Composing and Optimising Services in the Semantic Web

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Mulhuddart, Dublin 15, Ireland
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Education, Research & Industry Experience

- 2010-Now: Research Fellow (€180,000 grant by EU BonFIRE)
  Knowledge Representation, Reasoning, Internet of Things
  University of Manchester, Centre for Service Research, UK
- 2008-2010: Research Associate (IEEE/ACM WI'08 Best Paper)
  Knowledge Representation, Reasoning, Service Systems
  University of Manchester, Centre for Service Research, UK
- 2005-2008: Ph.D (AFIA award, Cor Baayen award finalist)
  Knowledge Representation, Reasoning, Service Systems
  École des Mines de Saint-Etienne - France Telecom R&D
- 2003-2005: M.Sc in Computer Science (ranked 1st)
  Machine Learning
  École des Mines de Saint-Etienne, France

Objective

Modelling and Reasoning on Services in the Internet of Things for Smarter Cities.

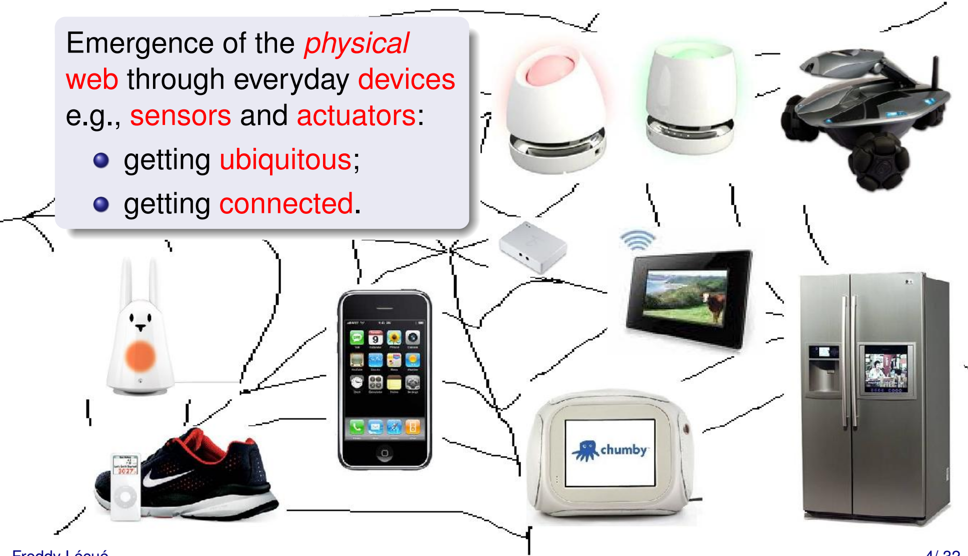
Internet of Things? Physical Mashups? Internet of Services?

[http://www.flickr.com/photos/72233349@N00/4746650074]

Embedded Devices are already All Around! ... and more to come!

Emergence of the *physical* web through everyday devices e.g., sensors and actuators:

- getting ubiquitous;
- getting connected.



Any Impact of their Composition?

- Creating a re-usable and composable physical world;
- From web to physical mashup mashup;
- Physical Object oriented Development.

Research Challenge

Optimal Web-based Service Composition

Combining services and optimising their selection.

[http://www.flickr.com/photos/brapke/]

Why is it Important?

- Added-value services;
- Higher level functionalities.

What is it Challenging? Why?

- Automation;
- Dynamicity;
- Scalability;
- ... in Industrial settings.

Related Work

Matthias Klusch
Semantic Web Service Coordination
Book Chapter 2007.

SWS Compostion Planners

- Service execution at planning time (interleaving)
  - **Reactive**
    - Any service
    - Pure reactive, Contingency
  - **Advanced**
    - Only info gathering services
    - Replanning (changes)
  - **Restricted**
    - Only info gathering services
- No service execution at planning time
  - **Non−Classical**
    - Contingency
    - Conformant
  - **Classical**
    - Deterministic
    - Complete Initial States

Planning under uncertainty

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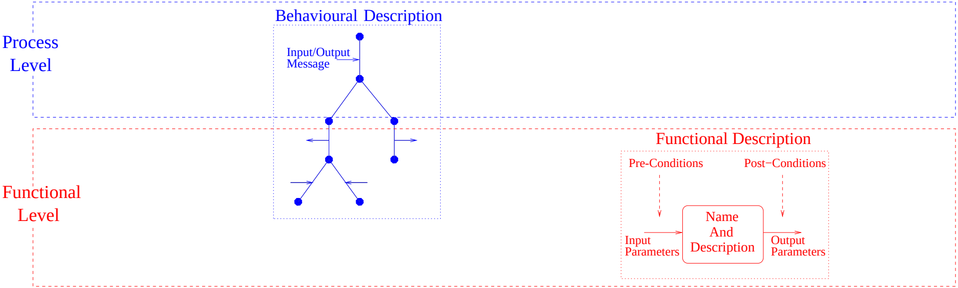
Planning under uncertainty



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Planning under uncertainty

Classical
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Process Level

OWLS−XPlan2 (Klusch+, 06)

SHOP2 (Sirin+, 02)
OWLS−XPlan1 (Klusch+, 06)

PLCP (Pistore+, 05)
Optop (McDermott, 02)
Roman Model (Berardi+, 05)
Mealy Model (Hull+, 03)

Functional Level

IW−RTC (Agre+,07)

- **Scalability Issues**
- **Restricted Expressivity**
- **Action-based Composability**
- **Planning Performance-based Optimisation**
- **No Industrial Application**

WSPLan (Peer, 05)
FFPanner (Hoffmann+, 07)
(Lassila, 04)
Golog-SCP (McIlraith+, 02)
Optop (McDermott, 02)

MetaComp (Botelho+, 07)
GOAL (Pfalzgraf, 06)
Agora−SCP (Rao+, 06)
SAWSDL−SCP (Wu+, 07)
OntoMat−S (Agarwal+, 04)
(Medjahed+, 03)
SemaPlan (Akkiraju+, 06)
Onto−Comp (Arpinar+, 05)

Advanced Semantics
Pure Planning

Contributions

Composing and Optimising Services in the Semantic Web

1. Composition
   - **Composability** criteria for services: semantic links;
   - Automated and scalable semantic link-based approach.
2. **Optimisation**
   - Semantics-driven quality of composition;
   - **Scalable** approach.

