Causal link matrix and AI planning:  
A model for Web service composition

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Overview and Contents

- Introduction
- Background
- Web Service Composition Problem
- Causal link matrix: A formal model for Web service composition
- An AI planning-oriented composition through a CLM
- A causal link-based optimization
- Related Work
- Conclusion and Future Work
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.
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;

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**Dynamic**

- Web Services
  - UDDI, WSDL, SOAP

**Static**

- WWW
  - URI, HTML, HTTP

**Semantics**

- Intelligent Web Services
- Semantic Web
  - RDF, RDF(S), OWL

*Bringing the web to its full potential*

SAWSDL, OWL-S, WSMO ...
Challenges for the Success of Semantic Web Services

From

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 ...
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 Input/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);
Semantic connection between Web services is considered as essential to form new value-added Web services (Functional Level composition);
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i.e., the semantic link between Input and Output parameters;
Semantic connection between Web services is considered as essential to form new value-added Web services (Functional Level composition);

- i.e., the semantic link between Input and Output parameters;

- The semantic connection is valued by the $Sim_T(Out_{s_y}, In_{s_x})$ function e.g., the Exact, Plug-in, Subsume and Fail matching functions [M.Paolucci et al. 2002];
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);
  - i.e., the semantic link between Input and Output parameters;
  - The semantic connection is valued by the $\text{Sim}_T(\text{Out}_{s_y}, \text{In}_{s_x})$ function e.g., the Exact, Plug-in, Subsume and Fail matching functions [M.Paolucci et al. 2002];

- So a **Causal link** is defined as a triple $\langle s_y, \text{Sim}_T(\text{Out}_{s_y}, \text{In}_{s_x}), s_x \rangle$. 
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);
  - i.e., the semantic link between Input and Output parameters;
  - The semantic connection is valued by the $Sim_T(Out_{sy}, In_{sx})$ function e.g., the Exact, Plug-in, Subsume and Fail matching functions [M.Paolucci et al. 2002];

- So a Causal link is defined as a triple $\langle sy, Sim_T(Out_{sy}, In_{sx}), sx \rangle$.

- 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 $sx \circ sy$.
Semantic connection between Web services is considered as essential to form new value-added Web services (Functional Level composition);

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So a Causal link is defined as a triple $\langle s_y, \text{Sim}_T(\text{Out}_{s_y}, \text{In}_{s_x}), s_x \rangle$.

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.
A **Causal link matrix** is defined as $M_{p,q}(P((S_{W}s \cup T) \times (0,1]))$.

- Rows $r_{i,i \in \{1,\ldots,p\}}$ are labelled by $\text{Input}(S_{W}s) \subseteq T$;
- Columns $c_{j,j \in \{1,\ldots,q\}}$ are labelled by $(\text{Input}(S_{W}s) \cup \beta) \subseteq T$;
- Each entry $m_{i,j}$ of a CLM $M$ is defined as a set of pairs $(s_y, \text{score})$ in $(S_{W}s \cup T) \times (0,1]$ such that

$$\begin{align*}
(s_y, \text{score}) &= \begin{cases} 
(s_y, \text{Sim}_T(\text{Out}_{s_y}, c_j)) & \text{if } s_y \in S_{W}s, \text{ Out}_{s_y} \in \text{Out}(s_y) \\
(s_y, 1) & \text{if } s_y \in T
\end{cases}
\end{align*}$$
AI planning and CLMs: A regression-based approach (1)

Requirements:
- An ontology $T$ to infer concepts Matching;

<table>
<thead>
<tr>
<th>Output/Input Parameters</th>
<th>$I_1$</th>
<th>$I_2$</th>
<th>$Organization$</th>
<th>$I_{#{Input{S_W}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_1$</td>
<td>$v_{1,1}$</td>
<td>$v_{1,2}$</td>
<td>$v_{1,i}$</td>
<td>$v_{1,n}$</td>
</tr>
<tr>
<td>$O_2$</td>
<td>$v_{2,1}$</td>
<td>$v_{2,2}$</td>
<td>$v_{2,i}$</td>
<td>$v_{2,n}$</td>
</tr>
<tr>
<td>EmergencyDpt</td>
<td>fail</td>
<td>fail</td>
<td>plug-in</td>
<td>fail</td>
</tr>
<tr>
<td>$O_{#{Output{S_W}}}$</td>
<td>$v_{m,1}$</td>
<td>$v_{m,2}$</td>
<td>$v_{m,i}$</td>
<td>$v_{m,n}$</td>
</tr>
</tbody>
</table>
AI planning and *CLMs*: A regression-based approach (1)

