Composition via Simulation

Bisimulation

- 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 $s \to_a s'$ then $\exists t' . t \to_a t'$ and $(s',t') \in R$
    - if $t \to_a t'$ then $\exists s' . s \to_a s'$ 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

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

Simulation

- 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 $s \to_a s'$ then $\exists t' . t \to_a t'$ 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!

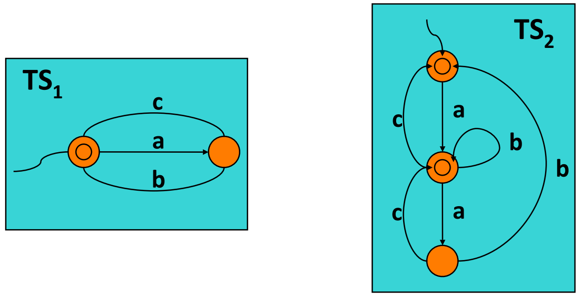
- NB: A simulation is just one of the two directions of a bisimulation

Computing Simulation on Finite Transition Systems

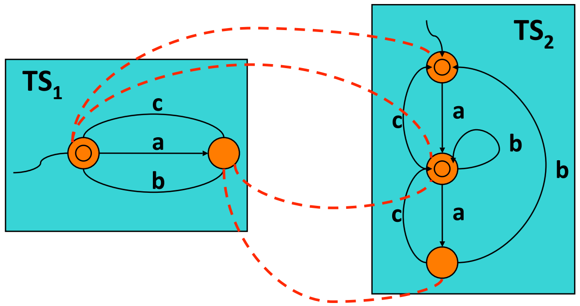
Algorithm ComputingSimulation
Input: transition system $TS_S = < A, S, S^0, \delta_S, F_S>$ and
transition system $TS_T = < A, T, T^0, \delta_T, F_T>$
Output: the **simulated-by** relation (the largest simulation)

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

Example of simulation



Example of simulation



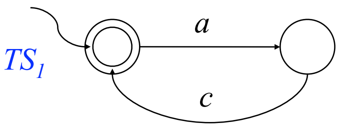
TS2's behavior "includes" TS1's

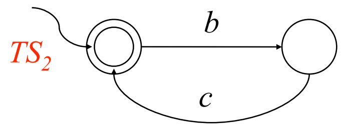
Potential Behavior of the Whole Community

- Let $TS_1, \cdots, TS_n$ be the TSs of the component services.
- The **Community TS** is defined as the **asynchronous product** of $TS_1, \cdots, TS_n$, namely:
  $TS_c = < A, S_c, S_c^0, \delta_c, F_c>$ where:
  - A is the set of actions
  - $S_c = S_1 \times \cdots \times S_n$
  - $S_c^0 = \{(s^0_1, \cdots, s^0_n)\}$
  - $F \subseteq F_1 \times \cdots \times F_n$
  - $\delta_c \subseteq S_c \times A \times S_c$ is defined as follows:
    $(s_1 \times \cdots \times s_n) \to_a (s'_1 \times \cdots \times s'_n)$ iff
    - $\exists i.\ s_i \to_a s'_i \in \delta_i$
    - $\forall j \neq i.\ s'_j = s_j$