What is Innovative?

Semantic robustness.

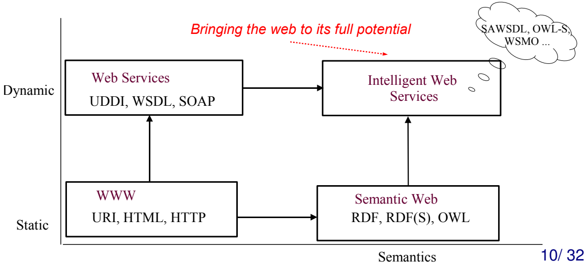
Industrial Context

Expressivity of services, their semantics and composition.

Outline

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;



Semantic Web Services at Functional Level

Input and Output Parameters

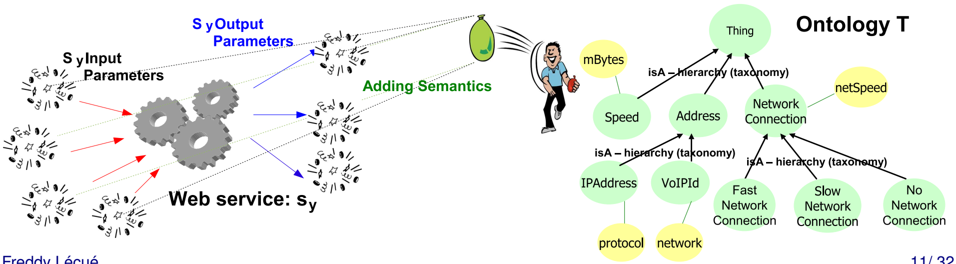
Concepts in a TBox $\mathcal{T}$ of an ontology.

- SA-WSDL, OWL-S profile level, WSMO capability level.

Preconditions and Effects

Horn-like rules expressed in terms of inputs and outputs.

- SWRL.



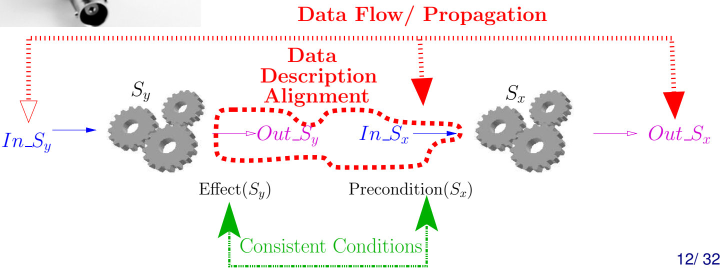
Causal Laws and Semantic Links

Causal Laws

- Consistent conditions.

Semantic Link

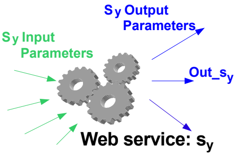
- Data description alignment;
- Data flow.

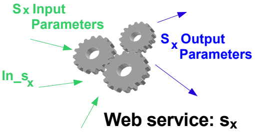


Semantic Links

Semantic connection between services;

- and their Output and Input parameters (as DL concepts);
- valued by $Sim_{\mathcal{T}}(Out\_s_y, In\_s_x)$;





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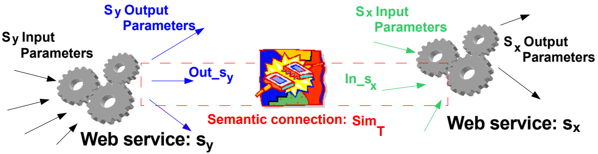

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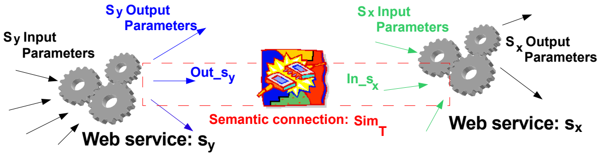

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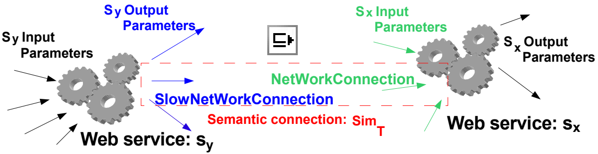

- $Sim_{\mathcal{T}}$ is reduced to the five matchmaking functions [M.Paolucci et al. ISWC'02, Li and Horrocks WWW'03]:
  - **Exact** i.e., $\mathcal{T} \models Out\_s_y \equiv In\_s_x$;
  - **PlugIn** i.e., $\mathcal{T} \models Out\_s_y \sqsubseteq In\_s_x$;
  - **Subsume** i.e., $\mathcal{T} \models In\_s_x \sqsubseteq Out\_s_y$;
  - **Intersection** i.e., $\mathcal{T} \not\models Out\_s_y \sqcap In\_s_x \sqsubseteq \perp$;
  - **Disjoint** i.e., $\mathcal{T} \models Out\_s_y \sqcap In\_s_x \sqsubseteq \perp$;

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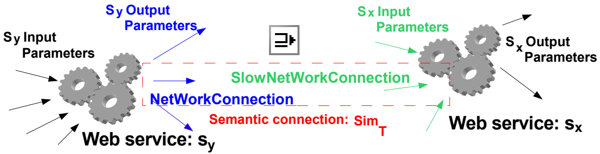
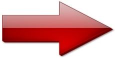


- $Sim_{\mathcal{T}}$ is reduced to the five matchmaking functions [M.Paolucci et al. ISWC'02, Li and Horrocks WWW'03]:
  - **Exact** which is Robust;
  - **PlugIn** which is Robust;
  - **Subsume** which is Non Robust;
  - **Intersection** which is Non Robust;
  - **Disjoint** which is Non Robust;

Non Robust Semantic Links

Open Issue

From a non robust semantic link to its robust form?