Requirements:

- An ontology $\mathcal{T}$ to infer concepts Matching;
- An AI planning problem $\Pi = \langle \mathcal{S}_{WS}, KB, \beta \rangle$;
  
  \(\mathcal{S}_{WS}\) refers to a set of possible state transitions;
AI planning and CLMs: A regression-based approach (1)

Requirements:

- An ontology \( T \) to infer concepts Matching;
- An AI planning problem \( \Pi = \langle S_{Ws}, KB, \beta \rangle \);
  - \( S_{Ws} \) refers to a set of possible state transitions;
  - \( KB \) is the Initial state. Individuals e.g., an instance of the concept Patient and another of Device Address.

Freddy Lécué & Alain Léger, Causal link matrix and AI planning: a model for Web service composition, France Telecom R&D, Rennes
AI planning and CLMs: A regression-based approach (1)

Requirements:
- An ontology $\mathcal{T}$ to infer concepts Matching;
- An AI planning problem $\Pi = \langle S_{W_s}, \mathcal{KB}, \beta \rangle$;
  - $S_{W_s}$ refers to a set of possible state transitions;
  - $\mathcal{KB}$ is the Initial state.
  - $\beta \subseteq \mathcal{T}$ is an explicit goal representation. A TBox element e.g., the concept Person.
AI planning and *CLMs*: A regression-based approach (1)

Requirements:
- An ontology *T* to infer concepts Matching;
- An AI planning problem *Π* = (*S*<sub>W</sub>, *KB*, *β*);
  - *S*<sub>W</sub> refers to a set of possible state transitions;
  - *KB* is the Initial state.
  - *β* ⊆ *T* is an explicit goal representation.
- A causal link matrix *ℳ* and its causal links;

\[
\begin{array}{cccccc}
\text{Device Address} & \text{Blood Pressure} & \text{Organization} & \text{Patient} & \text{Warning Level} & \text{Person} \\
\emptyset & \{(S_a, 1)\} & \emptyset & \emptyset & \emptyset & \emptyset \\
\emptyset & \emptyset & \emptyset & \emptyset & \{(S_c, 1)\} & \emptyset \\
\emptyset & \emptyset & \emptyset & \{(S_b, \frac{1}{3})\} & \emptyset & \{(S_b, 1)\} \\
\emptyset & \{(S_a, 1)\} & \emptyset & \emptyset & \emptyset & \emptyset \\
\emptyset & \emptyset & \{(S_d, \frac{2}{3}), (S_e, 1)\} & \emptyset & \emptyset & \emptyset \\
\end{array}
\]
AI planning and CLMs: A regression-based approach (1)

Requirements:

- An ontology \( T \) to infer concepts Matching;
- An AI planning problem \( \Pi = \langle S_{WS}, KB, \beta \rangle \);
  - \( S_{WS} \) refers to a set of possible state transitions;
  - \( KB \) is the Initial state.
  - \( \beta \subseteq T \) is an explicit goal representation.
- A causal link matrix \( M \) and its causal links;

Methodology:

- Computation of consistent, correct and complete solution plans of the Functional-level composition with the backward chaining technique: A plan of Web services is generated for finding an optimal plan among various compositions.
AI planning and CLMs: A regression-based approach (1)

Requirements:
- An ontology $T$ to infer concepts Matching;
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Methodology:
- Computation of consistent, correct and complete solution plans of the Functional-level composition with the backward chaining technique: A plan of Web services is generated for finding an optimal plan among various compositions.
- Computation of the optimal solution plan by pruning of the plan solution space.

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AI planning and CLMs: A regression-based approach (1)

Requirements:
- An ontology $\mathcal{T}$ to infer concepts Matching;
- An AI planning problem $\Pi = \langle S_{W_s}, KB, \beta \rangle$;
  - $S_{W_s}$ refers to a set of possible state transitions;
  - $KB$ is the Initial state.
  - $\beta \subseteq \mathcal{T}$ is an explicit goal representation.
- A causal link matrix $\mathcal{M}$ and its causal links;

Methodology:
- Computation of consistent, correct and complete solution plans of the Functional-level composition with the backward chaining technique: A plan of Web services is generated for finding an optimal plan among various compositions.
- Computation of the optimal solution plan by pruning of the plan solution space.

