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Transition Systems and Service Composition

Giuseppe De Giacomo

Coodination of Web Services - Models, Methods and Tools

INFWEST Seminar Tampere, June 5-7, 2007

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Transition Systems

Concentrating on behaviors: SUM two integers

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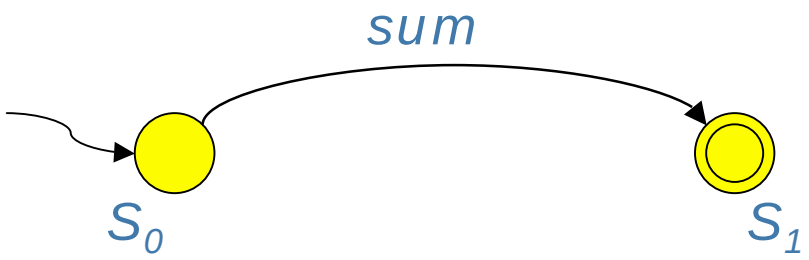
- Consider a program for computing the sum of two integers.
- Such a program has essentially two states
  - the state S_0 of the memory before the computation: including the two number to sum
  - the state S_1 of the memory after the computation: including the result of the computation
- Only one action, i.e. "*sum*", can be performed



Concentrating on behaviors: CheckValidity

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- Consider a program for computing the validity of a FOL formula:

- Also such a program has essentially two states
  - the state S_1 of the memory before the computation: including the formula to be checked
  - the state S_2 of the memory after the computation: including "yes", "no", "time-out"
- Only one action, i.e. "*checkValidity*", can be performed

Concentrating on behaviors

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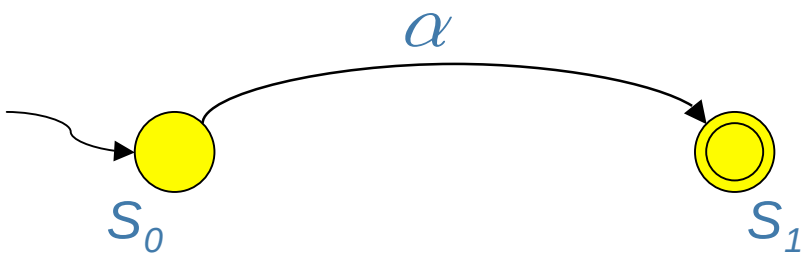
- The programs SUM and CheckValidity are very different from a computational point of view.
  - SUM is trivial
  - CheckValidity is a theorem prover hence very complex
- However they are equally trivial from a behavioral point of view:
  - two states S_1 and S_2
  - a single action α causing the transition



Concentrating on behaviors: RockPaperScissor

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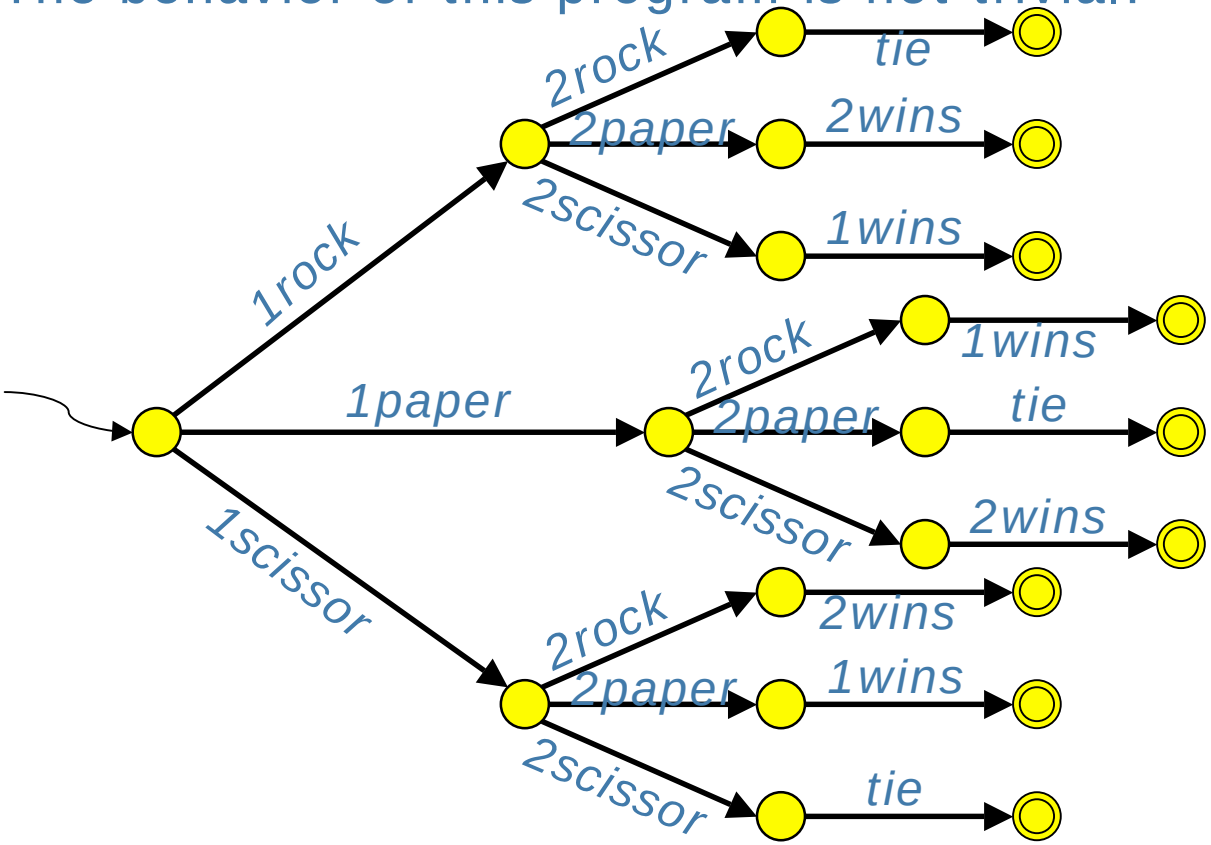
- Consider the program RockPaperScissor that allows to play two players the the well-known game.
- The behavior of this program is not trivial:



Concentrating on behaviors: RockPaperScissor (automatic)

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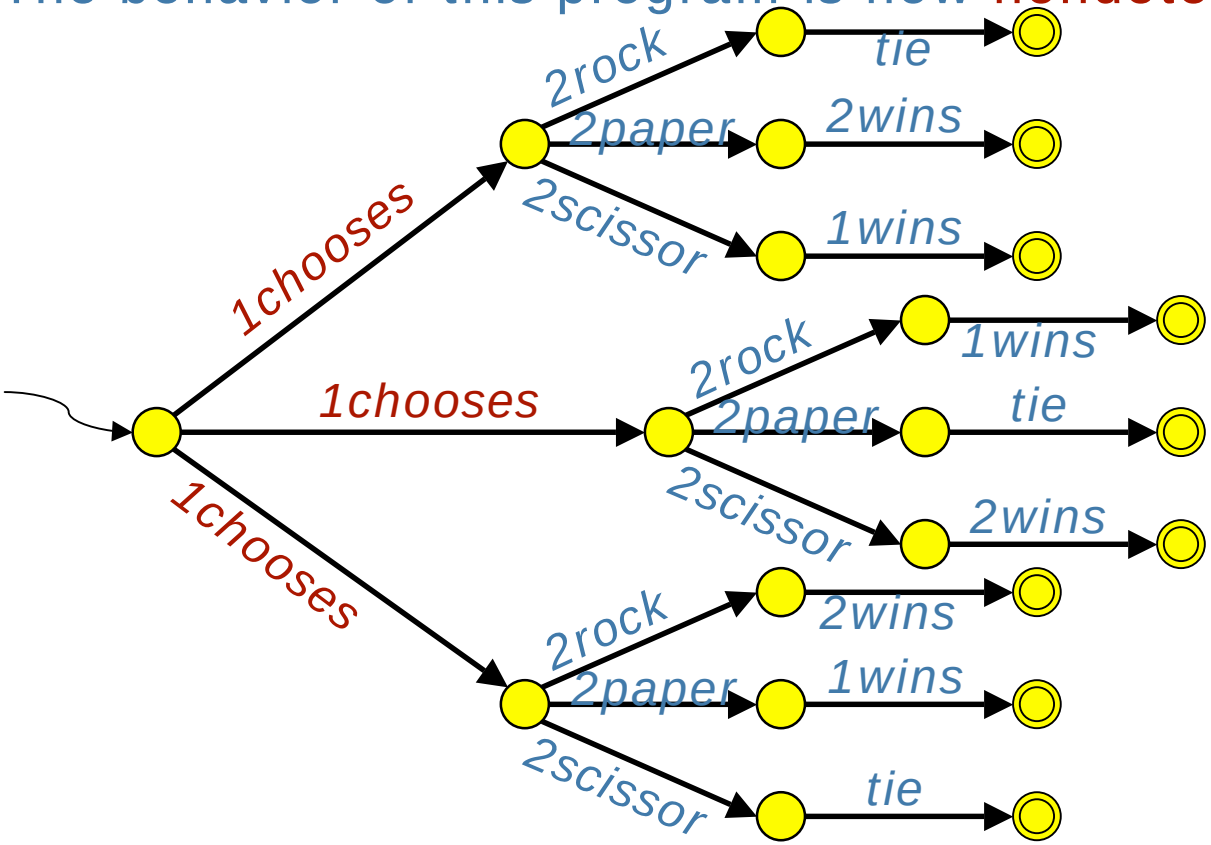
- Consider a variant of the program RockPaperScissor that allows one players to play against the computer.
- The behavior of this program is now nondeterministic:



Concentrating on behaviors: WebPage

http://www.informatik.uni-trier.de/~ley/db/

A web page can have a complex behavior!

dblp.uni-trier.de

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Concentrating on behaviors: Vending Machine

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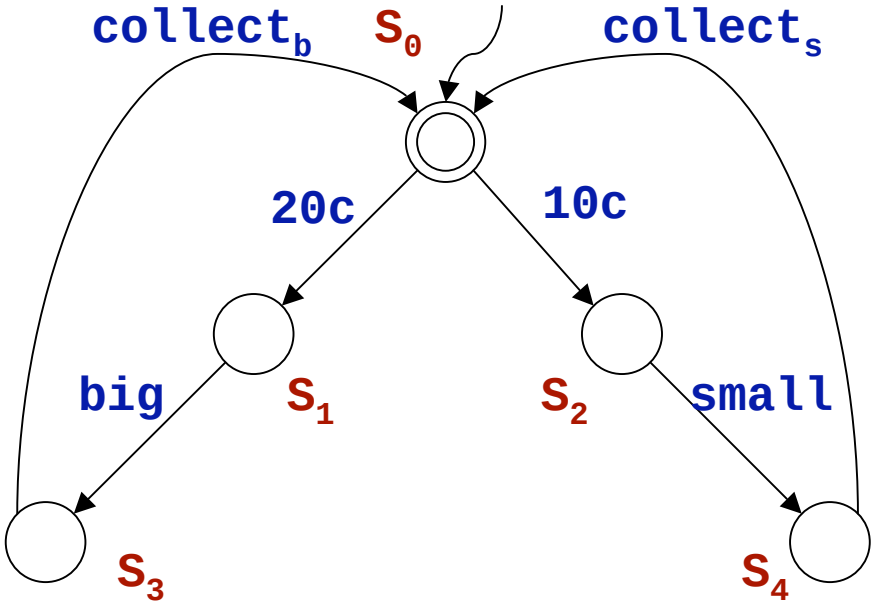

Concentrating on behaviors: Another Vending Machine

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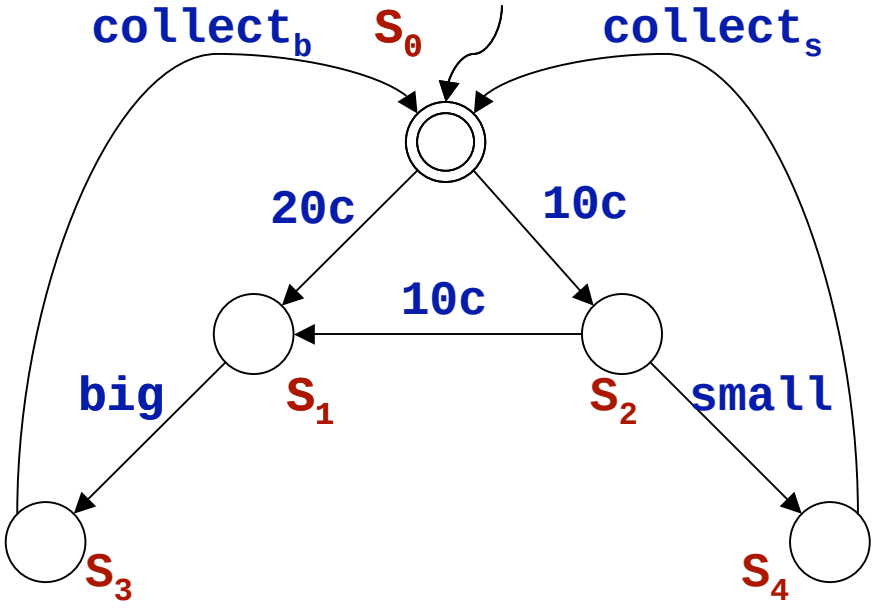

Concentrating on behaviors: Vending Machine with Tilt

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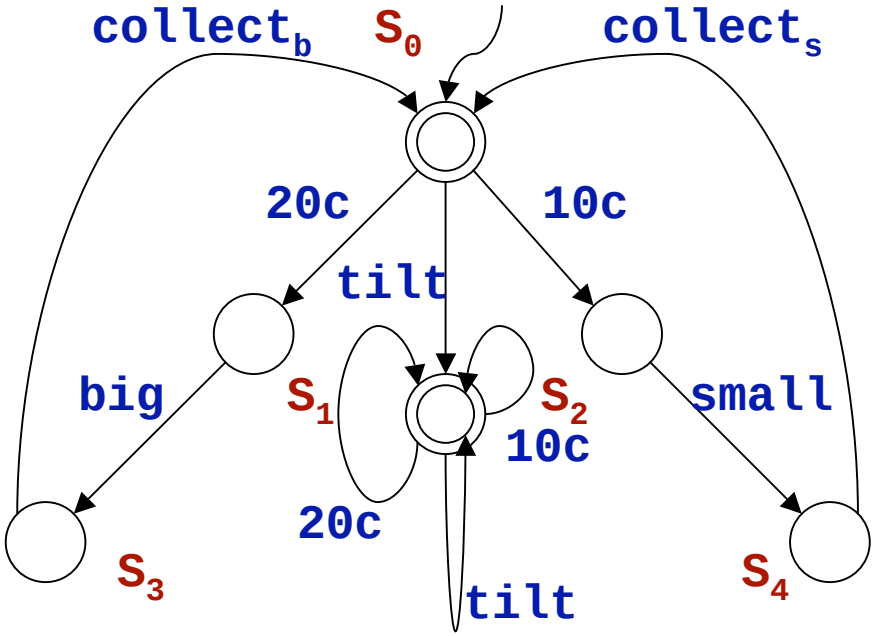

Transition Systems

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- A transition system TS is a tuple $T = < A, S, S^0, \delta, F>$ where:
  - A is the set of actions
  - S is the set of states
  - $S^0 \subseteq S$ is the set of initial states
  - $\delta \subseteq S \times A \times S$ is the transition relation
  - $F \subseteq S$ is the set of final states

- Variants:
  - No initial states *(c.f. Kripke Structure)*
  - Single initial state
  - Deterministic actions
  - States labeled by propositions other than Final/¬Final

Process Algebras are Formalisms for Describing TS

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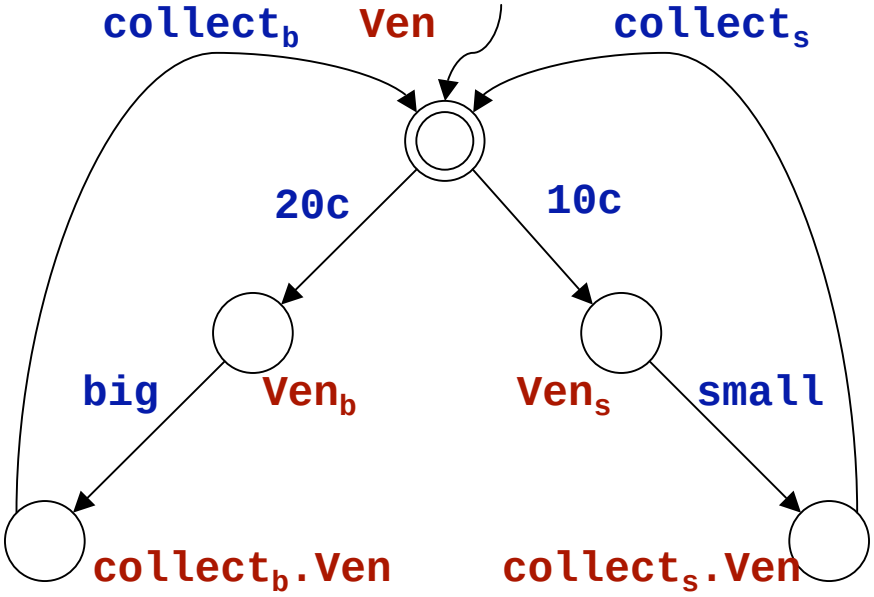
- Trans (a la CCS)
  - $Ven = 20c.Ven_b + 10c.Ven_s$
  - $Ven_b = big.collect_b.Ven$
  - $Ven_l = small.collect_s.Ven$
- Final
  - $\surd$ Ven



- *TS may have infinite states - e.g., this happens when generated by process algebras involving iterated concurrency*
- *However we have good formal tools to deal only with finite states TS*

Example (Clock)

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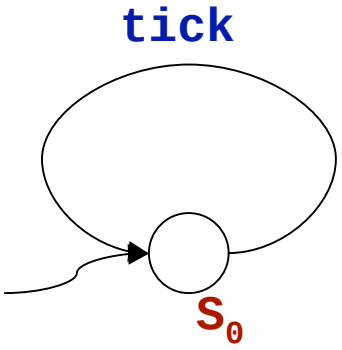
TS may describe (legal) nonterminating processes



Example (Slot Machine)

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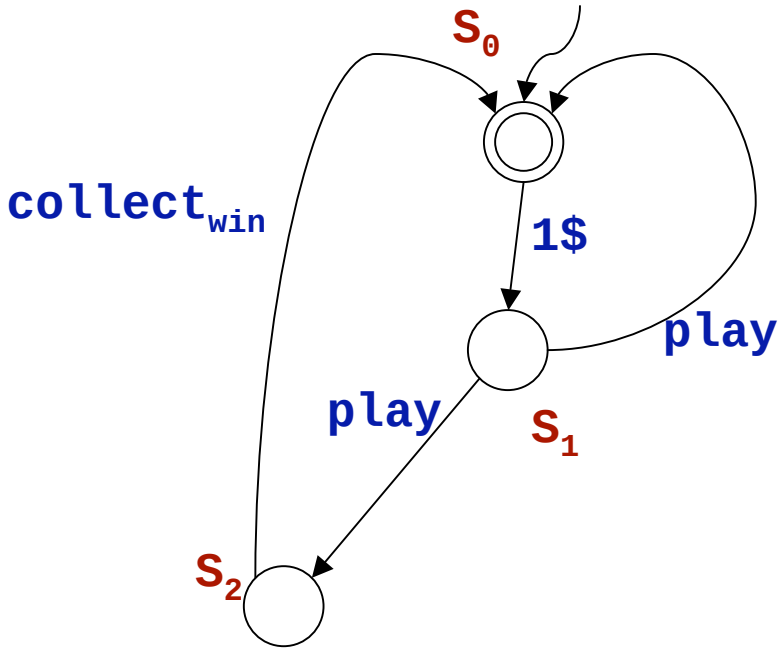
Nondereminisic transitions express
choice that is not under the control of clients



Example (Vending Machine - Variant 1)

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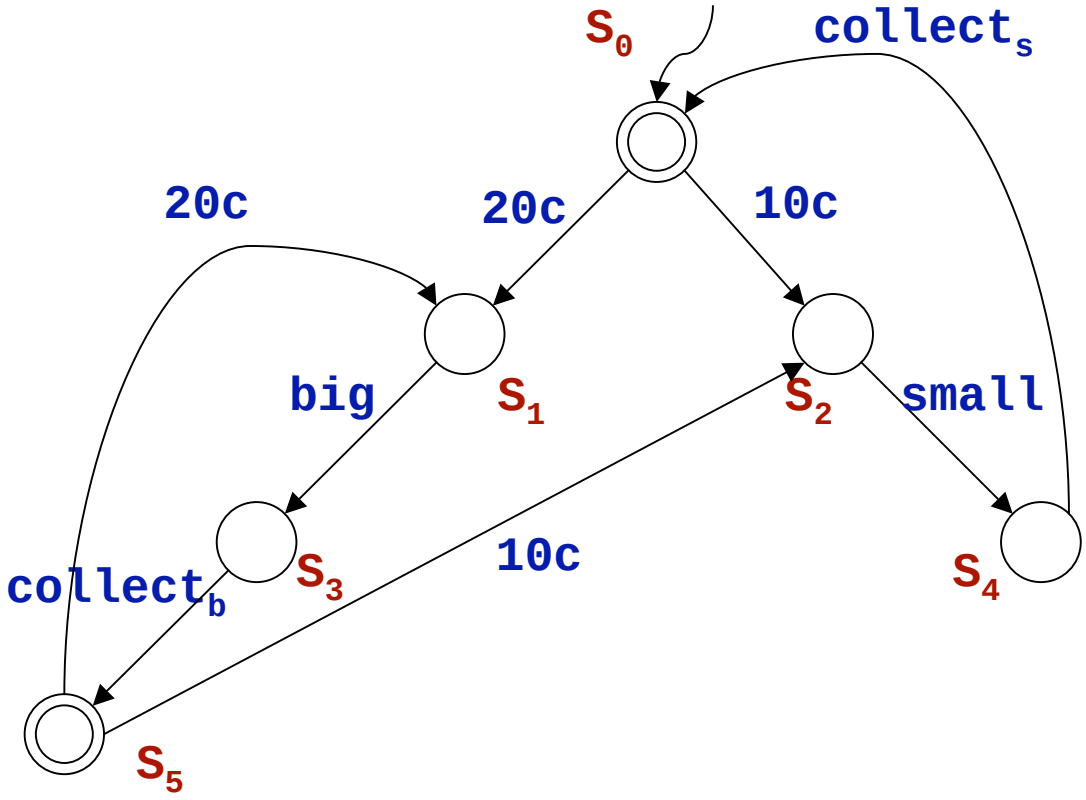