Approach

Discovering information in In_s_x and not in Out_s_y through **Concept Difference** or **Abduction**.

S. Brandt, R. Kusters, A. Thurhan.
Approximation and difference in description logics.
In *KR*, pages 203–214, Toulouse, France, 2002.

T. Di Noia, E. Di Sciascio *et al.*
Abductive matchmaking using description logics.
In *IJCAI*, pages 337–342, Acapulco, Mexico, 2003. MK.

Concept Difference for Ensuring Robustness (1)

Definition (Concept Difference)

The difference between two DL concepts In_s_x and Out_s_y is:

$$In\_s_x \backslash Out\_s_y := \min_{\preceq_d}\{H | H \sqcap Out\_s_y \equiv In\_s_x \sqcap Out\_s_y\}$$

Why is it not Robust?

Missing Description $In\_s_x \backslash Out\_s_y$.

Why it could be Robust?

Common Description $lcs(Out\_s_y, In\_s_x)$.

Objective

Explaining (proof) Where, Why and How ensuring robustness.

Concept Difference for Ensuring Robustness (2)

Definition (Concept Difference)

The difference between two DL concepts In_s_x and Out_s_y is:

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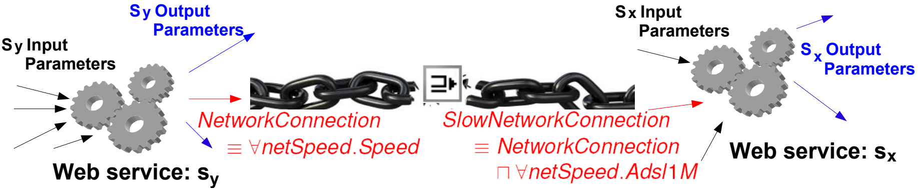
Example

Non robust semantic link valued by the Subsume match level.



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Example

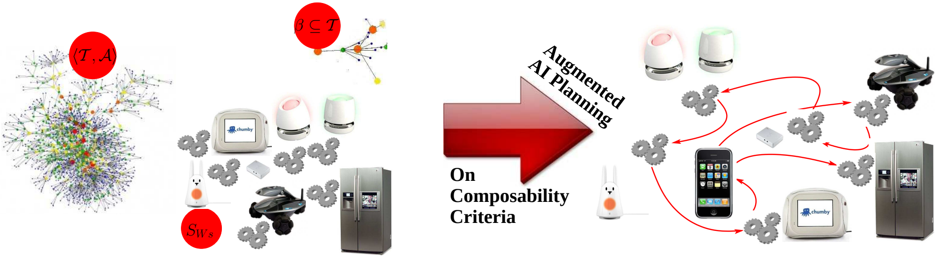
Non robust semantic link valued by the Subsume match level.

Composability and Robustness, Right!
What about automated composition?

Semantics Augmented AI Planning Problem

$\langle \mathcal{T}, S_{Ws}, \mathcal{A}, \beta \rangle$

- A knowledge based: A Terminological Box $\mathcal{T}$;
- A set of possible state transitions S_{Ws}: Services;
- A set of initial state $\mathcal{A}$: An Assertional Box;
- An explicit goal representation $\beta \subseteq \mathcal{T}$: DL concepts.



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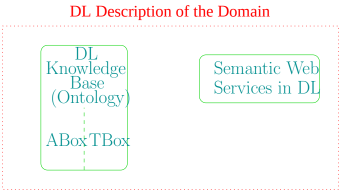
Vs. State-of-the-Art

- Services: **conditional** actions;
- Semantic links and causal laws -driven planning;
- Compositions: **conditional** and **concurrent** plans;

$\rightarrow$ AI Planning + DL Reasoning.

Semantics Augmented AI Planning Approach



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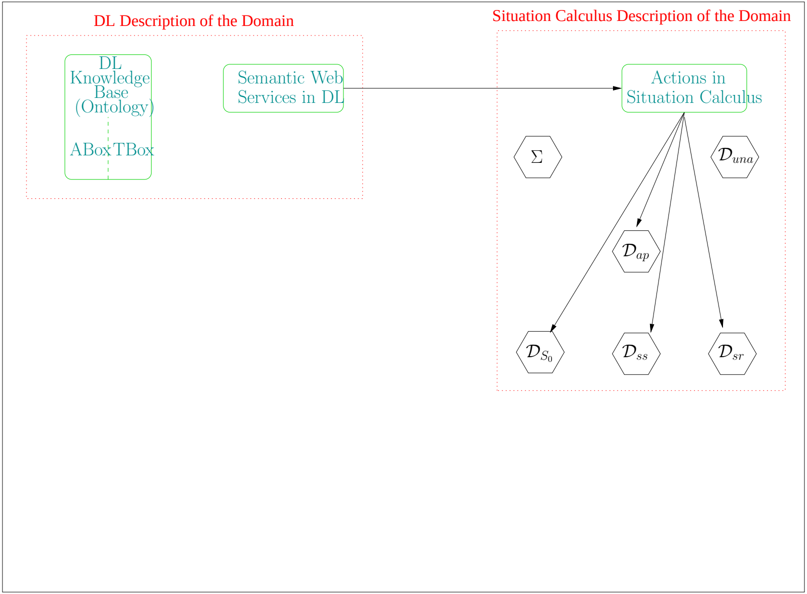

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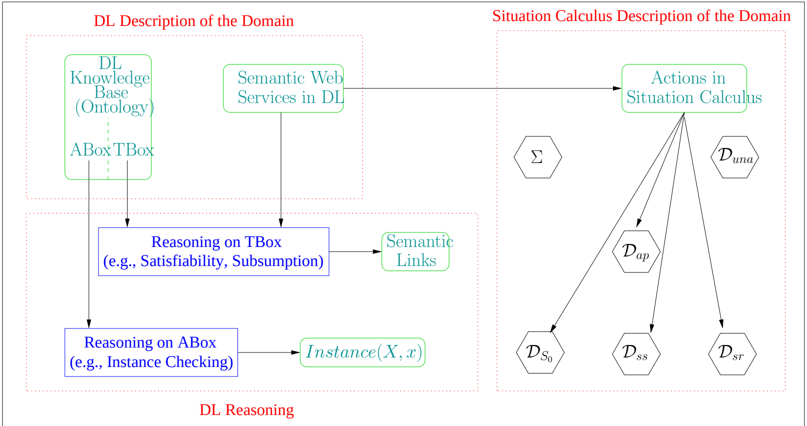

