Alignment-Based Trust for Resource Finding in Semantic P2P Systems

MANUEL ATENCIA

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Introduction

• trust is a central component in the Semantic Web
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- why is trust necessary?
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  - Web *motto*: “anyone can say anything about anything”
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• why is trust necessary?
  • Web motto: “anyone can say anything about anything”
  • open and dynamic environments: uncertainty of participants’ behaviour, information sources of varying quality
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- some definitions in the literature:
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  - trust is the firm belief in the competence of an entity to act dependably, securely, and reliably within a specified context [Grandison and Sloman’00]
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• some definitions in the literature:

  • trust is a **subjective** expectation an agent has about another’s future **behaviour** based on the **history** of their encounters [Mui et al.’02]

  • trust is the firm belief in the **competence** of an entity to act dependably, securely, and reliably within a specified **context** [Grandison and Sloman’00]

  • a unifying theme: trust is worth modelling when there is a possibility of **deception**, that is, when there is a chance of a different outcome than what is expected or has been agreed upon [Artz and Gil’07]
Semantic P2P Networks
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• peers and connections between peers
Semantic P2P Networks

- peers and connections between peers
• every peer is associated with one populated ontology
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Populated Ontologies
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- populated ontology: \( \mathcal{O} = \{O, I, \text{ext}\} \)
- an ontology: \( O = \{C, \leq, \bot\} \)
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\text{ext}(c) \subseteq I
\]
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Populated Ontologies

- populated ontology: \( O = \{O, I, ext\} \)
- an ontology: \( O = \{C, \leq, \perp\} \)
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\[ ext(c) \subseteq I \]
Semantic P2P Networks

\[ O_2 \sim P_2 \quad P_5 \sim O_5 \]
\[ O_1 \sim P_1 \quad P_3 \sim O_3 \]
\[ O_4 \sim P_4 \quad P_6 \sim O_6 \]
Semantic P2P Networks

- different ontologies need to be aligned
Semantic P2P Networks

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Alignments
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• a more general notion of alignment: algebra of relations [Euzenat08]
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Queries and Answers

• peers pose queries to obtain information that concerns others’ populated ontologies
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\[ P_i \quad P_j \]
Queries and Answers

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\[ P_i \xrightarrow{c(X)\ ?} P_j \]

where \( c \in C_i \), but if \( O_i \neq O_j \) …
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\[ A_{ij} \]

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\[ P_i \xrightarrow{c(X)\text{?}} A_{ij} \xrightarrow{} P_j \]
Queries and Answers

- queries are translated via correspondences of alignments

\[ A_{ij} \]

\[ \langle c, d, R \rangle \]

\[ P_i \rightarrow c(X) \]

\[ \rightarrow P_j \]

\[ \ldots \]
Queries and Answers

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\[ \langle c, d, R \rangle \]

\[ c(X) \]

\[ d(X) \]
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\[
\begin{align*}
\text{d}(X) \? \quad & \quad \text{B} = \text{ext}_j(d) \\
P_i & \xleftrightarrow{} \quad B \quad \xrightarrow{} \quad P_j
\end{align*}
\]
Queries and Answers

• the answer to a query is a set of instances

\[ d(X) ? \]

\[ P_i \quad \leftrightarrow \quad B = \text{ext}_j(d) \quad \rightarrow \quad P_j \]

• it is assumed that no translation of instances is ever required
the answer to a query is a set of instances

\[ d(X) \]

\[ P_i \leftrightarrow B = \text{ext}_j(d) \rightarrow P_j \]

it is assumed that no translation of instances is ever required

but it may happen that \( a \in B \) is not considered an instance of \( c \) by \( P_i \): it is an unsatisfactory instance
Towards a Definition of Trust
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• the uncertainty about a peer’s answer can be estimated with the help of a trust mechanism
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- the idea of satisfactory instance is faithfully captured by a reference populated ontology $O^*_i = \langle O_i, I^*_i, ext^*_i \rangle$
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$$a \in B = ext_t^j(d) \text{ is satisfactory iff } a \in ext_i^*(c)$$

• it is assumed that $ext_i(c) = ext_i^0(c) \subseteq ext_i^*(c)$

• in this way the proportion of satisfactory instances in an answer is the conditional probability $p(ext_i^*(c) | B)$
peers’ class extensions are increased over time
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\[ ext_i(c) = ext_i^0(c) \subseteq ext_i^1(c) \subseteq \ldots \subseteq ext_i^t(c) \subseteq \ldots \]
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so we have a sequence of populated ontologies
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so we have a sequence of populated ontologies

\[ \mathcal{O}_i = \mathcal{O}_i^0, \mathcal{O}_i^1, \ldots, \mathcal{O}_i^t, \ldots \]
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so we have a sequence of populated ontologies

\[ O_i = O_i^0, O_i^1, \ldots, O_i^t, \ldots \]

