# Nondeterministic Available Services

# Nondeterminism in Available Services

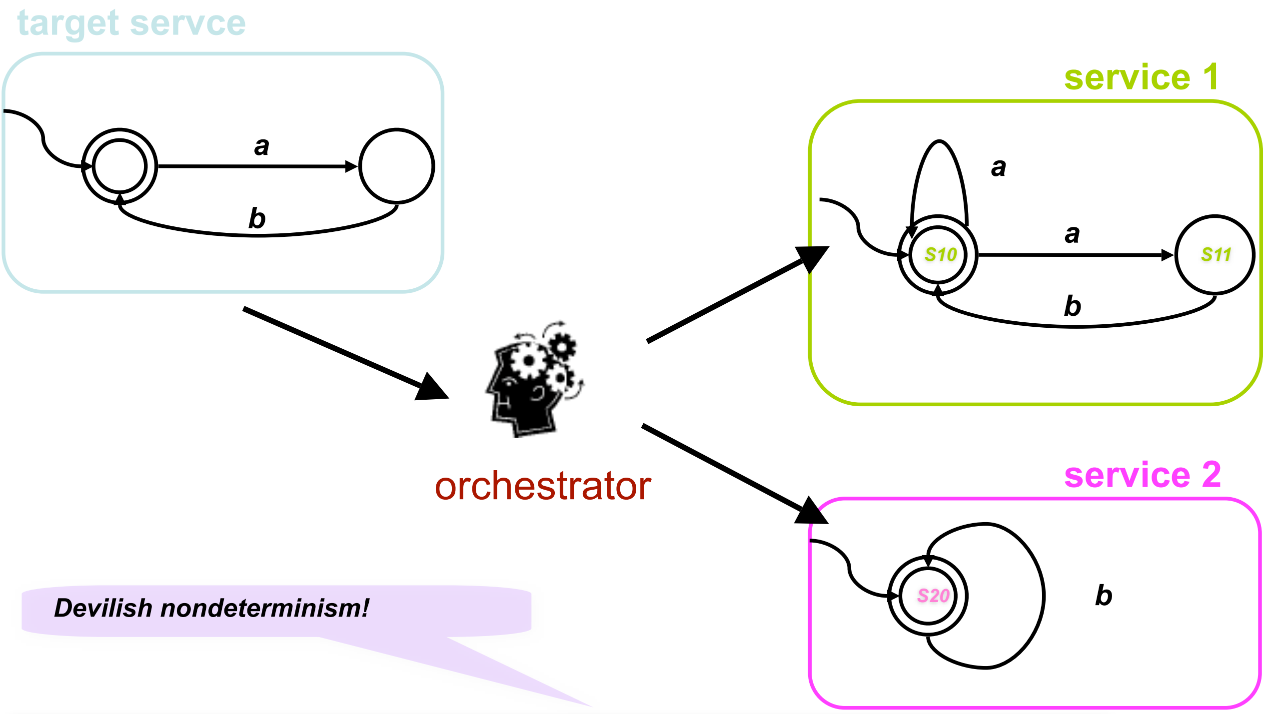
Devilish (don't know)!

- Nondeterministic available services
  - **Incomplete information** on the actual **behavior**
  - **Mismatch between behavior description** (which is in terms of the environment actions) and **actual behavior** of the agents/devices

- Deterministic target service
  - it's a spec of a desired service: (devilish) nondeterminism is banned

***In general, devilish nondeterminism difficult to cope with***
***eg. nondeterminism moves AI Planning from PSPACE (classical planning) to EXPTIME (contingent planning with full observability [Rintanen04])***

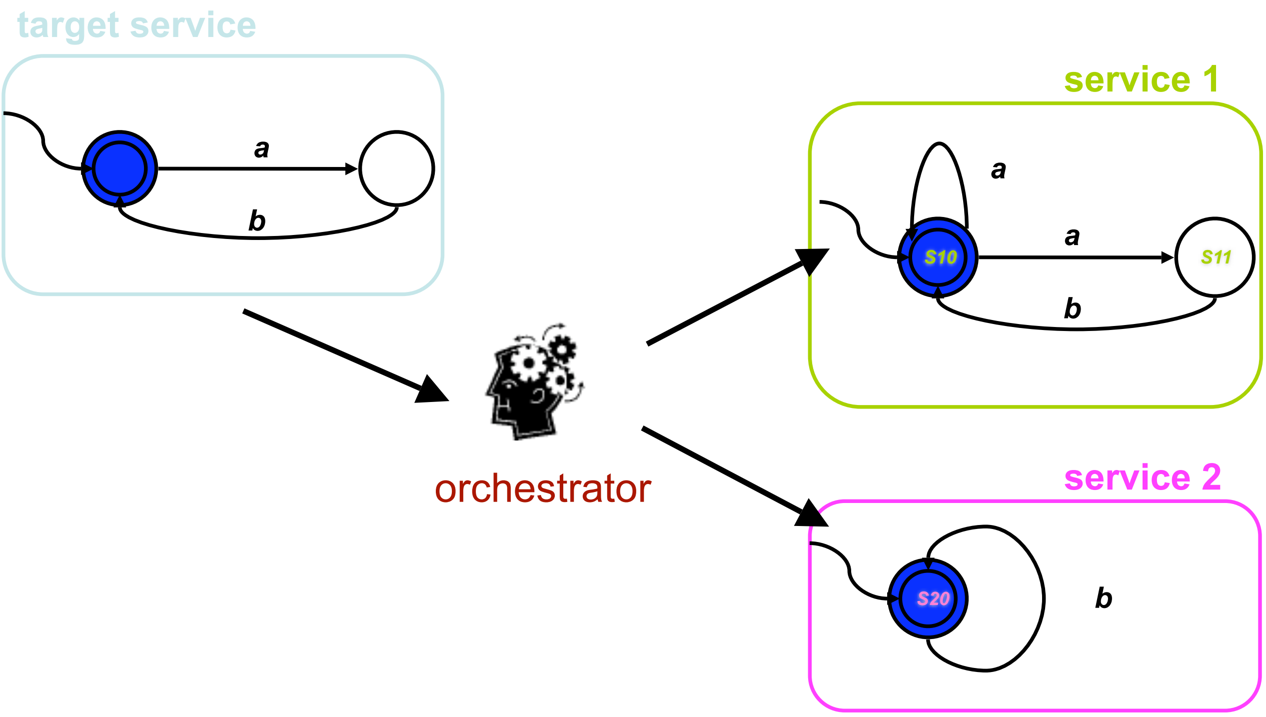
# Example: Nondeterministic Available Services




