Causal link matrix and AI planning:

A model for Web service composition

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- Causal link matrix: A formal model for Web service composition
- An AI planning-oriented composition through a *CLM*
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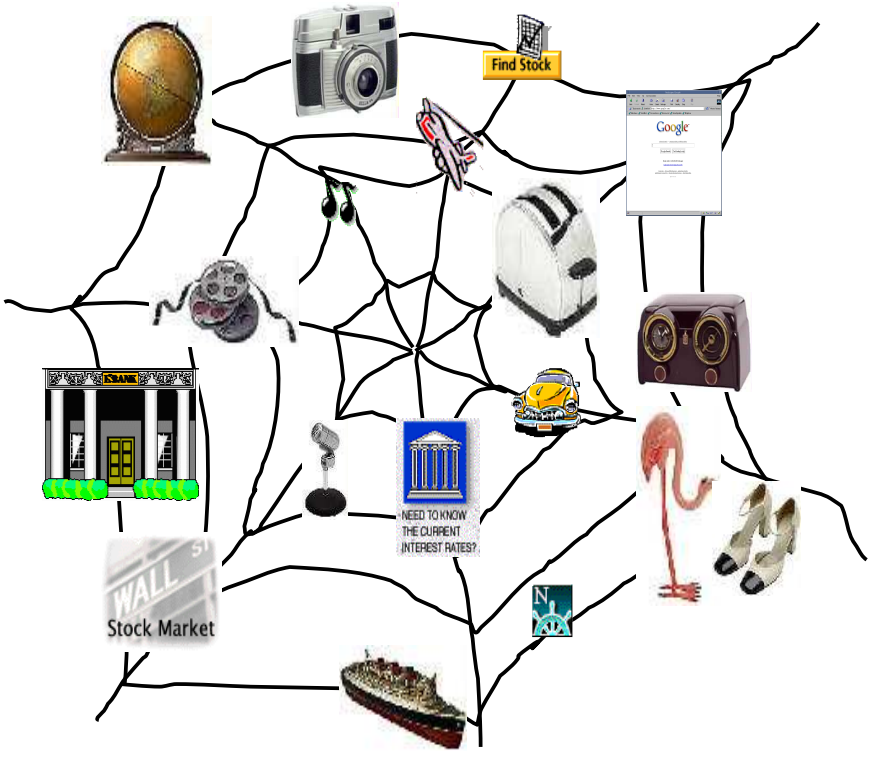
- Conclusion and Future Work

Introduction



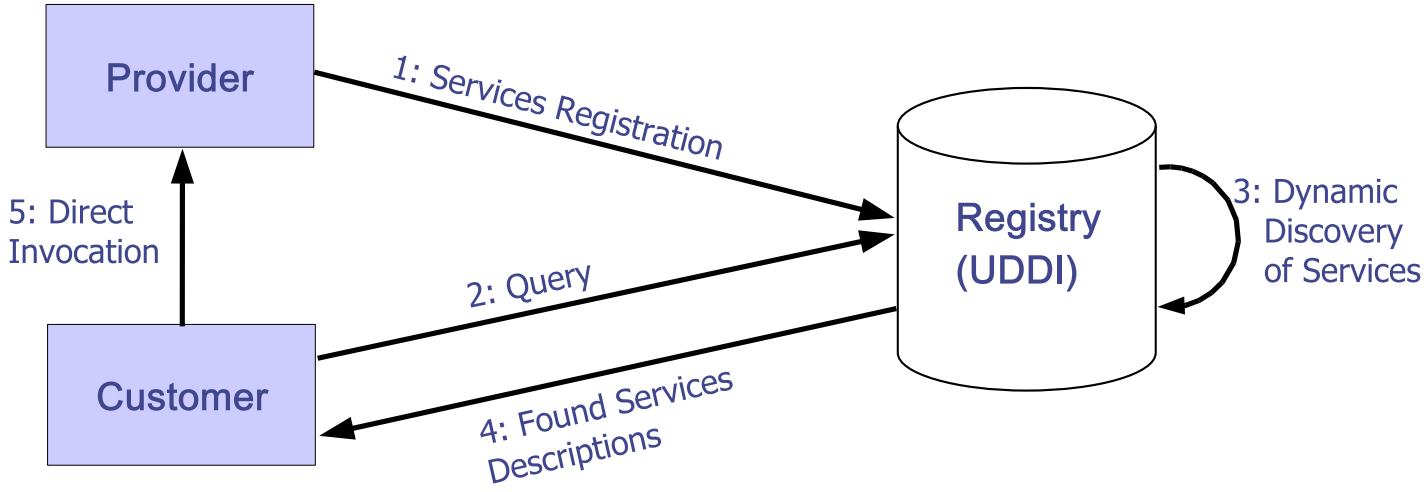
As Web services proliferate:

- It becomes difficult to find the specific service that can perform the task at hand;
- It becomes even more difficult when there is no single service capable of performing that task.
- But there are combinations of existing services that could.

- Ultimate goal: Automated Web service composition in a semantic context i.e., the Semantic Web.

Web Services

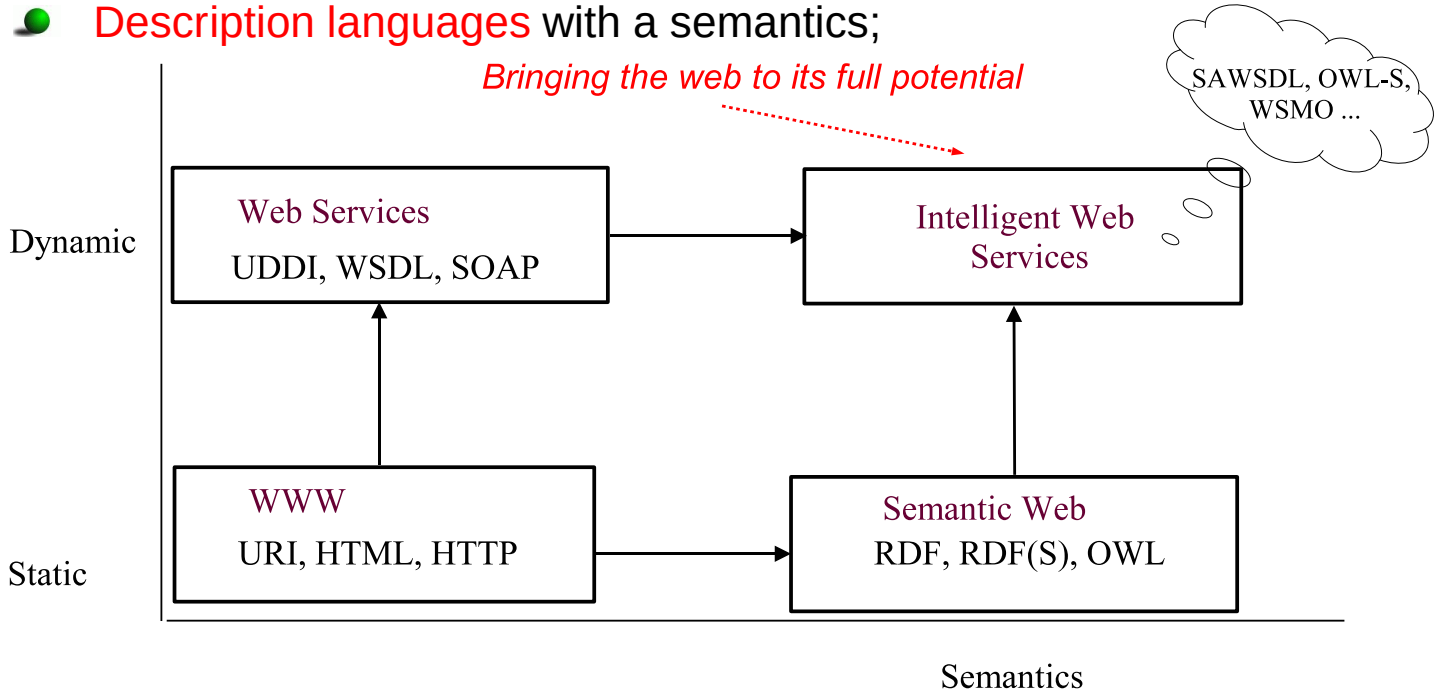
- A Web Service is a software application identified by a URI, whose interfaces and binding are capable of being defined, described and discovered by XML artifacts and supports direct interactions with other software applications using XML based messages via Internet-based protocols (W3C definition).



