Service Composition and Synthesis

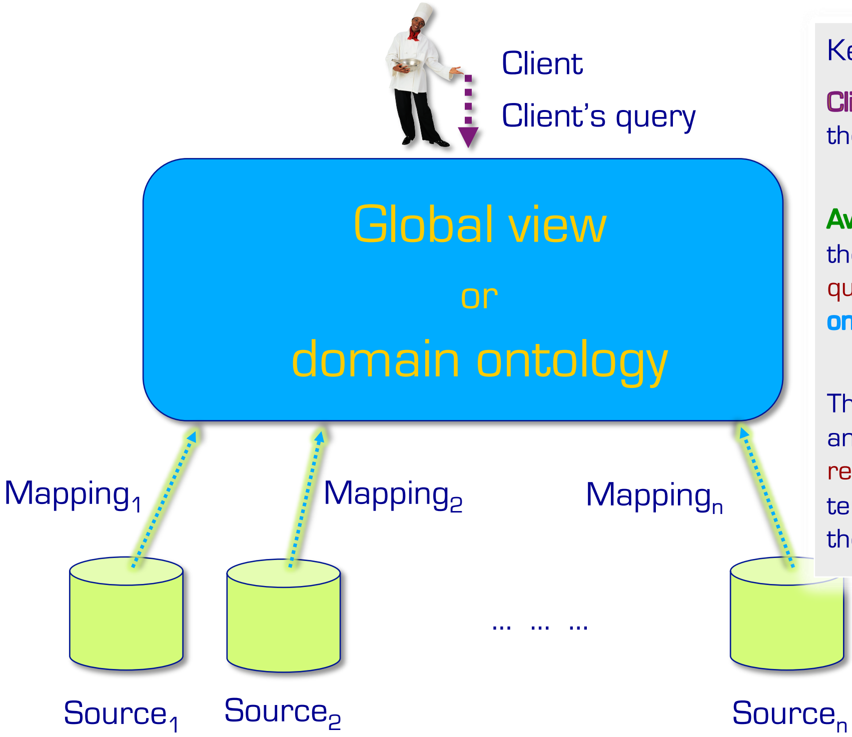
***The Roman Model** (including nondeterministic services)*

Giuseppe De Giacomo
SAPIENZA Università di Roma, Italy

Introduction

- The promise of **Service Computing** is to use services fundamental elements for realizing distributed applications/solutions.
- **Services** are processes that export their **abstract specification**
- When no available service satisfies a desired specification, one might check whether (parts of) available services can be **composed** and **orchestrated** in order to realize the specification.
- **Working at an abstract level** enable us to exploit results from **automatic verification and synthesis** to verify and compose services.
- The problem of automatic composition becomes especially interesting in the presence of **stateful** (conversational) services.
- Among the various frameworks proposed in the literature, here we concentrate on the so called ``**Roman Model**'' *(name by Rick Hull).*

Data Integration



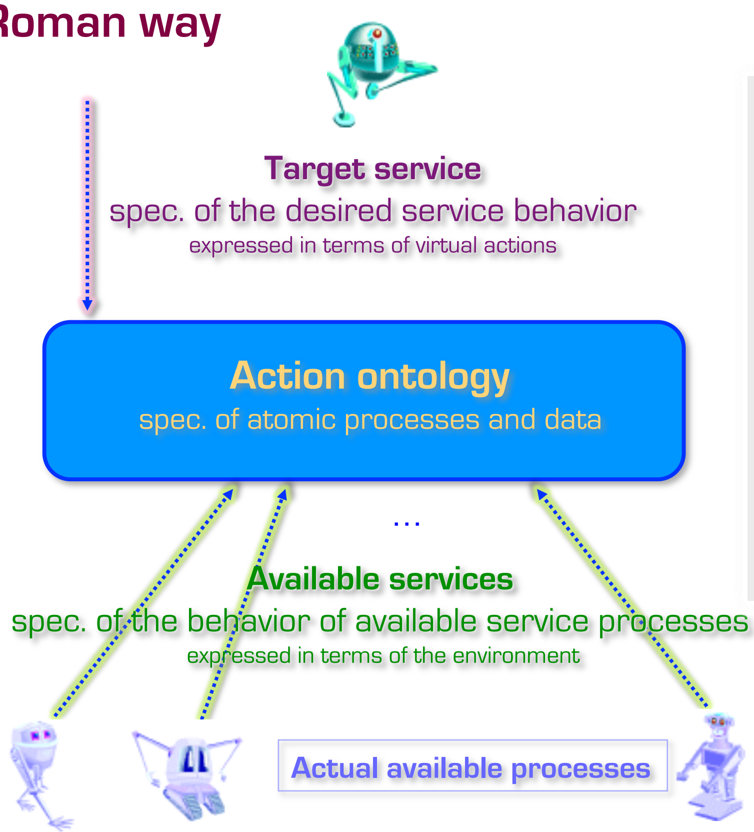
Key points

Client's request: query over the **domain ontology**

Available sources express their information in terms of a query over the **domain ontology**

The **data integration system** answers the **client's query** by reformulating/rewriting it in terms of the information in the **available sources**

Service integration/composition: The Roman way



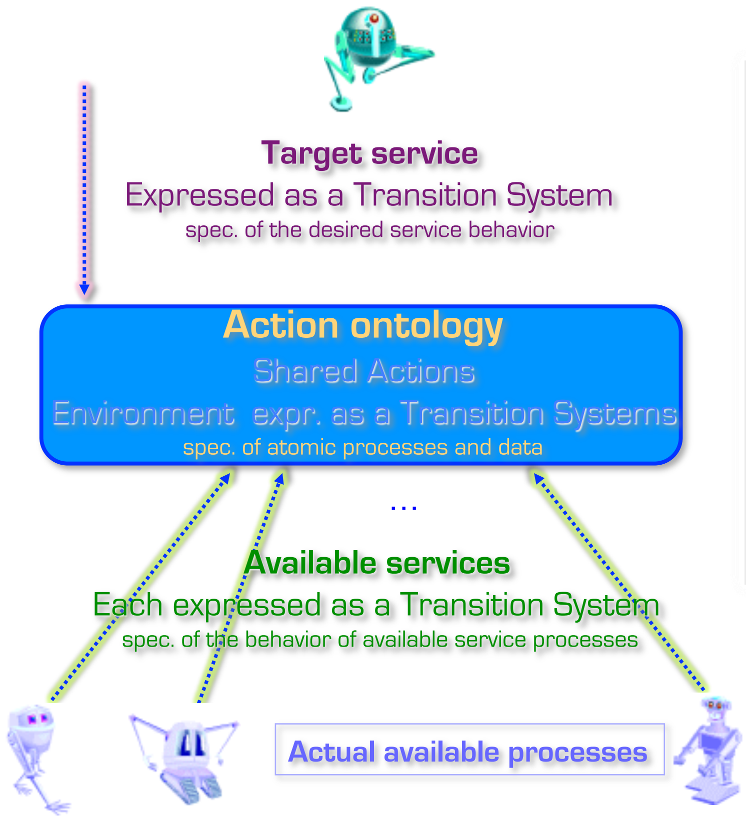
Key points

No available process for the target service

Must realize **target service** by **delegating** actual actions to **available services**

Available services are **stateful**, hence must **realize** the **target** using **fragments** of their **computations**

The Roman Model: *basics*



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Roman Model's main ingredients

- The Roman Model exemplifies what can be achieved by composing conversational services and uncovers relationships with automated synthesis of reactive processes in Verification and AI Planning.