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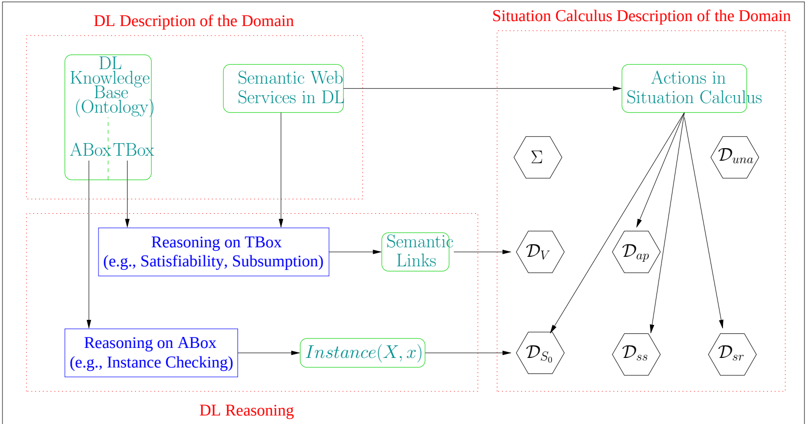

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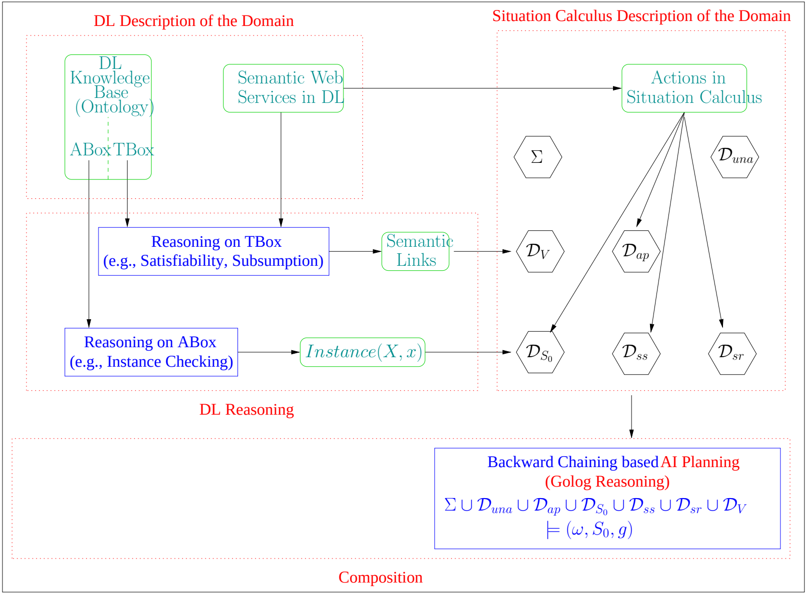

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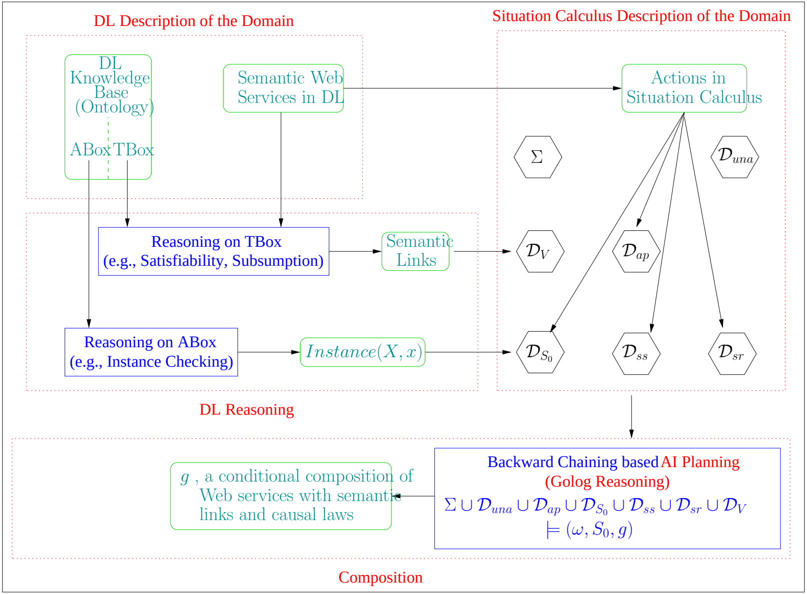

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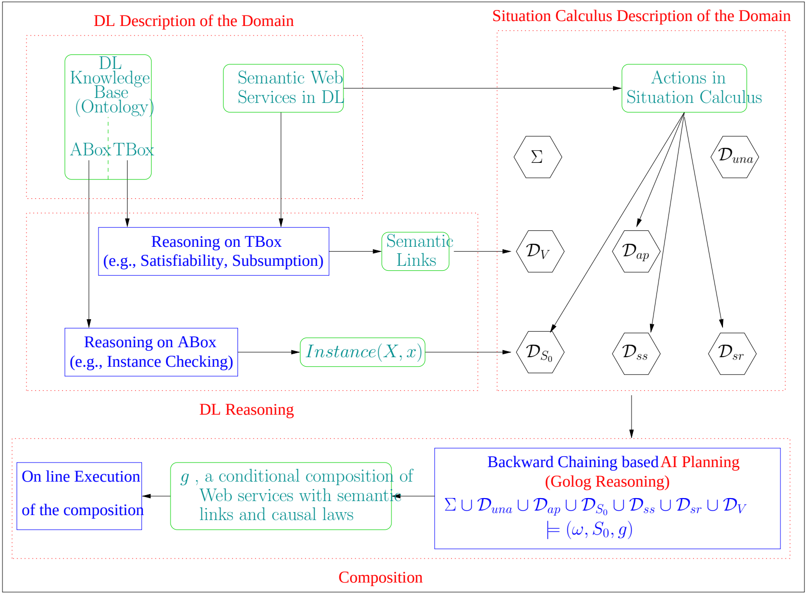