- A protocol communication.

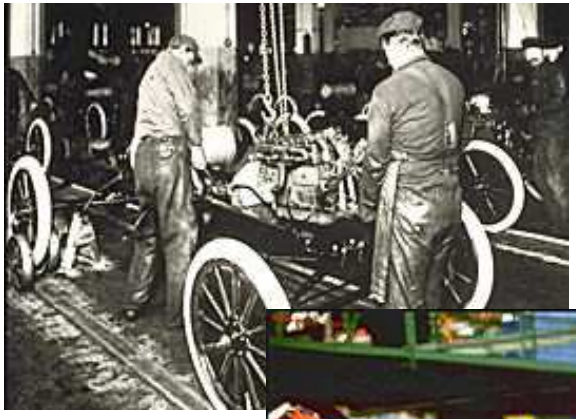
Web service, Semantic Web and Semantic Web Services

- Nowadays Web: syntax-based Web.
- Semantic Web is an extension of current Web in which information is given well-defined meaning.
  - Ontology: a key enabling technology (RDF, OWL)
- Semantic web principles applied to web services
  - Give a semantics to services description;
  - Description languages with a semantics;



Challenges for the Success of Semantic Web Services

From

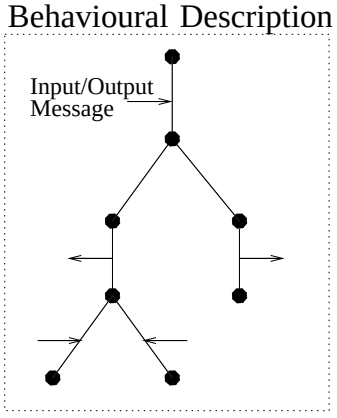


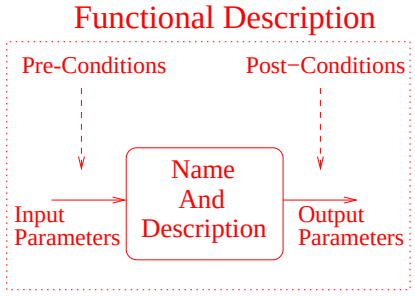
To

Sharing at best the skills of Human and Computer for:

- Better precision
- Repetitive tasks
- More creativity
- Time-to-product
- Time-to-market
- Lower price/better quality ...

*F*unctional *L*evel and *P*rocess *L*evel *D*escription/*C*omposition

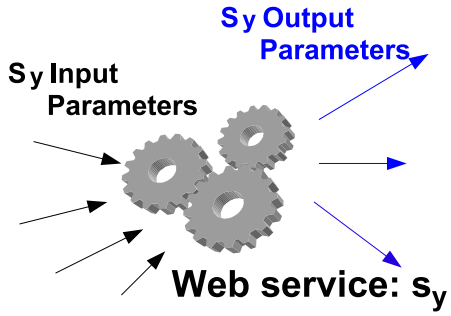


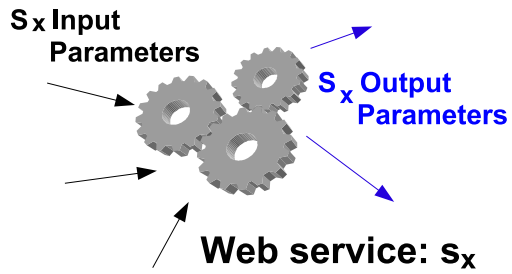


- Such as the Yin and the Yang, ***FLC*** and ***PLC***
  - are **not opposite** but **complementary**;
  - are **interdependent** i.e., they are mutually dependent;
  - can be **further subdivided** (e.g., *FLC* is divided into Inupt/Output and Pre-Condition/Post-Condition composition);
  - **consume** and **support** each other (e.g., *PLC* consumes *FLC*);
  - can be **transformed** into one another (e.g., *FLC* is transformed into *PLC*);

Causal link matrix: A formal model for Web service composition (1)

- Semantic connection between Web services is considered as essential to form new value-added Web services (Functional Level composition);





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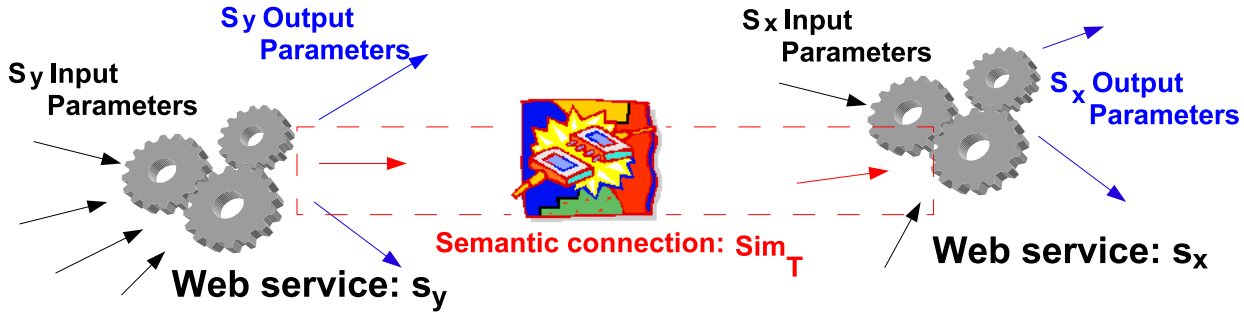