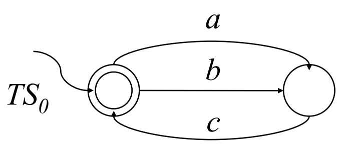
Example of Composition

- Available Services



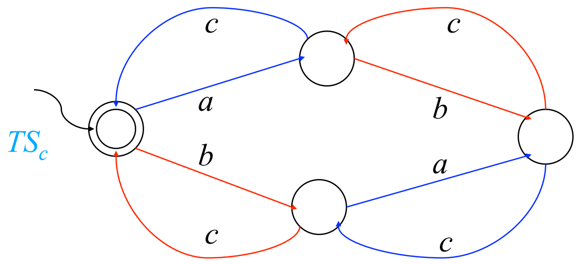


- Target Service



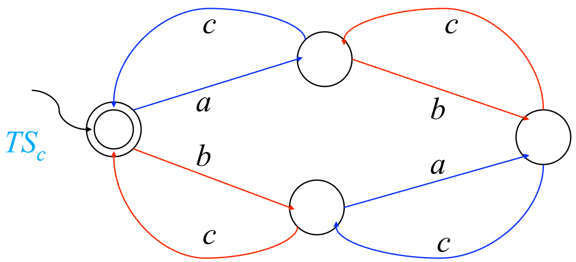
Example of Composition

Community TS

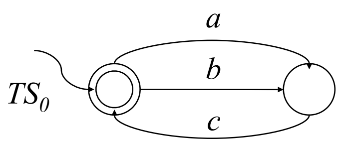


Example of Composition

Community TS

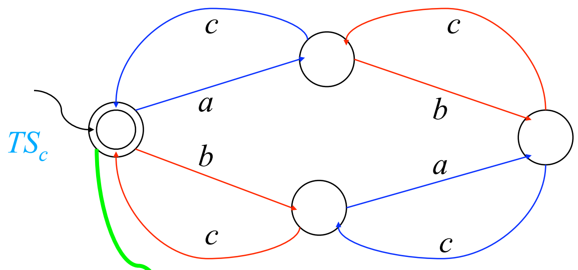


Target Service

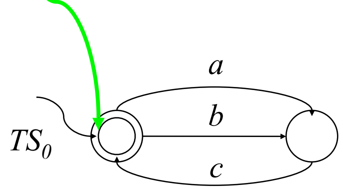


Example of Composition

Community TS

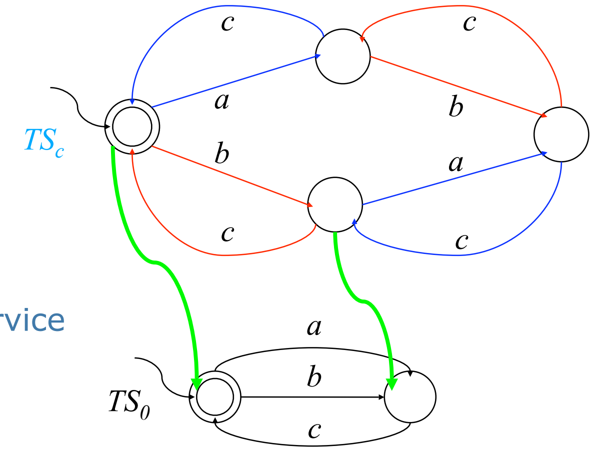


Target Service



Example of Composition

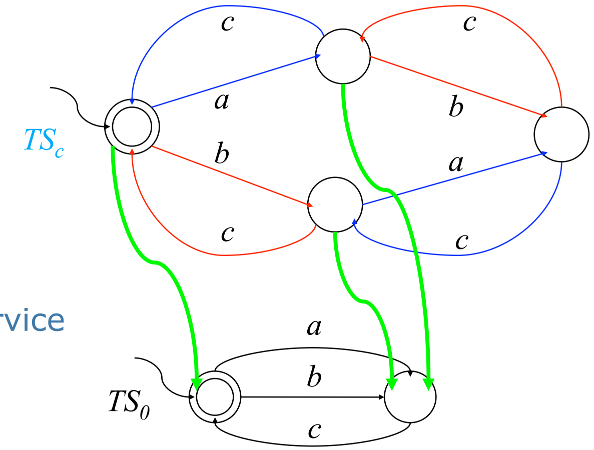
Community TS



Target Service

Example of Composition

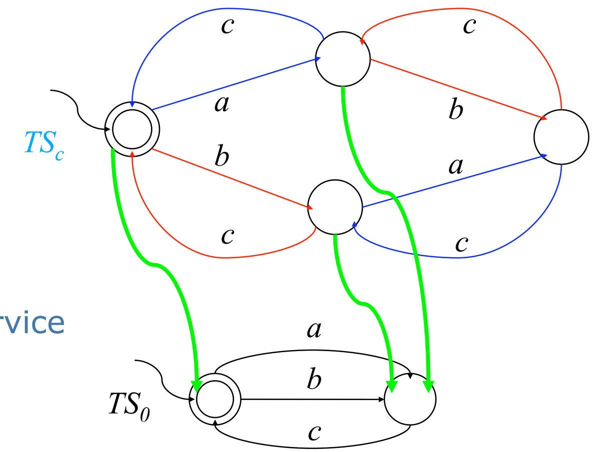
Community TS



Target Service

Example of Composition

Community TS



Target Service

Composition exists!

Composition via Simulation

- **Thm[IJFCS08]**
  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[IJFCS08]**
  A composition realizing a target service TS TS_t exists iff $(s_t^0 , (s_1^0, .., s_n^0)) \in \boldsymbol{S}$.
- **Thm[IJFCS08]**
  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

- 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: $OG = < A, [1,\dots,n], S_r, s_r^0, \omega_r, \delta_r, F_r>$ with
  - A : the **actions** shared by the community
  - $[1,\dots,n]$: 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