Assumption:
- The set of Web services $S_{W_s}$ is closed.
- Non determinism, Implicit goal, Fuzzy Web service description and behaviour are out of scope.
Suppose a \( CLM \ M \) and the planning problem \( \Pi = \langle S_{W,s}, K\beta, \beta \rangle \);

<table>
<thead>
<tr>
<th>Device Address</th>
<th>Blood Pressure</th>
<th>Organization</th>
<th>Patient</th>
<th>Warning Level</th>
<th>Person</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \emptyset )</td>
<td>{ ( (S_a, 1) ) }</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
</tr>
<tr>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( { (S_c, 1) } )</td>
<td>( \emptyset )</td>
</tr>
<tr>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( { (S_b, \frac{1}{3}) } )</td>
<td>( \emptyset )</td>
<td>( { (S_b, 1) } )</td>
</tr>
<tr>
<td>( \emptyset )</td>
<td>( { (S_a, 1) } )</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
</tr>
<tr>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( { (S_d, \frac{2}{3}), (S_e, 1) } )</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
<td>( \emptyset )</td>
</tr>
</tbody>
</table>
Suppose a CLM $\mathcal{M}$ and the planning problem $\Pi = (S_{WS}, KB, \beta)$;

According to the CLM definition, the set $S_{WS}$ is referred by $\mathcal{M}$. 
Suppose a CLM $\mathcal{M}$ and the planning problem $\Pi = \langle S_{W_s}, \mathcal{KB}, \beta \rangle$;

According to the CLM definition, the set $\mathcal{KB}$ is referred by $\mathcal{M}$.

in case _DeviceAddress_ and _Patient_ are instantiated concepts.
AI planning and CLMs: A regression-based approach (2)

Suppose a CLM $\mathcal{M}$ and the planning problem $\Pi = \langle S_{W_s}, KB, \beta \rangle$.

According to the CLM definition, the goal $\beta$ is referred by $\mathcal{M}$.

<table>
<thead>
<tr>
<th>Device Address</th>
<th>Blood Pressure</th>
<th>Organization</th>
<th>Patient</th>
<th>Warning Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\emptyset$</td>
<td>${(S_a, 1)}$</td>
<td>$\emptyset$</td>
<td>$\emptyset$</td>
<td>$\emptyset$</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>$\emptyset$</td>
<td>$\emptyset$</td>
<td>$\emptyset$</td>
<td>${(S_c, 1)}$</td>
</tr>
<tr>
<td>Organization</td>
<td>$\emptyset$</td>
<td>$\emptyset$</td>
<td>${(S_b, 1/3)}$</td>
<td>$\emptyset$</td>
</tr>
<tr>
<td>Patient</td>
<td>$\emptyset$</td>
<td>${(S_a, 1)}$</td>
<td>$\emptyset$</td>
<td>$\emptyset$</td>
</tr>
<tr>
<td>Warning Level</td>
<td>$\emptyset$</td>
<td>$\emptyset$</td>
<td>${(S_d, 2/3), (S_e, 1)}$</td>
<td>$\emptyset$</td>
</tr>
</tbody>
</table>
Suppose a CLM $M$ and the planning problem $\Pi = \langle S_{W_S}, KB, \beta \rangle$;

According to the CLM definition, $S_{W_S}, KB$ and $\beta$ are referred by $M$.

\[
\begin{array}{cccccc}
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\end{array}
\]
AI planning and CLMs: A regression-based approach (2)

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

According to the CLM definition, $S_{W_s}$, $KB$ and $\beta$ are referred by $\mathcal{M}$.

The composition process consists of a recursive and regression-based approach: $Ra_4C$;
AI planning and *CLMs*: A regression-based approach (2)

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

The composition process consists of a recursive and regression-based approach: $Ra_4C$;
- From the goal *Person*
AI planning and CLMs: A regression-based approach (2)

- Suppose a CLM $M$ and the planning problem $\Pi = \langle SW_s, KB, \beta \rangle$;
- According to the CLM definition, $SW_s$, $KB$ and $\beta$ are referred by $M$.

The composition process consists of a recursive and regression-based approach: $Ra_4 C$;
- From the goal $Person$

$(S_b, 1)$

$Pe.$
Suppose a CLM $\mathcal{M}$ and the planning problem $\Pi = \langle S_{W_s}, \mathcal{KB}, \beta \rangle$;

According to the CLM definition, $S_{W_s}$, $\mathcal{KB}$ and $\beta$ are referred by $\mathcal{M}$.

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

- From the goal $Person$, the new goal $Organization$
AI planning and CLMs: A regression-based approach (2)

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

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\end{array}
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The composition process consists of a recursive and regression-based approach: $Ra_4C$;

From the goal $Person$, the new goal $Organization$
AI planning and CLMs: A regression-based approach (2)

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

According to the CLM definition, $SW_s$, $KB$ and $\beta$ are referred by $\mathcal{M}$.