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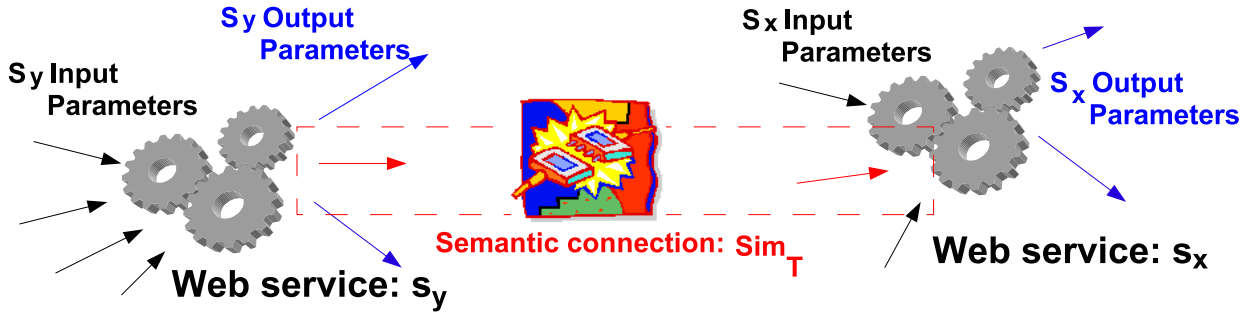

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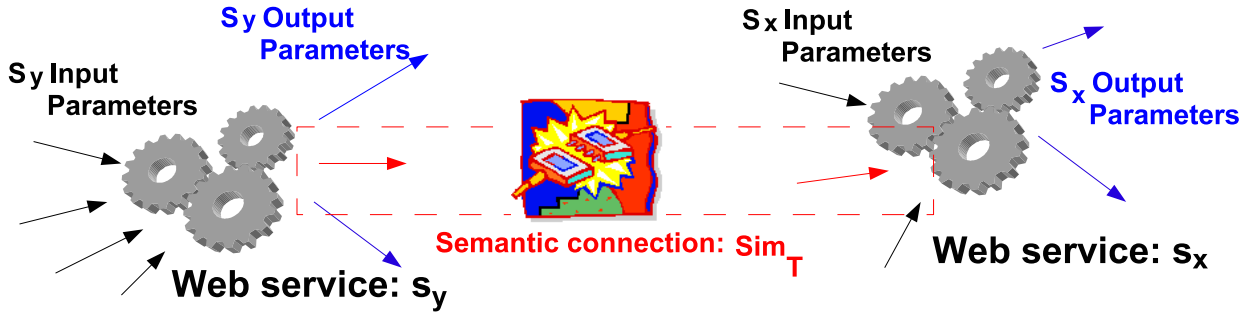

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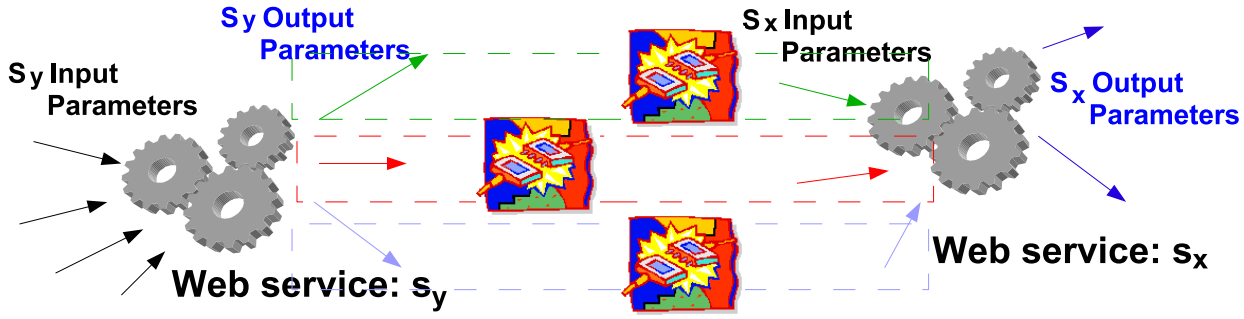

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- Composition as sequences of Web service is a necessary requirement to propose a solution plan.
  - Such a composition is defined by the (trivial) sequence-composability $s_x \circ s_y$;

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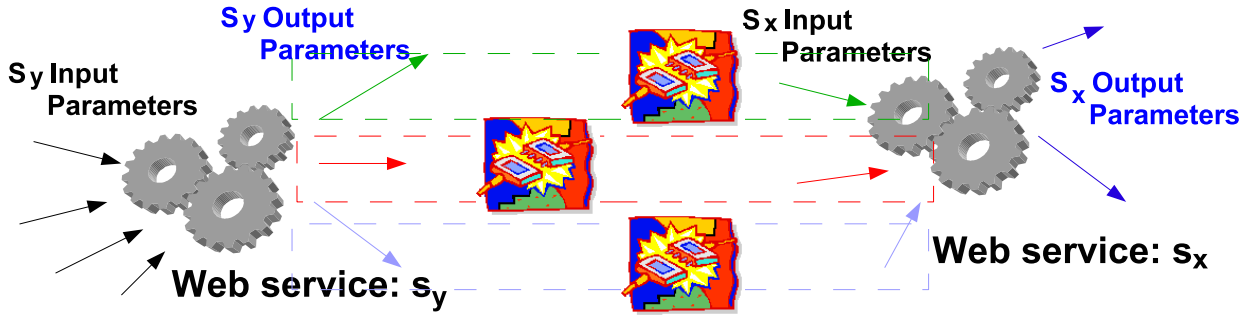

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- Composition as sequences of Web service is a necessary requirement to propose a solution plan.
  - Such a composition is defined by the (trivial) sequence-composability $s_x \circ s_y$;
- **... but not only e.g., (parallel) disjunction, and non determinism constructs.**

Causal link matrix: A formal model for Web service composition (2)

- Find an appropriate and innovative formal model for:
  - proposing a necessary starting point for the automation of WSC;
  - improving the way to store semantic links as Web service dependencies;
  - easing Web service composition and selection;
  - ... under the **Sequence-composability** constraints;

- The **key contribution** of the **Causal link matrix** is a **formal** and **semantic model** to **control a set of Web services** which are relevant for a Web service composition.

- The *CLM* aims at storing all those connections (i.e., causal links) by a pre-computation of Input and Output parameters matching: **Sequence-composability**.

- The *CLM* describes all possible interactions between all the known Web services in S_{WS} as semantic connections.