- Roman Model's main ingredients
  - **Each available service** is formally specified as a **transition system** that captures its possible conversations with a generic client.
  - Desired specification is a **target service**, described itself as a **transition system**.
  - the aim is to **automatically synthesize orchestrators** that realize the target service by delegating its actions to the available services, exploiting fragments of their execution.

Transition systems

- We represent services as **transition systems**:

- A TS is a tuple $< A, S, s_0, \delta, F>$ where:
  - A is the set *shared* of actions
  - S is the set of states
  - $s_0 \in S$ 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

Service composition

Problem of composition existence

- Given:
  - available services $B_1,\ldots,B_n$
  - target service T

  over the same environment (same set of atomic actions)
- Check whether T can be realized by **delegating** actions to $B_1,\ldots,B_n$ so as to ***mimic*** T over time *(forever!)*

Composition synthesis

synthesis of the ***orchestrator*** *that does the delegation*

Service composition as a game

There are at least two kinds of games. One could be called finite, the other infinite.

A finite game is played for the purpose of winning ...
... an infinite game for the purpose of continuing the play.

Finite and Infinite Games
J. P. Carse, *philosopher*

Service composition as a game: Service composition vs Planning

Planning (Stateless service composition)

- **Operators:** atomic actions
- **Goal:** desired state of affair
- **Game:** *finite!*
  - compose operators sequentially so as to reach the goal
- **Playing strategy:** plan
  (program having operators invocation as atomic instructions)

Service composition (Roman model)

- **Operators:** available transition systems
- **Goal:** target transition system
- **Game:** *infinite!*
  - compose available transition systems concurrently so as to play the target transition system
- **Playing strategy:** orchestrator
  (process that delegate target actions to the available service

Nondeterminism in Available Services

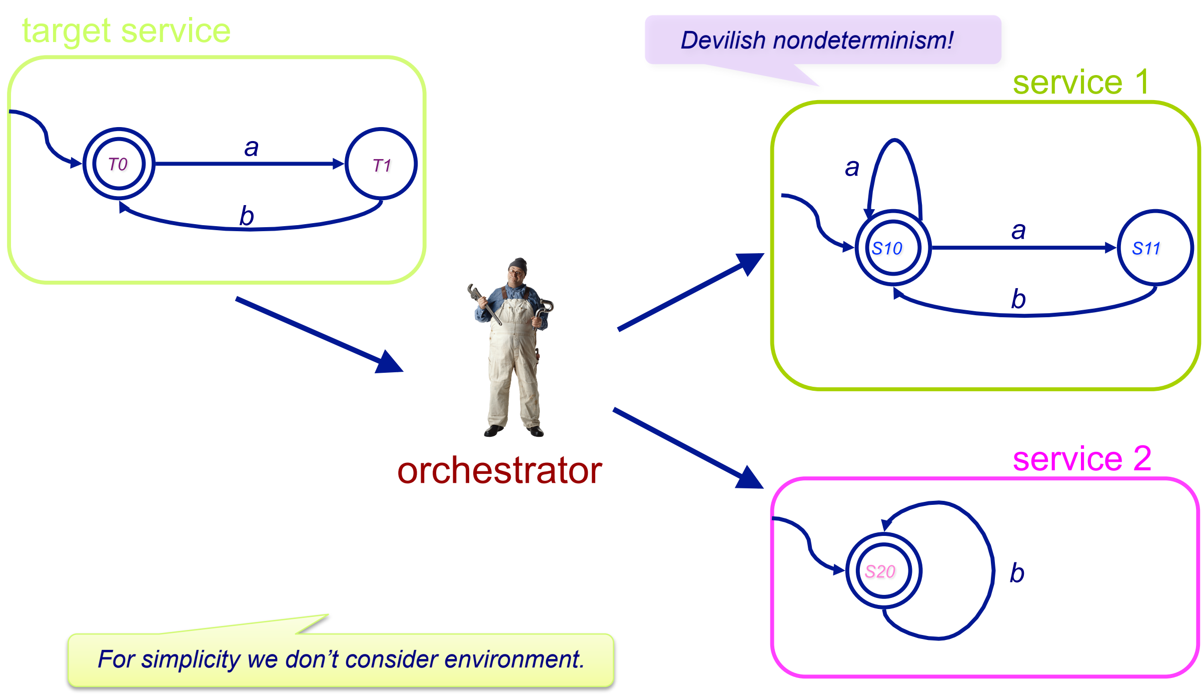
Devilish (don't know)!

- 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])

Simple example of service composition



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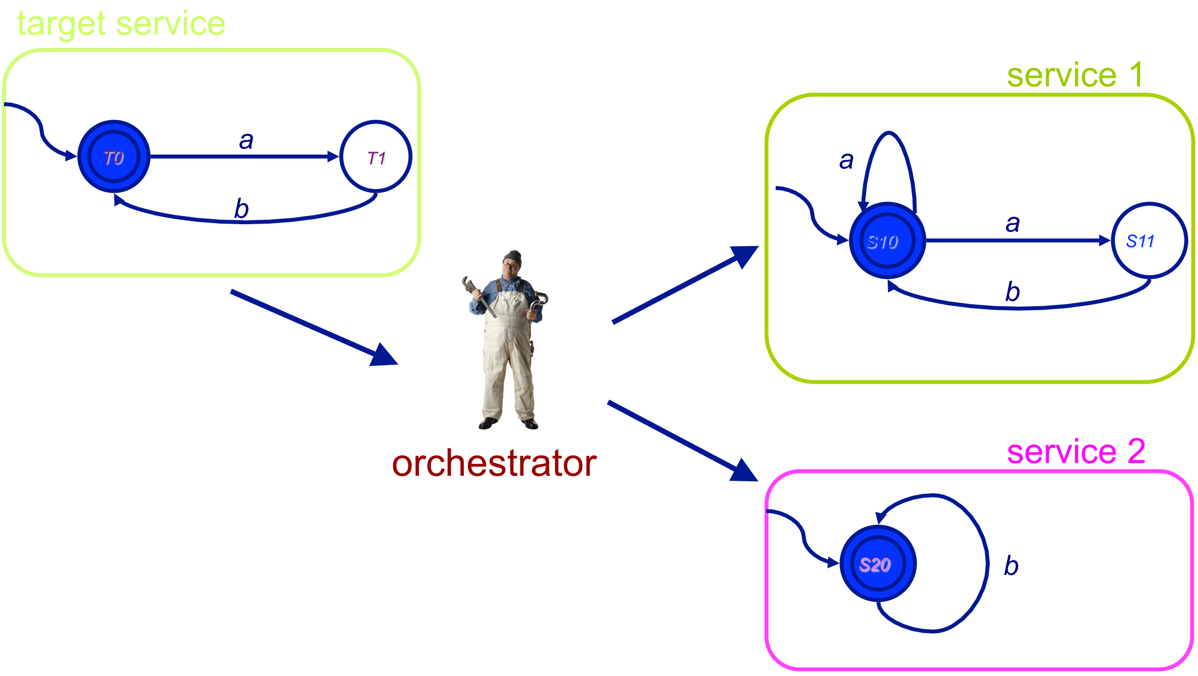