*Available services represented as nondeterministic transition systems*



# Example: Nondeterministic Available Services



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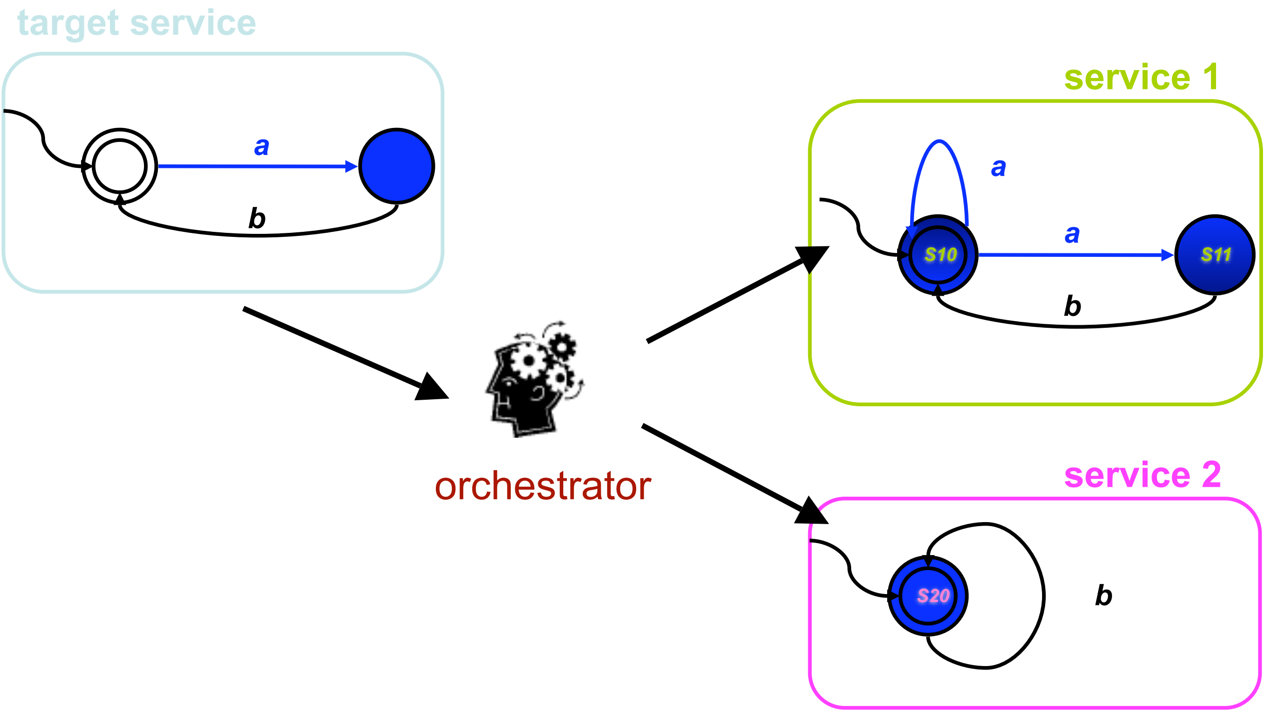




