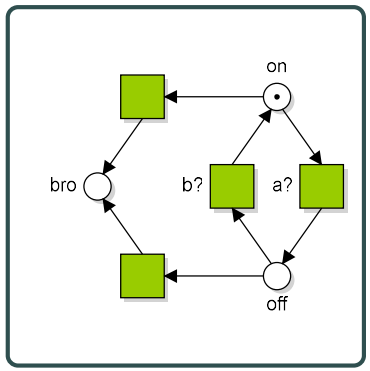
Back to our lamps: now as Petri nets
Synchronous communication







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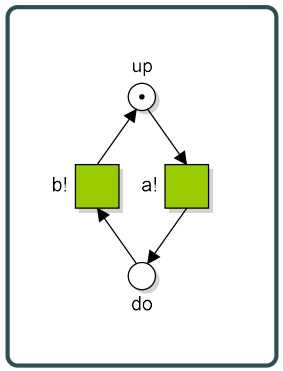
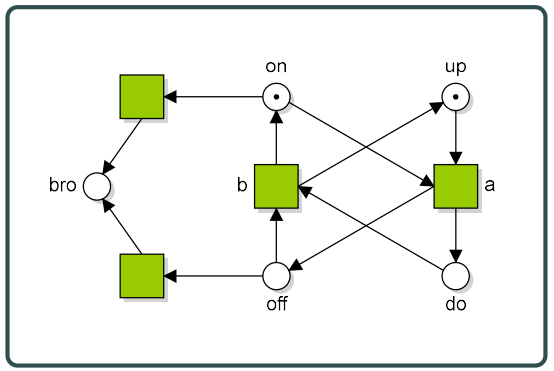
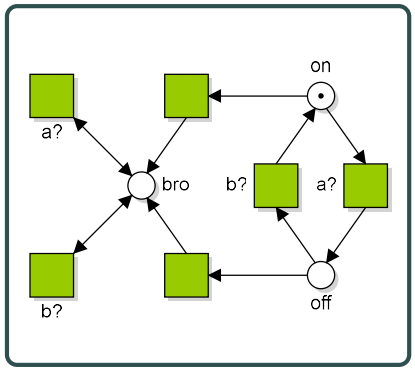
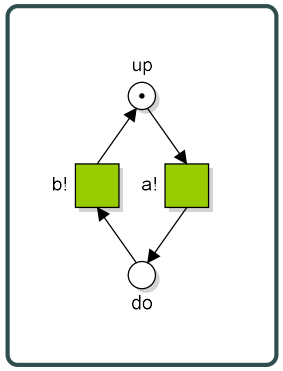