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From the goal $Person$, $Organization$, the new goal $WL$

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AI planning and CLMs: A regression-based approach (2)

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

According to the CLM definition, $S_{W_s}$, $KB$ and $\beta$ are referred by $M$.

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

From the goal Person, Organization, the new goal $WL$

$$
\begin{bmatrix}
\emptyset & \{(S_a, 1)\} & \emptyset & \emptyset & \emptyset & \emptyset \\
\emptyset & \emptyset & \emptyset & \emptyset & \{(S_c, 1)\} & \emptyset \\
\emptyset & \emptyset & \emptyset & \{(S_b, \frac{1}{3})\} & \emptyset & \{(S_b, 1)\} \\
\emptyset & \{(S_a, 1)\} & \emptyset & \emptyset & \emptyset & \emptyset \\
\emptyset & \emptyset & \{(S_d, \frac{2}{3}), (S_e, 1)\} & \emptyset & \emptyset & \emptyset \\
\end{bmatrix}
$$

$$
\begin{align*}
(S_c, 1) \rightarrow WL \rightarrow (S_d, \frac{2}{3}) \rightarrow (S_b, 1) \rightarrow Or. \rightarrow Pe.
\end{align*}
$$
Suppose a CLM $\mathcal{M}$ and the planning problem $\Pi = \langle S_{Ws}, KB, \beta \rangle$;

According to the CLM definition, $S_{Ws}$, $KB$ and $\beta$ are referred by $\mathcal{M}$.

The composition process consists of a recursive and regression-based approach: $Ra_{4C}$;

From the goal $Person, Organization, WL$, the new goal $BP$
AI planning and CLMs: A regression-based approach (2)

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

According to the CLM definition, $S_{W_s}$, $\mathcal{KB}$ and $\beta$ are referred by $\mathcal{M}$.

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

From the goal $Person$, $Organization$, $WL$, the new goal $BP$.
AI planning and CLMs: 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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The composition process consists of a recursive and regression-based approach: $Ra_4C$;
- From goals $Person$, $Organization$, $WL$, $BP$ until concepts are referred in $\mathcal{KB}$.

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AI planning and CLMs: A regression-based approach (2)

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

The composition process consists of a recursive and regression-based approach: $Ra_4C$;
- From the goal Person, the new goal Organization

\[
\begin{pmatrix}
\emptyset & \{(S_a, 1)\} \\
\emptyset & \emptyset \\
\emptyset & \emptyset \\
\emptyset & \{(S_a, 1)\} \\
\emptyset & \emptyset \\
\emptyset & \{(S_d, \frac{2}{3}), (S_e, 1)\} \\
\emptyset & \emptyset \\
\emptyset & \emptyset \\
\emptyset & \emptyset \\
\emptyset & \emptyset
d\end{pmatrix}
\]
Suppose a \( CLM \) \( M \) and the planning problem \( \Pi = \langle S_{Ws}, KB, \beta \rangle \);

According to the \( CLM \) definition, \( S_{Ws} \), \( KB \) and \( \beta \) are referred by \( M \).

The composition process consists of a recursive and regression-based approach: \( Ra_{4C} \);

From the goal \( Person \), the new goals \( Organization, WL \)

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\begin{array}{cccccc}
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\[ (S_c, 1) \quad (S_e, 1) \quad (S_b, 1) \]

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The composition process consists of a recursive and regression-based approach: $R\alpha_4 C$;

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\[
\begin{pmatrix}
\emptyset & \{(S_a, 1)\} & \emptyset & \emptyset & \emptyset & \emptyset \\
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According to the CLM definition, $S_{W_s}$, $\mathcal{KB}$ and $\beta$ are referred by $\mathcal{M}$.

The composition process consists of a recursive and regression-based approach: $Ra_4 C$;

From the goal $Person$, $Organization$, $WL$, the new goal $BP$
Suppose a CLM $M$ and the planning problem $\Pi = \langle S_{W_s}, KB, \beta \rangle$;

According to the CLM definition, $S_{W_s}$, $KB$ and $\beta$ are referred by $M$.

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

From goals $Person$, $Organization$, $WL$, $BP$ until concepts are referred in $KB$.