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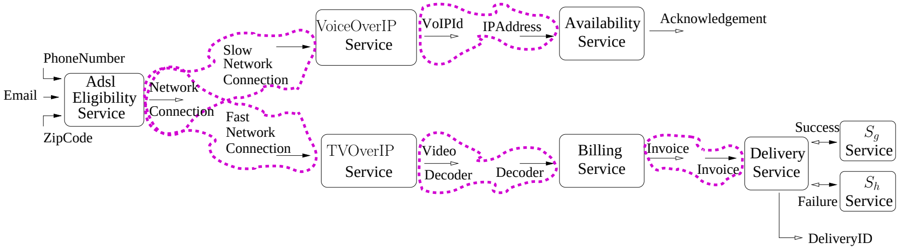
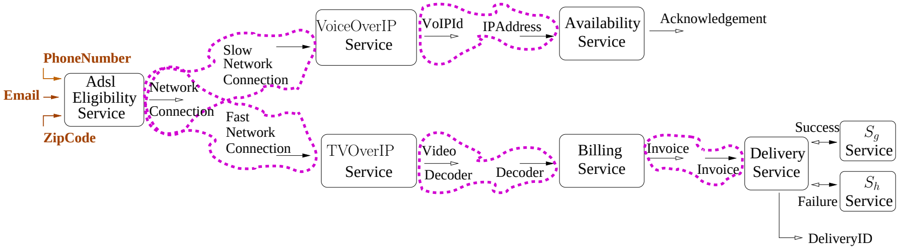


Required Axioms: Σ, $\mathcal{D}_{una}$, $\mathcal{D}_{V}$ and ...

- $\mathcal{D}_{S_0}$, $\mathcal{D}_{ss}$, $\mathcal{D}_{sr}$, $\mathcal{D}_{ap}$,

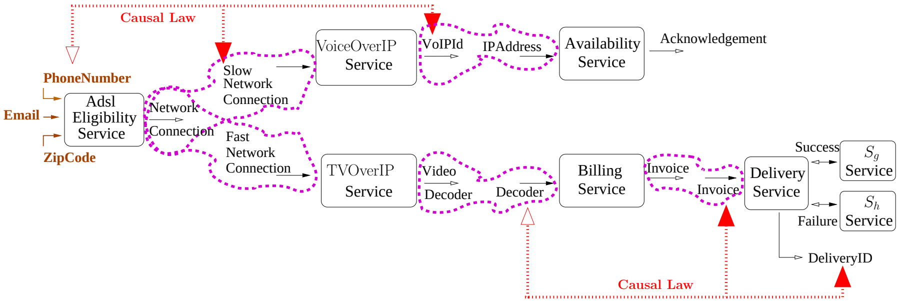
Example



Required Axioms: Σ, $\mathcal{D}_{una}$, $\mathcal{D}_V$ and ...

- $\mathcal{D}_{S_0}$, $\mathcal{D}_{ss}$, $\mathcal{D}_{sr}$, $\mathcal{D}_{ap}$,
  - $UKPhoneNumber(+447767411876, S_0)$;
  - $UKZipCode(M156PB, S_0)$;
  - $validMail(freddy.lecue@manchester.ac.uk, S_0)$.

Example



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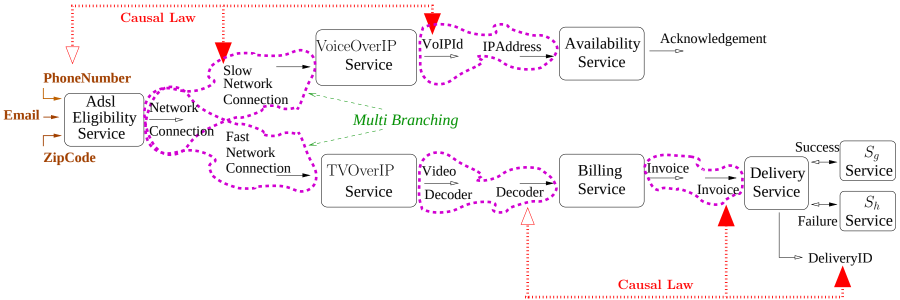
$$
\begin{aligned}
&phoneNumberOf(output(\texttt{VoiceOverIP}\ (x), 1), ph\_nb, do(\texttt{VoiceOverIP}\ (x), s)) \leftarrow \\
&\qquad Poss(\texttt{VoiceOverIP}\ (x), s)\ \wedge (phoneNumberOf(x, ph\_nb, s) \vee \\
&\qquad phoneNumberOf(output(\texttt{VoiceOverIP}\ (x), 1), ph\_nb, s))
\end{aligned}
$$

Example



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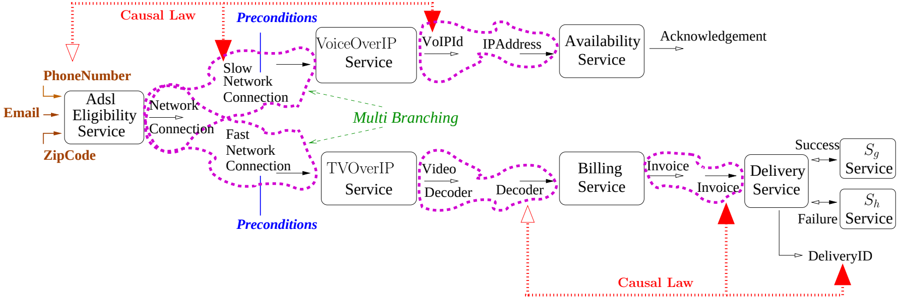
$$sr(\texttt{AdslEligibility}, s) \leftarrow NetworkConnection(x, s)$$

Example



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$$
\begin{aligned}
Poss(\mathtt{VoiceOverIP}(x), s) \equiv\ & validNetworkConnection(x, s) \wedge \\
& supportConnectionType(x, s) \wedge \\
& \mathbf{KRef}(NetworkConnection(x), s)
\end{aligned}
$$

Composability, Robustness, and Composition! What about optimal results?