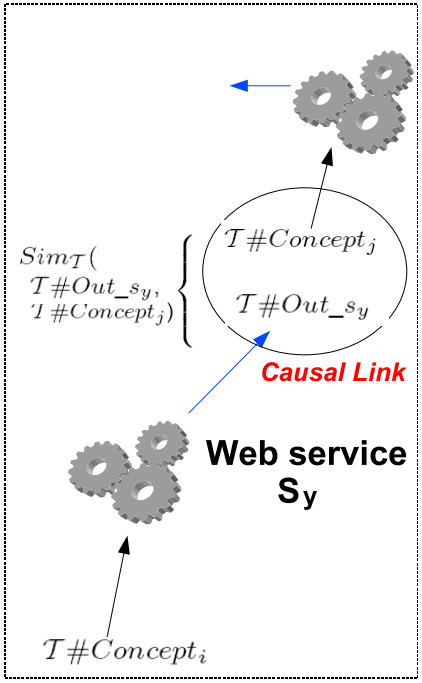
Causal link matrix: A formal model for Web service composition (3)

- A **Causal link matrix** is defined as $\mathrm{M}_{p,q}(\mathcal{P}((S_{WS} \cup \mathcal{T}) \times (0,1]))$.
  - Rows $r_{i,i\in\{1,\ldots,p\}}$ are labelled by $Input(S_{WS}) \subseteq \mathcal{T}$;
  - Columns $c_{j,j\in\{1,\ldots,q\}}$ are labelled by $(Input(S_{WS}) \cup \beta) \subseteq \mathcal{T}$;
- Each entry $m_{i,j}$ of a *CLM* $\mathcal{M}$ is defined as a set of pairs $(s_y, score)$ in $(S_{WS} \cup \mathcal{T}) \times (0,1]$ such that

$$(s_y, score) = \begin{cases} (s_y, Sim_{\mathcal{T}}(Out\_s_y, c_j)) & if\ s_y \in S_{WS},\ Out\_s_y \in Out(s_y) \\ (s_y, 1) & if\ s_y \in \mathcal{T} \end{cases}$$

- $$Input(S_{WS}) \subseteq \mathcal{T} \left\{ \begin{pmatrix} m_{1,1} & m_{1,2} & \ldots & \ldots & m_{1,q} \\ m_{2,1} & m_{2,2} & \ldots & \ldots & m_{2,q} \\ \vdots & \vdots & & & \vdots \\ m_{p,1} & m_{p,2} & \ldots & \ldots & m_{p,q} \end{pmatrix} \right. \overbrace{\qquad\qquad}^{(Input(S_{WS}) \cup \beta) \subseteq \mathcal{T}}$$

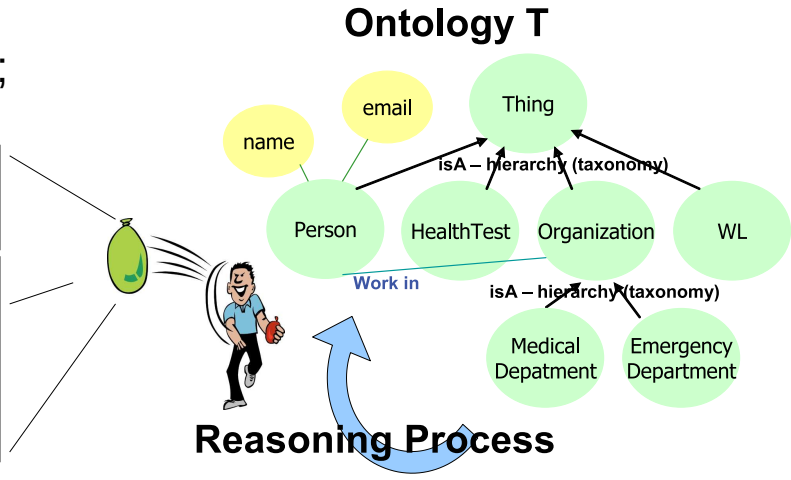
  $m_{i,j-1}$ $\{(s_y, score)\}$



AI planning and *CLM*s: A regression-based approach (1)

- Requirements:
  - An ontology $\mathcal{T}$ to infer concepts Matching;

Output/Input Parameters		Input Parameters			
		I_1	I_2	$Organization$	$I_{\#\{Input\{S_{Ws}\}\}}$
Output Parameters	O_1	$v_{1,1}$	$v_{1,2}$	$v_{1,i}$	$v_{1,n}$
	O_2	$v_{2,1}$	$v_{2,2}$	$v_{2,i}$	$v_{2,n}$
	$EmergencyDpt$	fail	fail	plug-in	fail
	$O_{\#\{Output\{S_{Ws}\}\}}$	$v_{m,1}$	$v_{m,2}$	$v_{m,i}$	$v_{m,n}$



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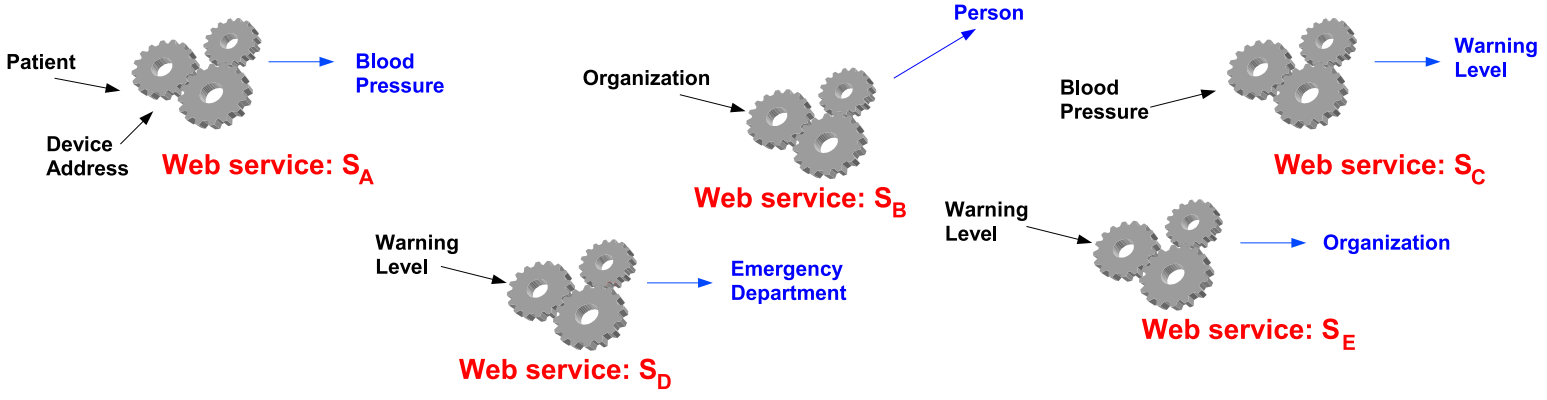

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    - $\mathcal{KB}$ is the *Initial state*. *Individuals e.g., an instance of the concept Patient and another of Device Address*.

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    - $\beta \subseteq \mathcal{T}$ is an explicit goal representation. *A TBox element e.g., the concept Person*.