Example (Vending Machine - Variant 2)

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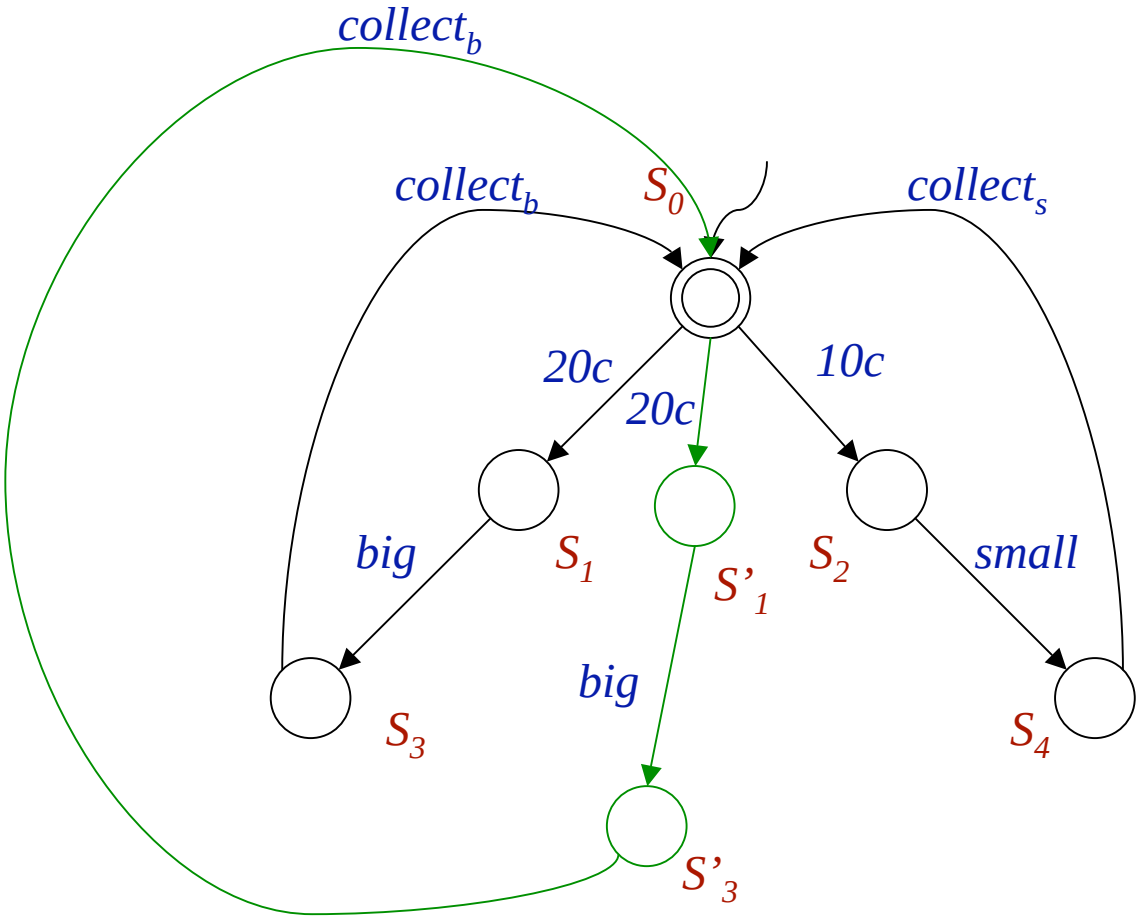

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Inductive vs Coinductive Definitions: Reachability, Bisimilarity, ...

Reachability

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- A binary relation R is a **reachability-like relation** iff:
  - $(s,s) \in R$
  - if $\exists$ a. s'. $s \rightarrow_a s' \wedge (s',s'') \in R$ then $(s,s'') \in R$
- A state s_0 of transition system S is **reachable-from** a state s_f iff for **all** a **reachability-like relations** R we have $(s_0, s_f) \in R$.
- Notably that
  - **reachable-from** is a reachability-like relation itself
  - **reachable-from** is the smallest reachability-like relation

Note it is a inductive definition!

Computing Reachability on Finite Transition Systems

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Algorithm ComputingReachability

Input: transition system TS
Output: the **reachable-from** relation (the smallest reachability-like relation)

Body
R = ∅
R' = {(s,s) | s ∈ S}
while (R ≠ R') {
R := R'
R' := R' ∪ {(s,s'') | ∃ s',a. s $\rightarrow_a$ s' ∧ (s',s'')∈ R }
}
return R'
YdoB

Bisimulation

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- A binary relation R is a **bisimulation** iff:

  $(s,t) \in R$ implies that
  - s is *final* iff t is *final*
  - for all actions a
    - if $s \rightarrow_a s'$ then $\exists\, t' \,.\, t \rightarrow_a t'$ and $(s',t') \in R$
    - if $t \rightarrow_a t'$ then $\exists\, s' \,.\, s \rightarrow_a s'$ and $(s',t') \in R$

- A state s_0 of transition system S is **bisimilar**, or simply **equivalent,** to a state t_0 of transition system T iff there **exists** a **bisimulation** between the initial states s_0 and t_0.

- Notably
  - **bisimilarity** is a bisimulation
  - **bisimilarity** is the largest bisimulation

Note it is a co-inductive definition!

Computing Bisimilarity on Finite Transition Systems

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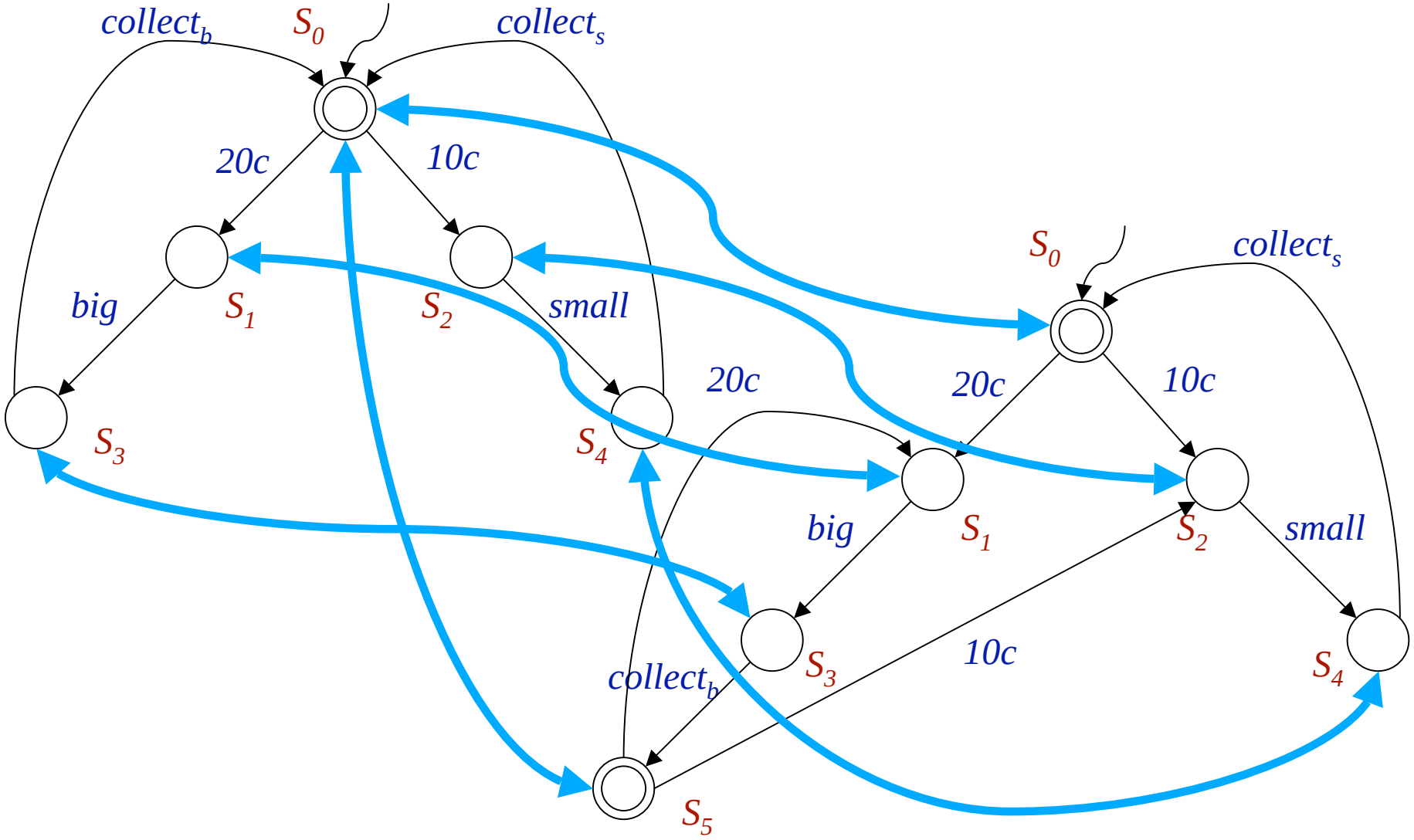
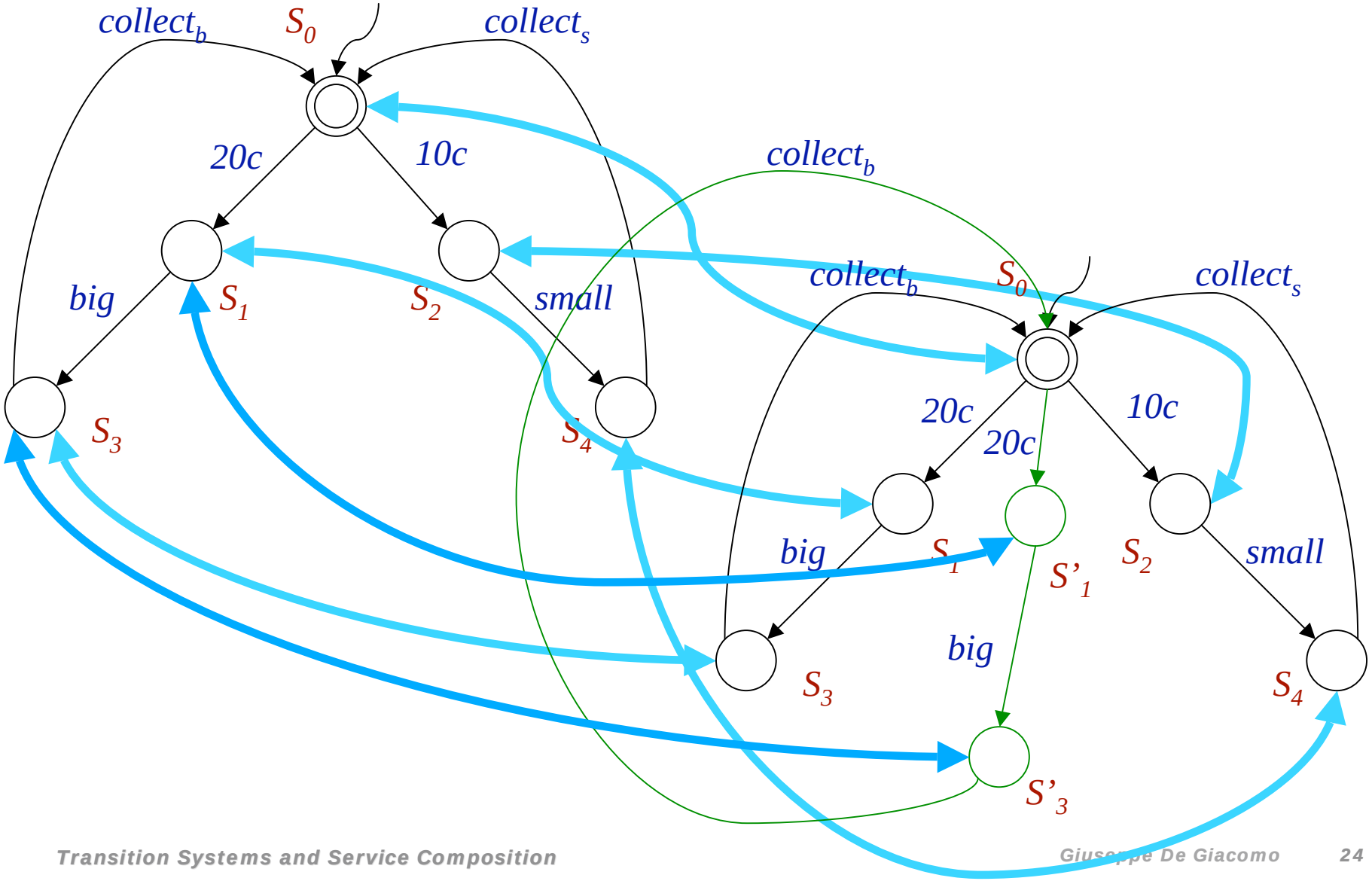
Algorithm ComputingBisimulation
Input: transition system $TS_S = < A, S, S^0, \delta_S, F_S >$ and
transition system $TS_T = < A, T, T^0, \delta_T, F_T >$
Output: the **bisimilarity** relation (the largest bisimulation)

Body
$R = \emptyset$
$R' = S \times T - \{(s,t) \mid \neg(s \in F_S \equiv t \in F_T)\}$
while $(R \neq R')$ {
$R := R'$
$R' := R' - (\{(s,t) \mid \exists s',a.\ s \rightarrow_a s' \wedge \neg\exists t' .\ t \rightarrow_a t' \wedge (s',t') \in R' \}$
$\{(s,t) \mid \exists t',a.\ t \rightarrow_a t' \wedge \neg\exists s' .\ s \rightarrow_a s' \wedge (s',t') \in R' \})$
}
return R'
Ydob

Example of Bisimulation

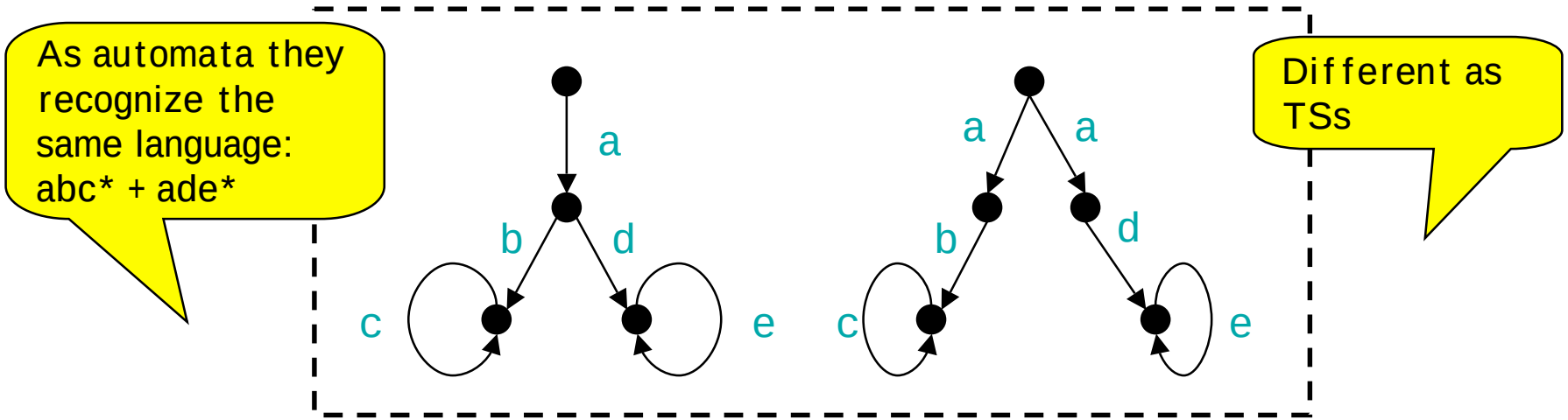


Example of Bisimulation



Automata vs.Transition Systems

- Automata
  - define sets of runs (or traces or strings): (finite) length sequences of actions
- TSs
  - … but I can be interested also in the alternatives “encountered” during runs, as they represent client’s “choice points”



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Logics of Programs

Logics of Programs

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- Are modal logics that allow to describe properties of transition systems
- Examples:
  - HennesyMilner Logic
  - Propositional Dynamic Logics
  - Modal (Propositional) Mu-calculus
- Perfectly suited for describing transition systems: they can tell apart transition systems modulo bisimulation

HennessyMilner Logic

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- $\Phi := P \mid$ *(atomic propositions)*
  $\neg \Phi \mid \Phi_1 \wedge \Phi_2 \mid \Phi_1 \vee \Phi_2 \mid$ *(closed under boolean operators)*
  $[a]\Phi \mid \langle a \rangle \Phi$ *(modal operators)*

- Propositions are used to denote final states

- $\langle a \rangle \Phi$ means there exists an a-transition that leads to a state where Φ holds; i.e., expresses the capability of executing action a bringing about Φ

- $[a]\Phi$ means that all a-transitions lead to states where Φ holds; i.e., express that executing action a brings about Φ

Logics of Programs: Examples

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- Usefull abbreviation:
  - $\langle any \rangle \Phi$ stands for $\langle a_1 \rangle \Phi \vee L \vee \langle a_n \rangle \Phi$
  - $[any] \Phi$ stands for $[a_1] \Phi \wedge L \wedge [a_n] \Phi$
  - $\langle any - a_1 \rangle \Phi$ stands for $\langle a_2 \rangle \Phi \vee L \vee \langle a_v \rangle \Phi$
  - $[any - a_1] \Phi$ stands for $[a_2] \Phi \wedge L \wedge [a_v] \Phi$

- Examples:
  - $\langle a \rangle true$ *cabability of performing action a*
  - $[a] false$ *inability of performing action a*
  - $\neg Final \wedge \langle any \rangle true \wedge [any\text{-}a] false$
    necessity/inevitability of performing action a
    (i.e., action a is the only action possible)
  - $\neg Final \wedge [any] false$ *deadlock!*

Propositional Dynamic Logic

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- $\Phi := P \mid$ *(atomic propositions)*
  $\neg \Phi \mid \Phi_1 \wedge \Phi_2 \mid \Phi_1 \vee \Phi_2 \mid$ *(closed under boolean operators)*
  $[r]\Phi \mid \langle r \rangle \Phi$ *(modal operators)*

  $r := a \mid r_1 + r_2 \mid r_1 ; r_2 \mid r^* \mid P?$ *(complex actions as regular expressions)*

- Essentially add the capability of expressing partial correctness assertions via formulas of the form
  - $\Phi_1 \rightarrow [r]\Phi_2$ *under the conditions Φ_1 all possible executions of r that terminate reach a state of the TS where Φ_2 holds*

- Also add the ability of asserting that a property holds in all nodes of the transition system
  - $[(a_1 + \ldots + a_\nu)^*]\Phi$ *in every reachable state of the TS Φ holds*

- Useful abbereviations:
  - any stands for $(a_1 + \ldots + a_\nu)$ *Note that + can be expressed also in HM Logic*
  - u stands for any* *This is the so called master/universal modality*

Modal Mu-Calculus

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- $\Phi := P \mid$ *(atomic propositions)*
  $\neg \Phi \mid \Phi_1 \wedge \Phi_2 \mid \Phi_1 \vee \Phi_2 \mid$ *(closed under boolean operators)*
  $[r]\Phi \mid \langle r \rangle \Phi$ *(modal operators)*

  $\mu X.\Phi(X) \mid \nu X.\Phi(X)$ *(fixpoint operators)*

- It is the most expressive logic of the family of logics of programs.
- It subsumes
  - PDL (modalities involving complex actions are translated into fomulas involving fixpoints)
  - LTL (linear time temporal logic),
  - CTS, CTS* (branching time temporal logics)

- Examples:
- $[any^*]\Phi$ can be expressed as $\nu X.\ \Phi \wedge [any]X$

- $\mu X.\ \Phi \vee [any]X$ *along all runs eventually Φ*
- $\mu X.\ \Phi \vee \langle any \rangle X$ *along some run eventually Φ*
- $\nu X.\ [a](\mu Y.\ \langle any \rangle true \wedge [any\text{-}b]Y) \wedge X$
  every run that that contains a contains later b

Model Checking

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- Model checking is polynomial in the size of the TS for
  - HennessyMilner Logic
  - PDL
  - Mu-Calculus
- Also model checking is wrt the formula
  - Polynomial for HennessyMiner Logic
  - Polynomial for PDL
  - Polynomial for Mu-Calculus with bounded alternation of fixpoints and NP∩coNP in general

Model Checking

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- Given a TS T, one of its states s, and a formula Φ verify whether the formula holds in s. Formally:

$$T,s \models \Phi$$

- Examples (TS is our vending machine):
  - $S_0 \models$ Final
  - $S_0 \models$ <10c>true — *capability of performing action 10c*
  - $S_2 \models$ [big]false — *inability of performing action big*
  - $S_0 \models$ [10c][big]false — *after 10c cannot execute big*
  - $S_i \models \mu X.\ \text{Final} \vee [\text{any}]\ X$ — *eventually a final state is reached*
  - $S_0 \models \nu Z.\ (\mu X.\ \text{Final} \vee [\text{any}]\ X) \wedge [\text{any}]\ Z$ — *or equivalently*
    $S_0 \models [\text{any}^*](\mu X.\ \text{Final} \vee [\text{any}]\ X)$
    from everywhere eventually final

AI Planning as Model Checking

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- **Build the TS of the domain:**
  - Consider the set of states formed all possible truth value of the propositions (this works only for propositional setting).
  - Use Pre's and Post of actions for determining the transitions

  Note: the TS is exponential in the size od the description.

- **Write the goal in a logic of program**
  - typically a single least fixpoint formula of Mu-Calculus (compute ***reachable*** states intersection states where goal true)

- **Planning:**
  - model check the formula on the TS starting from the given initial state.
  - use the path (paths) used in the above model checking for returning the plan.