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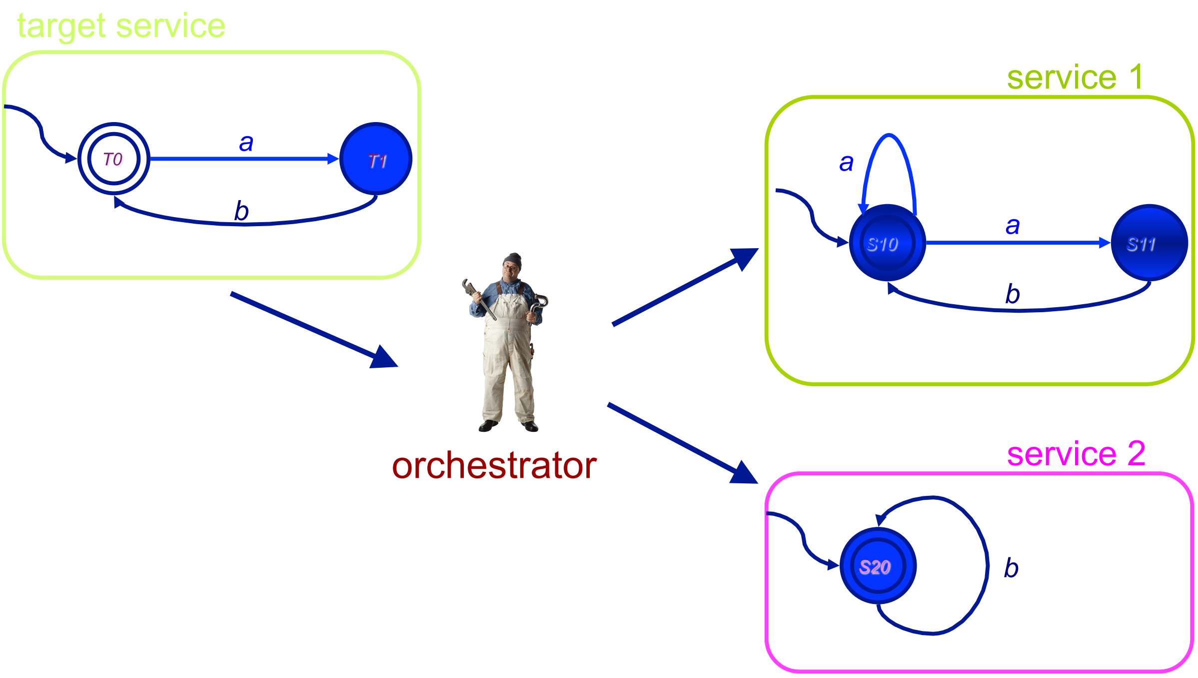

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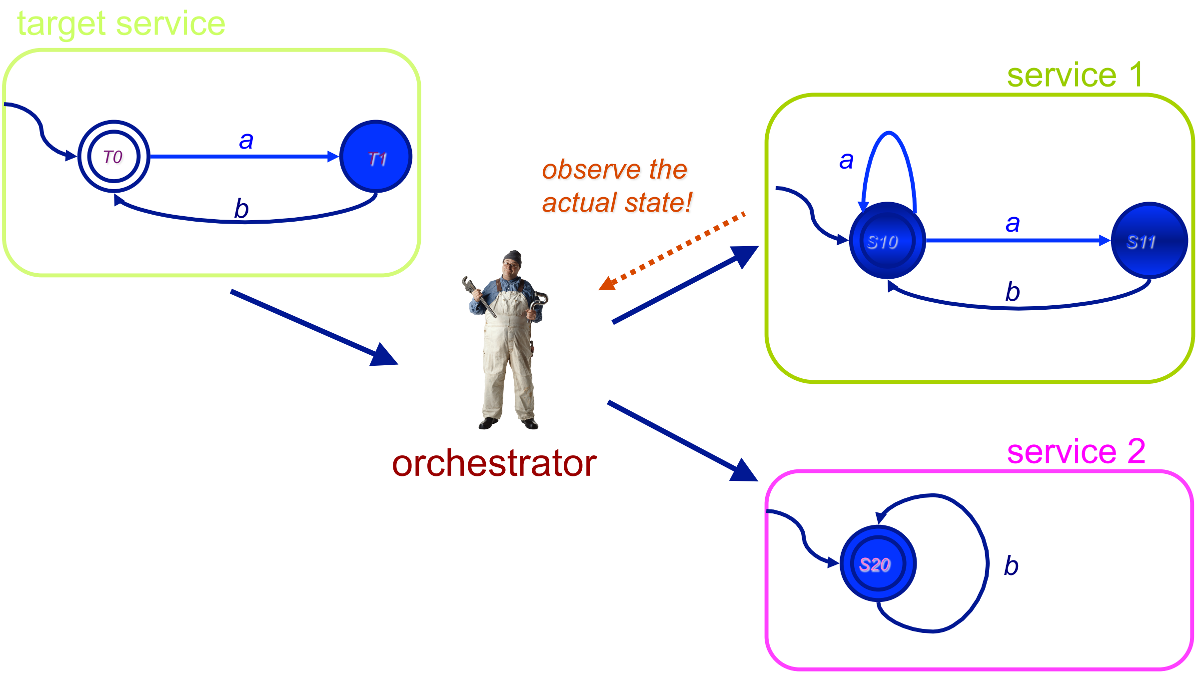

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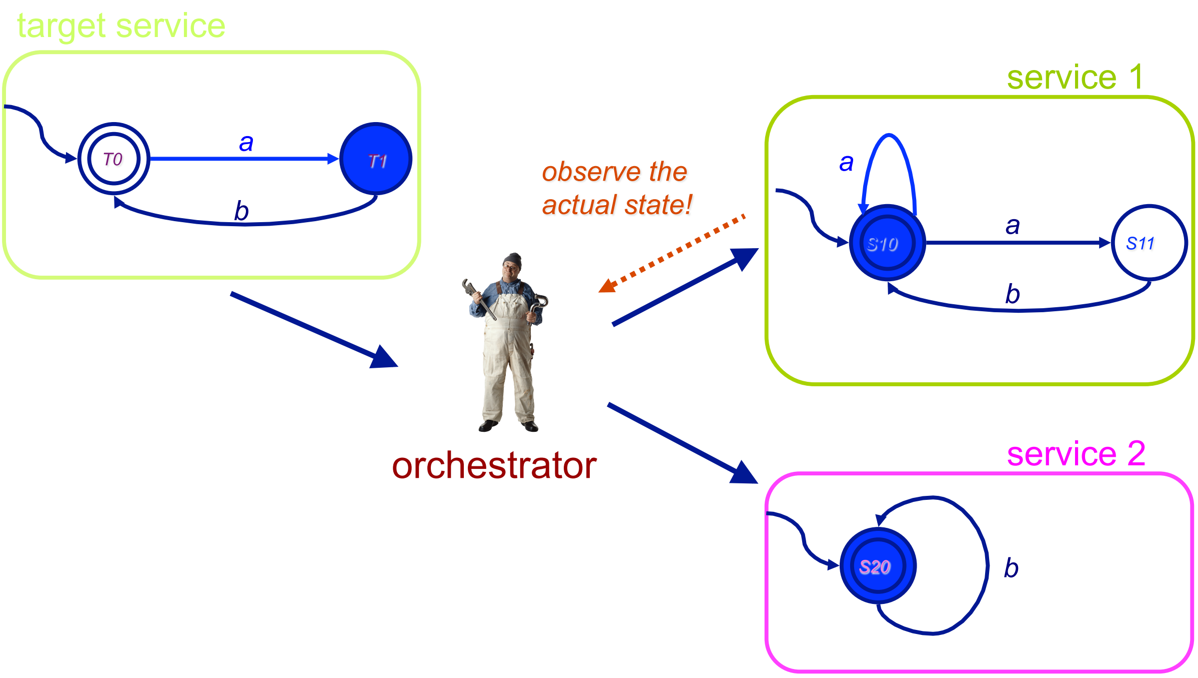