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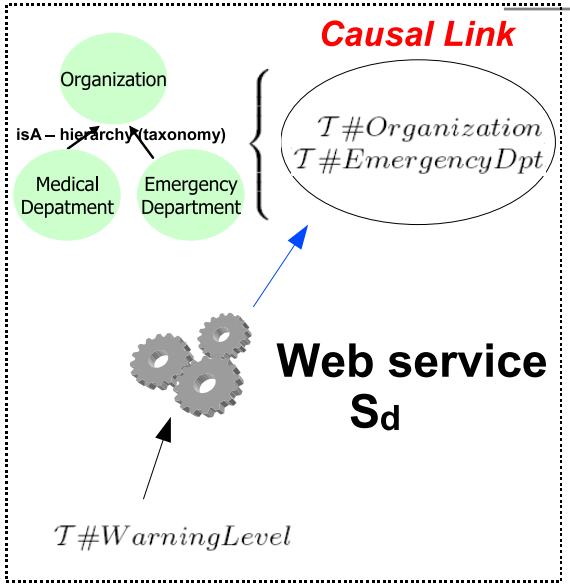

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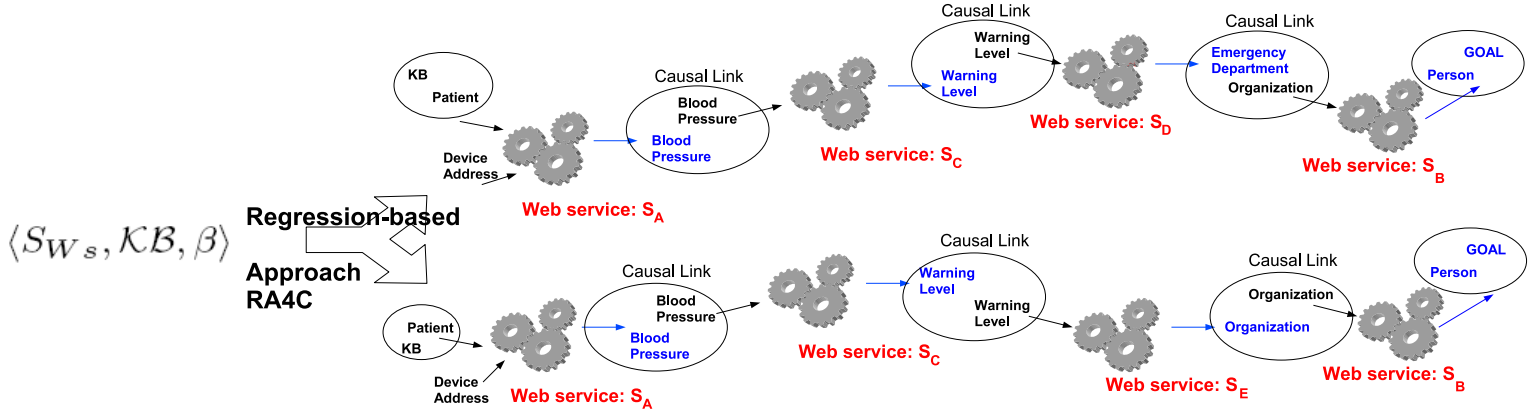

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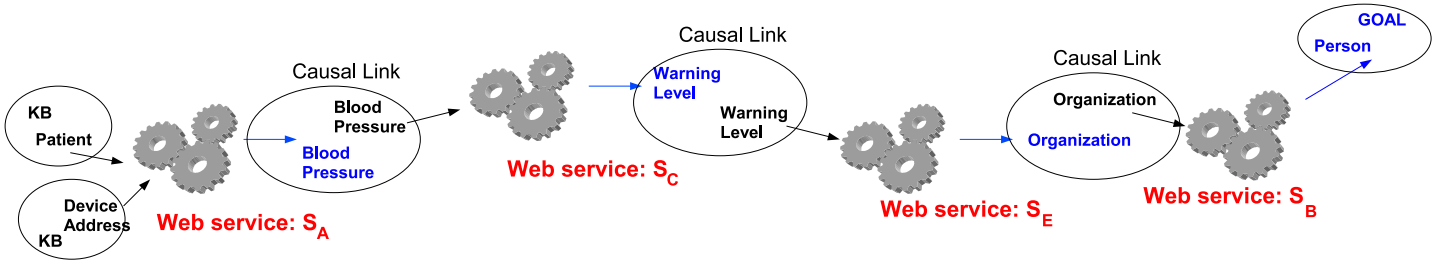

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- Assumption:
  - The set of Web services S_{WS} is closed.
  - **Non determinism, Implicit goal, Fuzzy Web service description and behaviour are out of scope.**

AI planning and *CLM*s: A regression-based approach (2)

- Suppose a *CLM* $\mathcal{M}$ and the planning problem $\Pi = \langle S_{Ws}, \mathcal{KB}, \beta \rangle$;
-

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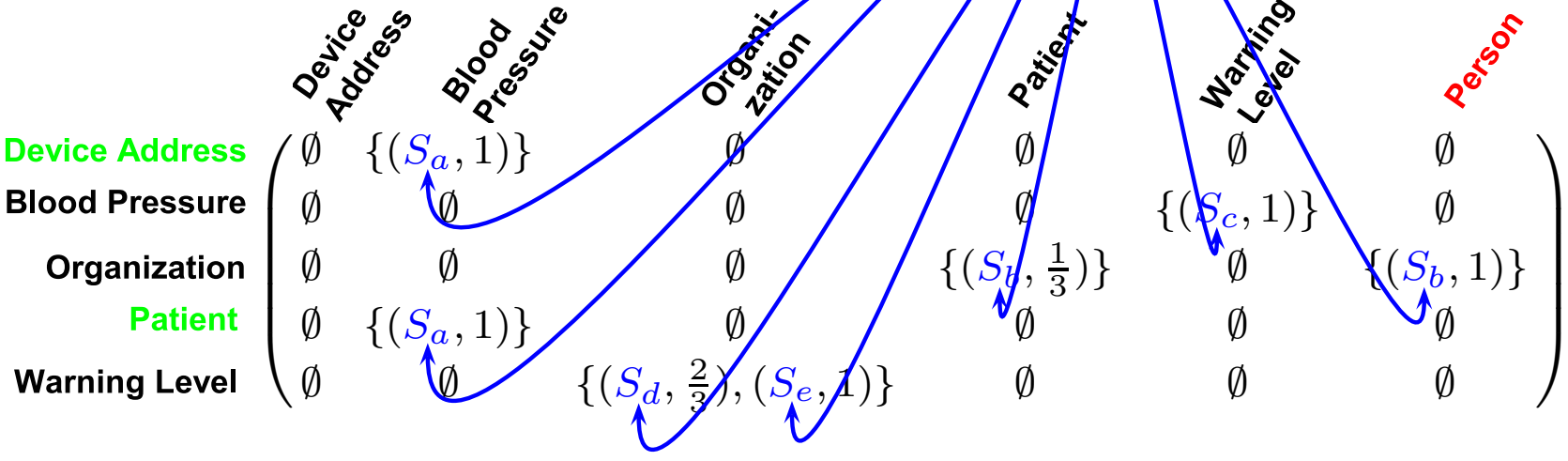

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- in case $DeviceAddress$ and $Patient$ are instantiated concepts.