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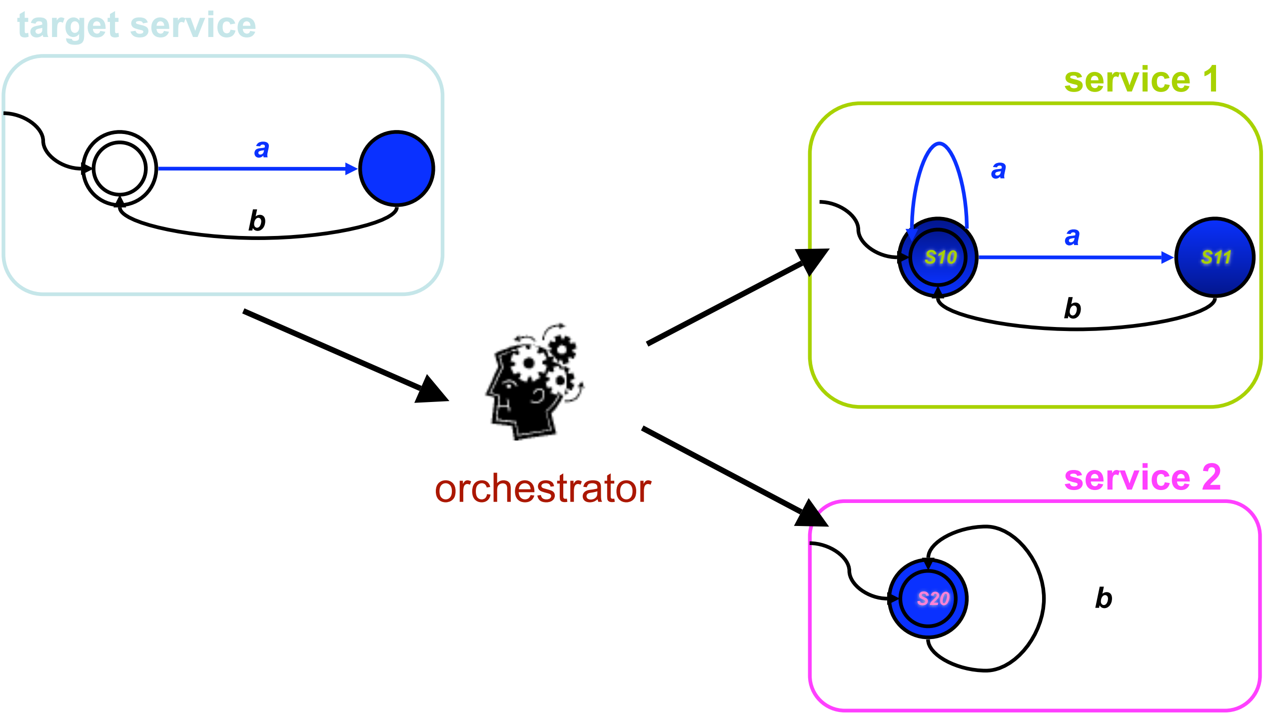

## Example: Nondeterministic Available Services

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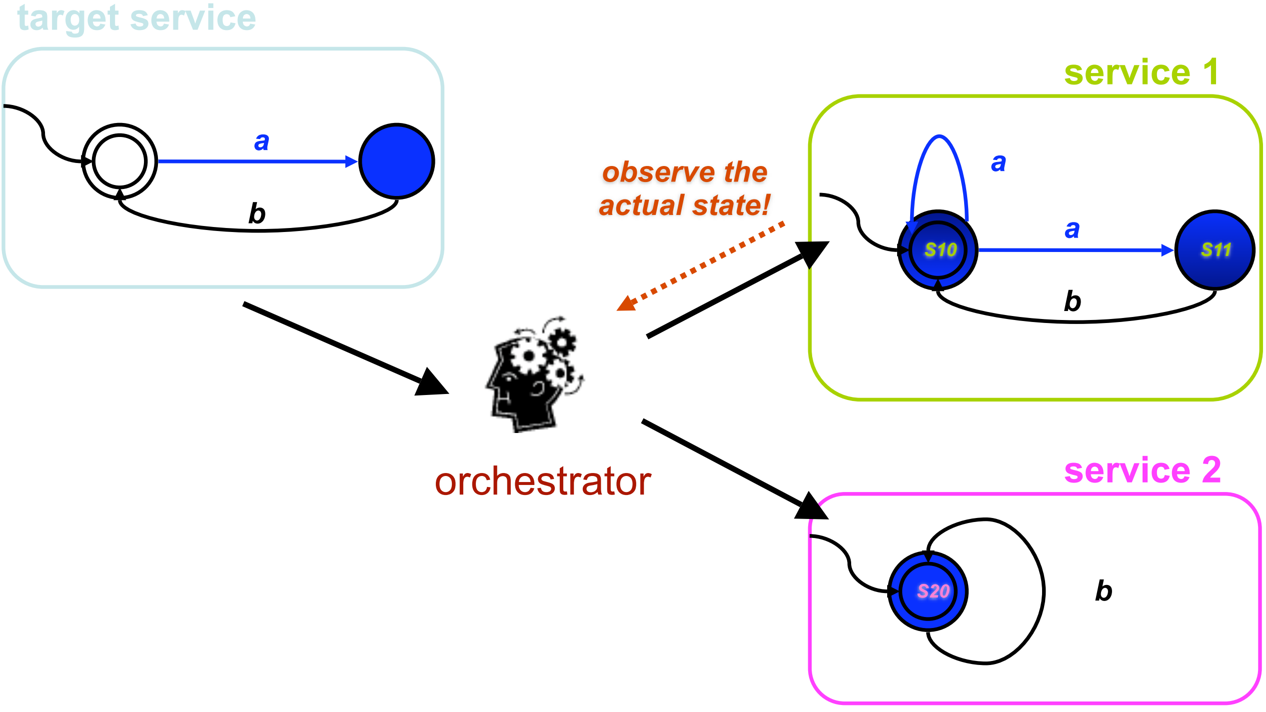