- *This basic technique works only when we have complete information (or at least total observability on state):*
  - *Sequiential plans if initial state known and actions are deterministic*
  - *Conditional plans if many possible initial states and/or actions are nondeterministic*

Example

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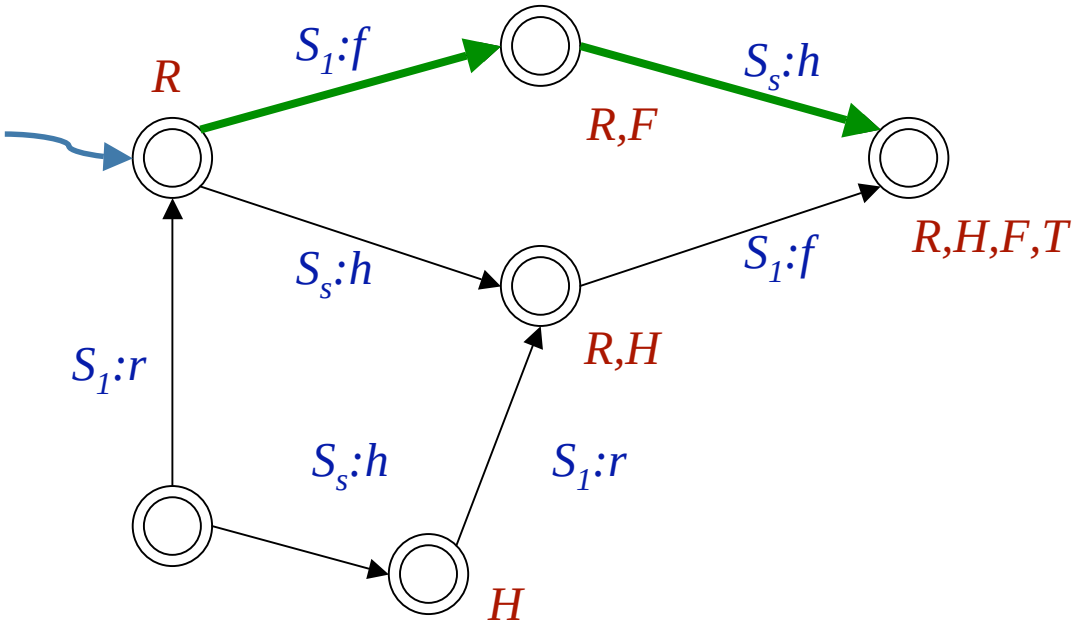
- Operators (Services + Mappings)
  - $\text{Registered} \wedge \neg\text{FlightBooked} \rightarrow [S_1:\text{bookFlight}]\ \text{FlightBooked}$
  - $\neg\text{Registered} \rightarrow [S_1:\text{register}]\ \text{Registered}$
  - $\neg\text{HotelBooked} \rightarrow [S_2:\text{bookHotel}]\ \text{HotelBooked}$
- Additional constraints (Community Ontology):
  - $\text{TravelSettledUp} \equiv \text{FlightBooked} \wedge \text{HotelBooked} \wedge \text{EventBooked}$
- Goals (Client Service Requests):
  - Starting from state
    $\text{Registered} \wedge \neg\text{FlightBooked} \wedge \neg\ \text{HotelBooked} \wedge \neg\text{EventBooked}$
    check $\langle \text{any}^* \rangle \text{TravelSettedUp}$
  - Starting from all states such that
    $\neg\text{FlightBooked} \wedge \neg\ \text{HotelBooked} \wedge \neg\text{EventBooked}$
    check $\langle \text{any}^* \rangle \text{TravelSettledUp}$

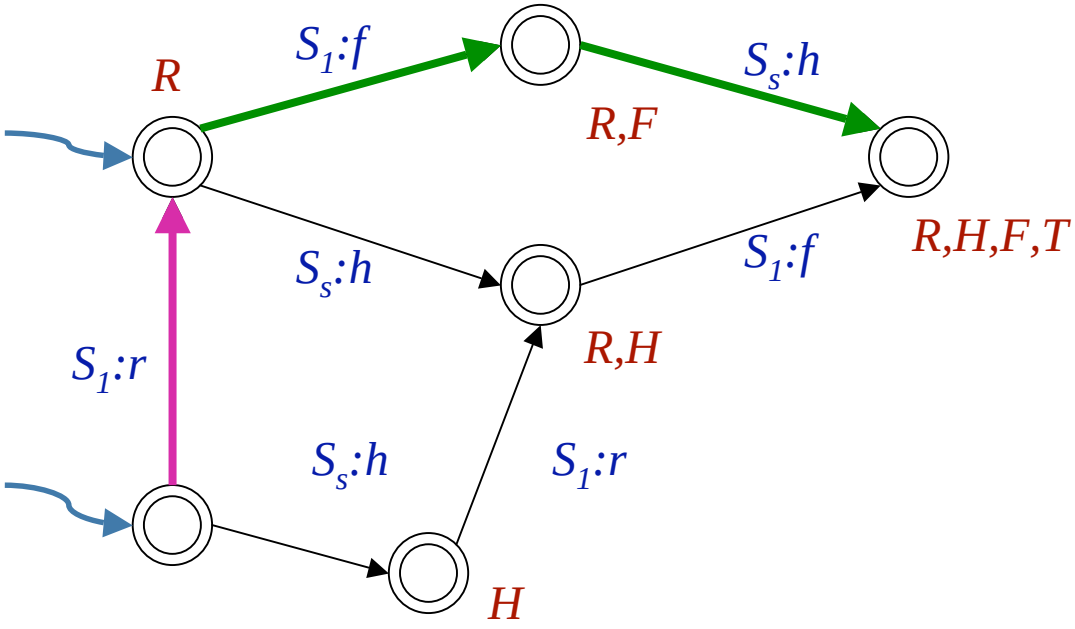
Example



Plan:
S_1:bookFlight;
S_2:bookHotel

Starting from state
Registered ∧ ¬ FlightBooked ∧ ¬ HotelBooked ∧ ¬ EventBooked
check
<any*>TravelSettledUp

Example



Plan:

```
if(¬Registered) {
    S1:register;
}
S1:bookFlight;
S2:bookHotel
```

Starting from states where

¬ FlightBooked ∧ ¬ HotelBooked ∧ ¬ EventBooked

check

<any*>TravelSettledUp

Satisfiability

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- Observe that a formula Φ may be used to select among all TS T those such that for a given state s we have that $T,s \models \Phi$
- SATISFIABILITY: Given a formula Φ verify whether there exists a TS T and a state s such that. Formally:

  check whether exists T, s such that $T,s \models \Phi$

- Satisfiability is:
  - PSPACE for HennesyMilner Logic
  - EXPTIME for PDL
  - EXPTIME for Mu-Calculus

References

[Stirling Banff96] C. Stirling: Modal and temporal logics for processes. Banff Higher Order Workshop LNCS 1043, 149-237, Springer 1996

[Bradfield&Stirling HPA01] J. Bradfield, C. Stirling: Modal logics and mu-calculi. Handbook of Process Algebra, 293-332, Elsevier, 2001.

[Stirling 2001] C. Stirling: Modal and Temporal Properties of Processes. Texts in Computer Science, Springer 2001

[Kozen&Tiuryn HTCS90] D. Kozen, J. Tiuryn: Logics of programs. Handbook of Theoretical Computer Science, Vol. B, 789–840. North Holland, 1990.

[HKT2000] D. Harel, D. Kozen, J. Tiuryn: Dynamic Logic. MIT Press, 2000.

[Clarke& Schlingloff HAR01] E. M. Clarke, B. Schlingloff: Model Checking. Handbook of Automated Reasoning 2001: 1635-1790

[CGP 2000] E.M. Clarke, O. Grumberg, D. Peled: Model Checking. MIT Press, 2000.

[Emerson HTCS90] E. A. Emerson. Temporal and Modal Logic. Handbook of Theoretical Computer Science, Vol B: 995-1072. North Holland, 1990.

[Emerson Banff96] E. A. Emerson. Automated Temporal Reasoning about Reactive Systems. Banff Higher Order Workshop, LNCS 1043, 111-120, Springer 1996

[Vardi CST] M. Vardi: Alternating automata and program verification. Computer Science Today -Recent Trends and Developments, LNCS Vol. 1000, Springer, 1995.

[Vardi etal CAV94] M. Vardi, O. Kupferman and P. Wolper: An Automata-Theoretic Approach to Branching-Time Model Checking (full version of CAV'94 paper).

[Schneider 2004] K. Schenider: Verification of Reactive Systems, Springer 2004.

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Name by
Rick Hull

Composition: the "Roman" Approach

The Roman Approach

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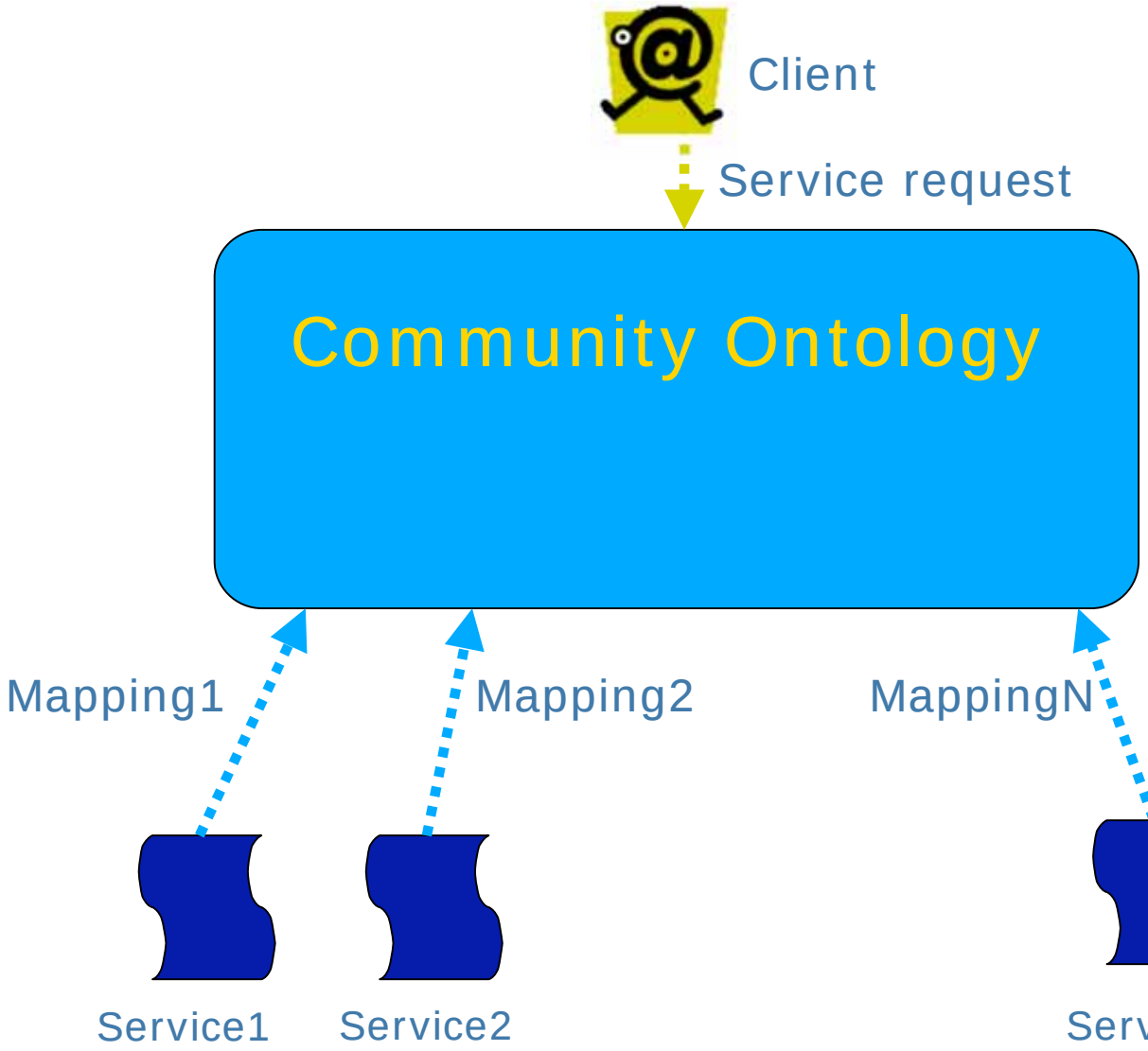

Client-tailored!

Community ontology: just a set of **actions**

Client formulates the service it requires as a **TS** using the **actions** of the common ontology

Available services: described in terms of a **TS** using **actions** of the community ontology

The **community** realizes the **client's target service** by "reversing" the mapping and hence using **fragments** of the computation of the the **available services**

Community of Services

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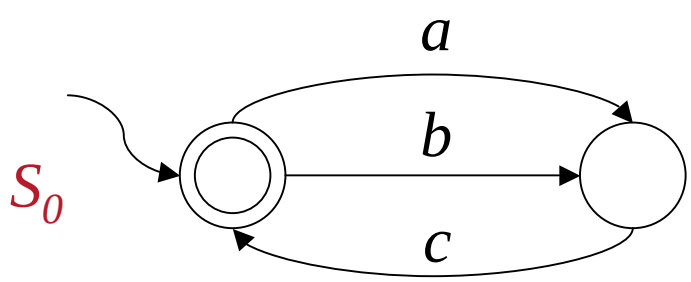
- A community of Services is
  - a set of services …
  - … that share implicitly a *common understanding* on a common set of actions (common ontology limited to the alphabet of actions)…
  - … and export their behavior using (finite) TS over this common set of actions
- A client specifies needs as a service behavior, i.e, a (finite) TS using the common set of actions of the community

(Target & Available) Service TS

- We model services as finite TS $T = (\Sigma, S, s^0, \delta, F)$ with
  - single initial state *(s^0)*
  - deterministic transitions *(i.e., δ is a partial function from $S \times \Sigma$ to S)*

Note: In this way the client entirely controls/chooses the transition to execute

Example:



a: "search by author (and select)"
b: "search by title (and select)"
c: "listen (the selected song)"

Composition: an Example

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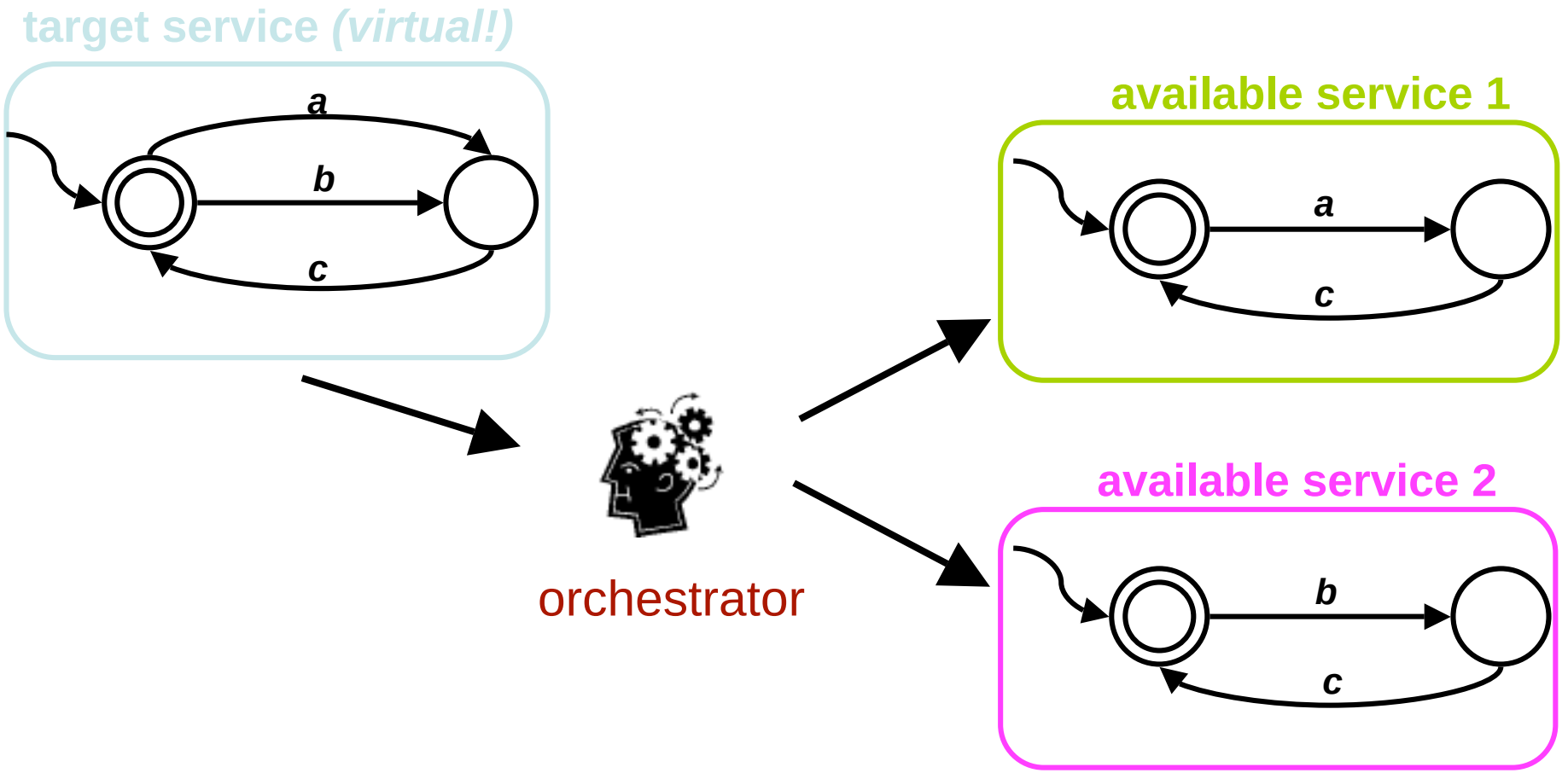
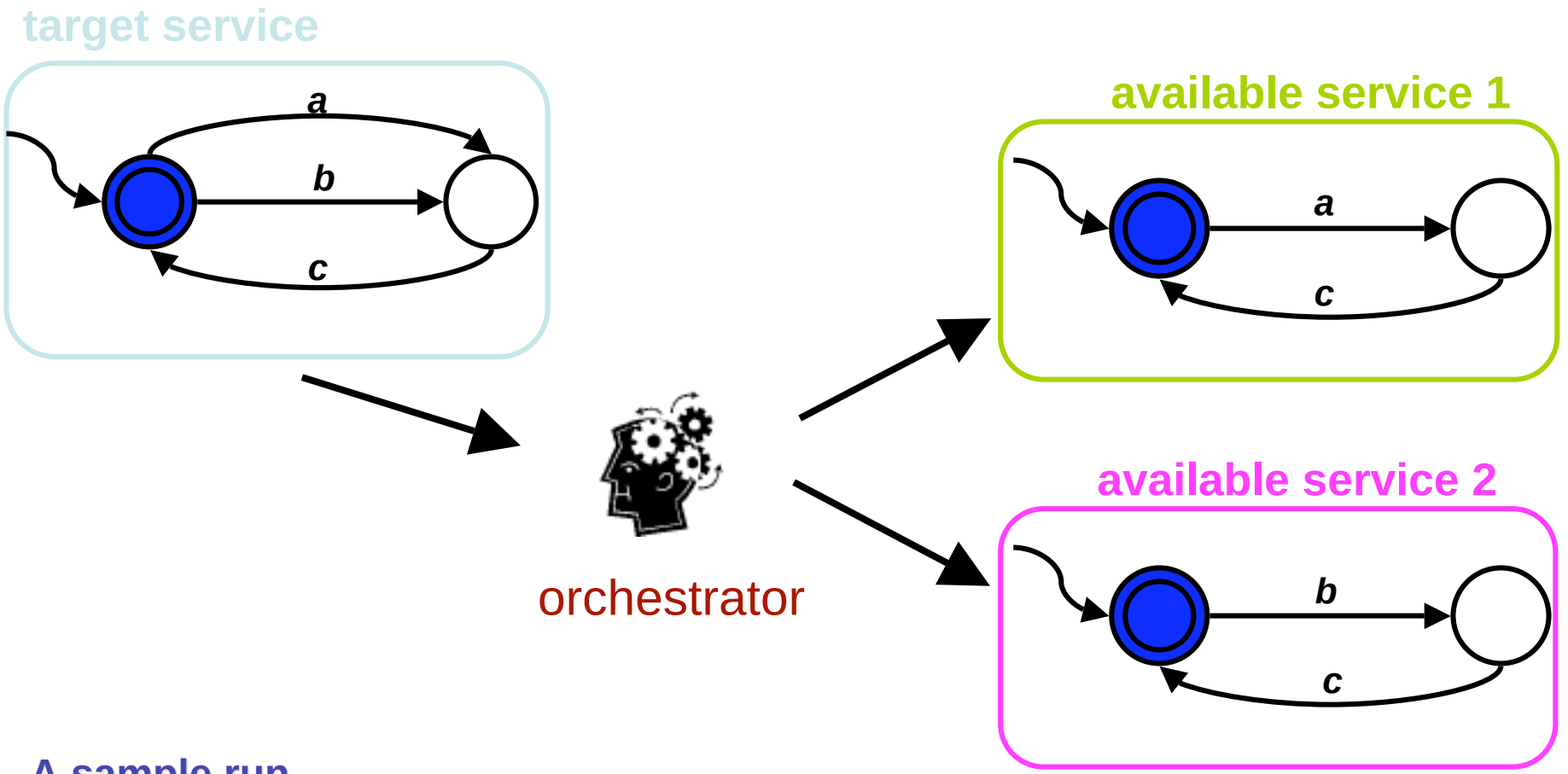


Lets get some intuition of what a composition is through an example

Composition: an Example



A sample run

action request:

orchestrator response:

Composition: an Example

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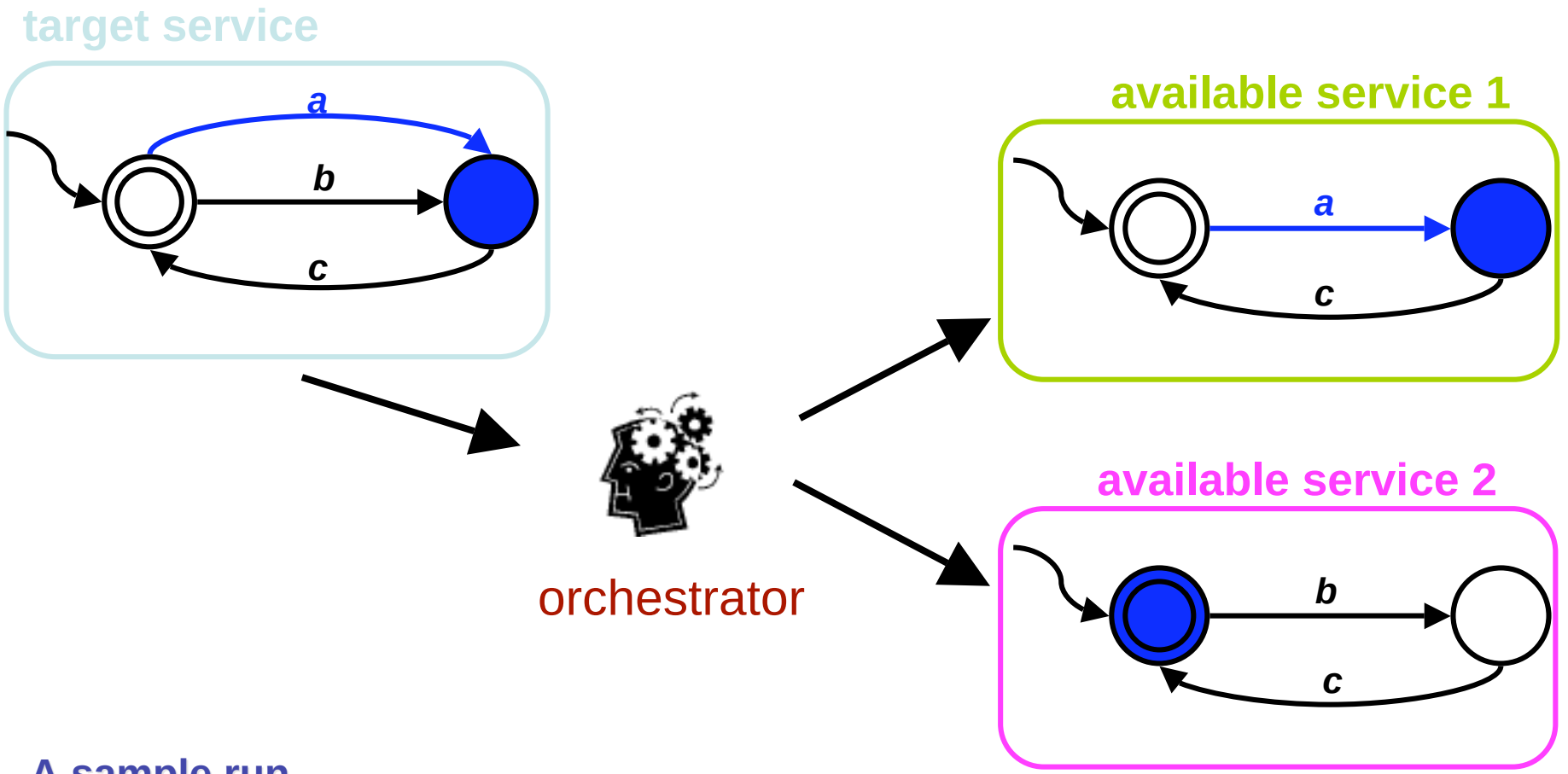
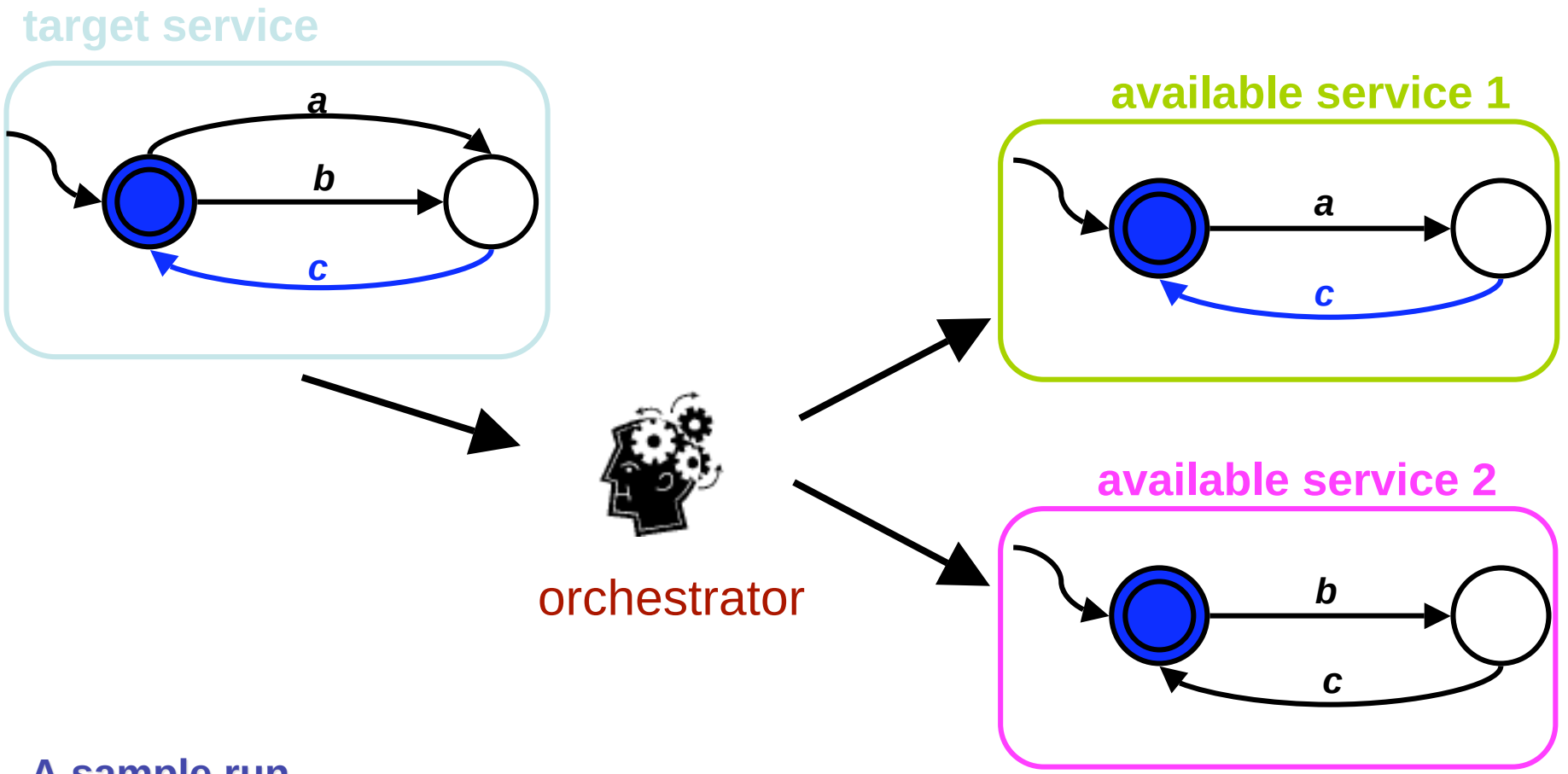


A sample run

action request: *a*

orchestrator response: *a,1*

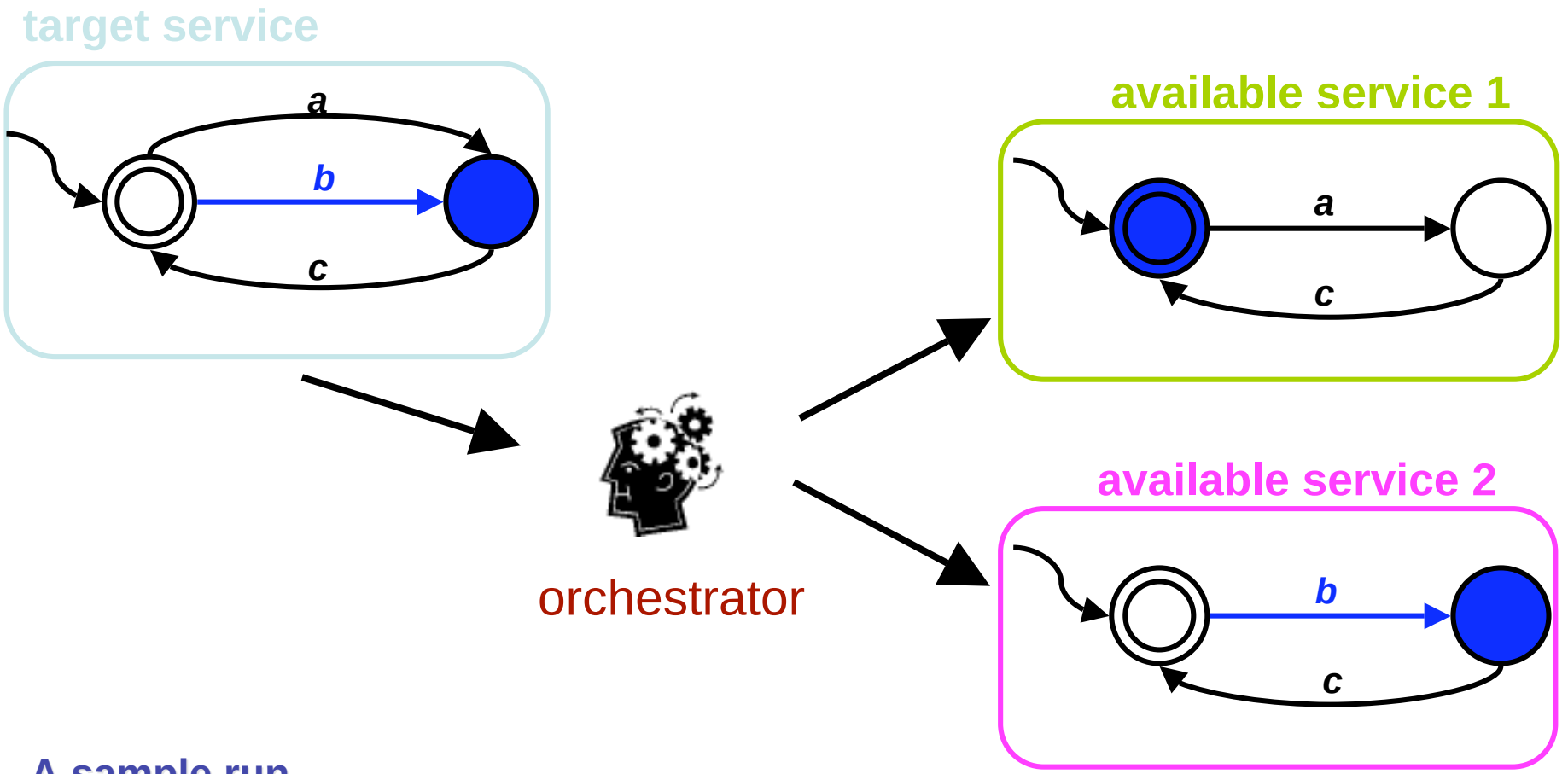
Composition: an Example



A sample run

action request:	*a*	*c*
orchestrator response:	***a,1***	***c,1***

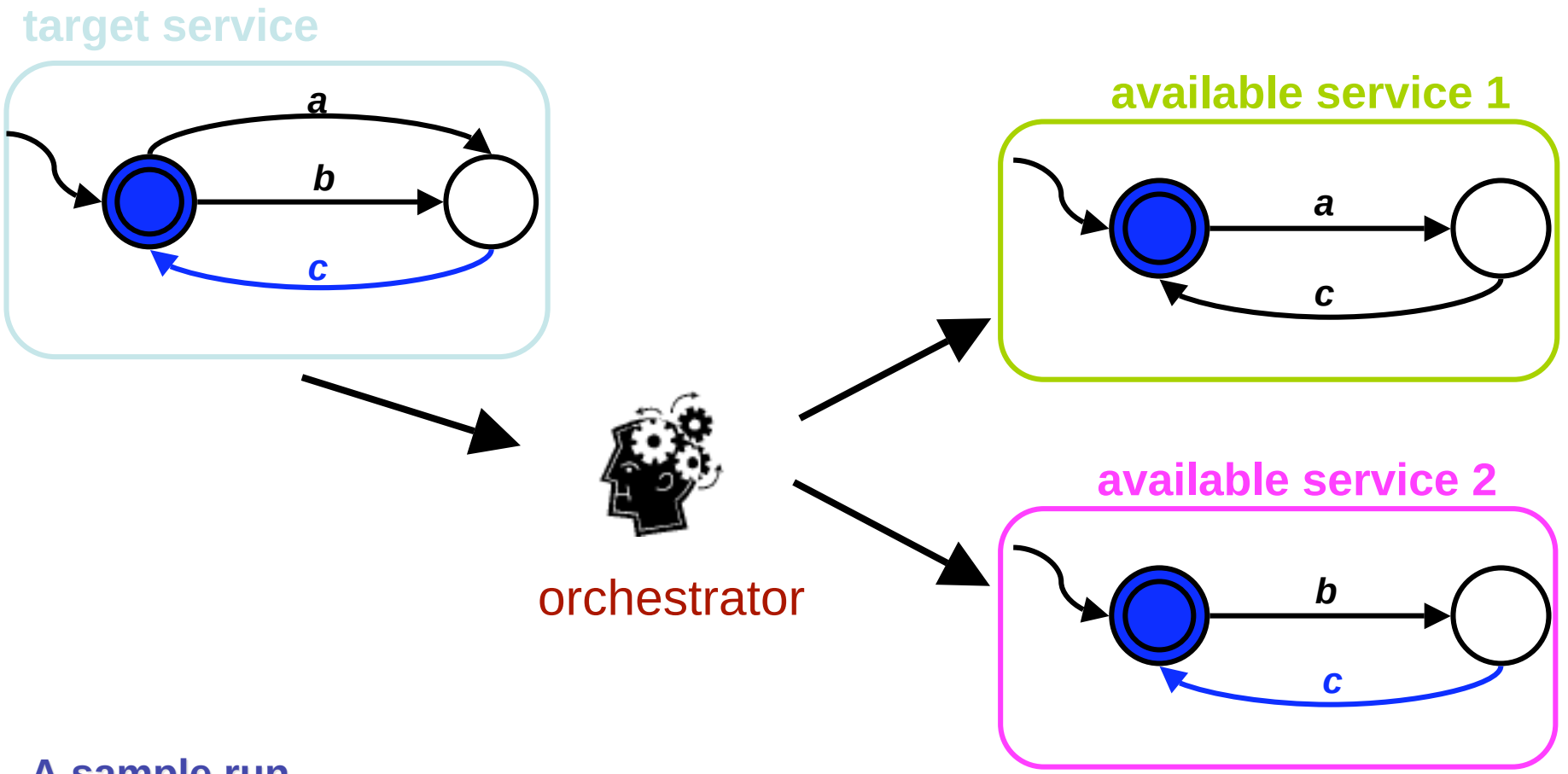
Composition: an Example



A sample run

action request:	*a*	*c*	*b*
orchestrator response:	***a,1***	***c,1***	***b,2***

Composition: an Example



A sample run

action request:	*a*	*c*	*b*	*c*	*...*
orchestrator response:	***a,1***	***c,1***	***b,2***	***c,2***	

A orchestrator program realizing the target behavior

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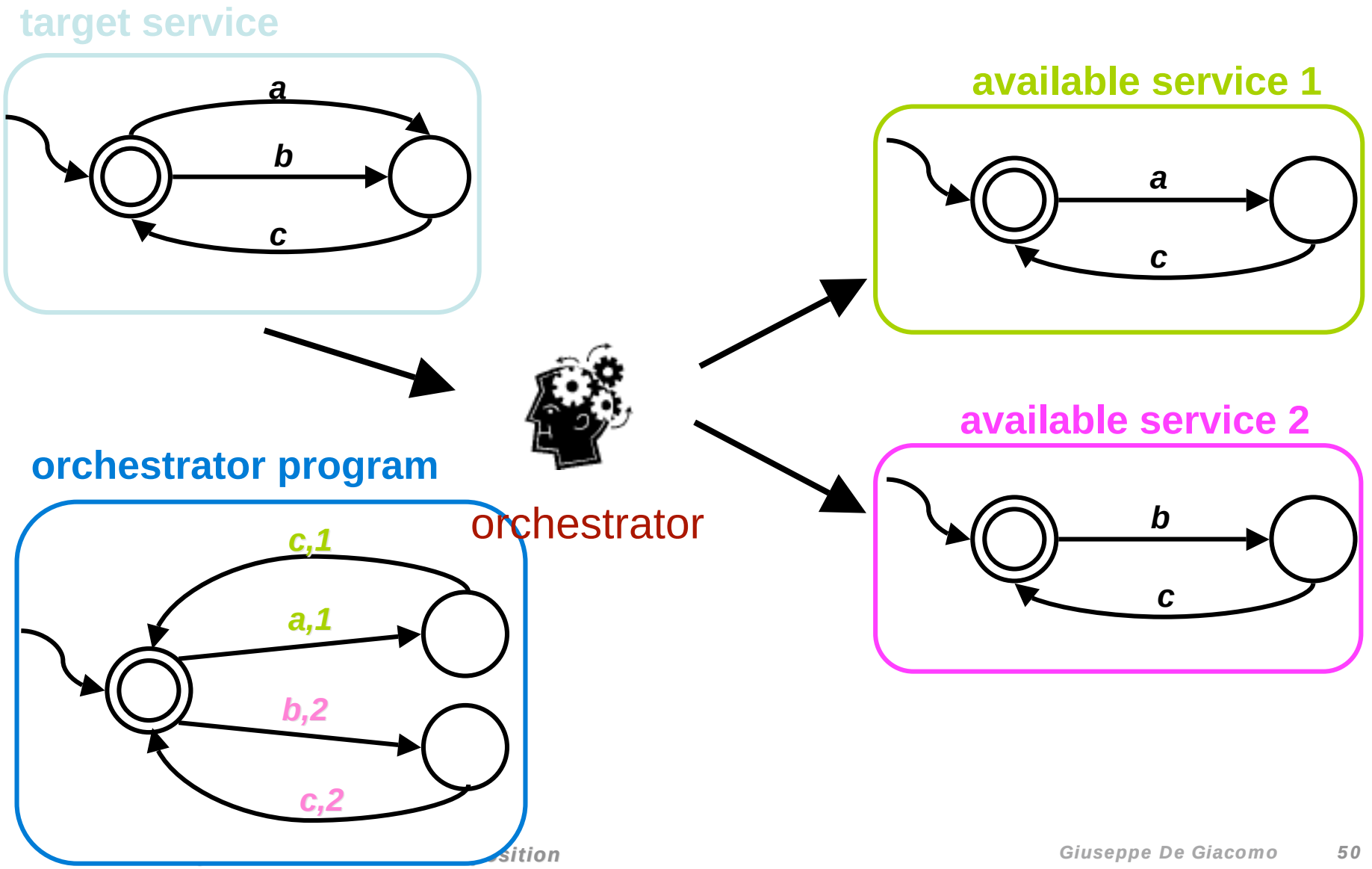

Orchestrator programs

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- **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 the sequence of actions done so far:

  $h = a_1 a_2 \ldots a_k$

- Observe that to take a decision P has **full access to the past**, but no access to the future
  - *Note given an history* $h = a_1 a_2 \ldots a_k$ *an the function* P *we can reconstruct the state of the target service and of each available service*
    - $a_1 a_2 \ldots a_k$ *determines the state of the target service*
    - $(a_1, P([\,], a_k))(a_2, P([a_1], a_2)) \ldots (a_k, P([a_1 a_2 \ldots a_{k-1}], a_k))$ *determines the state of of each available service*
- ***Problem: synthesize a orchestrator program P that realizes the target service making use of the available services***

Service Execution Tree

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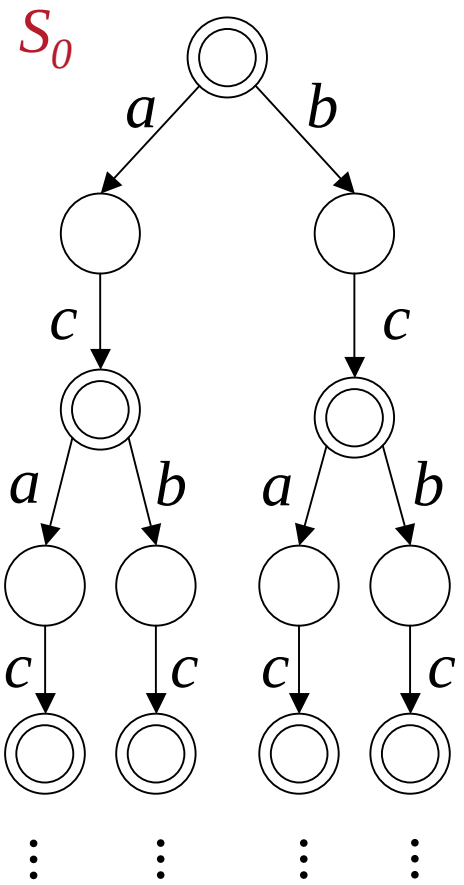
By "unfolding" a (finite) TS one gets an (infinite) execution tree
-- yet another (infinite) TS which bisimilar to the original one)



- *Nodes: history i.e., sequence of actions executed so far*
- *Root: no action yet performed*
- *Successor node x·a of x: action a can be executed after the sequence of action x*
- *Final nodes: the service can terminate*

Alternative (but Equivalent) Definition of Service Composition

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Composition:

- coordinating program …
- … that realizes the target service …
- … by suitably coordinating available services

⇒ Composition can be seen as:

- a labeling of the execution tree of the **target service** such that …
- … each action in the execution tree is labeled by the available service that executes it …
- … and each possible sequence of actions on the target service execution tree corresponds to possible sequences of actions on the available service execution trees, suitably interleaved