  - $s_r^0 = (s^0_t, s^0_1, \dots, s^0_m)$: the **initial state** of the orchestrator program
  - $F_r \subseteq \{ (s_t, s_1, \dots, s_n) \mid s_t \in F_t$: the **final states** of the orchestrator program
  - $\omega_r : S_r \times A_r \to [1,\dots,n]$: 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 *S*}

    i.e., …= $\{i \mid s_t \to_{a,} s'_t \wedge \exists s_i'. s_i \to_{a,} s_i' \wedge (s_t', (s_1, \dots, s'_i, \dots, s_n)) \in S\}$
  - $\delta_r \subseteq S_r \times A_r \times [1,\dots,n] \to S_r$: the **state transition function**, defined as follows:
    Let $k \in \omega_r(s_t, s_1, \dots, s_k, \dots, s_n, a)$ then
    $(s_t, s_1, \dots, s_k, \dots, s_n) \to_{a,k} (s_t', s_1, \dots, s'_k, \dots, s_n)$ where $s_k \to_{a,} s'_k$

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Composition via Simulation

- 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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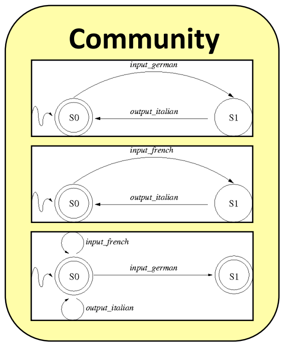
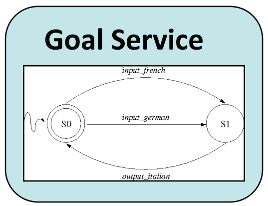
Example of composition via simulation (1)

- A *Community* of *services* over a shared alphabet $\mathcal{A}$
- A (Virtual) *Goal* service over $\mathcal{A}$





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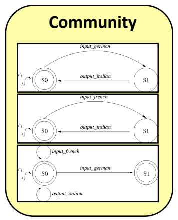
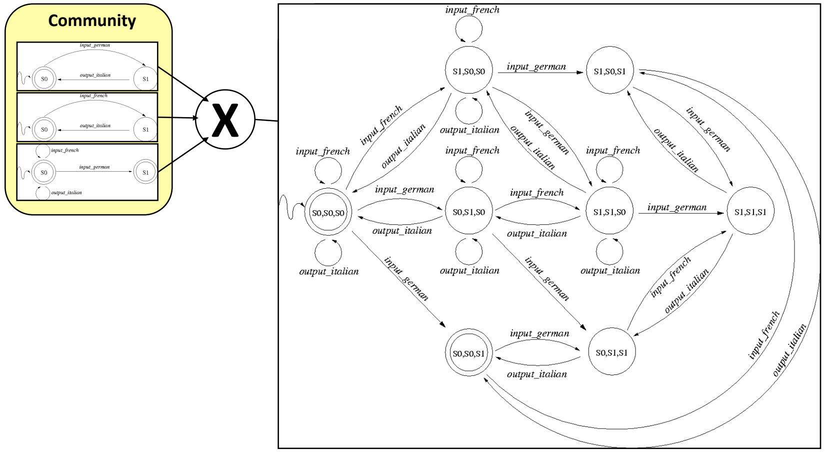
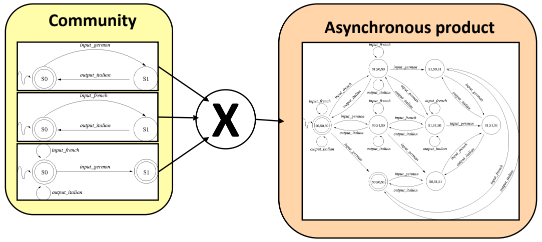
Example of composition via simulation (2)