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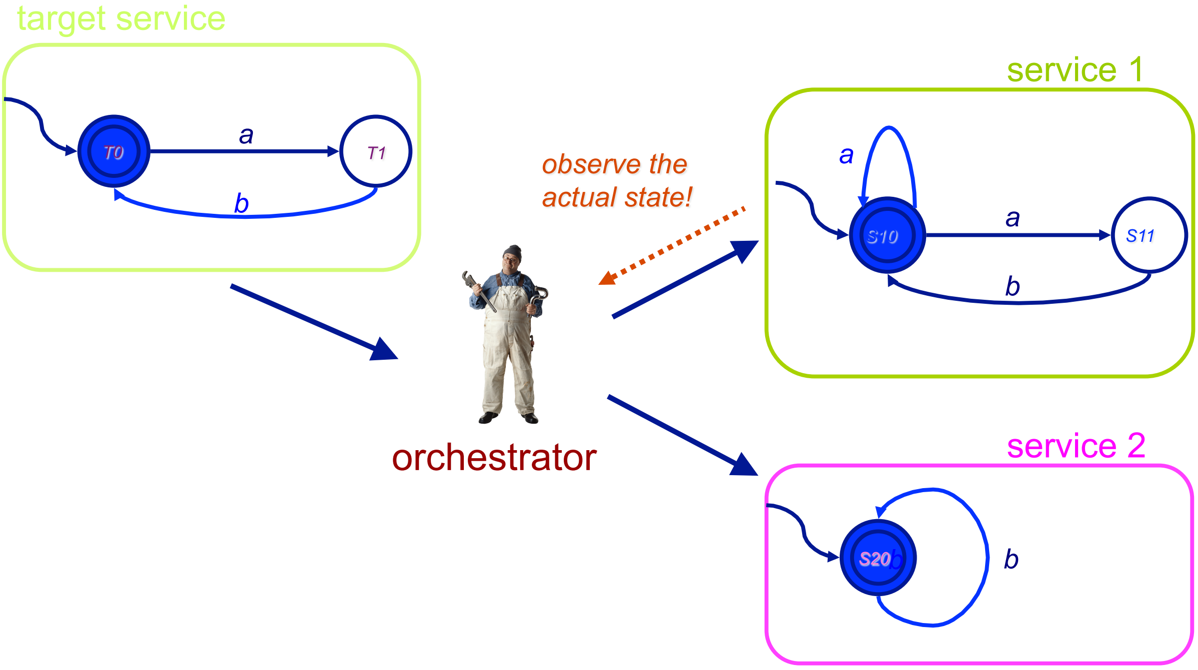

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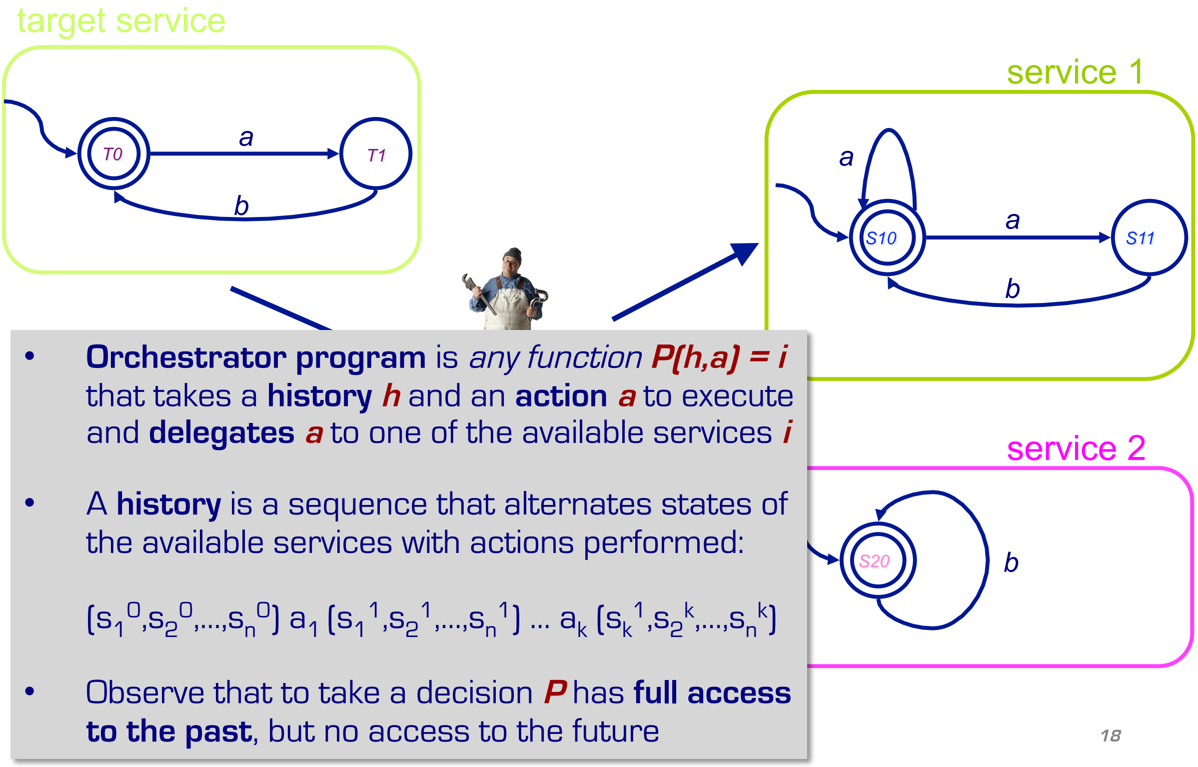


- **Orchestrator program** is *any function* ***P(h,a) = i*** that takes a **history** ***h*** and an **action** ***a*** to execute and **delegates** ***a*** to one of the available services ***i***

- A **history** is a sequence that alternates 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

Synthesizing compositions

- Techniques for computing compositions:
- Reduction to PDL SAT
- Simulation-based ←
- LTL synthesis as model checking of game structure

(all techniques are for finite state services)

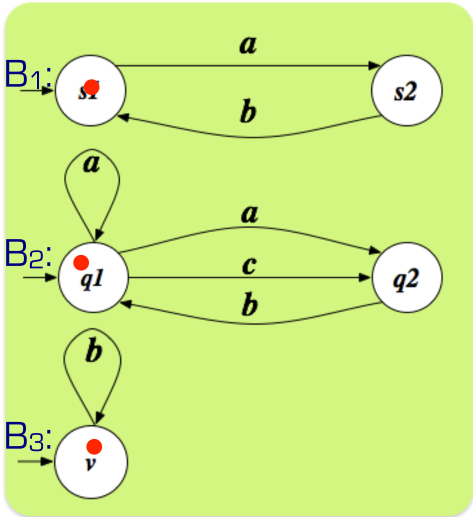
Simulation-based technique

Directly based on

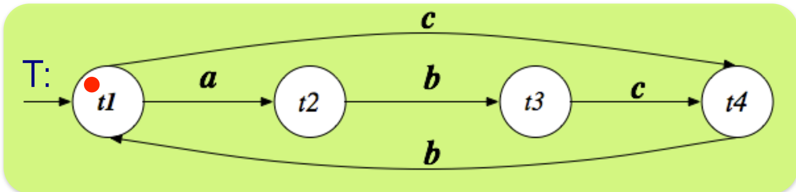
... *controlling* the concurrent execution of available services $B_1,\ldots,B_n$ so as to ***mimic*** the target service T

Thm: *Composition exists iff the asynchronous (Cartesian) product C of $B_1,\ldots,B_n$ can* ***(ND-)simulate*** *T*

Example of composition by simulation



Given from available and target service ...