Example of Composition

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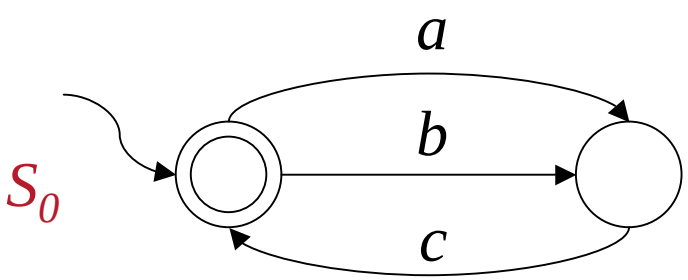
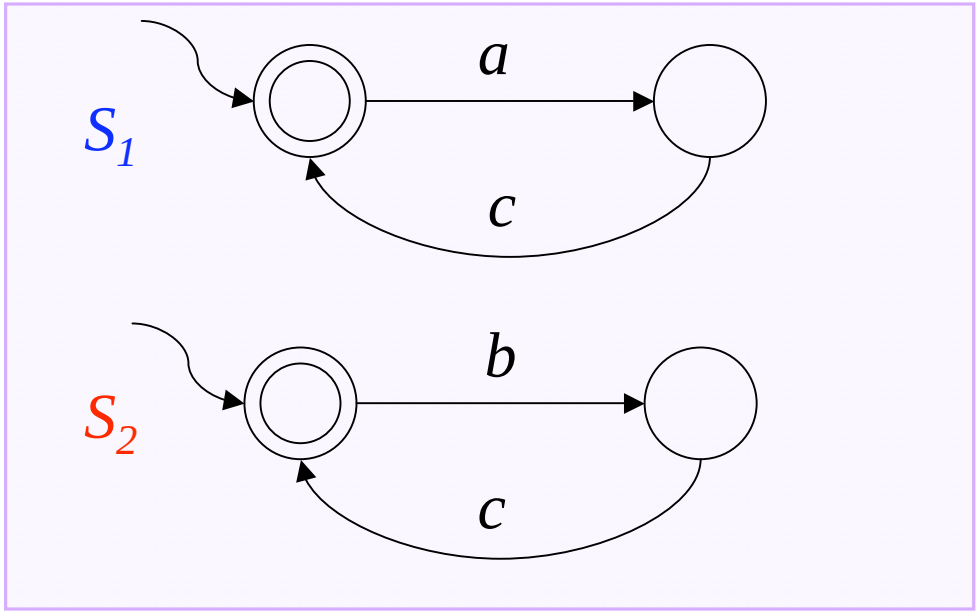
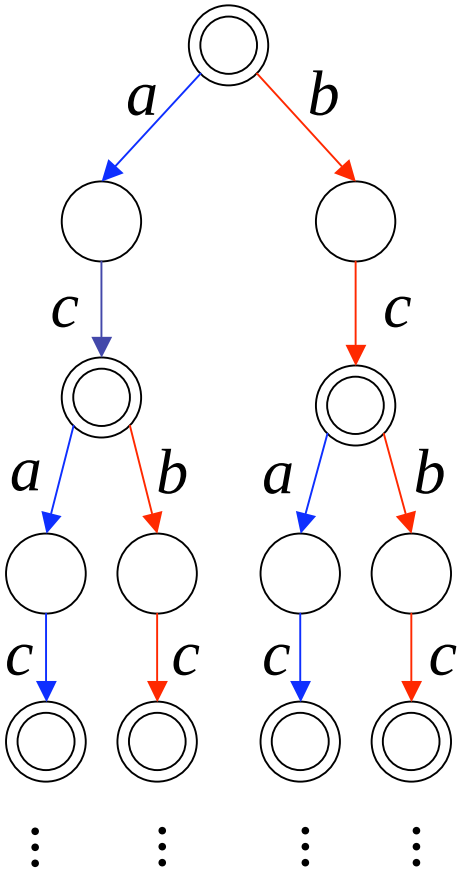




$S_0 = orch(S_1 \| S_2)$



Example of Composition

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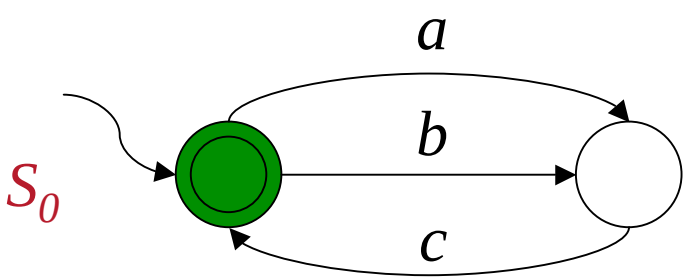
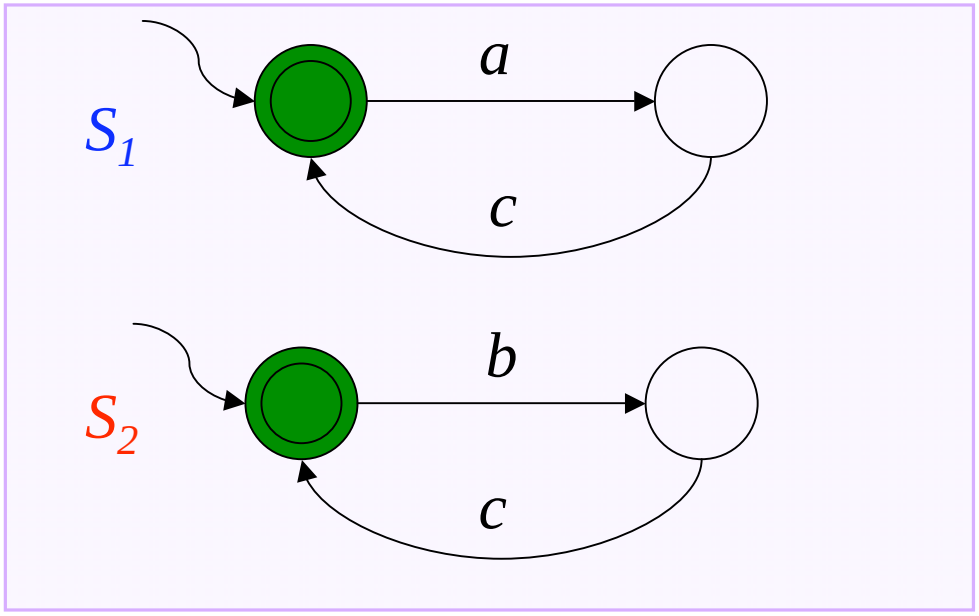
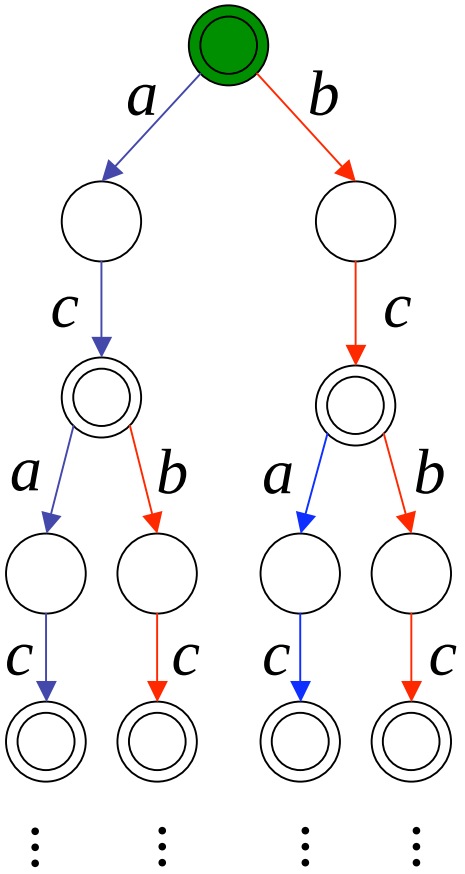




$S_0 = orch(S_1 \| S_2)$



All services start from their starting state

Example of Composition (5)

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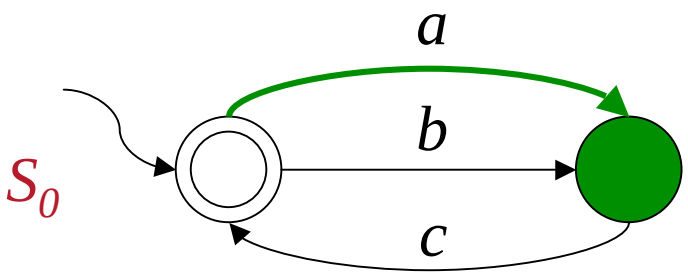
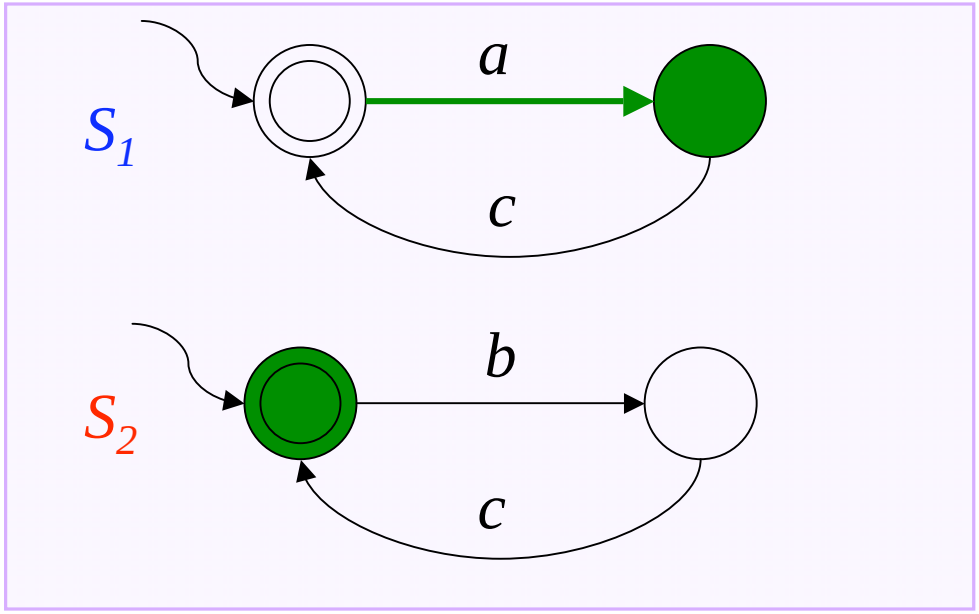
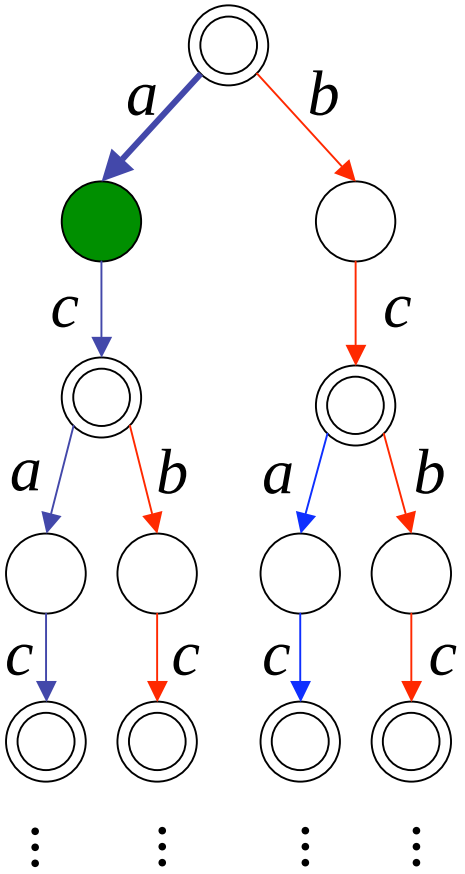
$S_0 = orch(S_1 \| S_2)$







Each action of the target service is executed by at least one of the component services

Example of composition (6)

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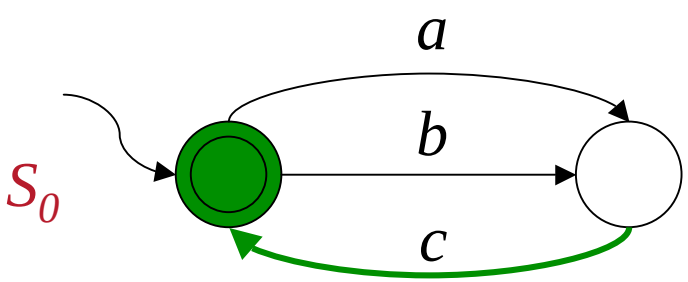
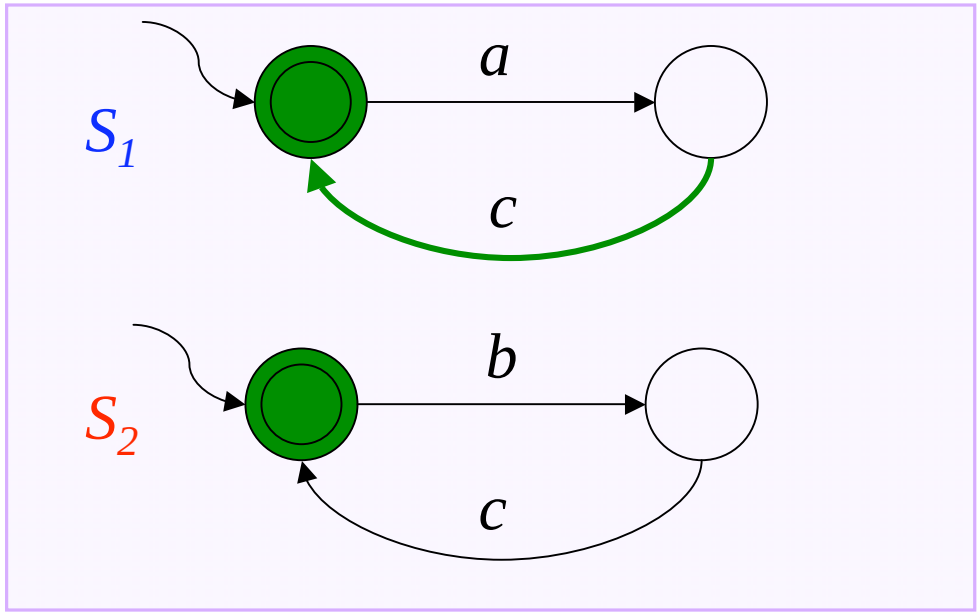
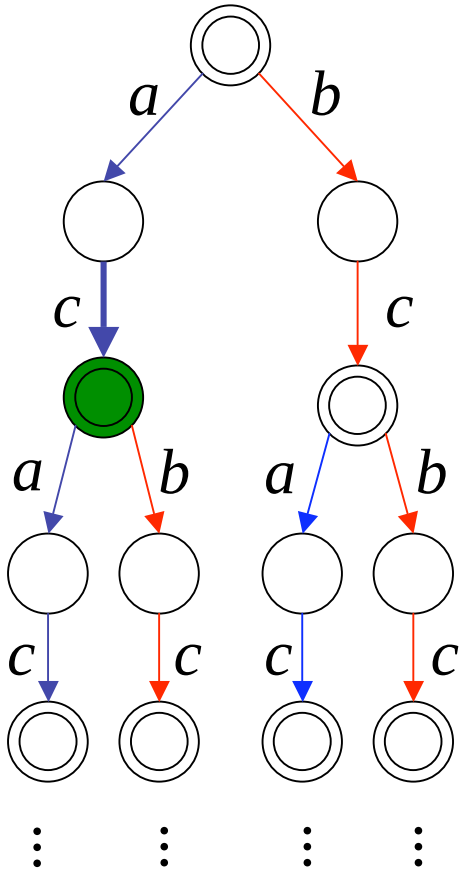




$S_0 = orch(S_1 \| S_2)$



When the target service can be left, then all component services must be in a final state

Example of composition (7)

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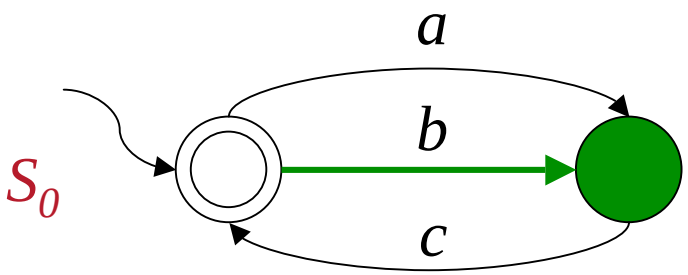
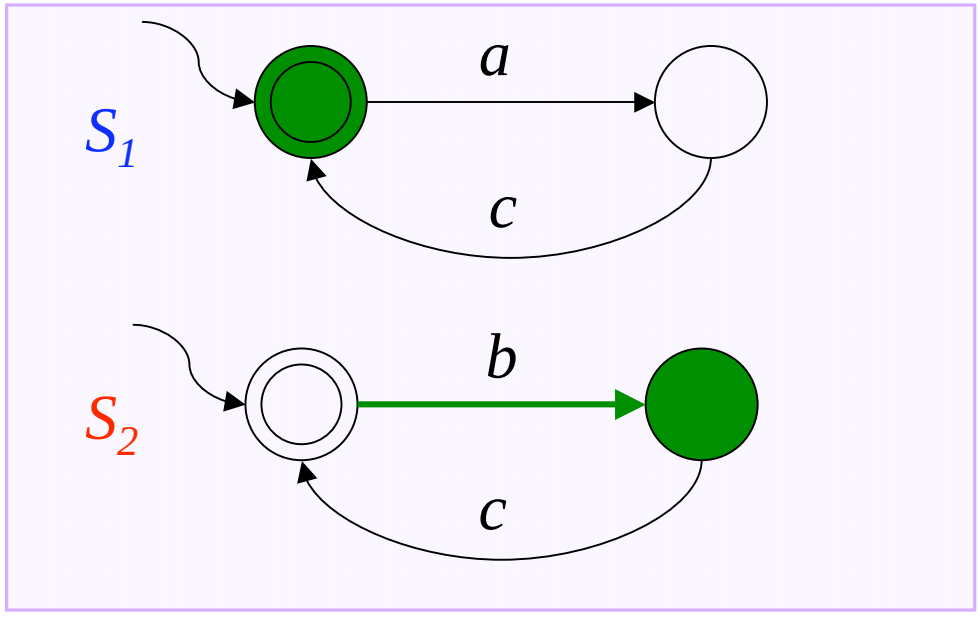
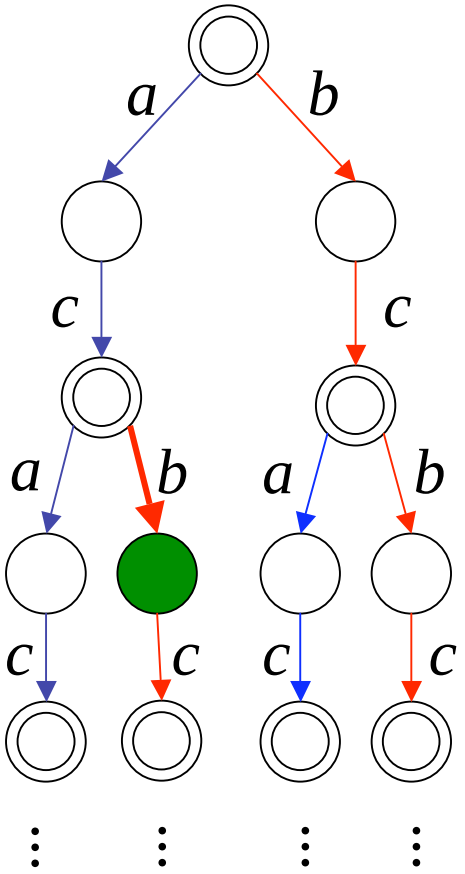




$S_0 = orch(S_1 \| S_2)$



Example of composition (8)

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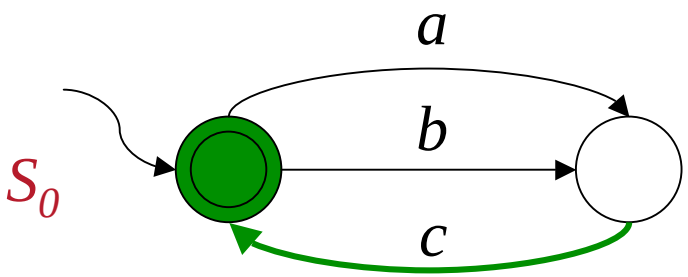
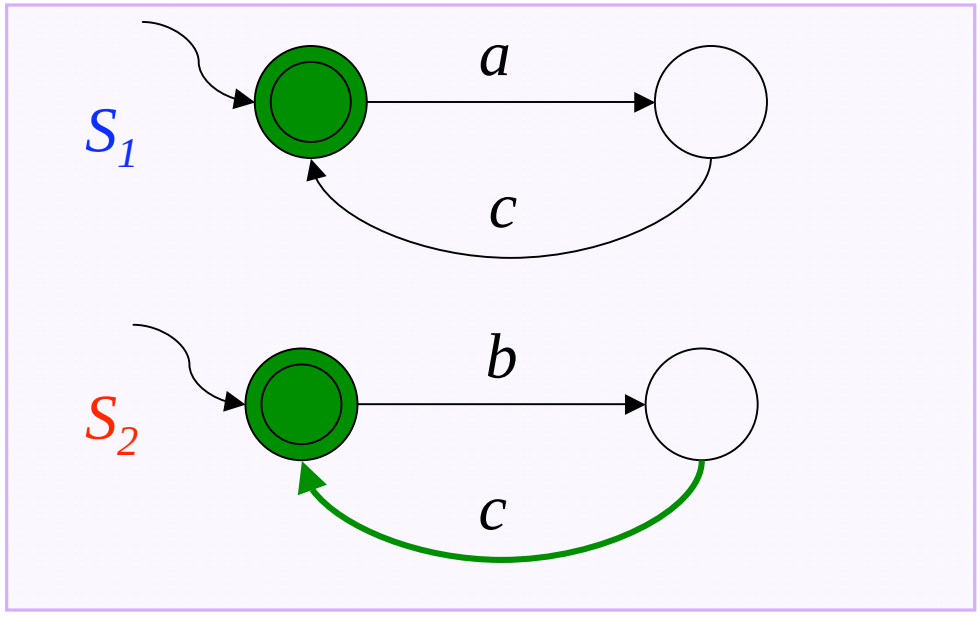
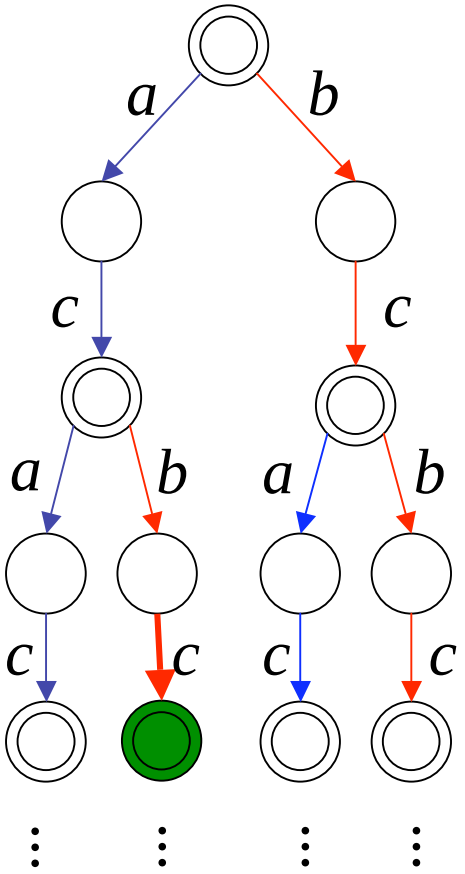


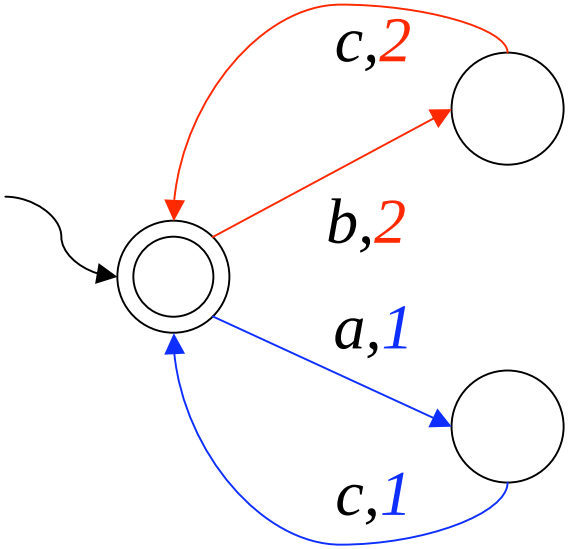


$S_0 = orch(S_1 \| S_2)$



Observation

- This labeled execution tree has a finite representation as a finite TS …
- …with transitions labeled by an action and the service performing the action



Is this always the case when we deal with services expressible as finite TS? See later…

Questions

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Assume services of community and target service are finite TSs

- Can we always check composition existence?
- If a composition exists there exists one which is a finite TS?
- If yes, how can a finite TS composition by computed?