[http://www.flickr.com/photos/62220986@N04]

Issues

- Quality model;
- Optimisation approach.

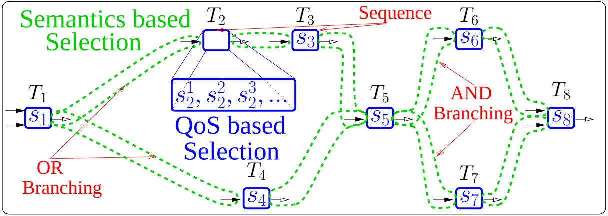
While most of approaches focus on:

Non functional quality of services e.g., QoS.

L. Zeng, B. Benatallah *et al.*
Quality Driven Web Services Composition.
In *WWW*, pages 411–421, 2003.

Our focus is on:

QoS and functional constraints (between services).



Our Quality Model

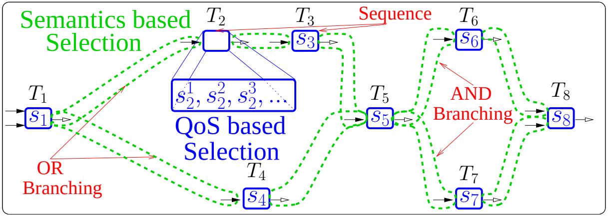
- Execution price;
- Response time;
- Common description rate;
- Matching quality.

Constraints Satisfaction Optimization Problem (CSOP)

- T is the set of tasks (*variables*) $\{T_1, T_2, ..., T_n\}$;
- D is the set of *domains* $\{D_1, D_2, ..., D_n\}$ i.e., services;
- C is the set of *constraints* i.e., local C_L and global C_G;

$$e.g., \frac{1}{|sl^A_{i,j}|}\sum_{sl^A_{i,j}} q_{cd}(sl^A_{i,j}) \geq v, \;\; v \in [0,1] \qquad \sum_{T_i} q_{pr}(T_i) \leq v, \;\; v \in \Re^+$$

- f is an evaluation function.



Objective

Optimal (service, task) assignement in term of QoS and functional quality, satisfying constraints C.

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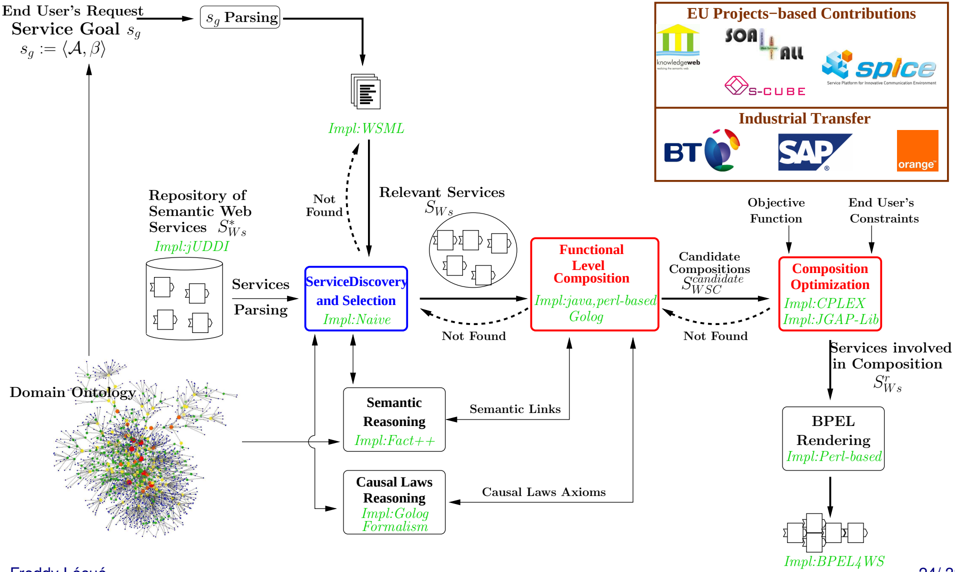
Experimented Approaches

- Integer Programming (optimal, appropriate scalability);
- Genetic Algorithm (sub-optimal, better scalability);
- Stochastic Search (no optimal, best scalability);

What About an Integrated Approach? Where? and How?



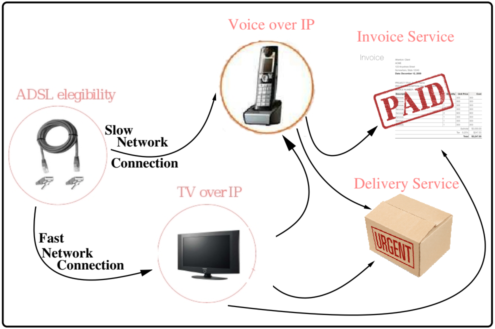
... and on Top of Service Composition and Optimisation?

[http://www.flickr.com/photos/72233349@N00/4746650074]

Automated Internet Package Configuration (France Telecom R&D)

Objective

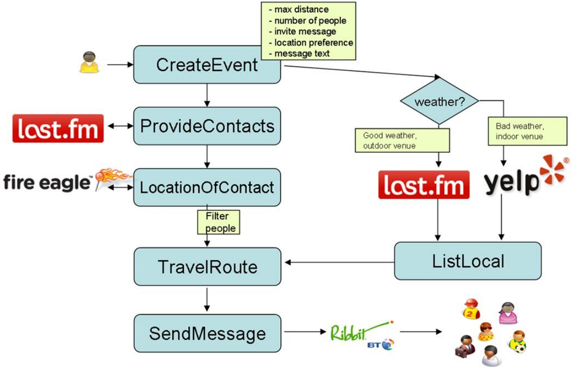
- Nowadays: Static/Predefined packages e.g., *ADSL Max$^+$ + HDTV.*
- Future: Dynamic, automated configuration of Orange's services.