## Example: Nondeterministic Available Services

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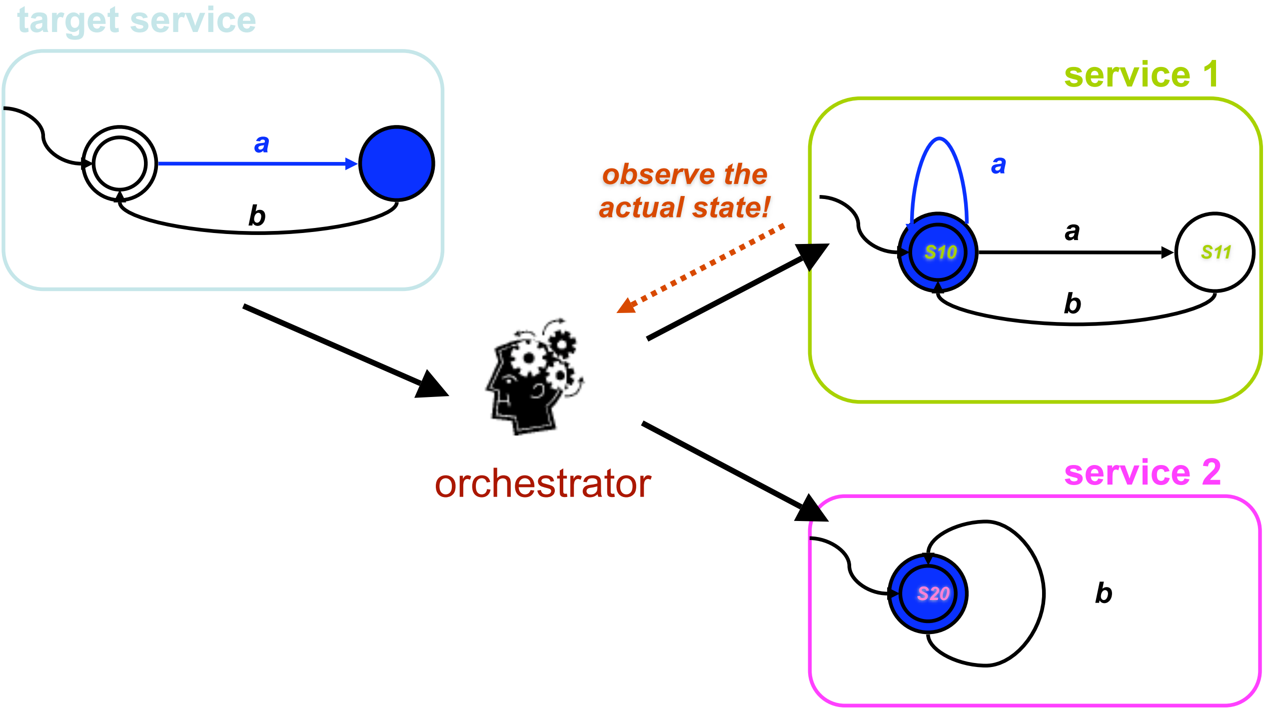
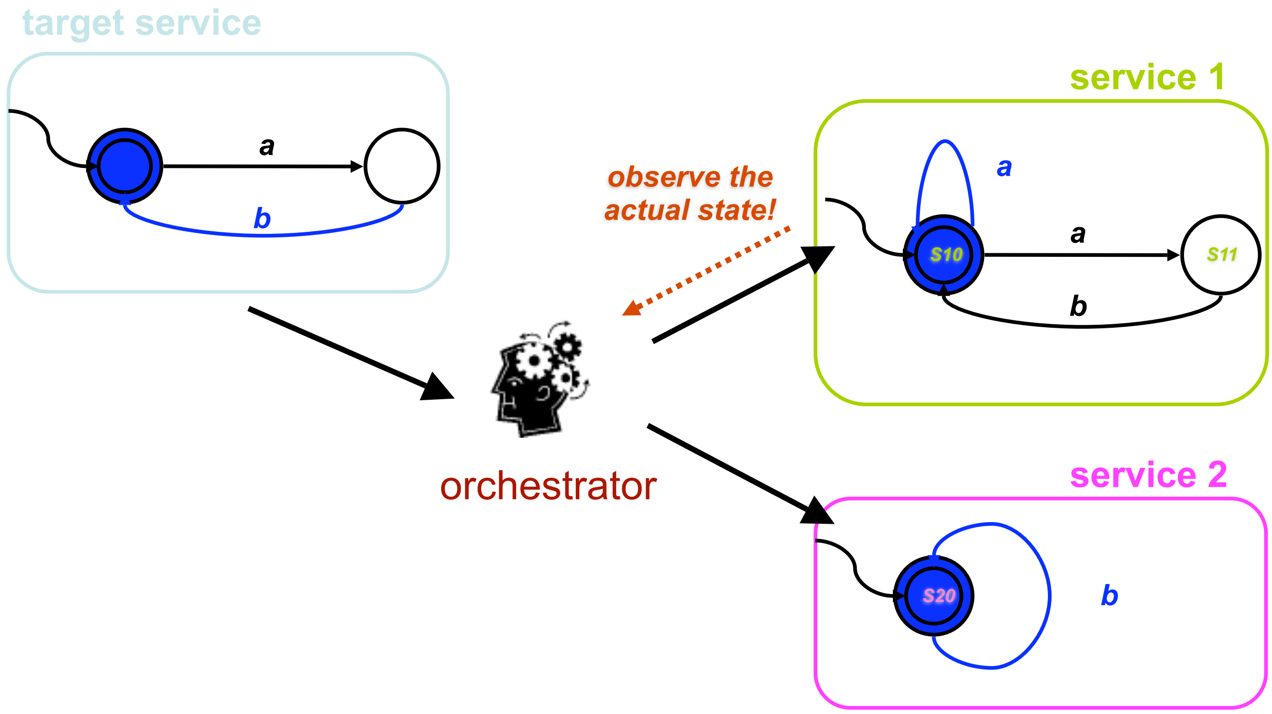
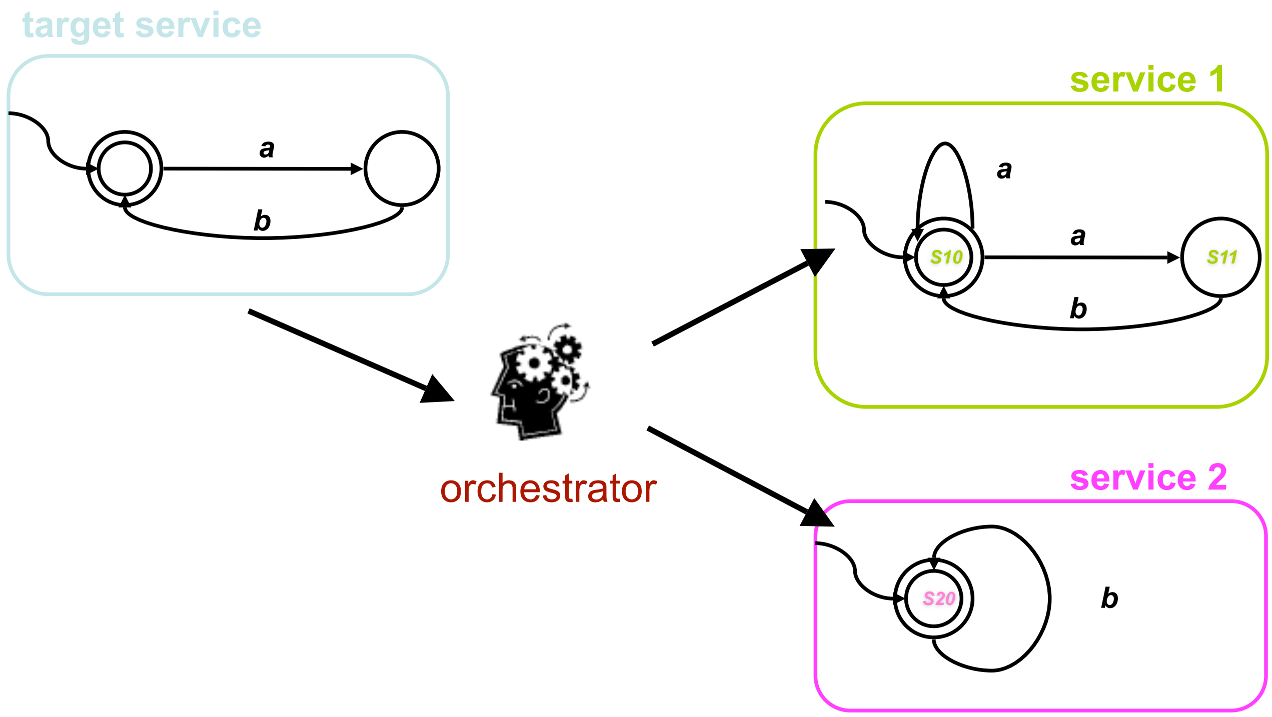