Computing composition via simulation

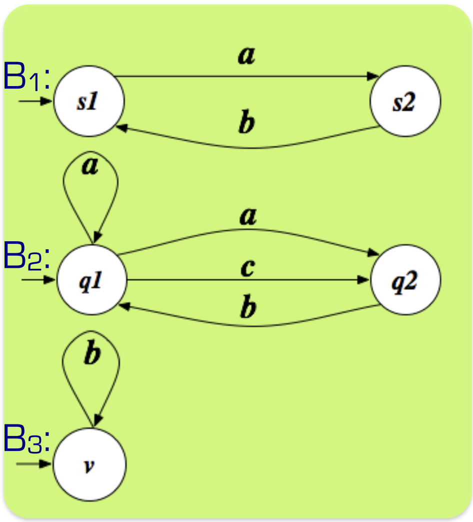
Let $B_1,\ldots,B_n$ be the TSs of the available services.

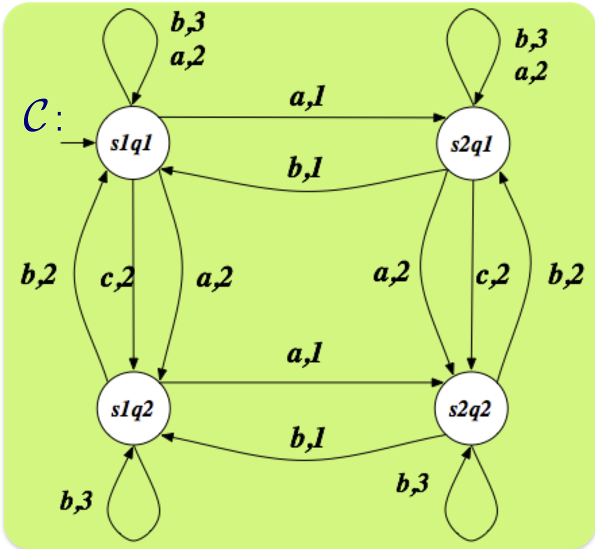
The **available services TS** $\mathcal{C} = < A, S_\mathcal{C}, s_\mathcal{C}^0, \delta_\mathcal{C}, F_\mathcal{C} >$ is the **asynchronous product** of $B_1,\ldots,B_n$ where:

- A is the set of actions
- $S_\mathcal{C} = S_1 \times\ldots\times S_n$
- $s_\mathcal{C}^0 = (s^0{}_1,\ldots, s^0{}_m)$
- $F_\mathcal{C} = F_1 \times\ldots\times F_n$
- $\delta_\mathcal{C} \subseteq S_\mathcal{C} \times A \times S_\mathcal{C}$ is defined as follows:
- $(s_1 \times\ldots\times s_n) \rightarrow_a (s'_1 \times\ldots\times s'_n)$ iff

$$\exists\, i.\ s_i \rightarrow_a s'_i \in \delta_i \text{ and } \forall\, j\neq i.\ s'_j = s_j$$

Example of composition by simulation





… consider the **asynchronous product** of the available services …

23

Simulation relation

Given a target service T and (the asynchronous product of) available services $\mathcal{C}$, an (**ND-**)**simulation** is a relation R between the states $t \in \mathcal{T}$ an $(s_1,..,s_n)$ of $\mathcal{C}$ such that:

$(t, s_1,..,s_n) \in R$ implies that

- if t *is final* then s_i *is final* (i=1,..,n)
- for all $t \to_a t'$ in T, exists a $B_i \in \mathcal{C}$ s.t.
  - $\exists\, s_i \to_a s'_i$ in B_i $\wedge$
  - $\forall\, s_i \to_a s'_i$ in $B_i \Rightarrow (t', s_1,..,s'_i,..,s_n) \in R$

- If **exists a simulation** relation *R* (such that $(t^0, s_1^0,..,s_n^0) \in R$, then we say that or **T is simulated by** $\mathcal{C}$ (or $\mathcal{C}$ **simulates T**).

- **Simulated-by** is

–(i) a simulation;

–(ii) the largest simulation.

Simulated-by is a coinductive definition

Simulation relation (cont.)

Algorithm Compute (ND-)simulation
Input: target behavior T and (async. prod. of) available services $\mathcal{C}$
Output: the **simulated-by** relation (the largest simulation)

Body

$R = \emptyset$

$R' = S_T \times S_1 \times .. \times S_n - \{(t, s_1,..,s_n) \mid t \in F_T \wedge s_i \notin F_i \text{ for some } i\}$

while $(R \neq R')$ {

$R := R'$

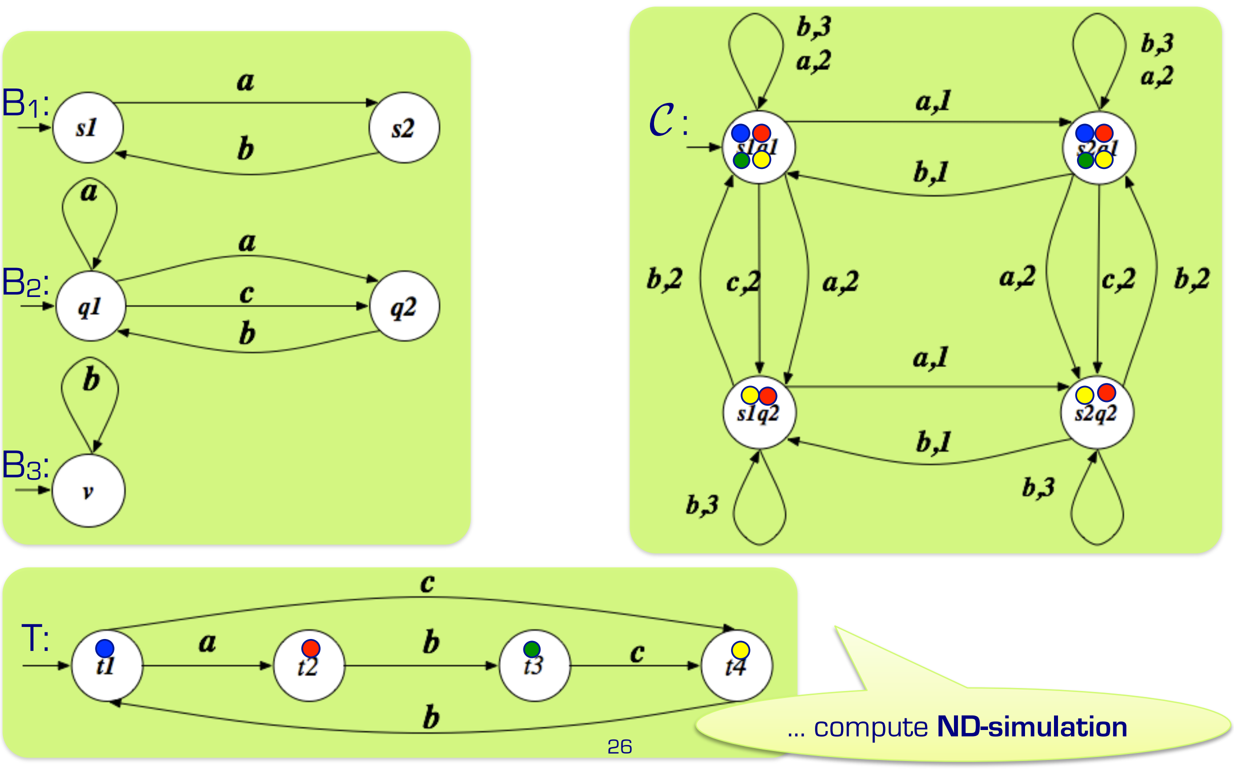
$R' := R' - \{(t, s_1,..,s_n) \mid \exists\, t \rightarrow_a t' \text{ in } T \wedge$
$\neg (\exists\, s_i \rightarrow_a s'_i \text{ in } B_i \wedge \forall\, s_i \rightarrow_a s'_i \text{ in } B_i \Rightarrow (t', s_1,..s'_i,..s_n) \in R')\}$

}

return R'

End

Example of composition by simulation



... compute **ND-simulation**

Using simulation for composition

- Given the largest simulation R of T by C, we can build every composition through the ***orchestrator generator (OG)***.