Challenge

Selecting, combining existing services to provide higher level functionalities !

Web2.0 Meet Friends Service (British Telecom)



Objective

Organising a meeting with a group of friends at short notice using most efficient and reliable Web 2.0 based services.

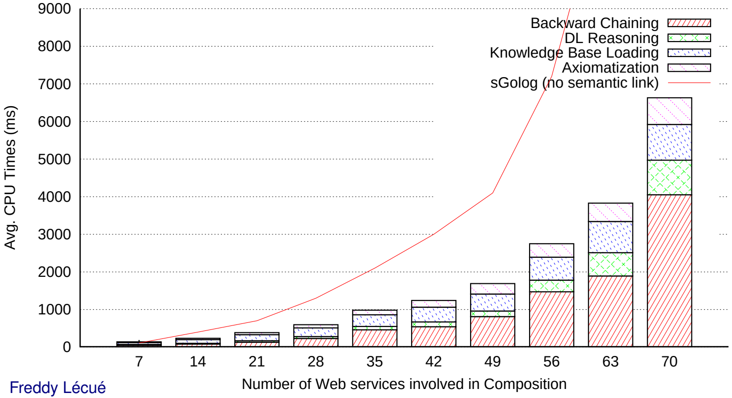
Challenge

Selecting, organising, aggregating heteogeneous content from data-oriented services!

Composition - *Random Generation of Services*

Main Formal Results and Experiments

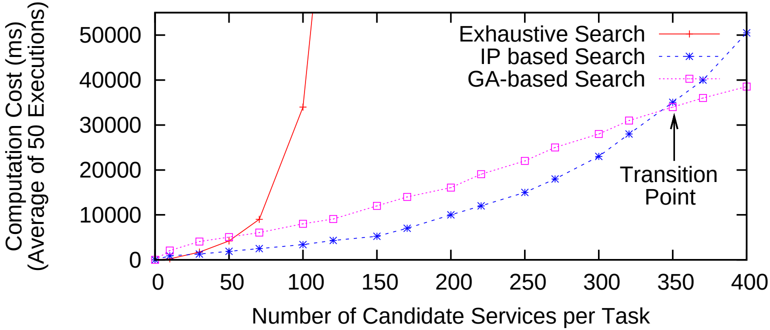
- Computational complexity: Θ(DL Reasoning) $<$ Θ(AI Planning);
- Validation in a EU and Industrial context.



Optimisation - *Random Generation of Services*

Main Formal Results and Experimentation

- Constraints Satisfaction Optimisation Problem, formal model for evaluating compositions:
- Computational complexity: Θ(GA or IP) $<$ Θ(DL Reasoning);



Composition & Optimisation - *Random Generation of Services*

Main Results (Scenarios-Dependence!)

- Computation time: Θ(Optimisation) $<<$ Θ(Composition).
- Θ(GA or IP) $<$ Θ(DL Reasoning) $<$ Θ(AI Planning)

Best Practices for using our Approach

Process	Parameters	Computation Time in ms			
		(0, 1000]	(1000, 2000]	(2000, 5000]	(5000, 10000]
Semantic Links oriented	**Nb services**	35	53	65	71
	Nb Inputs, Outputs	2	2	2	2
Semantic Links and Causal Laws oriented	Nb services	**69**	**74**	**78**	**83**
	Nb Inputs, Outputs	4	4	4	4
	Nb Preconditions, Effects Axioms	4	4	4	4
Composition Optimization	Nb Services	220	260	350	450
	Nb Candidate semantic Link	100	100	100	100

Take Away Notes

- Objective: Web-based service composition.
- Challenge: Automation, Scalability, Optimality and Expressivity.
- Approach: Semantics-based.
- Impact:
  - Automated interaction of services in the Internet of Things.
  - Limiting cost of data integration.
- Applications: Everything's connected.
- Lessons Learnt: NP Hard... but tradeoff Complexity/Expressivity.

Future Work: Serving Smarter Cities

- Seeking services in the Linked Open Data initiative;
- Lightweight reasoning for better scalability;

Contributions

Academics

IEEE TRANSACTIONS ON KNOWLEDGE AND DATA ENGINEERING

Web Intelligence and Agent Systems — An International Journal

International Journal of Web Services Research

ICSC 2010

International Journal of Cooperative Information Systems

ISWC 2006 — Hosted by LSDIS

AAAI-07 — Vancouver, Canada, July 22-26

International Journal of Semantic Computing

ICWS Web Services

ECAI Patras 2008

ECOWS'09 — European Conference on Web Services — November 9 - 11 2009, Eindhoven, The Netherlands

ISWC 2009

aaai-11 – san francisco — august 7–11 – www.aaai.org / aaai11

ECOWS'06

ICSOC - ServiceWave 2009 — Joint ICSOC-ServiceWave 2009 — 23rd-27th November 2009 - Stockholm, Sweden

Web Intelligence (WI'08) — Held in conjunction with The 2008 IEEE/WIC/ACM International Conference on Intelligent Agent Technology

ICSC 2009

FP6, FP7 European Projects

SOA4All

knowledgeweb — realizing the semantic web

S-CUBE

spice — Service Platform for Innovative Communication Environment

Industry

orange

SAP

BT

Atos Origin

Selected Academic Contributions

F. Lécué and N. Mehandjiev
Seeking Quality of Web Service Composition in a Semantic Dimension
In *IEEE Transactions on Knowledge and Data Engineering*, pages 942-959, Vol 23 No 6. 2011.

F. Lécué and N. Mehandjiev
Satisfying End User Constraints in Service Composition by Applying Stochastic Search Methods
In *International Journal of Web Services Research*, pages 41-63, Vol 7 No 4. Idea Group. 2010

F. Lécué, A. Delteil and A. Leger
Towards a Semantic State Transition System for Automated Generation of Data Flow in Service Composition
In *International Journal of Semantic Computing*, pages 499-526, Vol 3 No 4 December 2009

F. Lécué and A. Delteil and A. Léger
DL Reasoning and AI Planning for Web Service Composition
In *Web Intelligence*, pages 445-453, Sydney, Australia, December 2008. (Best Paper Award).