## *Example: Nondeterministic Available Services*

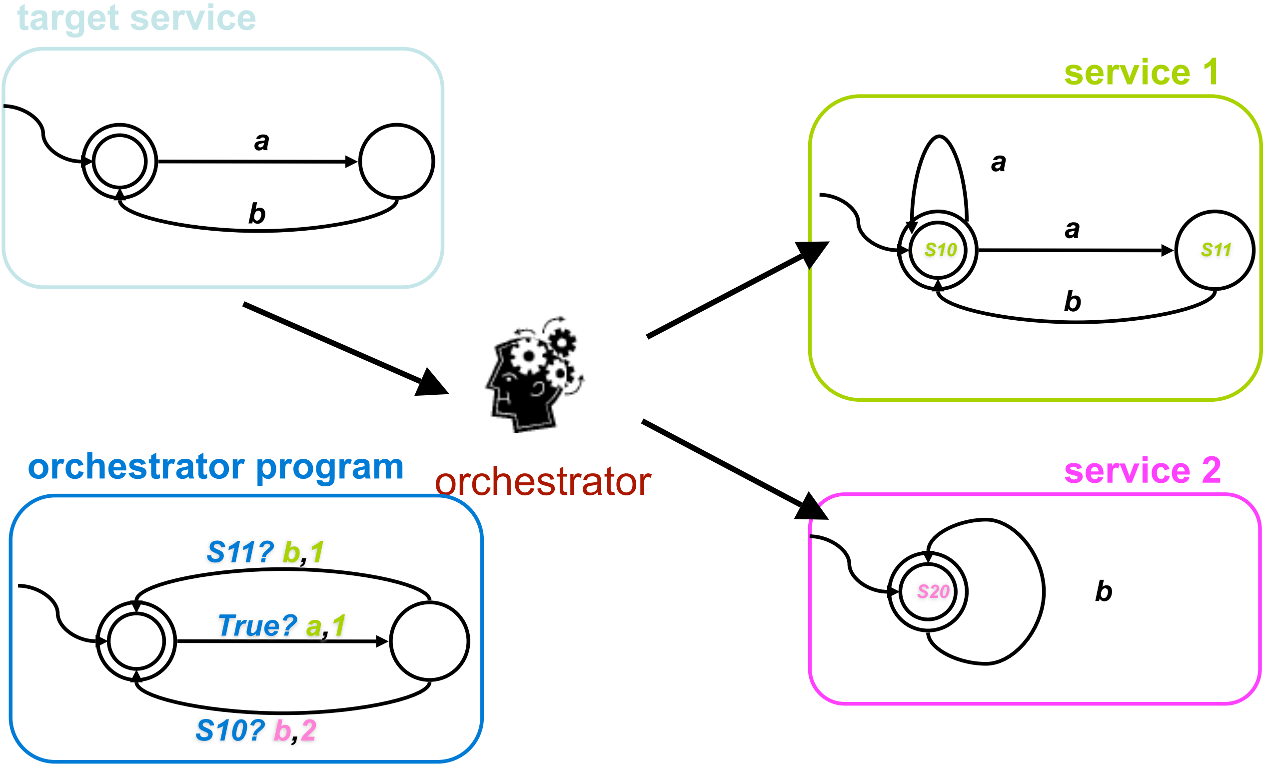





## *An Orchestrator Program Realizing the Target Service*



## An Orchestrator Program Realizing the Target Service



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# Orchestrator Programs

***contains all the observable information up the current situation***

- **Orchestrator program** is *any function P(h,a) = i* that takes a **history** *h* and an **action** *a* to execute and **delegates** *a* to one of the available services *i*

- A **history** is a sequence of the form, which alternate states of the available services with actions performed:

  $(s_1^0,s_2^0,\ldots,s_n^0)\ a_1\ (s_1^1,s_2^1,\ldots,s_n^1)\ \ldots\ a_k\ (s_k^1,s_2^k,\ldots,s_n^k)$

- Observe that to take a decision *P* has **full access to the past**, but no access to the future

- *Problem: synthesize a orchestrator program P that realizes the target service making use of the available services*

# Technique1: Reduction to PDL

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Basic idea:

- A orchestrator program *P* realizes the target service *T* iff at each point:
  - ∀ transition labeled *a* of the target service *T* …
  - … ∃ an available service $B_i$ (the one chosen by *P*) which can make an *a*-transition …
  - … and ∀ *a*-transition of $B_i$ realize the *a*-transition of *T*
- Encoding in PDL:
  - ∀ transition labeled *a* …
    use **branching**
  - ∃ an available service $B_i$ …
    use underspecified predicates **assigned through SAT**
  - ∀ *a*-transition of $B_i$ … :
    use **branching** again



# Technical Results: Theoretical

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**Thm[IJCAI'07]** Checking the existence of orchestrator program realizing the target service is **EXPTIME-complete**.

***EXPTIME-hardness due to Muscholl&Walukiewicz07 for deterministic services***

**Thm [IJCAI'07]** If a **orchestrator program exists** there exists one that is **finite state**.

***Exploits the finite model property of PDL***

***Note: same results as for deterministic services!***

# Technical Results: Practical

*Reduction to PDL provides also a practical sound and complete technique to compute the orchestrator program also in this case*

***eg, PELLET @ Univ. Maryland***

- Use state-of-the-art tableaux systems for OWL-DL for checking SAT of PDL formula $\Phi$ coding the composition existence
- *If SAT, the tableau returns a finite model of* $\Phi$

***exponential in the size of the behaviors***

- Project away irrelevant predicates from such model, and possibly minimize
- *The resulting structure is a finite orchestrator program that realizes the target behavior*

***polynomial in the size of the model***



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# Nondeterministic Available Services: Technique based on Composition via ND-Simulation

# Composition via ND-Simulation

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- We consider binary relations *R* satisfying the following co-inductive condition (ND-similarity):

  $(t,(s_1, .., s_n)) \in R$ implies that
  - if t is *final* then $s_i$, with i=1, .., n, is *final*
  - for **all** actions a
    - If $t \to_a t'$ then $\exists$ k $\in$ 1..n.
      - $\exists s_k' . s_k \to_a s_k'$
      - $\forall s_k'. s_k \to_a s_k' \supset (t',(,s_1,..,s_k', .., s_n)) \in R$

  *Note similar in the spirit to simulation relation!*
  *But more involved, since it deals with*

  - *the existential choice (as the simulation) of the service, and*
  - *the universal condition on the nondeterministic branches!*

- A composition realizing a target service TS $TS_t$ exists if there **exists** a relation *R* satisfying the above condition between the initial state $t^0$ of $TS_t$ and the initial state $(s_1^0, .., s_n^0)$ of the community big TS $TS_c$.