To answer ICSOC'03 exploits PDL SAT

Answers

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Reduce service composition synthesis to satisfability in (deterministic) PDL

- Can we always check composition existence?

  Yes, SAT in PDL is decidable in EXPTIME

- If a composition exists there exists one which is a finite TS?

  Yes, by the small model property of PDL

- How can a finite TS composition be computed?

  From a (small) model of the corresponding PDL formula

Encoding in PDL

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Basic idea:

- A orchestrator program P realizes the target service T iff at each point:
  - $\forall$ transition labeled a of the target service T ...
  - ... $\exists$ an available service B_i (the one chosen by P) that can make an a-transition, realizing the a-transition of T

- Encoding in PDL:
  - $\forall$ transition labeled a ...
    use **branching**
  - $\exists$ an available service B_i that can make an a-transition ...
    use underspecified predicates **assigned through SAT**

Structure of the PDL Encoding

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$$\Phi = \mathit{Init} \wedge [u](\Phi_0 \wedge \bigwedge_{i=1,\ldots,n} \Phi_i \wedge \Phi_{aux})$$

Initial states of all services

PDL encoding of target service

PDL encoding of *i*-th component service

PDL additional domain-independent conditions

PDL encoding is polynomial in the size of the service TSs

PDL Encoding

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- Target service $S_0 = (\Sigma, S_0, s^0_0, \delta_0, F_0)$ in PDL we define Φ_0 as the conjunction of:
  - $s \rightarrow \neg s'$ for all pairs of distinct states in S_0

    service states are pair-wise disjoint
  - $s \rightarrow \langle a \rangle \top \wedge [a]s'$ for each $s' = \delta_0(s,a)$

    target service can do an a-transition going to state s'
  - $s \rightarrow [a] \bot$ for each $\delta_0(s,a)$ undef.

    target service cannot do an a-transition
  - $F_0 \equiv \vee_{s \in F0} s$

    denotes target service final states
- ...

PDL Encoding (cont.d)

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- available services $S_i = (\Sigma, S_i, s^0_i, \delta_i, F_i)$ in PDL we define Φ_i as the conjunction of:
  - $s \rightarrow \neg\, s'$ for all pairs of distinct states in S_i
    Service states are pair-wise disjoint
  - $s \rightarrow [a](moved_i \wedge s' \vee \neg\, moved_i \wedge s)$ for each $s'=\delta_i(s,a)$
    if service moved then new state, otherwise old state
  - $s \rightarrow [a](\neg\, moved_i \wedge s)$ for each $\delta_i(s,a)$ undef.
    if service cannot do a, and a is performed then it did not move
  - $F_i \equiv \vee_{s \in Fi}\, s$
    denotes available service final states
- ...

PDL Encoding (cont.d)

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- Additional assertions Φ_{aux}
  - $\langle a \rangle T \rightarrow [a] \bigvee_{i=1,\ldots,n} moved_i$ for each action a

    at least one of the available services must move at each step
  - $F_0 \rightarrow \bigwedge_{i=1,\ldots,n} F_i$

    when target service is final all comm. services are final
  - $Init \equiv s^0_0 \wedge_{i=1\ldots n} s^0_i$

    Initially all services are in their initial state

PDL encoding: $\Phi = Init \wedge [u](\Phi_0 \wedge_{i=1,\ldots,n} \Phi_i \wedge \Phi_{aux})$

Results

Thm[ICSOC'03,IJCIS'05]:

Composition exists iff PDL formula Φ SAT

From composition labeling of the target service one can build a tree model of the PDL formula and viceversa

Information on the labeling is encoded in predicates moved$_i$

Corollary [ICSOC'03,IJCIS'05]:

Checking composition existence is decidable in **EXPTIME**

Thm[Muscholl&Walukiewicz FoSSaCS'07]:

Checking composition existence is **EXPTIME-hard**

Results on TS Composition

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Thm[ICSOC'03,IJCIS'05]:

If composition exists then finite TS composition exists.

From a small model of the PDL formula Φ, one can build a finite TS machine

Information on the output function of the machine is encoded in predicates moved$_i$

$\Rightarrow$ finite TS composition existence of services expressible as finite TS is EXPTIME-complete

Example (1)

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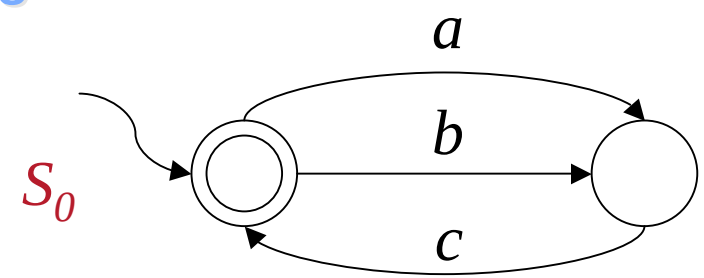
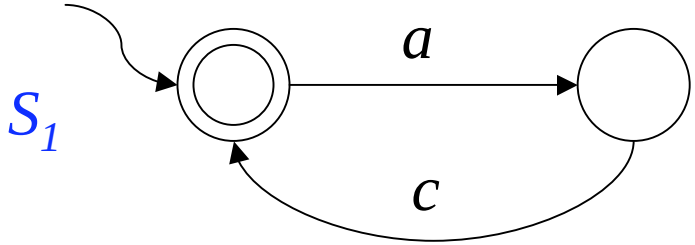
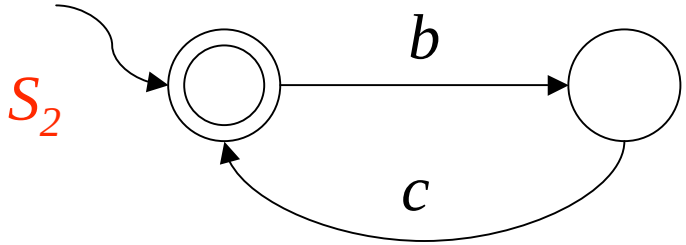
Target service



Available services





PDL

...

...

...

$s_0^0 \wedge s_1^0 \wedge s_2^0$

$\langle a \rangle T \rightarrow [a] (moved_1 \vee moved_2)$

$\langle b \rangle T \rightarrow [b] (moved_1 \vee moved_2)$

$\langle c \rangle T \rightarrow [c] (moved_1 \vee moved_2)$

$F_0 \rightarrow F_1 \wedge F_2$

Example (2)

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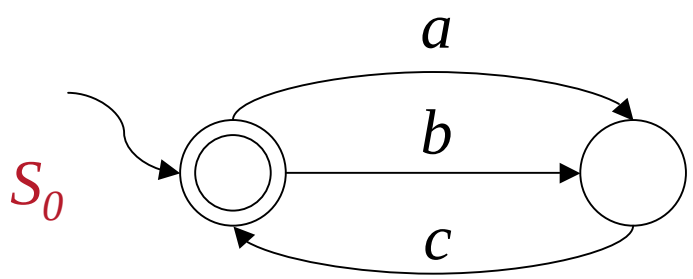
Target service



$s_0^0 \rightarrow \neg\, s_0^1$

$s_0^0 \rightarrow \langle a \rangle\, \top \wedge [a]\, s_0^1$

$s_0^0 \rightarrow \langle b \rangle\, \top \wedge [b]\, s_0^1$

$s_0^1 \rightarrow \langle c \rangle\, \top \wedge [c]\, s_0^0$

$s_0^0 \rightarrow [c]\, \bot$

$s_0^1 \rightarrow [a]\, \bot$

$s_0^1 \rightarrow [b]\, \bot$

$F_0 \equiv s_0^0$

...

...

...

Example (3)

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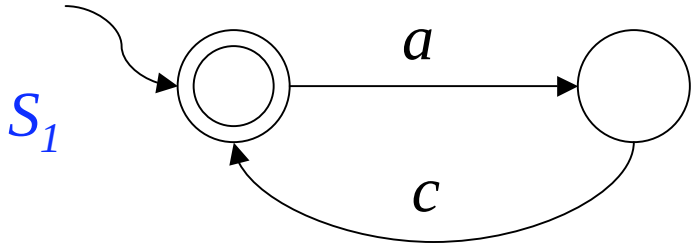
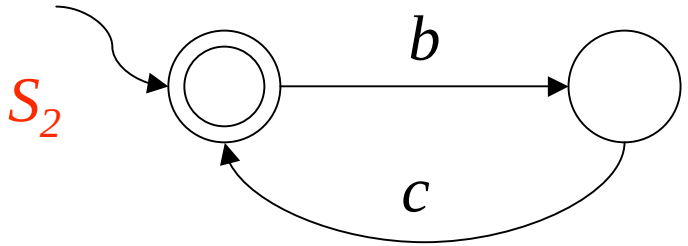
Available services





...

$s_1^0 \rightarrow \neg\, s_1^1$

$s_1^0 \rightarrow [a]\,(moved_1 \wedge s_1^1 \vee \neg moved_1 \wedge s_1^0)$

$s_1^0 \rightarrow [c]\,\neg moved_1 \wedge s_1^0$

$s_1^0 \rightarrow [b]\,\neg moved_1 \wedge s_1^0$

$s_1^1 \rightarrow [a]\,\neg moved_1 \wedge s_1^1$

$s_1^1 \rightarrow [b]\,\neg moved_1 \wedge s_1^1$

$s_1^1 \rightarrow [c]\,(moved_1 \wedge s_1^0 \vee \neg moved_1 \wedge s_1^0)$

$F_1 \equiv s_1^0$

$s_2^0 \rightarrow \neg\, s_2^1$

$s_2^0 \rightarrow [b]\,(moved_2 \wedge s_2^1 \vee \neg moved_2 \wedge s_2^0)$

$s_2^0 \rightarrow [c]\,\neg moved_2 \wedge s_2^0$

$s_2^0 \rightarrow [a]\,\neg moved_2 \wedge s_2^0$

$s_2^1 \rightarrow [b]\,\neg moved_2 \wedge s_2^1$

$s_2^1 \rightarrow [a]\,\neg moved_2 \wedge s_2^1$

$s_2^1 \rightarrow [c]\,(moved_2 \wedge s_2^0 \vee \neg moved_2 \wedge s_2^0)$

$F_2 \equiv s_2^0$

...

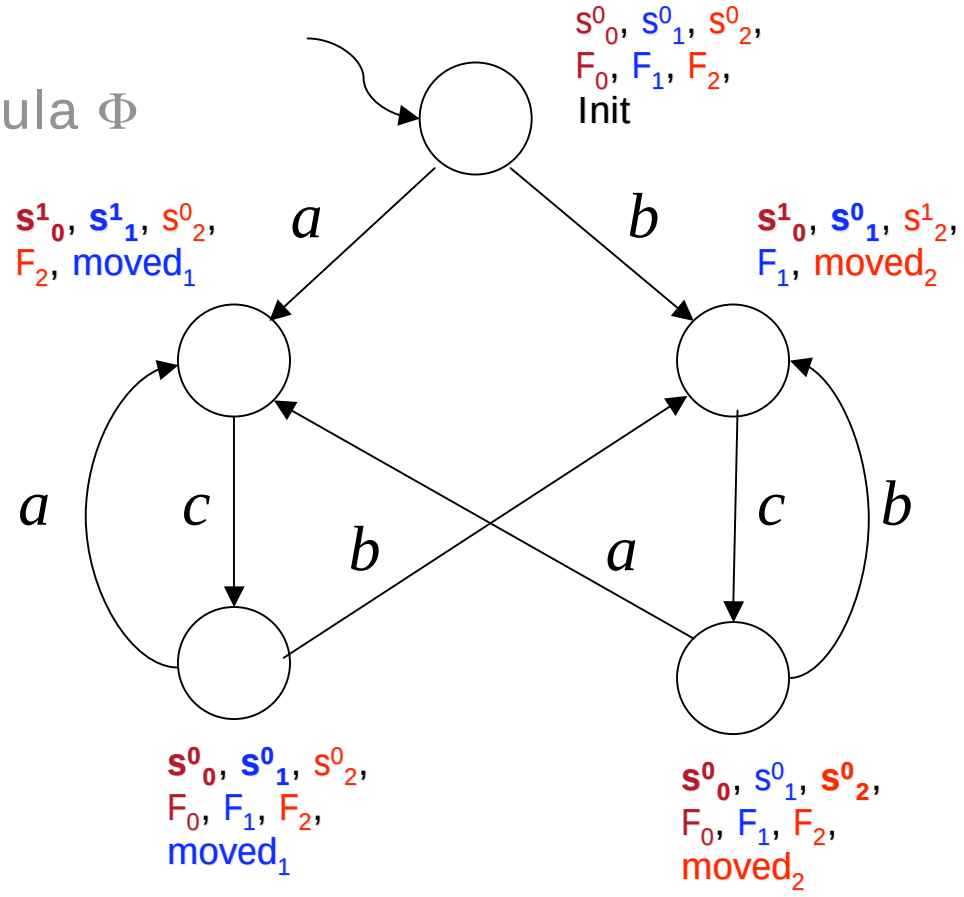
Example (4)

Check: run SAT on PDL formula Φ

Example

Check: run SAT on PDL formula Φ

Yes $\Rightarrow$ (small) model

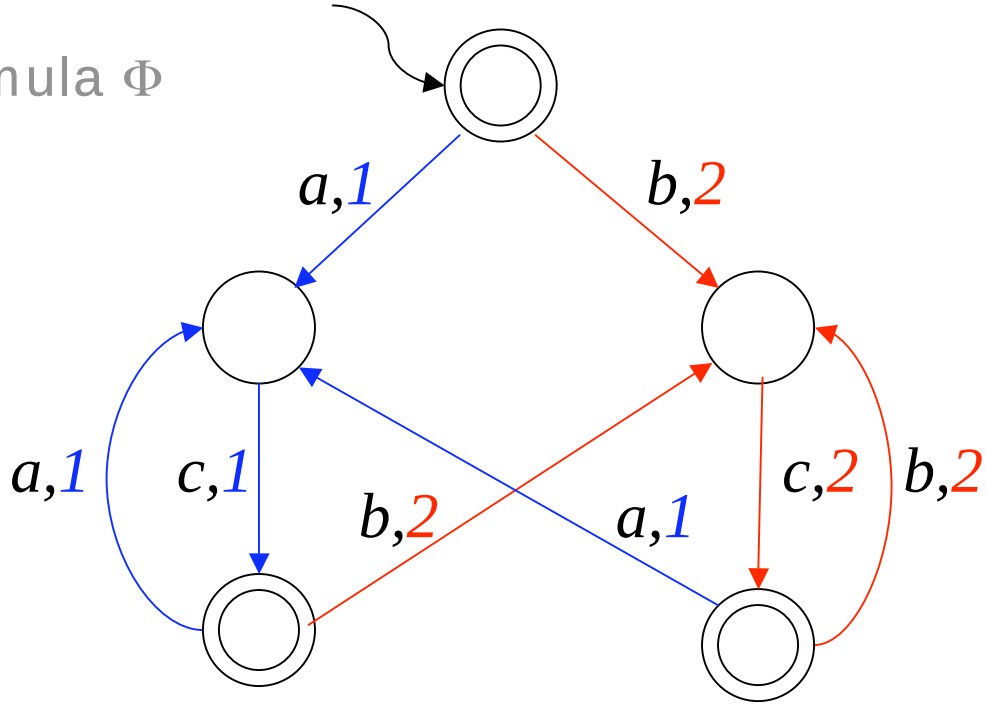


Example

Check: run SAT on PDL formula Φ

Yes $\Rightarrow$ (small) model

$\Rightarrow$ extract finite TS



Example

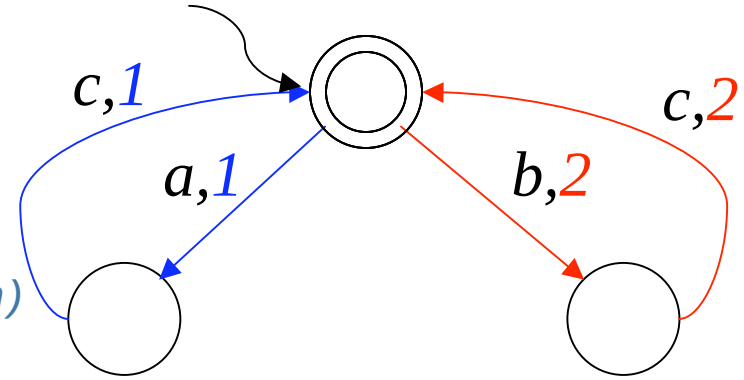
Check: run SAT on PDL formula Φ

Yes $\Rightarrow$ (small) model

$\Rightarrow$ extract finite TS

$\Rightarrow$ minimize finite TS

(similar to Mealy machine minimization)



Results on Synthesizing Composition

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- Using PDL reasoning algorithms based on model construction (cf. tableaux), build a (small) model

  Exponential in the size of the PDL encoding/services finite TS

  Note: SitCalc, etc. can compactly represent finite TS, PDL encoding can preserve compactness of representation

- From this model extract a corresponding finite TS

  Polynomial in the size of the model

- Minimize such a finite TS using standard techniques (opt.)

  Polynomial in the size of the TS

  Note: finite TS extracted from the model is not minimal because encodes output in properties of individuals/states

Tools for Synthesizing Composition

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- In fact we use only a fragment of PDL in particular we use fixpoint (transitive closure) only to get the universal modality …
- … thanks to a tight correspondence between PDLs and Description Logics (DLs), we can use current highly optimized DL reasoning systems to do synthesis …
- … when the ability or returning models will be added …

Pellet already has this ability, and we are exploring its use

- … meanwhile we have developed a prototype tool on this idea (see last Massimo's lecture)

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Composition via Simulation

Bisimulation

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- A binary relation R is a **bisimulation** iff:

  $(s,t) \in R$ implies that
  - s is *final* iff t is *final*
  - for all actions a
    - if $s \rightarrow_a s'$ then $\exists\, t' \,.\, t \rightarrow_a t'$ and $(s',t') \in R$
    - if $t \rightarrow_a t'$ then $\exists\, s' \,.\, s \rightarrow_a s'$ and $(s',t') \in R$

- A state s_0 of transition system S is **bisimilar**, or simply **equivalent,** to a state t_0 of transition system T iff there **exists** a **bisimulation** between the initial states s_0 and t_0.

- Notably
  - **bisimilarity** is a bisimulation
  - **bisimilarity** is the largest bisimulation

Note it is a co-inductive definition!

Computing Bisimilarity on Finite Transition Systems

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Algorithm ComputingBisimulation
Input: transition system $TS_S = < A, S, S^0, \delta_S, F_S >$ and
transition system $TS_T = < A, T, T^0, \delta_T, F_T >$
Output: the **bisimilarity** relation (the largest bisimulation)

Body
$R = \emptyset$
$R' = S \times T - \{(s,t) \mid \neg(s \in F_S \equiv t \in F_T)\}$
while $(R \neq R')$ {
$R := R'$
$R' := R' - (\{(s,t) \mid \exists s',a.\ s \rightarrow_a s' \wedge \neg\exists t' .\ t \rightarrow_a t' \wedge (s',t') \in R' \}$
$\{(s,t) \mid \exists t',a.\ t \rightarrow_a t' \wedge \neg\exists s' .\ s \rightarrow_a s' \wedge (s',t') \in R' \})$
}
return R'
Ydob

Simulation

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- A binary relation R is a **simulation** iff:

  $(s,t) \in R$ implies that
  - s is *final* implies that t is *final*
  - for all actions a
    - if $s \rightarrow_a s'$ then $\exists\, t' \,.\, t \rightarrow_a t'$ and $(s',t') \in R$

- A state s_0 of transition system S is **simulated by** a state t_0 of transition system T iff there **exists** a **simulation** between the initial states s_0 and t_0.

- Notably
  - **simulated-by** is a simulation
  - **simulated-by** is the largest simulation

Note it is a co-inductive definition!

- NB: A simulation is just one of the two directions of a bisimulation

Computing Simulation on Finite Transition Systems

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Algorithm ComputingSimulation
Input: transition system $TS_S = < A, S, S^0, \delta_S, F_S >$ and
transition system $TS_T = < A, T, T^0, \delta_T, F_T >$
Output: the **simulated-by** relation (the largest simulation)

Body

$R = \emptyset$

$R' = S \times T - \{(s,t) \mid s \in F_S \wedge \neg(t \in F_T)\}$

while $(R \neq R')$ {

$R := R'$

$R' := R' - \{(s,t) \mid \exists s', a.\ s \rightarrow_a s' \wedge \neg \exists t' .\ t \rightarrow_a t' \wedge (s',t') \in R' \}$

}

return R'

Ydob

Potential Behavior of the Whole Community

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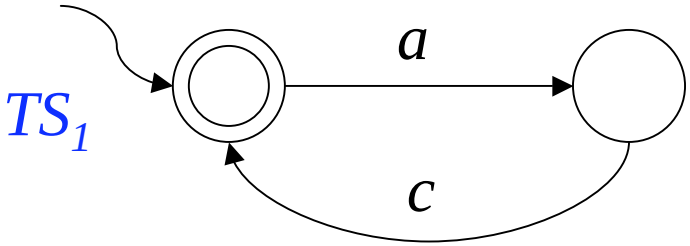
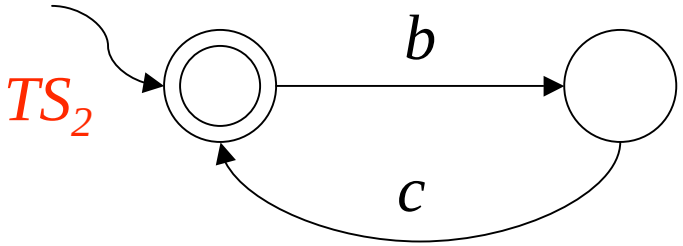
- Let $TS_1, \ldots, TS_n$ be the TSs of the component services.