Switch

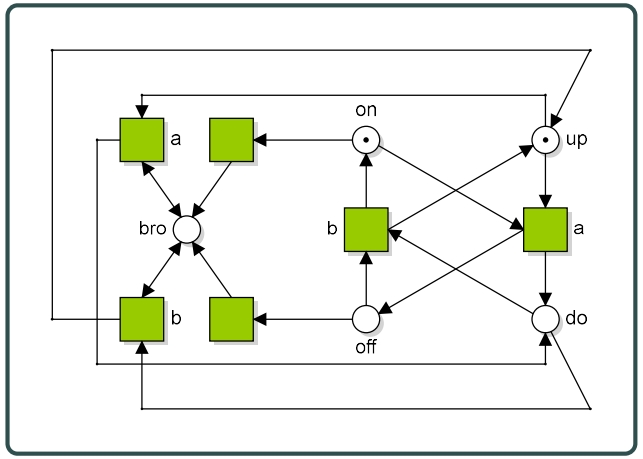




Lamp



Switch



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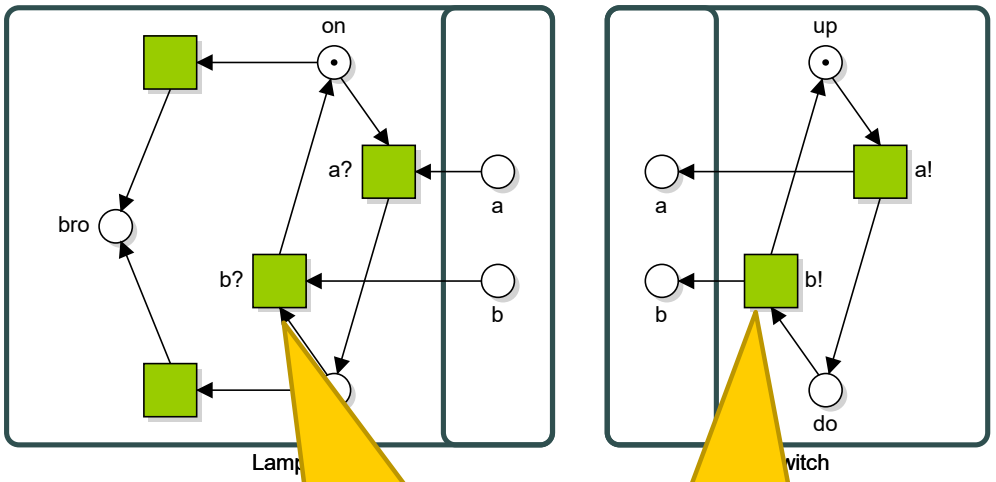
Back to our lamps: now as Petri nets
Asynchronous communication!



Transition receives a message by consuming a token from “message place” b

Transition sends a message by placing a token in the “message place” b

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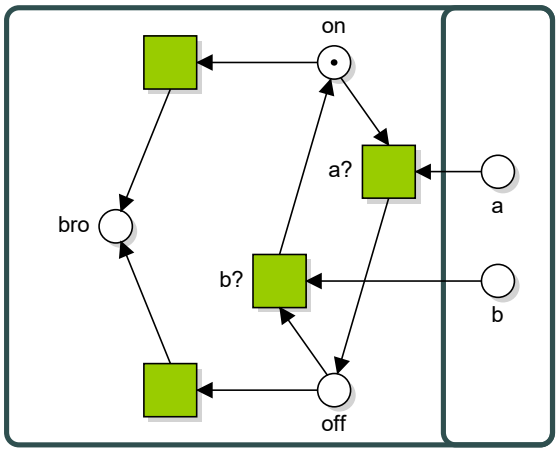
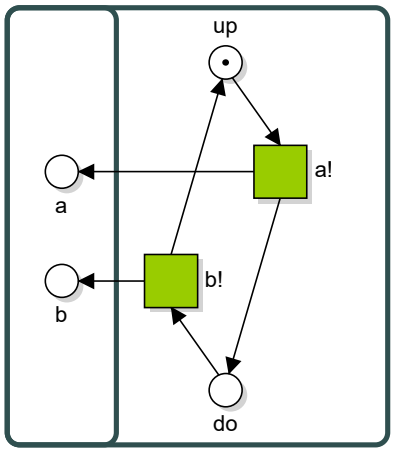
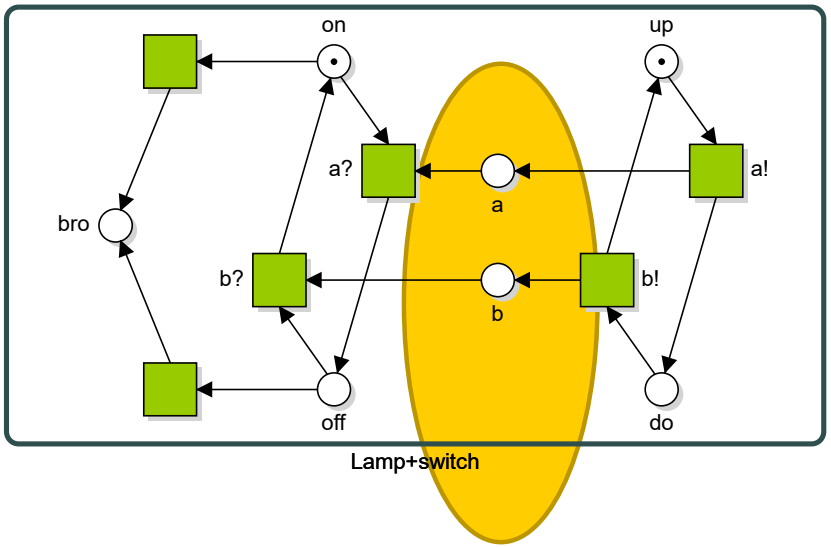
Back to our lamps: now as Petri nets
Asynchronous communication!