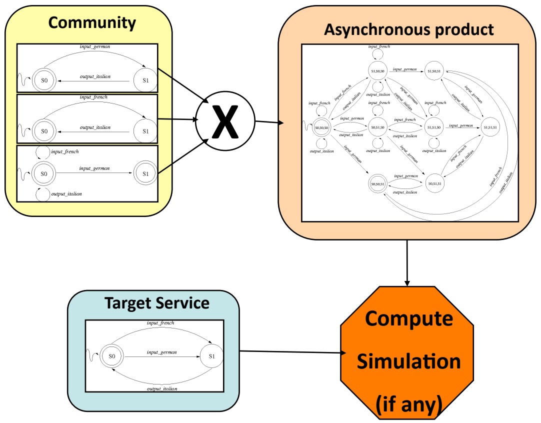
Example of composition via simulation (2)



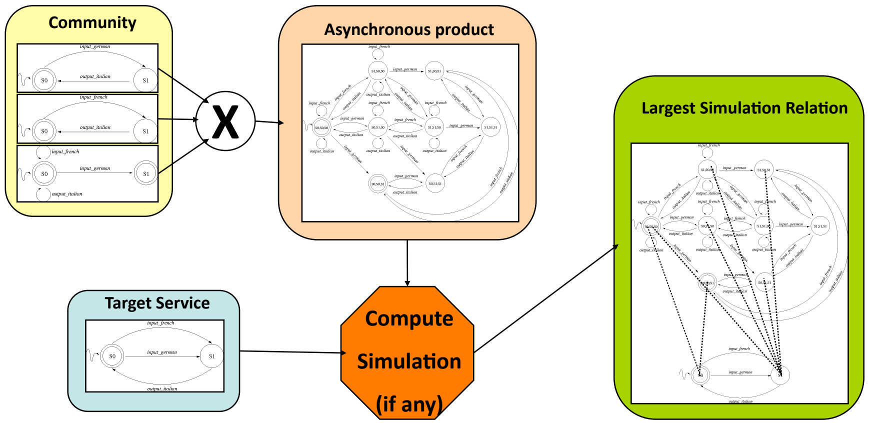
Example of composition via simulation (2)



Example of composition via simulation (2)



Example of composition via simulation (2)



Example of composition via simulation (3)

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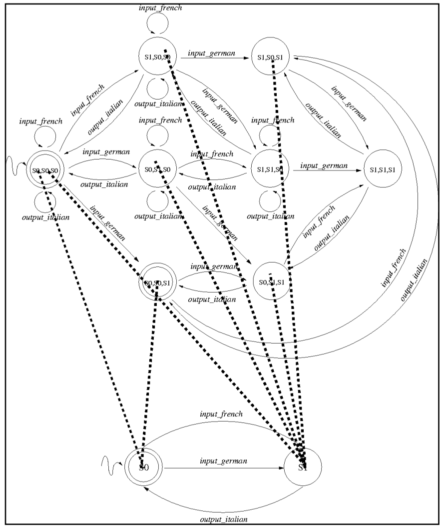

Example of composition via simulation (4)

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