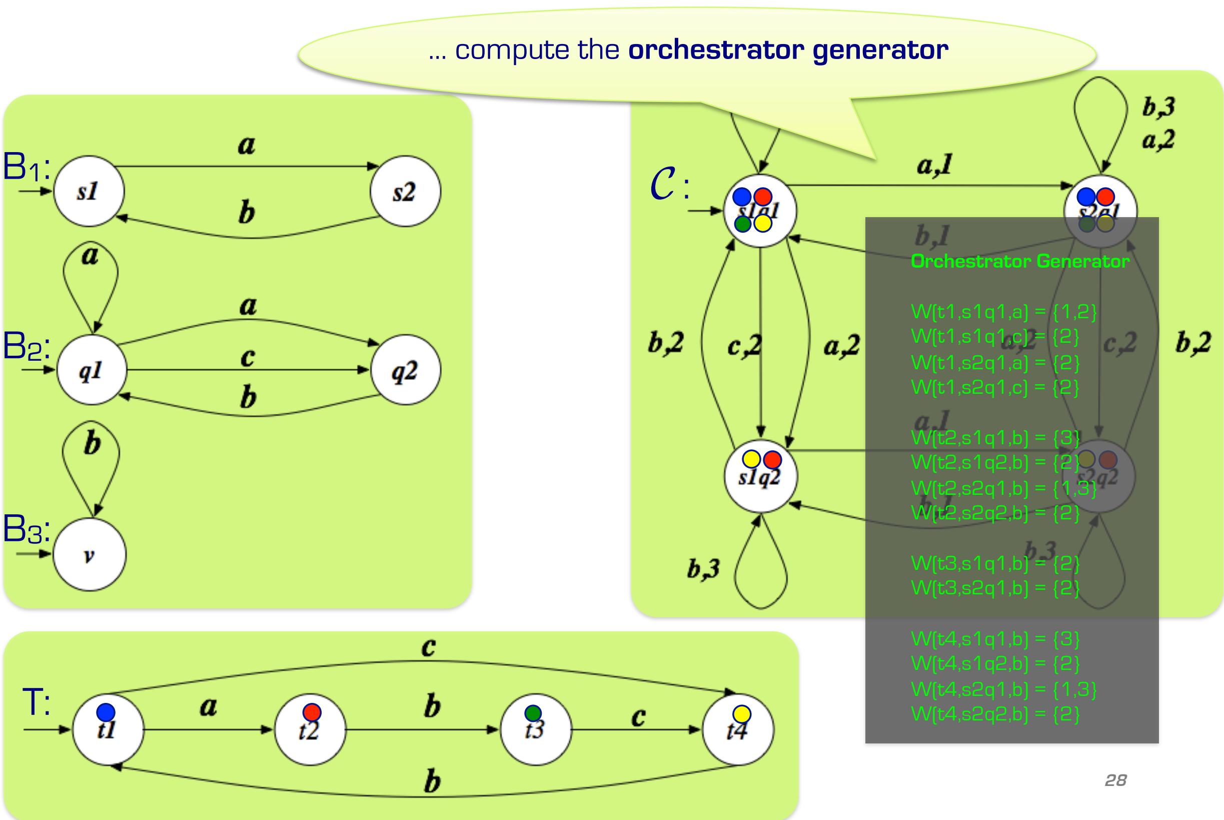
- **OG** = $< A, [1,\ldots,n], S_r, s_r^0, \delta_r, \omega_r, >$ with
- A : the **actions** shared by the behaviors
- [1,…,n]: the **identifiers** of the available services in the community
- $S_r = S_T \times S_1 \times \ldots \times S_n$: the **states** of the orchestrator generator
- $s_r^0 = (t^0, s^0_1, \ldots, s^0_n)$: the **initial state** of the orchestrator generator
- $\omega: S_r \times A_r \rightarrow 2^{[1,\ldots,n]}$: the **output function**, defined as follows:

$$\omega(t, s_1,..,s_n, a) = \{ i \mid \exists\, t \rightarrow_a t' \text{ in } T \wedge \exists\, s_i \rightarrow_a s_i' \text{ in } B_i \wedge (t', s_1,..,s'_i,..,s_n) \in R \}$$

- $\delta \subseteq S_r \times A \times [1,\ldots,n] \rightarrow S_r$: the **state transition function**, defined as follows

$(t, s_1, \ldots, s_i, \ldots, s_n) \rightarrow_{a,i} (t', s_1, \ldots, s'_i, \ldots, s_n)$ iff $i \in \omega(t, s_1, .., s_i, .., s_n, a)$

Example of composition by simulation



Results

- ***Thm:*** *choosing at each point any value in returned by the orchestrator generator gives us a composition.*

- ***Thm:*** *every composition can be obtained by choosing, at each point a suitable value among those returned by the orchestrator generator.*

Note: there ***infinitely many compositions*** *but only* ***one orchestrator generator*** *that captures them all*

- ***Thm:*** *computing the orchestrator generator is EXPTIME, and in fact exponential only in the number (and not the size) of the available behaviors.*

Composition in the Roman Model was shown to be EXPTIME-hard
[Muscholl&Walukiewicz07]

Just-in-time composition

- Once we have the orchestrator generator …
- … we can **avoid choosing any particular composition** a priori …
- … and **use directly *ω*** 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.

Just-in-time compositions can be used to reactively act upon failures [KR08]!

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 R_{raw} including the simulated-by relation
- relation R_{sure} included the simulated-by relation

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

Body

$Q = \emptyset$

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

while ($Q \neq Q'$) {

$Q := Q'$

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

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

}

return $Q' \cup R_{sure}$

End

Parsimonious failure recovery (2)

- Let [1,.., n] = W∪F be the available services.
- Let $\boldsymbol{R}_{W \cup F}$ be the **simulated-by** relation of target by services W∪F.
- Then the following holds:
- $\boldsymbol{R}_W \subseteq \pi_w(\boldsymbol{R}_{W \cup F})$
  - $\pi_w(\boldsymbol{R}_{W \cup F})$ 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:* $R_W \times F$ *is a simulation of target by services* W∪F

Parsimonious failure recovery (3)

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

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

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 $W \cup F$

Tools for computing composition based on simulation

- Computing simulation is a well-studied problem (related to computing **bisimulation** a key notion in process algebra). Tools, like the Edinburgh Concurrency Workbench and its clones, can be adapted to compute composition via simulation.