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- Suppose a *CLM* $\mathcal{M}$ and the planning problem $\Pi = \langle S_{Ws}, \mathcal{KB}, \beta \rangle$;
- According to the *CLM* definition, the goal β is referred by $\mathcal{M}$.

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- The composition process consists of a recursive and regression-based approach: Ra_4C;

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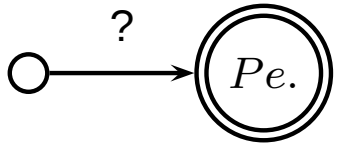

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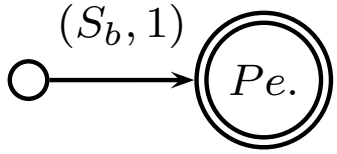

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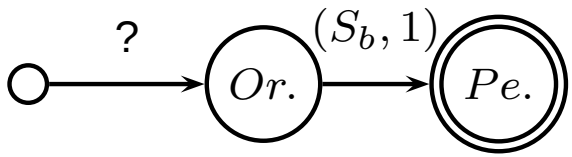

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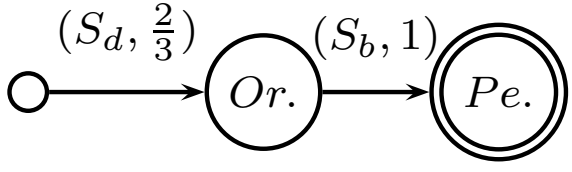

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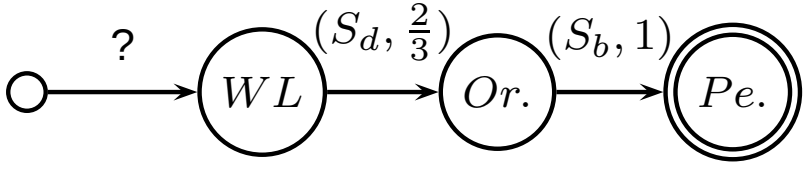

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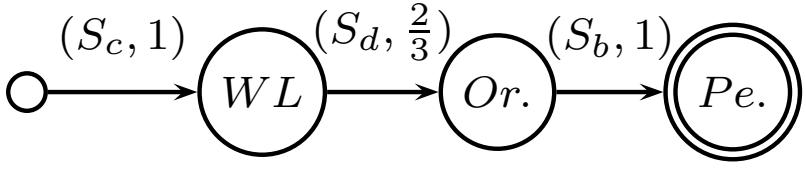

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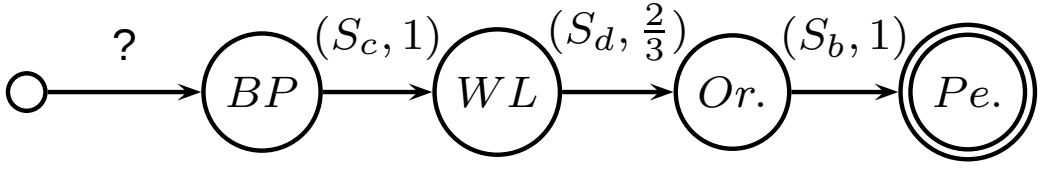

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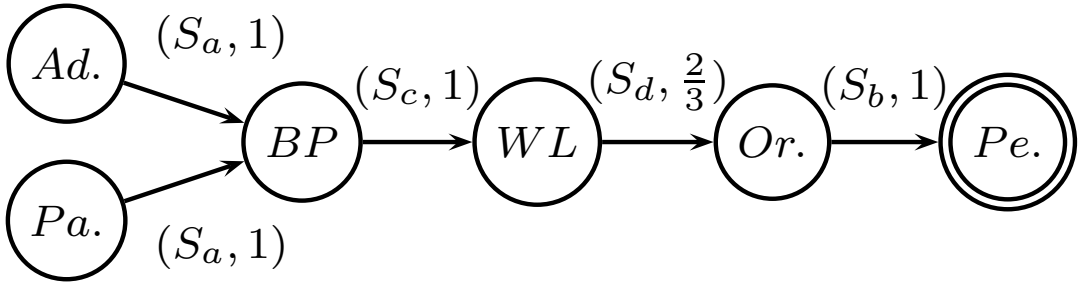

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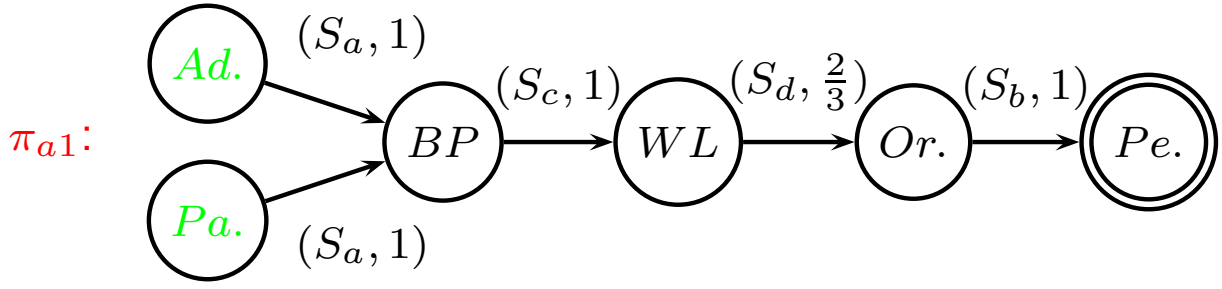

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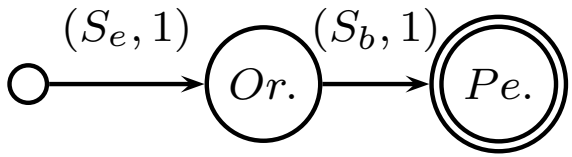

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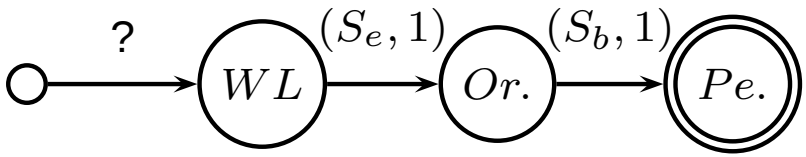

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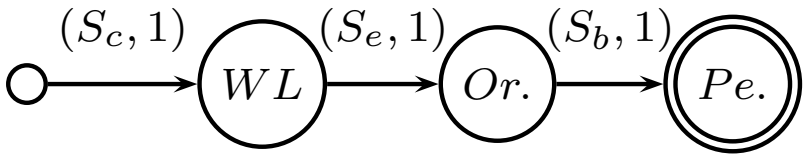