- The **Community TS** is defined as the **asynchronous product** of $TS_1, \ldots, TS_n$, namely:
  $TS_c = \langle A, S_c, S_c^0, \delta_c, F_c \rangle$ where:
  - A is the set of actions
  - $S_c = S_1 \times \ldots \times S_n$
  - $S_c^0 = \{(s^0_1, \ldots, s^0_m)\}$
  - $F \subseteq F_1 \times \ldots \times F_n$
  - $\delta_c \subseteq S_c \times A \times S_c$ is defined as follows:
    $(s_1 \times \ldots \times s_n) \rightarrow_a (s'_1 \times \ldots \times s'_n)$ iff
    1. $\exists\, i.\ s_i \rightarrow_a s'_i \in \delta_i$
    2. $\forall\, j \neq i.\ s'_j = s_j$

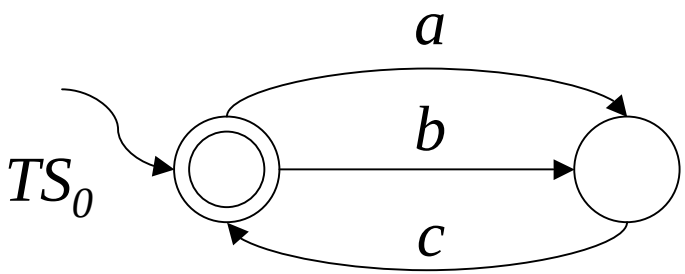
Example of Composition

- Available Services





- Target Service



Example of Composition

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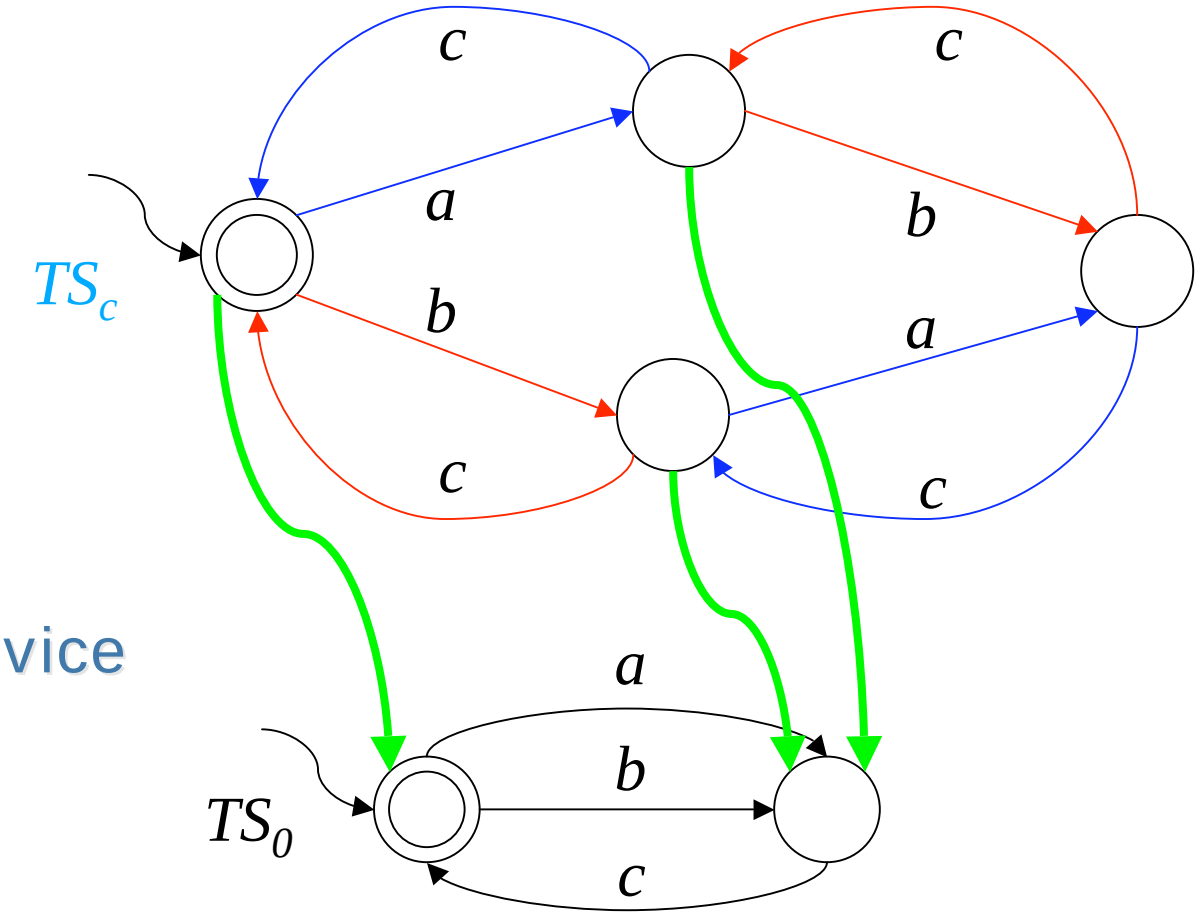
Community TS



Composition exists!

Composition via Simulation

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- **Thm[Subm07]**
  A composition realizing a target service TS TS_t exists if there **exists** a simulation relation between the initial state s_t^0 of TS_t and the initial state $(s_1^0, .., s_n^0)$ of the community TS TS_c.

- Notice if we take the union of all simulation relations then we get the largest simulation relation ***S***, still satisfying the above condition.

- **Corollary[Subm07]**
  A composition realizing a target service TS TS_t exists
  iff $(s_t^0 , (s_1^0, .., s_n^0)) \in \boldsymbol{S}$.

- **Thm[Subm07]**
  Computing the largest simulation ***S*** is polynomial in the size of the target service TS and the size of the community TS…
- … hence it is EXPTIME in the size of the available services.

Composition via Simulation

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- Given the largest simulation ***S*** form TS_t to TS_c(which include 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: $OG = < A, [1,...,n], S_r, s_r^0, \omega_r, \delta_r, F_r >$ with
  - A : the **actions** shared by the community
  - [1,...,n]: the **identifiers** of the available services in the community
  - $S_r = S_t \times S_1 \times L \times S_n$: 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

  - $\omega_r : S_r \times A_r \rightarrow [1,...,n]$: the **service selection function**, defined as follows:
    - If $s_t \rightarrow_{a,} s'_t$ then
      chose k s.t. $\exists\, s_k'.\ s_k \rightarrow_{a,} s_k' \wedge (s_t', (s_1, \ldots, s'_k, \ldots, s_n)) \in \boldsymbol{S}$

  - $\delta_r \subseteq S_r \times A_r \times [1,...,n] \rightarrow S_r$: the **state transition function**, defined as follows:
    - Let $\omega_r(s_t, s_1, \ldots, s_k, \ldots, s_n, a) = k$ then
      $(s_t, s_1, \ldots, s_k, \ldots, s_n) \rightarrow_{a,k} (s_t', s_1, \ldots, s'_k, \ldots, s_n)$ where $s_k \rightarrow_{a,} s'_k$

Composition via Simulation

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

- For running an orchestrator from the OG we need to store and access ***S*** *(polynomial time, exponential space)* ...
- ... and compute ω_r and δ_r at each step *(polynomial time and space)*

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Extension to the Roman Model

Extensions

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- **Nondeterministic** (angelic) **target** specification
  - Loose specification in client request
  - **Angelic (don't care)** vs devilish (don't know) nondeterminism
  - See [ICSOC'04]
- **Nondeterministic** (devilish) available **services**
  - Incomplete specification in available services
  - **Devilish (don't know)** vs angelic (don't care) nondeterminism
  - See below & [IJCAI'07]
- **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]
- 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]

See later

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Nondeterministic Available Services

Nondeterminism in Available Services

Devilish (don't know)!

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- 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

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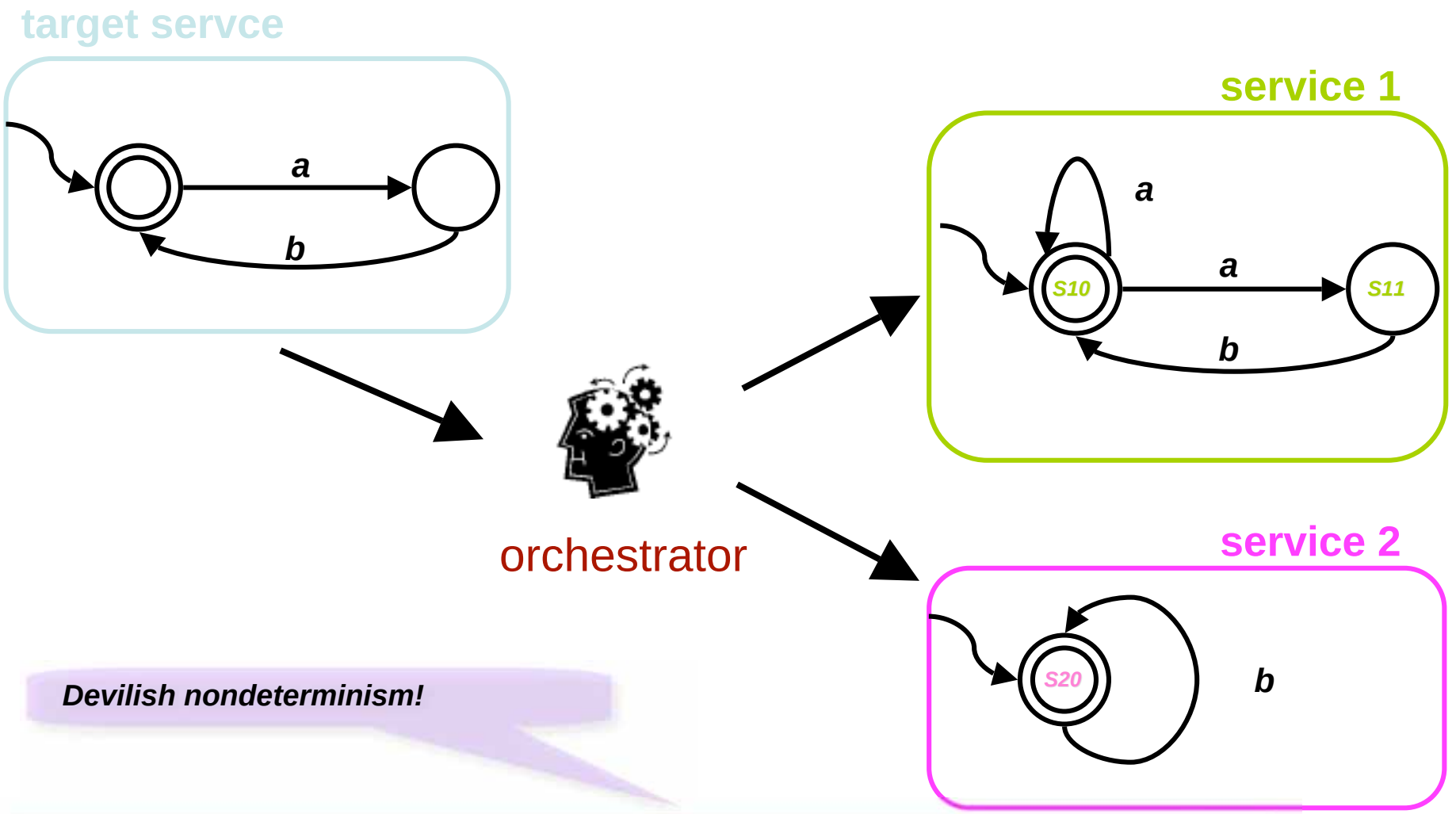

Available services represented as nondeterministic transition systems

Example: Nondeterministic Available Services

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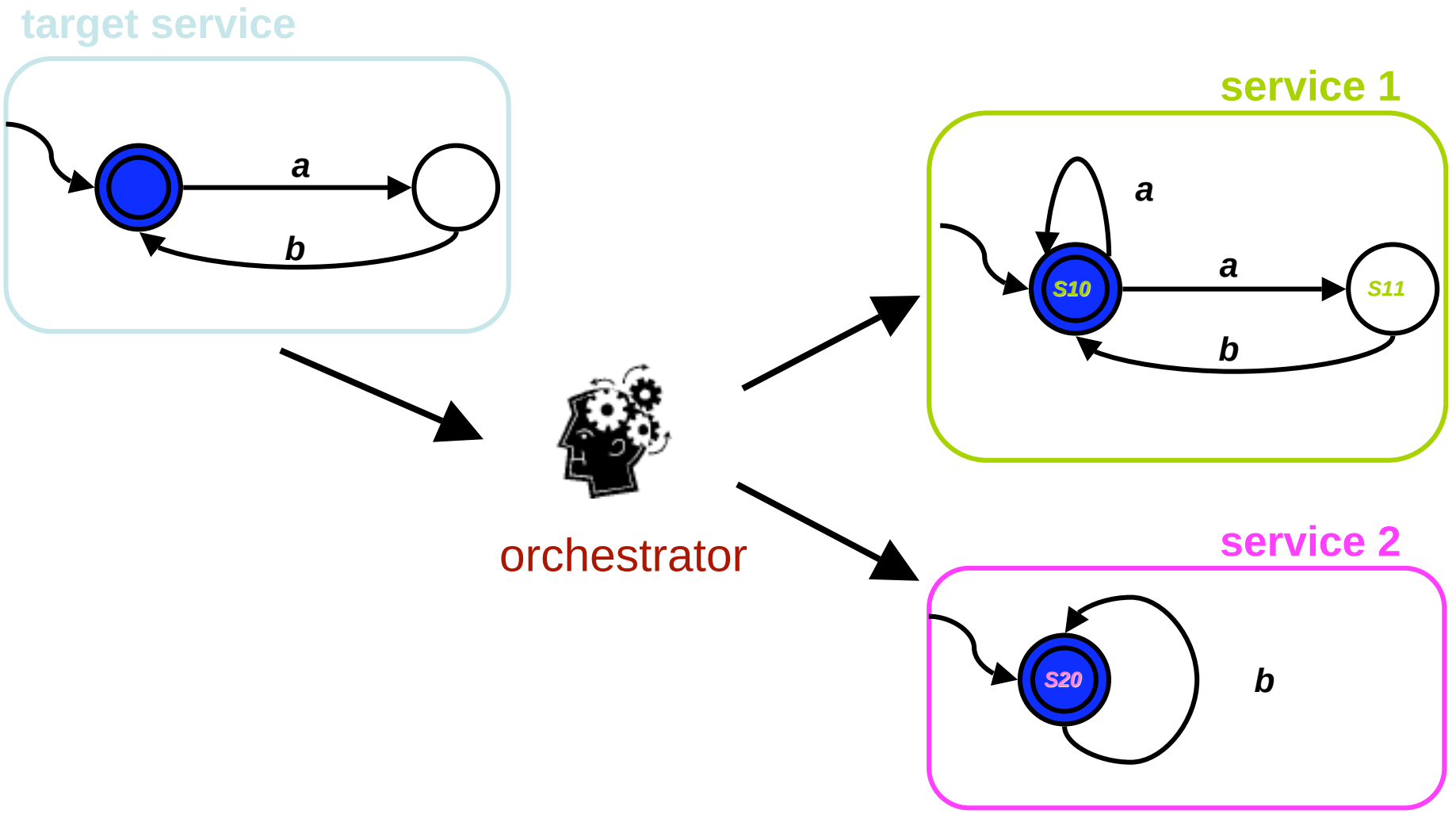

Example: Nondeterministic Available Services

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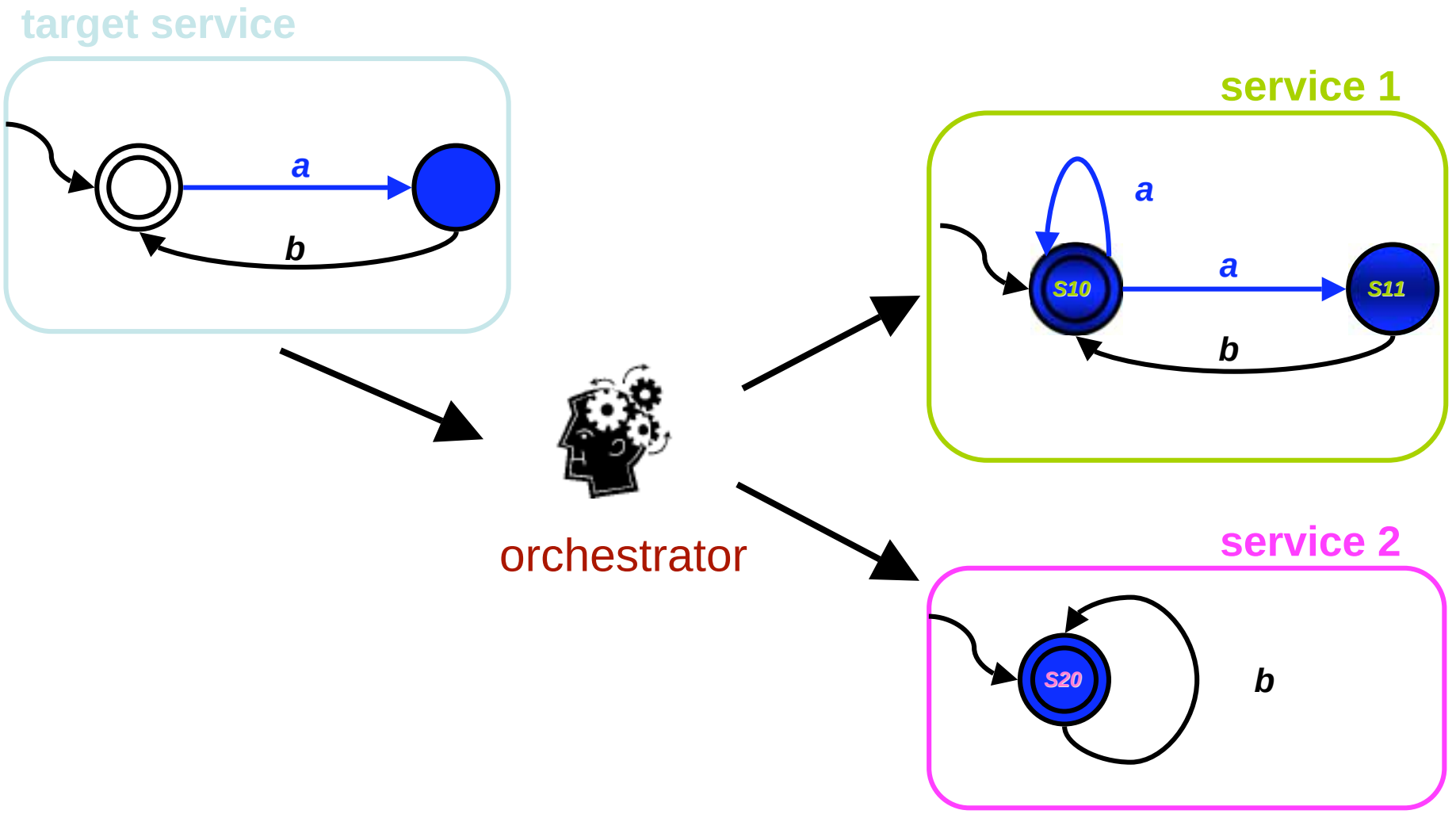