- Also **LTL-based synthesis** tools, like TLV, can be used for (indirectly) computing composition via simulation [Patrizi PhD09]

We are currently focusing on the second approach.

Adding data to the Roman Model

Adding data is crucial in certain contexts:

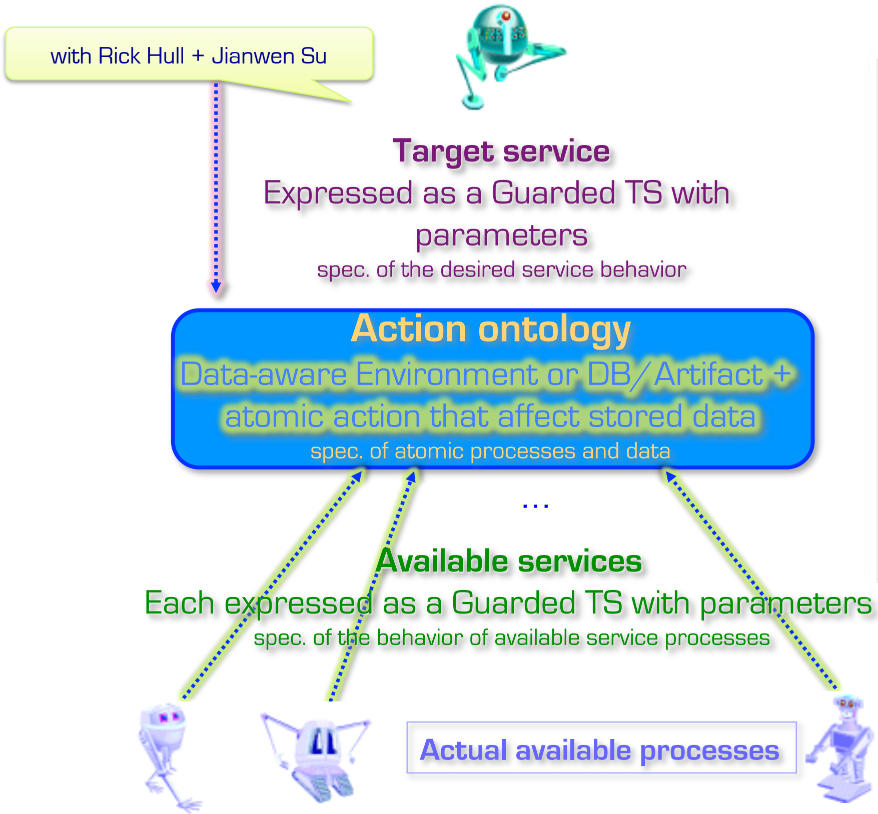
- Data - rich description of the **static information** of interest.
- Behaviors - rich description of the **dynamics** of the process

But makes the approach extremely challenging:

- We get to work with infinite transition systems
- Simulation can still be used for capturing composition
- But it cannot be computed explicitly anymore.

We present two orthogonal approaches to deal with them.

The Roman Model: *American tweak*



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Data-Aware Service Composition

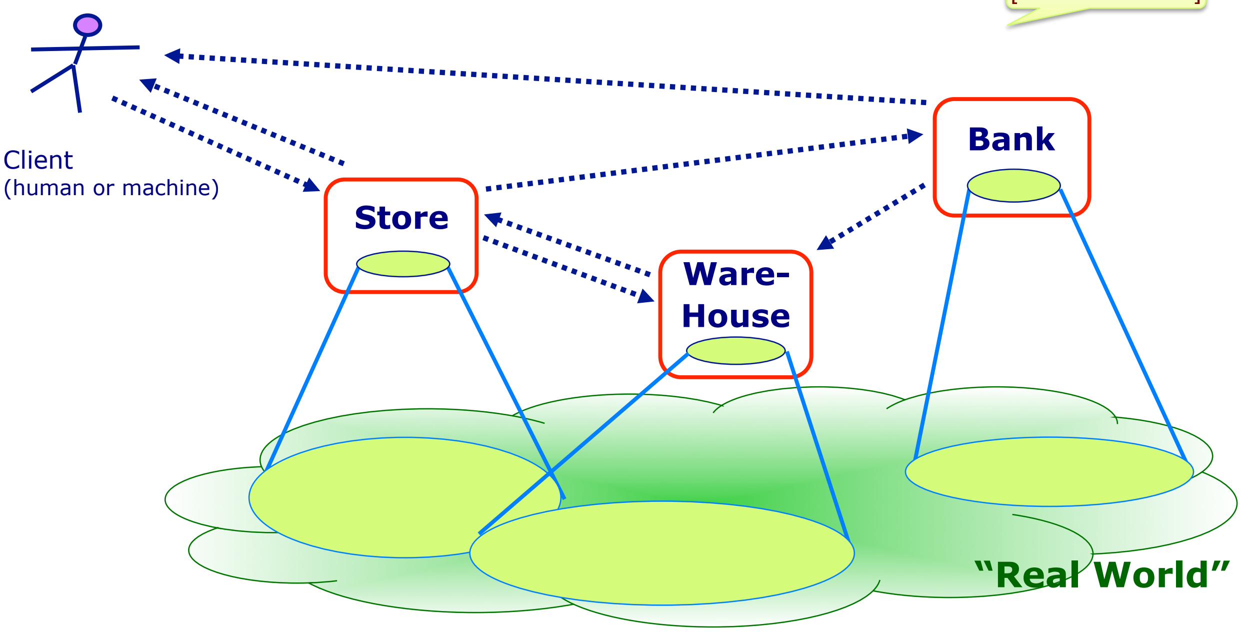

Data-Aware Service Composition

Fabio Patrizi & Giuseppe De Giacomo

Dipartimento di Informatica e Sistemistica "Antonio Ruberti"
SAPIENZA Università di Roma, Rome, ITALY

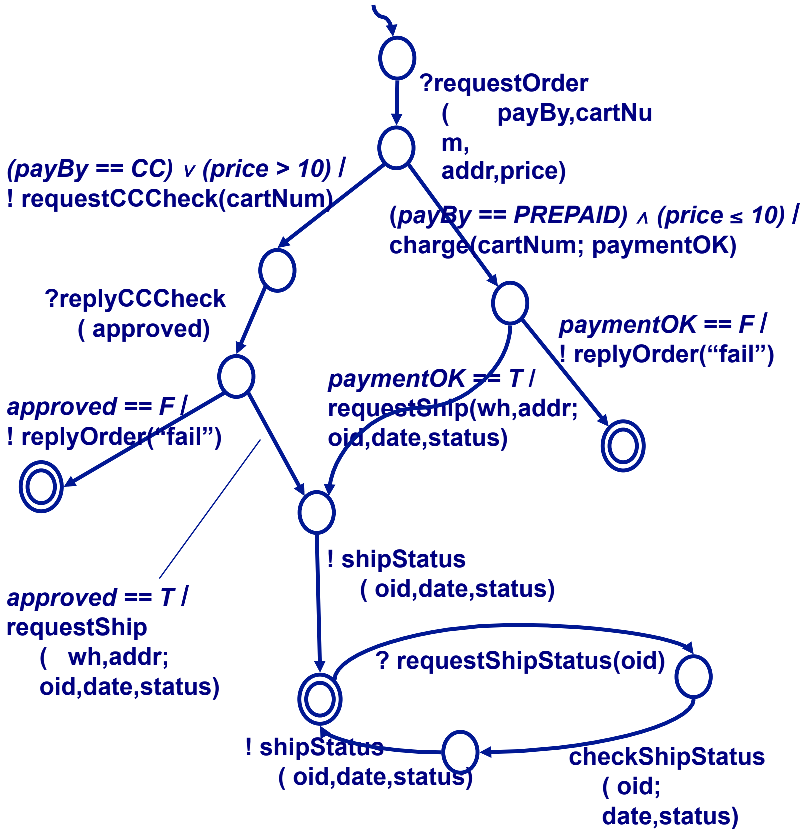
Services act on an integrated view of the world ...