- Notice if we take the union of all such relation *R* then we get the largest relation ***RR*** satisfying the above condition.

- A composition realizing a target service TS T exists iff $(t^0 , (s_1^0, .., s_n^0)) \in$ ***RR***.



# Algorithm for ND-simulation

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**Algorithm** Compute (ND-)simulation

**Input:** target service T = $<A, S_T, t^0, \delta_T, F_T>$ and ..
available services $\mathcal{S}_i = <A, S_i, s_i^0, \delta_i, F_i>$ , i = 1,..,n

**Output:** the **simulated-by** relation ***RR*** (the largest simulation)

**Body**

R = $\emptyset$

R' = $S_T \times S_1 \times .. \times S_n$

while (R ≠ R') {

R := R'

R' := R' - $\{(t, s_1,..,s_n) \mid \exists\, t \to_a t'$ in T $\wedge\ \neg\exists$ k = 1,..,n s.t.
$(\exists\, s_k \to_a s_k' \wedge \forall\, s_k \to_a s'_k \supset (t', s_1,..,s'_k,..,s_n) \in R')\}$

}

return R'

**End**

# Composition via ND-Simulation

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- Given the maximal ND-simulation ***RR*** form $TS_t$ to $TS_c$ (which includes the initial states), we can build the ***orchestrator generator***.
- This is an orchestrator program that can change its behavior reacting to the information acquired at run-time.
- Def: OG = $< A, [1,\ldots,n], S_r, s_r^0, \omega_r, \delta_r, F_r >$ with
  - A : the **actions** shared by the community
  - [1,…,n]: the **identifiers** of the available services in the community
  - $S_r = S_t \times S_1 \times \cdots \times S_n$ : the **states** of the orchestrator program
  - $s_r^0 = (s^0_t, s^0_1, \ldots, s^0_m)$ : the **initial state** of the orchestrator program
  - $F_r \subseteq \{ (s_t, s_1, \ldots, s_n) \mid s_t \in F_t$ : the **final states** of the orchestrator program
  - $\omega_r : S_r \times A_r \to [1,\ldots,n]$ : the **service selection function**, defined as follows:

    **$\omega_r(t, s_1,..,s_n, a)$ = { i | $TS_t$** and **$TS_i$** can do **a** and remain in **RR}**

    i.e. …={i | $s_t \to_a s'_t \wedge \exists s_i'.\ s_i \to_a s_i' \wedge \forall s_i'.\ s_i \to_a s_i' \supset (s_t', (s_1, \ldots, s_i', \ldots, s_n)) \in$ ***RR***}
  - $\delta_r \subseteq S_r \times A_r \times [1,\ldots,n] \times S_r$ : the **state transition relation**, defined as follows:
    - Let $k \in \omega_r(s_t, s_1, \ldots, s_k, \ldots, s_n, a)$ then
      $(s_t, s_1, \ldots, s_k, \ldots, s_n) \to_{a,k} (s_t', s_1, \ldots, s'_k, \ldots, s_n)$ for each $s_k \to_a s'_k$



# Composition ND-Simulation

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- Computing ***RR*** is polynomial in the size of the target service TS and the size of the community TS…
- ... composition can be done in EXPTIME in the size of the available services

- For generating OG we need only to compute ***RR*** and then apply the template above

- For running the OG we need to store and access ***RR*** *(polynomial time, exponential space)* …
- … and compute $\omega_r$ and $\delta_r$ at each step *(polynomial time and space)*

# Example of Composition

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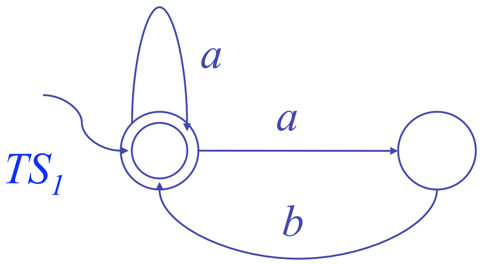
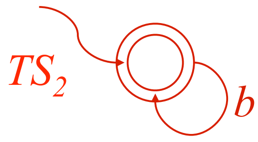
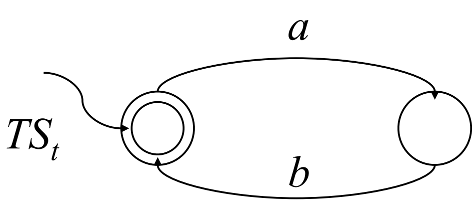
## Available Services




## Target Service






# Example of Composition

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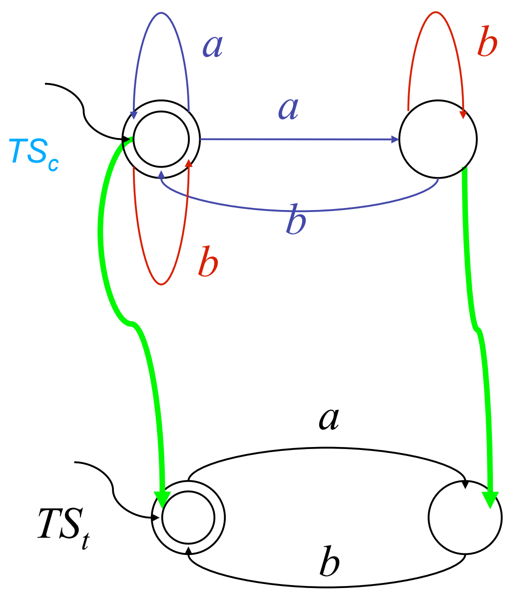
## Community TS