F. Lécué and A. Delteil and A. Léger
Optimizing Causal Link-based Web Service Composition
In *European Conference on Artificial Intelligence*, pages 45-49, Patras, Greece, July 2008.

F. Lécué and A. Delteil
Making the Difference in Semantic Web Service Composition
In *Ass. for the Advancement of Artificial Intelligence*, pages 1383-1388, Vancouver, Canada, July 2007.

Thank you for your attention!

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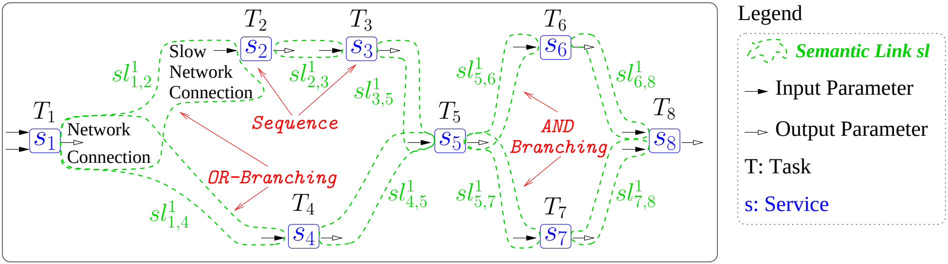
Composition Result Modelling

Process Model as a Statechart

- Its states refer to services;
- Its transitions are labelled with semantic links;
- with basic composition constructs.



Quality Criteria for Semantic Links & Services

$q(sl_{i,j})$ for Elementary Semantic Links $sl_{i,j}$

- Common Description rate $q_{cd} \in (0, 1]$:

$$q_{cd}(sl_{i,j}) = \frac{|lcs(Out\_s_i, In\_s_j)|}{|H_{\in\langle\mathcal{L}, Out\_s_i, In\_s_j, \mathcal{T}\rangle}| + |lcs(Out\_s_i, In\_s_j)|}$$

- Matching Quality $q_m \in (0, 1]$, valued by $Sim_{\mathcal{T}}(Out\_s_i, In\_s_j)$ (*Exact:* 1, *PlugIn:* $\frac{3}{4}$, *Subsume:* $\frac{1}{2}$, *Intersection:* $\frac{1}{4}$).

- $|.|$ refers to the size of $\mathcal{ALE}$ concept descriptions:
  - $|\top|$, $|\bot|$, $|A|$, $|\neg A|$ and $|\exists r|$ is 1;
  - $|C \sqcap D| \doteq |C| + |D|$;
  - $|\forall r.C|$ and $|\exists r.C|$ is $1 + |C|$;
- for instance $|Speed \sqcap \forall mBytes.1M| = 3$.

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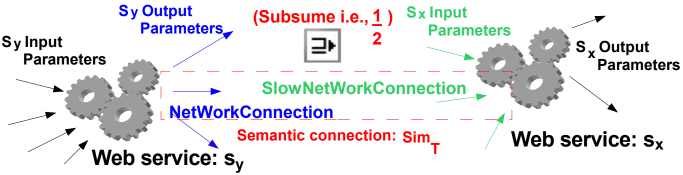

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$q(s_i)$ for Elementary Services s_i

- Execution Price $q_{pr} \in \Re^+$;
- Response Time $q_t \in \Re^+$.

Quality Criteria for Semantic Links & Services

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$q(s_i)$ for Elementary Services s_i

- Execution Price $q_{pr} \in \Re^+$;
- Response Time $q_t \in \Re^+$.

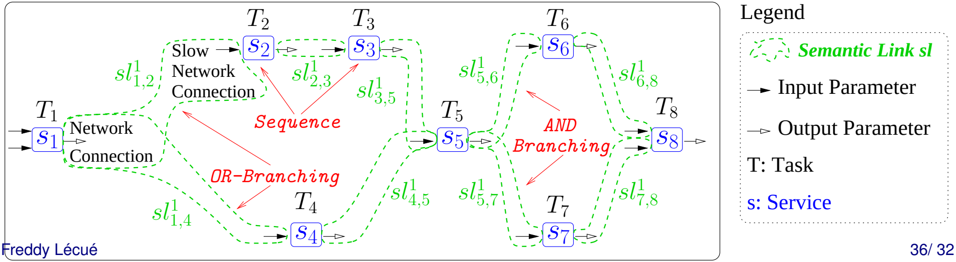
QoS-extended quality vector of a semantic link $sl_{i,j}$

$$\overset{*}{q}(sl_{i,j}) \doteq (q(s_i), q(sl_{i,j}), q(s_j))$$

Quality Criteria for Composition

Quality Aggregation Rules for Compositions

Composition Construct	Quality Criterion			
	Semantic		Non Functional	
	Q_{cd}	Q_m	Q_t	Q_{pr}
Sequential/	$\frac{1}{\lvert sl \rvert} \sum_{sl} q_{cd}(sl)$	$\prod_{sl} q_m(sl)$	$\sum_s q_t(s)$	$\sum_s q_{pr}(s)$
AND- Branching			$\max_s q_t(s)$	
OR-Branching	$\sum_{sl} q_{cd}(sl).p_{sl}$	$\sum_{sl} q_m(sl).p_{sl}$	$\sum_s q_t(s).p_s$	$\sum_s q_{pr}(s).p_s$



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OR-Branching	$\sum_{sl} q_{cd}(sl).p_{sl}$	$\sum_{sl} q_m(sl).p_{sl}$	$\sum_s q_t(s).p_s$	$\sum_s q_{pr}(s).p_s$

A Quality Vector for Web Service Composition

“A” way to differentiate compositions:

$$Q(c) \doteq (Q_{cd}(c), Q_m(c), Q_t(c), Q_{pr}(c))$$