Example: Nondeterministic Available Services

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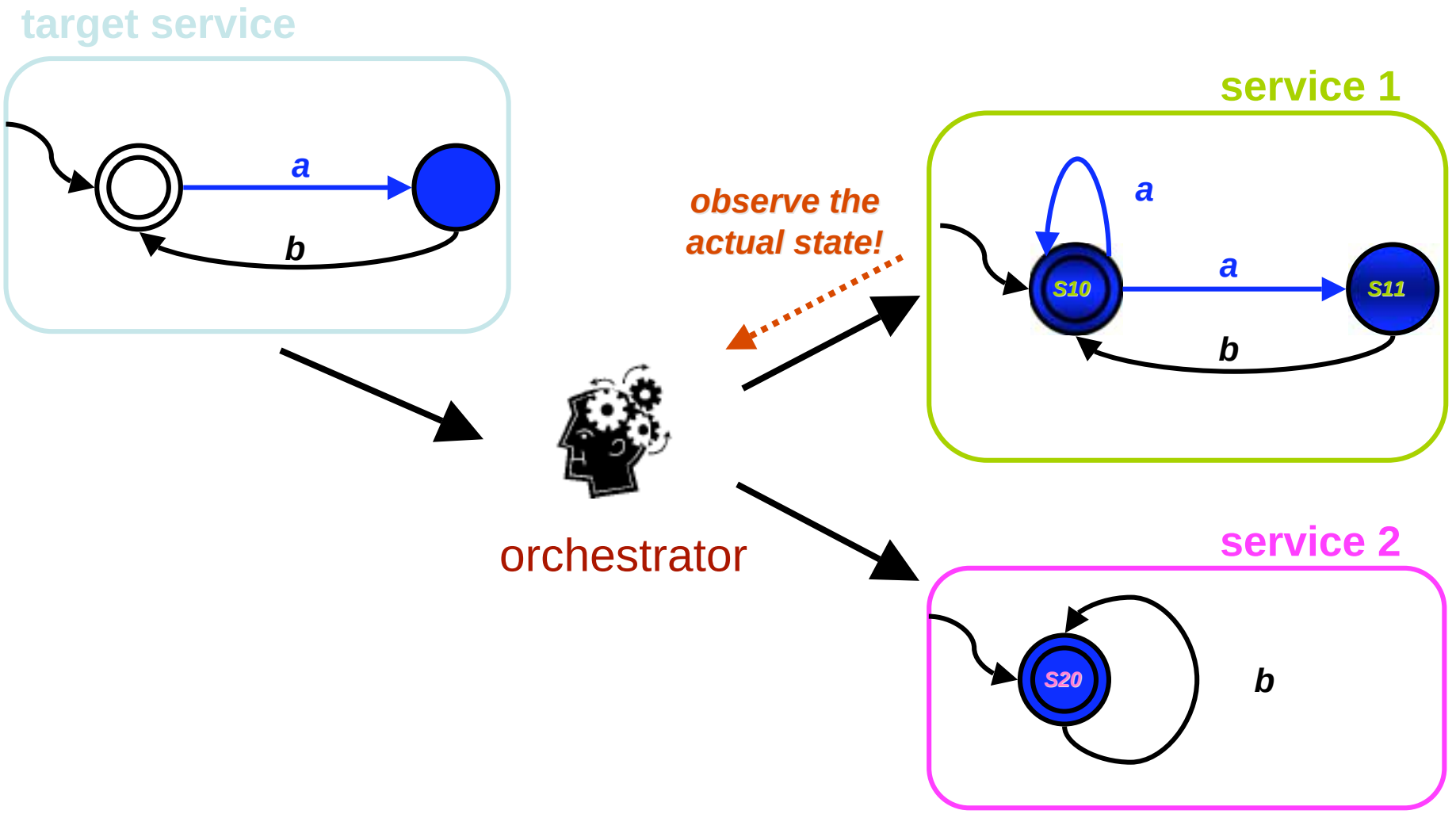
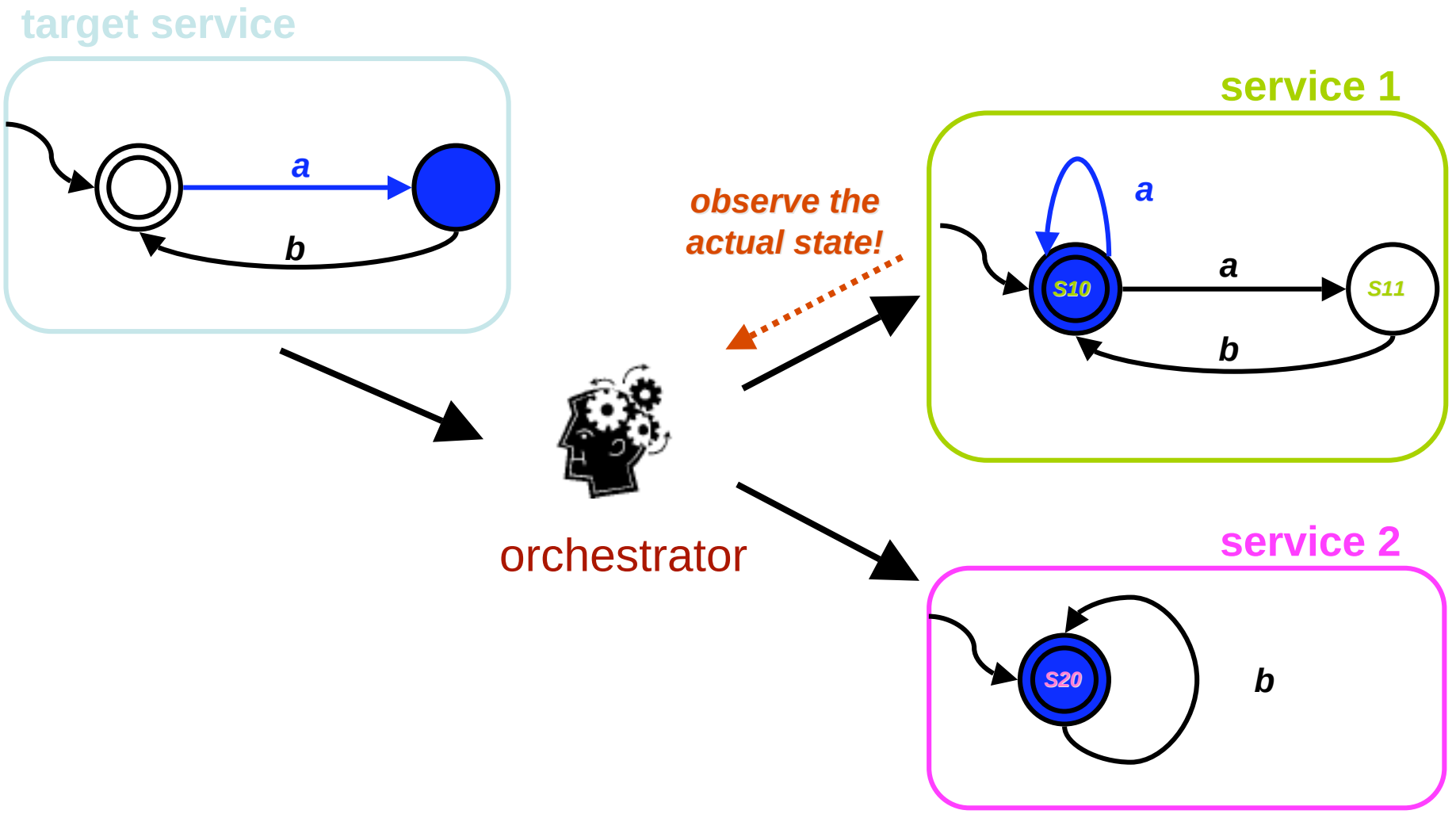


Example: Nondeterministic Available Services



Example: Nondeterministic Available Services

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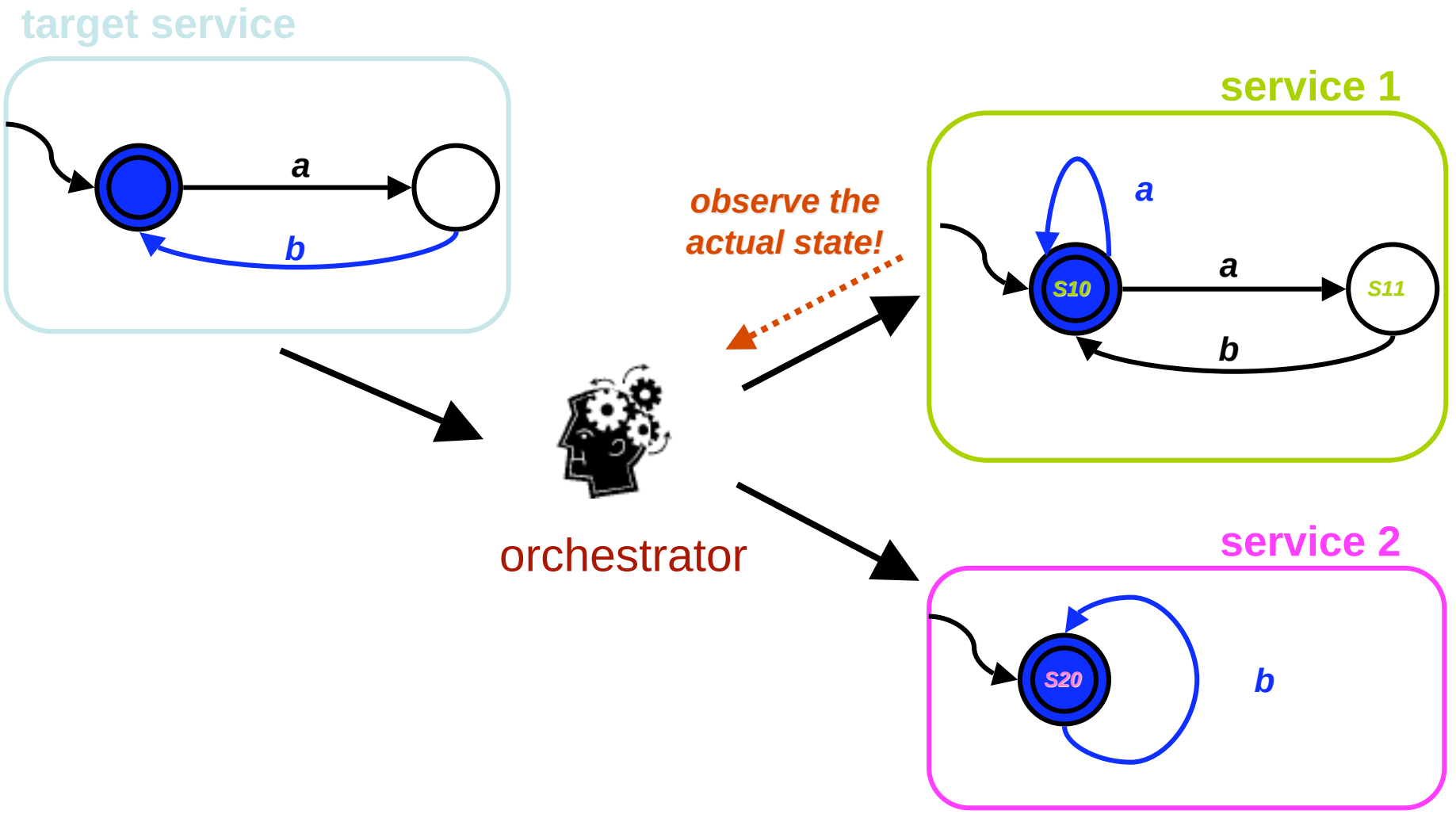

An Orchestrator Program Realizing the Target Service

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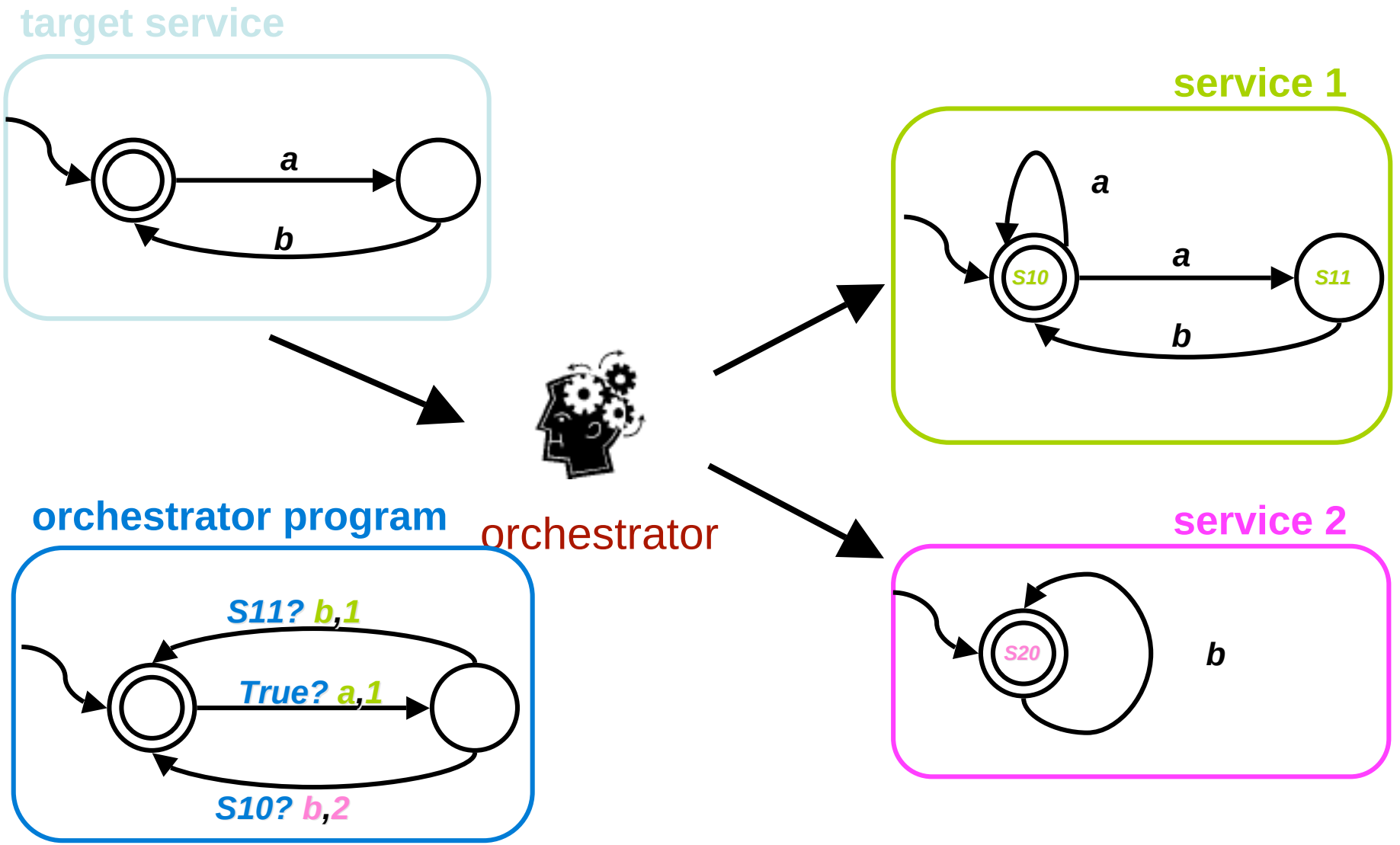

Orchestrator Programs

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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:

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

- 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*

Technique: Reduction to PDL

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Basic idea:

- A orchestrator program P realizes the target service T iff at each point:
  - $\forall$ transition labeled a of the target service T ...
  - ... $\exists$ an available service B_i (the one chosen by P) which can make an a-transition ...
  - ... and $\forall$ a-transition of B_i realize the a-transition of T

- Encoding in PDL:
  - $\forall$ transition labeled a ...
    use **branching**
  - $\exists$ an available service B_i ...
    use underspecified predicates **assigned through SAT**
  - $\forall$ 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 Φ coding the composition existence
- *If SAT, the tableau returns a finite model of* Φ

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: Composition à la Simulation

Composition à la Simulation

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- We consider binary relations R satisfying the following co-inductive condition:

  $(s,(q_1, .., q_n)) \in R$ implies that
  - if s is *final* then q_i, with i=1, .., n, is *final*
  - for **all** actions a
    - if $s \rightarrow_a s'$ then $\exists\ k \in 1..n$.
      - $\exists\ q_k' \,.\, q_k \rightarrow_a q_k'$
      - $\forall\ q_k'.\ q_k \rightarrow_a q_k' \supset (s',(,q_1,..,q_k', .., q_n)) \in R$

  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 s_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 $(s_t^0 , (s_1^0, .., s_n^0)) \in \boldsymbol{RR}$.

Composition à la Simulation

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- Given ***RR*** form TS_t to TS_c(which include 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: $OG = < A, [1,...,n], S_r, s_r^0, \omega_r, \delta_r, F_r >$ with
  - A : the **actions** shared by the community
  - [1,...,n]: the **identifiers** of the available services in the community
  - $S_r = S_t \times S_1 \times L \times S_n$: 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

  - $\omega_r : S_r \times A_r \rightarrow [1,...,n]$: the **service selection function**, defined as follows:
    - If $s_t \rightarrow_{a,} s'_t$ then
      chose k s.t. $\exists\, s_k'.\ s_k \rightarrow_{a,} s_k' \wedge \forall\, s_k'.\ s_k \rightarrow_{a,} s_k' \supset (s_t', (s_1, \ldots, s'_k, \ldots, s_n)) \in$ ***RR***

  - $\delta_r \subseteq S_r \times A_r \times [1,...,n] \times S_r$: the **state transition relation**, defined as follows:
    - Let $\omega_r(s_t, s_1, \ldots, s_k, \ldots, s_n, a) = k$ then
      $(s_t, s_1, \ldots, s_k, \ldots, s_n) \rightarrow_{a,k} (s_t', s_1, \ldots, s'_k, \ldots, s_n)$ for each $s_k \rightarrow_{a,} s'_k$

Composition à la 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 ω_r and δ_r at each step *(polynomial time and space)*

Example of Composition

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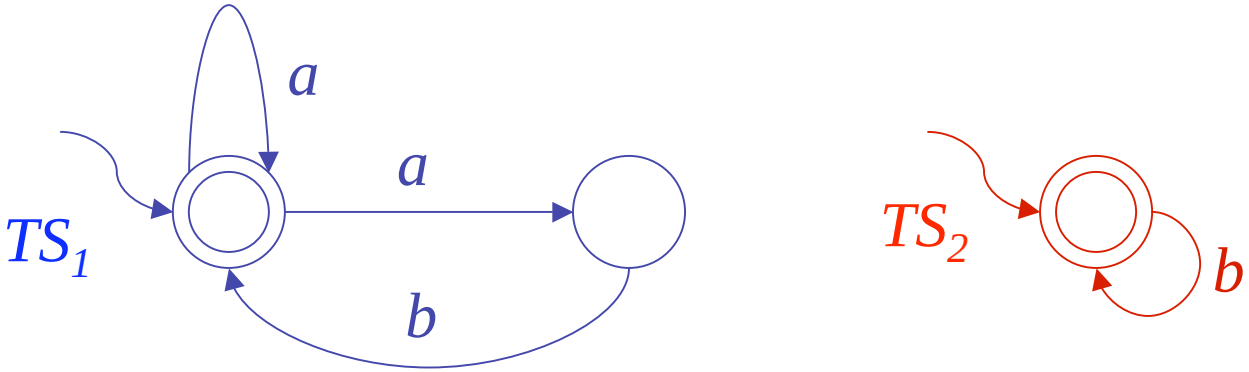
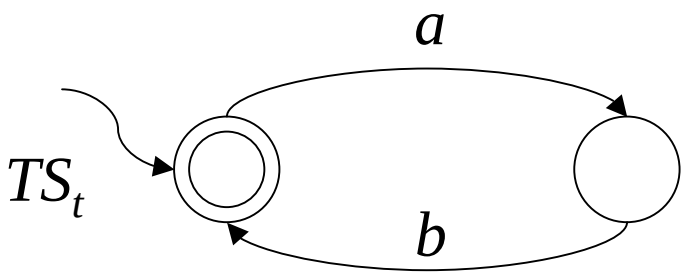
Available Services



Target Service



Example of Composition

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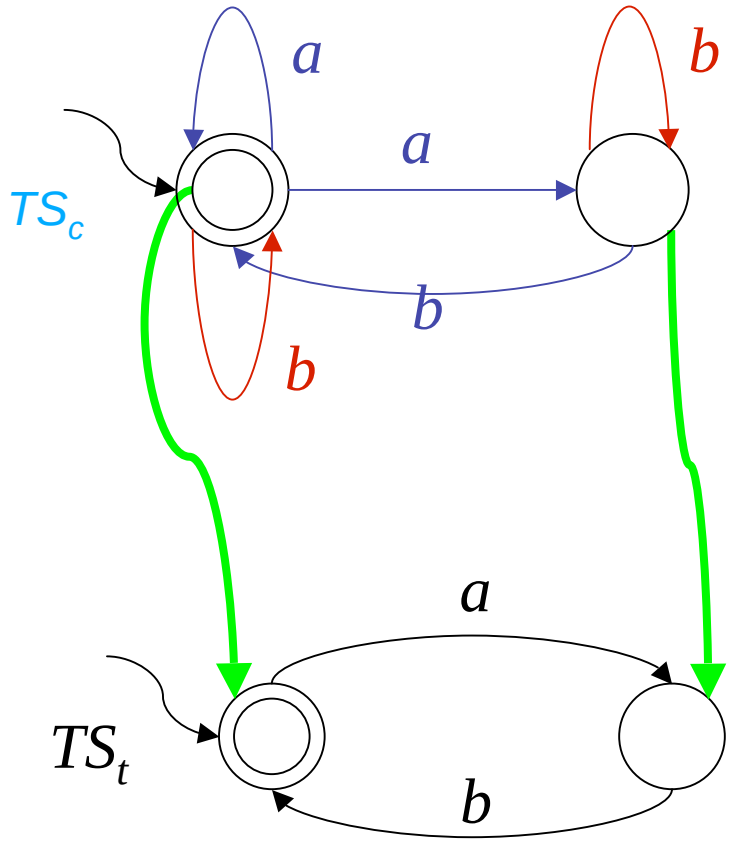
Community TS



Target Service

Composition exists!

References

[ICSOC'03] Daniela Berardi, Diego Calvanese, Giuseppe De Giacomo, Maurizio Lenzerini, Massimo Mecella: Automatic Composition of E-services That Export Their Behavior. ICSOC 2003: 43-58

[WES'03] Daniela Berardi, Diego Calvanese, Giuseppe De Giacomo, Maurizio Lenzerini, Massimo Mecella: A Foundational Vision of e-Services. WES 2003: 28-40

[TES'04] Daniela Berardi, Diego Calvanese, Giuseppe De Giacomo, Maurizio Lenzerini, Massimo Mecella: : A Tool for Automatic Composition ofServices Based on Logics of Programs. TES 2004: 80-94

[ICSOC'04] Daniela Berardi, Giuseppe De Giacomo, Maurizio Lenzerini, Massimo Mecella, Diego Calvanese: Synthesis of underspecified composite e-services based on automated reasoning. ICSOC 2004: 105-114

[IJCIS'05] Daniela Berardi, Diego Calvanese, Giuseppe De Giacomo, Maurizio Lenzerini, Massimo Mecella: Automatic Service Composition Based on Behavioral Descriptions. Int. J. Cooperative Inf. Syst. 14(4): 333-376 (2005)

[VLDB'05] Daniela Berardi, Diego Calvanese, Giuseppe De Giacomo, Richard Hull, Massimo Mecella: Automatic Composition of Transition-based Semantic Web Services with Messaging. VLDB 2005: 613-624

[ICSOC'05] Daniela Berardi, Diego Calvanese, Giuseppe De Giacomo, Massimo Mecella: Composition of Services with Nondeterministic Observable Behavior. ICSOC 2005: 520-526

[SWS'06] Fahima Cheikh, Giuseppe De Giacomo, Massimo Mecella: Automatic web services composition in trustaware communities. Proceedings of the 3rd ACM workshop on Secure web services 2006. Pages: 43 - 52.

[AISC'06] Daniela Berardi, Diego Calvanese, Giuseppe De Giacomo, Massimo Mecella. Automatic Web Service Composition: Service-tailored vs. Client-tailored Approaches. In Proc. AISC 2006, International Workshop jointly with ECAI 2006.

[FOSSACS'07] Anca Muscholl, Igor Walukiewicz: A lower bound on web services composition. Proceedings FOSSACS, LNCS, Springer, Volume 4423, page 274--287 - 2007.

[IJCAI'07] Giuseppe De Giacomo, Sebastian Sardiña: Automatic Synthesis of New Behaviors from a Library of Available Behaviors. IJCAI 2007: 1866-1871

[AAAI'07] Sebastian Sardiña, Fabio Patrizi, Giuseppe De Giacomo: Automatic synthesis of a global behavior from multiple distributed behaviors. In Proceedings of the National Conference on Artificial Intelligence (AAAI), Vancouver, Canada, July 2007.

[Subm07] Daniela Berardi, Fahima Cheikh, Giuseppe De Giacomo, Fabio Patrizi: Automatic Service Composition via Simulation. Submitted.