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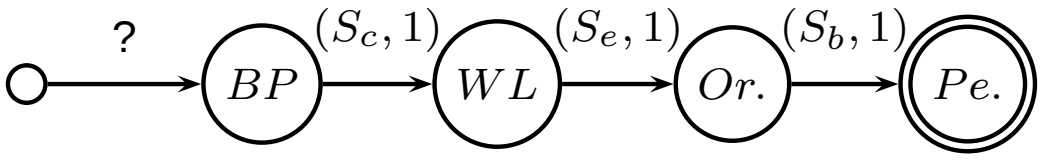

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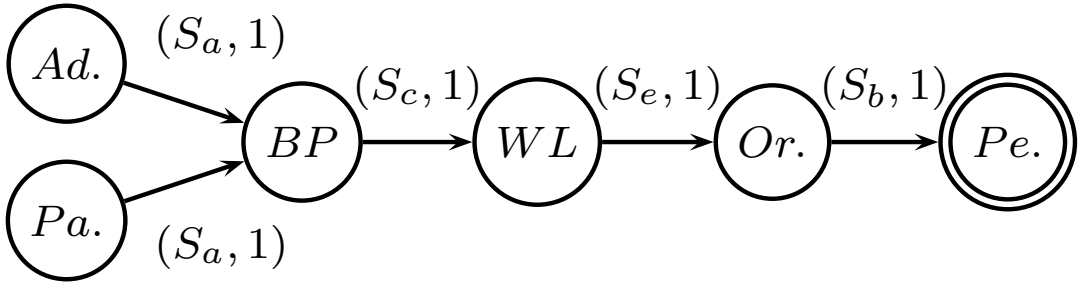

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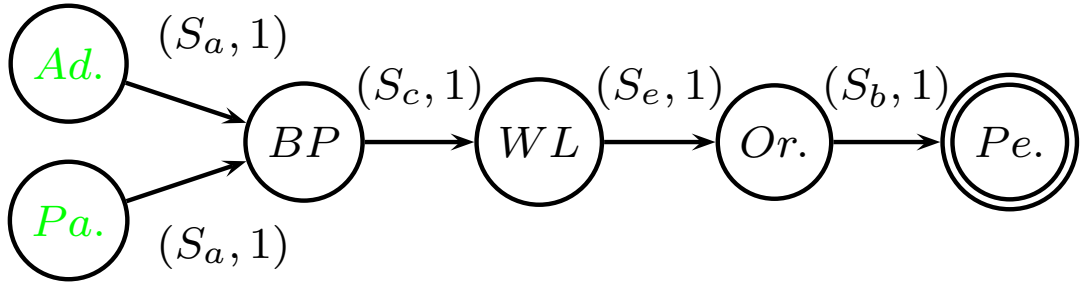

Formal results

- The algorithmic complexity for the *CLM* construction is:
  - $\theta(\#(Input(S_{Ws})) \times \#(Output(S_{Ws})))$;
  - i.e., $\theta((Max\{\#(Input(S_{Ws})), \#(Output(S_{Ws}))\}^2)$;
  - so square in the worst case.
- The algoritmic complexity of the Ra_4C algorithm is time polynomial
  - in
    - $\#rows$, $\#columns$ of the *Causal Link Matrix*,
    - i.e., $\#(Input(S_{Ws}))$.
  - with
    - Fail nodes detection;
    - Loop nodes detection;
- In general cases $\theta(BuildClm) > \theta(Ra_4C)$.

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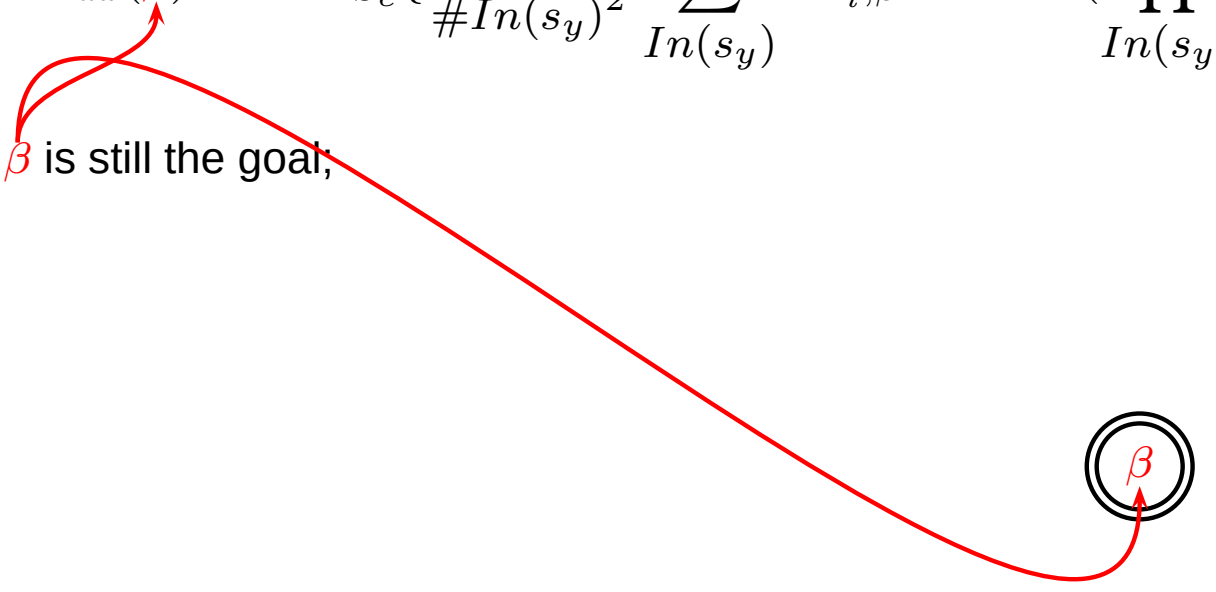
- β is still the goal;



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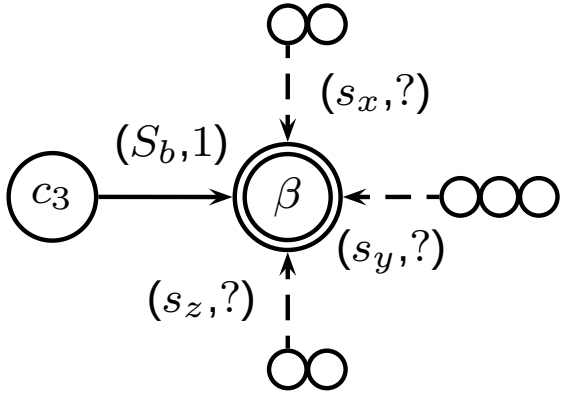
- S_c is a set of couple (s_y, v) such that s_y is a Web service with an output β and inputs $I_{i,1\leq i\leq \#In(s_y)}$: $\langle s_y, Sim_{\mathcal{T}}(Out\_s_y, \beta), s_x\rangle$ is a valid causal link.