## Target Service




**Composition exists!**

# Failures

- Available services may become unexpectedly unavailable for various reasons. We consider four kinds of behavioral failures:
  - A service **temporarily freezes**; it will eventually resume in the same state it was in;
  - A service unexpectedly and arbitrarily (i.e., without respecting its transition relation) **changes its current state**;
  - A **service dies**; that is, it becomes permanently unavailable;
  - A dead service unexpectedly comes **alive again** (this is an opportunity more than a failure).



# Just-in-time composition

- Once we have the controller generator ...
- ... we can **avoid choosing any particular composition** apriori ...
- ... and **use directly** $\omega r$ to choose the available behavior to which delegate the next action.
- We can be ***lazy*** and make such choice ***just-in-time***, possibly adapting reactively to ***runtime*** feedback.

# Parsimonious failure recovery (1)

**Algorithm** Computing ND-simulation - parameterized version

**Input:** - target service $T = \langle A, S_T, t^0, \delta_T, F_T \rangle$

- available services $\mathcal{S}_i = \langle A, S_i, s_i^0, \delta_i, F_i \rangle$ , $i = 1,..,n$
- relation $\mathbf{R_{raw}}$ including the simulated-by relation
- relation $\mathbf{R_{sure}}$ included the simulated-by relation

**Output:** the **simulated-by** relation (the largest simulation)

**Body**

$Q = \emptyset$

$Q' = \mathbf{R_{raw}} - \mathbf{R_{sure}}$ //Note $R' = Q' \cup \mathbf{R_{sure}}$

while $(Q \neq Q')$ {

$Q := Q'$

$Q' := Q' - \{(t, s_1,..,s_n) \mid \exists\, t \rightarrow_a t'$ in $T \wedge \neg\exists\, k = 1,..,n$ s.t.

$(\exists\, s_k \rightarrow_a s_k' \wedge \forall\, s_k \rightarrow_a s'_k \supset (t', s_1,..,s'_k,..,s_n) \in Q' \cup \mathbf{R_{sure}})\}$

}

return $Q' \cup \mathbf{R_{sure}}$

**End**



# Parsimonious failure recovery (2)

- Let $[1,.., n] = W \cup F$ be the available services.
- Let $\boldsymbol{R}_{W \cup F}$ be the **simulated-by** relation of target by services $W \cup F$.
- Then the following holds:

⑩ $\boldsymbol{R}_W \subseteq \Pi_W(\boldsymbol{R}_{W \cup F})$

  - $\Pi_W(\boldsymbol{R}_{W \cup F})$ is the **projection on W** of a relation: easy to compute
  - *Note:* $\Pi_W(\boldsymbol{R}_{W \cup F})$ *is not a simulation of target by services W*

- $\boldsymbol{R}_W \times F \subseteq \boldsymbol{R}_{W \cup F}$
  - $\boldsymbol{R}_W \times F$ is the **cartesian product** of 2 relations (F is trivial): easy to compute
  - *Note:* $\boldsymbol{R}_W \times F$ *is a simulation of target by services* $W \cup F$

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# Extension to the Roman Model

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# Parsimonious failure recovery (3)

- If **services F die**
  compute simulated-by $\boldsymbol{R}_W$ with $\mathbf{R_{raw}} = \Pi_W(\boldsymbol{R}_{W \cup F})$ !

- If **dead services F** come back
  compute simulated-by $\boldsymbol{R}_{W \cup F}$ with $\mathbf{R_{sure}} = \boldsymbol{R}_W \times F$ !

- Remember:
  - $\boldsymbol{R}_W \subseteq \Pi_W(\boldsymbol{R}_W \cup F)$
  - $\boldsymbol{R}_W \times F \subseteq \boldsymbol{R}_W \cup F$ and $\boldsymbol{R}_W \times F$ is a simulation of target by services WUF

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# Extensions

- **Nondeterministic** (angelic) **target** specification
  - Loose specification in client request
  - **Angelic (don't care)** vs devilish (don't know) nondeterminism
  - See [ICSOC'04]
- **Distributing** the orchestration
  - Often a centralized orchestration is unrealistic: eg. services deployed on mobile devices
    - too tight coordination
    - too much communication
    - orchestrator cannot be embodied anywhere
  - Drop centralized orchestrator in favor of **independent controllers** on single available services (exchanging messages)
  - Under suitable conditions: a distributed orchestrator exists iff a centralized one does
  - Still decidable (EXPTIME-complete)
  - See [AAAI'07]

*See later*

- Dealing with **data**
  - This is the single most difficult issue to tackle
    - First results: actions as DB updates, see [VLDB'05]
    - Literature on Abstraction in Verification
  - From finite to **infinite transition** systems!
- **Security and trust** aware composition [SWS'06]
- Automatic **Workflows** Composition of Mobile Services [ICWS'07]



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