[BCDHM-VLDB05]



- Actions may impact "real world" – modeled as FOL relations
- Also actions may be messages between services

Service behavior of as abstract finite state machines that query and act on the infinite state world …



- Local store
- Edge conditions based on local store [and incoming message]
- Edge actions
  - Atomic Process
    - acting on the world
    - set the local store
  - Create/send message
  - Read message

[BCDHM-VLDB05]

The Roman Model: *Australian/Canadian tweak*

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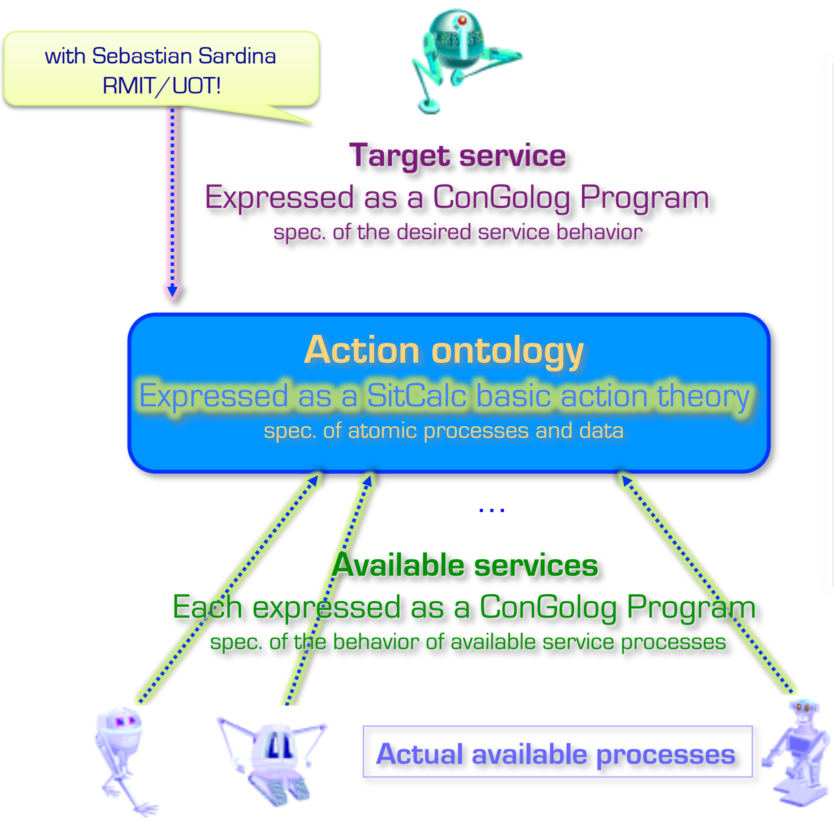

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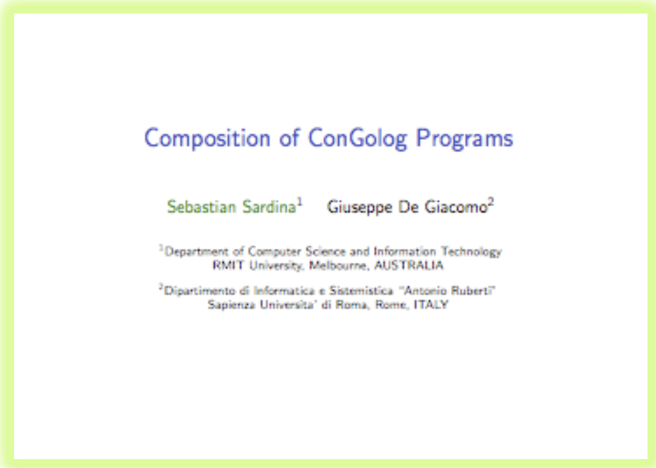
Composition of ConGolog Programs



Mixing data and service integration: A real challenge for the whole CS

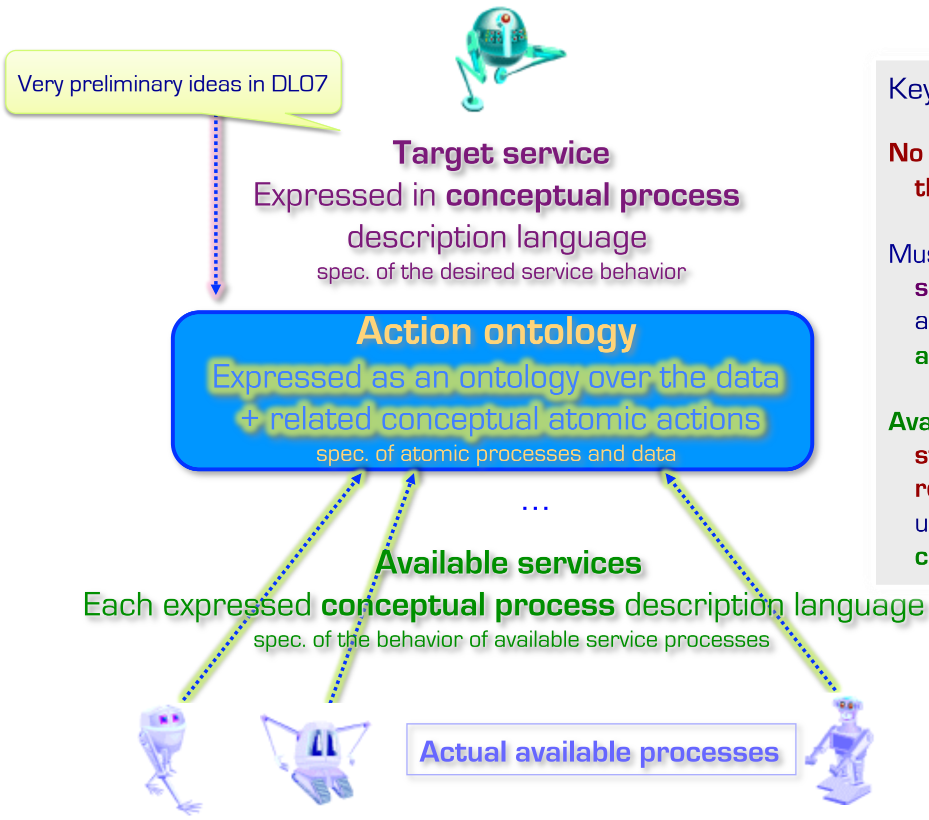
We have all the issues of data integration but in addition …

- Behavior: description of the **dynamics** of the process!
- Behavior should be formally and **abstractly** described: conceptual modeling of dynamics (not a la OWL-S). *Which?*
  - Workflows community may help
  - Business process community may help
  - Services community may help
  - Process algebras community may help
  - AI & Reasoning about actions community may help
  - DB community may help
  - … may help

Artifact-centric approach promising!

- Techniques for **analysis/synthesis** of **services** in presence of **unbounded data** can come from different communities:
  - Verification (CAV) community: abstraction to finite states
  - AI (KR) community: working directly in FOL/SOL, e.g., SitCalc
  - DB (PODS) community: including theory of conjunctive queries

The Roman Model: *Italian dream*



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