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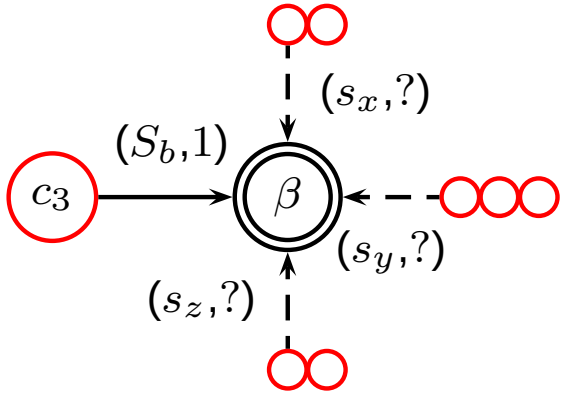
- The first ratio is depending on the cardinal of the input parameters of s_y.



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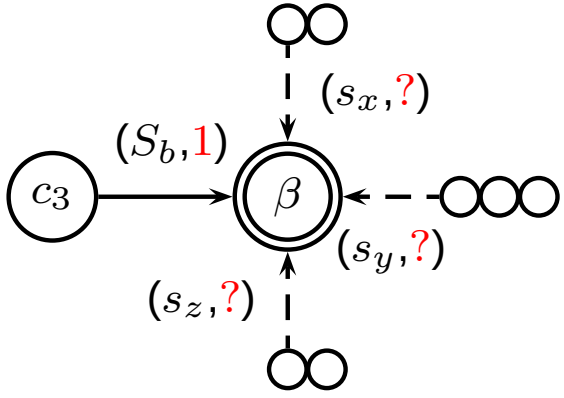
- The first sum is depending on semantic similarity between an output parameter of s_y and β.



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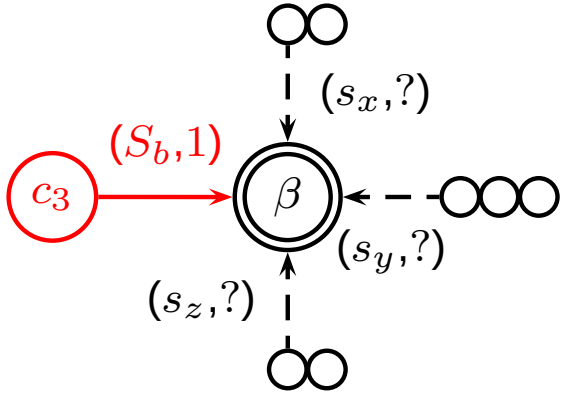
- The first component proposes a *causal link*-based optimization: The shorter is the solution path the better it is.



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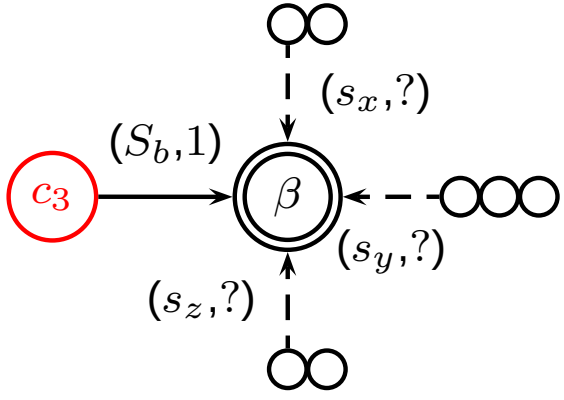
- The second component is the recursive process.



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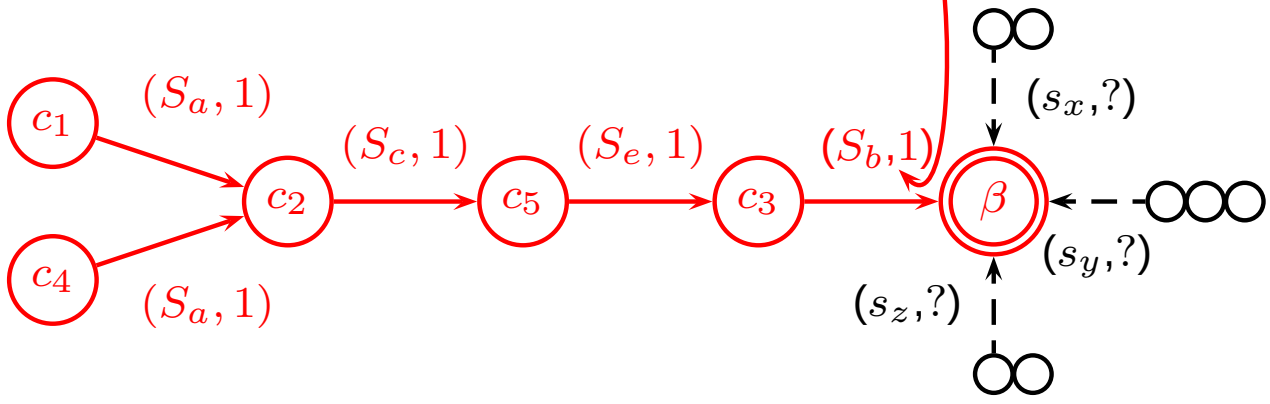
- Max_{S_c} is a n-arity function which returns the maximum value between n float value(s) depending on the S_c elements.



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- Even if the optimal global plan may be obtained by $Max_{p \in Plan}\{Weight(p)\}$.
  - wherein the function $Weight(p)$ computes the weight of each solution plan discovered by the Ra_4C algorithm.

Related Work

- Models for automatic composition have roots in
  - AI planning (Situation calculii: `Strips` influence, HTN) e.g., [Golog], [ConGoloG], [SHOP2];
  - Logic (Description Logics, Linear Logic, first-order logic);
  - (Guarded) Finite State Automata e.g., [WSAT], [Roman Model], [Mealy Model], [COCOA];
  - Petri nets, Coloured Petri Nets;
  - π Calculus, Process Calculus.
- *What is the right way to model web services and their compositions?*
- Web services composition:
  - Functional-level composition: e.g., [M.Paolucci et al. 2002], [E.Sirin, J.Hendler, and B.Parsia 2003], [J.Cardoso and A.Sheth 2003], [R.Zhang et al. 2003].
  - Process-level composition: e.g., [D.Berardi et al. 2003], [T.Bultan et al. 2003], [S.Narayanan and S.McIlraith 2002], [M.Pistore et al. 2005].

Conclusion and Future work

- A model is proposed to help automation of Web service composition at functional level:
  - by capturing semantic connections between Web services: **Causal links**;
  - by provinding a relevant starting point to solve an AI planning problem: **Causal link matrix**;
  - by applying a regression-based approach: Ra_4C;
  - by satisfying an optimization criteria;
  - in order to obtain correct, complete, consistent and optimal plans through the **Sequence-composability** property.
- Easily applied to Web services which are described according to SAWSDL, OWL-S (service profile) or WSMO (capability model) specification;
- Future Work:
  - Extending the set of semantic Web service matching functions for optimization reasons;
  - Scalability of the model.

Questions?