Lamp



Switch



Lamp+switch

Message buffers

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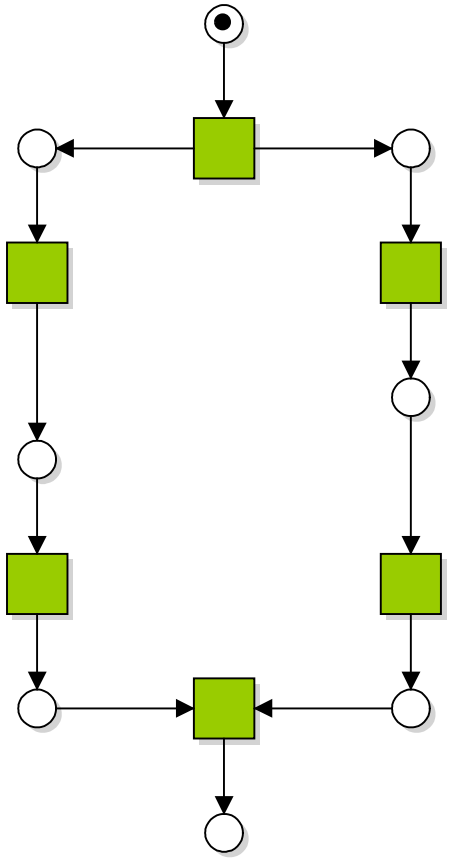
Petri nets and communication mechanisms



- Synchronous communication
  - **Transitions that consume from multiple places**
- Asynchronous communication
  - **Places resemble pools of messages to be handled**
  - **Random access of messages in these pools**

Both communication mechanisms in a single, **graphical** formalism!

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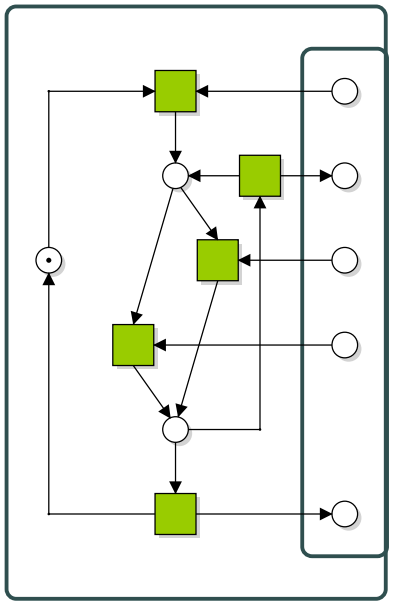
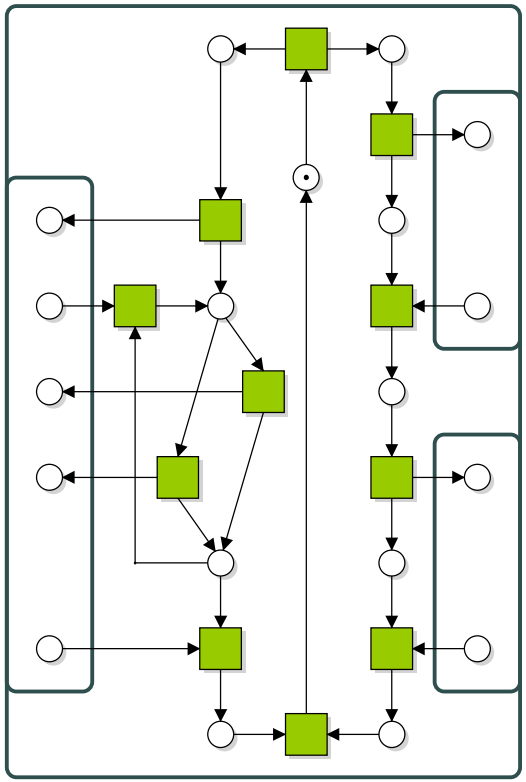
Teaser for next week:





- Modelling communication between components
- Different perspectives on message handling

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For the remainder of today:

- Work on the assignment

- Thursday: first presentation session!
  - ➔ **No need for a complete presentation**
  - ➔ **Schedule will be made available Thursday morning**

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