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# Formal results

The algorithmic complexity for the $CLM$ construction is:
\[ \theta(\#(Input(S_{WS})) \times \#(Output(S_{WS}))); \]
\[ \text{i.e.}, \theta((\text{Max}\{\#(Input(S_{WS})), \#(Output(S_{WS}))\})^2); \]
\[ \text{so square in the worst case}. \]

The algorithmic complexity of the $Ra_4C$ algorithm is time polynomial
\[ \text{in} \]
\[ \#\text{rows}, \#\text{columns of the Causal Link Matrix}, \]
\[ \text{i.e., } \#(Input(S_{WS})). \]

with

Fail nodes detection;
Loop nodes detection;

In general cases $\theta(BuildClm) > \theta(Ra_4C)$. 

A causal link-based optimization

The $Ra_4C$ algorithm returns a set of correct, complete and consistent plans.
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However such a set may contain a large number of plans:

- Pruning strategies of plans’ space is necessary to propose an optimal solution;
- A causal link-based optimization criteria is proposed to detect the optimal plan.
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- The weight of the optimal plan is computed by means of the CLM and $Ra_4C$ algorithm.

$$W_{Max}(\beta) = \max_{S_c} \left\{ \frac{1}{\#In(s_y)^2} \sum_{In(s_y)} m_{I_i,\beta}.score \times \left( \prod_{In(s_y)} (W_{Max}(I_i)) \right) \right\}$$
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- $\beta$ is still the goal;
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$$W_{Max}(\beta) = \max_{S_c} \left\{ \frac{1}{\#In(s_y)^2} \sum_{I(n(s_y)}} m_{I_i,\beta}.score \times \left( \prod_{I(n(s_y)} (W_{Max}(I_i)) \right) \right\}$$

$S_c$ is a set of couple $(s_y, v)$ such that $s_y$ is a Web service with an output $\beta$ and inputs $I_i, 1 \leq i \leq \#I(n(s_y))$: $\langle s_y, Sim_T(Out_{s_y}, \beta), s_x \rangle$ is a valid causal link.
A causal link-based optimization

- The $Ra_4C$ algorithm returns a set of **correct**, **complete** and **consistent plans**.
- However such a set may contain a **large number of plans**:
  - **Pruning strategies** of plans’ space is necessary to propose an **optimal solution**;
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$$W_{Max}(\beta) = \text{Max}_{sc}\left\{ \frac{1}{\#In(s_y)^2} \sum_{In(s_y)} m_{I_i,\beta}.score \times \left( \prod_{In(s_y)} (W_{Max}(I_i)) \right) \right\}$$

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

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\[
W_{Max}(\beta) = \max_{Sc}\{\sum_{In(s_y)} \frac{1}{\#In(s_y)^2} \sum_{In(s_y)} m_{I_i,\beta}.score \times (\prod_{In(s_y)} (W_{Max}(I_i)))\}
\]

- The **first sum** is depending on semantic similarity between an output parameter of $s_y$ and $\beta$. 

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\]

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

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- The weight of the optimal plan is computed by means of the $CLM$ and $Ra_4C$ algorithm.

\[
W_{Max}(\beta) = Max_{Sc} \left\{ \frac{1}{\#In(s_y)^2} \sum_{In(s_y)} m_{I_i,\beta}.score \times (\prod_{In(s_y)} (W_{Max}(I_i))) \right\}
\]

- The second component is the recursive process.
A causal link-based optimization

The Ra₄C algorithm returns a set of correct, complete and consistent plans.

However such a set may contain a large number of plans:

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- A causal link-based optimization criteria is proposed to detect the optimal plan.

The weight of the optimal plan is computed by means of the CLM and Ra₄C algorithm.

\[
W_{Max}(\beta) = \text{Max}_{Sc}\left\{ \frac{1}{\#In(s_y)^2} \sum_{In(s_y)} m_{I_i,\beta}.score \times \left( \prod_{In(s_y)} (W_{Max}(I_i)) \right) \right\}
\]

- \text{Max}_{Sc} is a \(n\)-arity function which returns the maximum value between \(n\) float value(s) depending on the \(S_c\) elements.
A causal link-based optimization

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$$W_{Max}(\beta) = \max_{S_c} \left\{ \frac{1}{\#\text{In}(s_y)^2} \sum_{\text{In}(s_y)} m_{I_i,\beta}.\text{score} \times \left( \prod_{\text{In}(s_y)} W_{\text{Max}}(I_i) \right) \right\}$$

- Even if the optimal global plan may be obtained by $\max_{p \in \text{Plan}} \{\text{Weight}(p)\}$.
- wherein the function $\text{Weight}(p)$ 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: \textit{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;
- $\pi$ Calculus, Process Calculus.

What is the right way to model web services and their compositions?

Web services composition:
- 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 providing 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?