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but since instances may not be 100% satisfactory, peers are associated with probabilistic populated ontologies
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\[ \tilde{O}_i = \tilde{O}_i^0, \tilde{O}_i^1, \ldots, \tilde{O}_i^t, \ldots \]
Probabilistic Populated Ontologies
• a probabilistic class extension $\tilde{e}xt^t_i(c)$
• a probabilistic class extension $\tilde{ext}_t(c)$
• a probabilistic class extension $\tilde{ext}_i^t(c)$

\[
A^* \subseteq ext_i^*(c)
\]

\[
p(ext_i^*(c)|A^1) \gtrsim .97
\]
\[
p(ext_i^*(c)|A^2) \gtrsim .90
\]
\[
p(ext_i^*(c)|A^3) \gtrsim .85
\]
\[
p(ext_i^*(c)|A^4) \gtrsim .76
\]
Towards a Definition of Trust
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- trust of peer $P_i$ towards peer $P_j$ wrt the translation $\langle c, d \rangle$ at time $t$
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\[
\text{trust}^t(P_i, P_j, \langle c, d \rangle) = \text{def } p(ext_i^*(c)|\text{ext}_j^t(d))
\]
Towards a Definition of Trust

• trust of peer $P_i$ towards peer $P_j$ wrt the translation $\langle c, d \rangle$ at time $t$

\[
\text{trust}^t(P_i, P_j, \langle c, d \rangle) \overset{\text{def}}{=} p(\text{ext}_i^*(c) | \text{ext}_j^t(d))
\]

• some remarks:
Towards a Definition of Trust

- trust of peer $P_i$ towards peer $P_j$ wrt the translation $\langle c, d \rangle$ at time $t$

$$trust^t(P_i, P_j, \langle c, d \rangle) =_{def} p(ext^*_i(c) | ext^t_j(d))$$

- some remarks:

  - cheating is not directly addressed: unsatisfactory answers are the result of peers’ incapacity to understand each other
• trust of peer $P_i$ towards peer $P_j$ wrt the translation $\langle c, d \rangle$ at time $t$

$$trust^t(P_i, P_j, \langle c, d \rangle) =_{def} p(ext_i^*(c) | ext_j^t(d))$$

• some remarks:

• cheating is not directly addressed: unsatisfactory answers are the result of peers’ incapacity to understand each other

• trust depends on time and class translations
Computation of Trust
Computation of Trust

- typically based on two kinds of information sources
  - direct experience
  - witness (third-party) information
Computation of Trust

• typically based on two kinds of information sources
  • direct experience
  • witness (third-party) information

• our approach:
  • exploits the logical structure of ontologies and alignments
  • estimation of probabilities: bayesian inference
Computation of Trust
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- probability distribution representing peer $P_i$’s belief about trust
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\[ T^t(P_i, P_j, \langle c, d \rangle) \sim \theta = trust^t(P_i, P_j, \langle c, d \rangle) \]
\[ = p(ext^*_i(c)|ext^t_j(d)) \]
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• bayesian inference: estimation of the parameter of a binomial distribution by means of a family of beta distributions
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\]

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• probability distribution representing peer $P_i$’s belief about trust

$$T^t(P_i, P_j, \langle c, d \rangle) \sim \theta = trust^t(P_i, P_j, \langle c, d \rangle) = p(ext^*_t(c)|ext^t_j(d))$$

• bayesian inference: estimation of the parameter of a binomial distribution by means of a family of beta distributions

$$T^t = Beta(\alpha, \beta) \quad \text{sampling on} \quad ext^t_j(d) \quad T^{t+1} = Beta(\alpha + k, \beta + n - k)$$
Computation of Trust
Computation of Trust

- sampling on peer $P_j$’s answer $ext_j^t(d)$
Computation of Trust

- sampling on peer $P_j$'s answer $ext^t_j(d)$

- automatically by exploiting the logical structure of ontologies
• sampling on peer $P_j$’s answer $ext_j^t(d)$

• automatically by exploiting the logical structure of ontologies

• calling an oracle (typically the user) as a last resort
Computation of Trust
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draw an instance from the answer (with replacement)
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is it already an instance of the current local populated ontology?
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YES

does it belong to the set of 100% satisfactory instances of the class $c$?
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does it belong to the set of 100% satisfactory instances of the class c?

YES

\[ k = k + 1 \]
Computation of Trust

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\[ n = n + 1 \]
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\( k = k + 1 \)

\( n = n + 1 \)
Computation of Trust

draw an instance from the answer (with replacement)

is it already an instance of the current local populated ontology?

YES

does it belong to the set of 100\% satisfactory instances of the class c?

YES

$k = k + 1$

NO

does it belong to the set of 100\% satisfactory instances of a class disjoint from c?

n = n + 1
Computation of Trust

draw an instance from the answer (with replacement)

is it already an instance of the current local populated ontology?

YES

does it belong to the set of 100% satisfactory instances of the class c?

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YES

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draw an instance from the answer (with replacement)

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YES

does it belong to the set of 100% satisfactory instances of the class $c$?

YES

$k = k + 1$

NO

does it belong to the set of 100% satisfactory instances of a class disjoint from $c$?

YES

$n = n + 1$

NO

...
Computation of Trust

draw an instance from the answer (with replacement)

...
Computation of Trust

draw an instance from the answer (with replacement)

... is oracle's answer positive?

CALL THE ORACLE

is the number of oracle calls \( m \) lower than the threshold?

NO

STOP

YES

\[ k = k + 1 \]

\[ m = m + 1 \] \[ n = n + 1 \]
Computation of Trust
Computation of Trust

• if there is no direct experience: priors are based on alignments
Computation of Trust

• if there is no direct experience: priors are based on alignments

• intended meaning of alignments

\[
R = \{=\} \quad \text{iff} \quad ext_i^*(c) = ext_j^*(d)
\]

\[
R = \{>\} \quad \text{iff} \quad ext_i^*(c) \supset ext_j^*(d)
\]

\[
R = \{<\} \quad \text{iff} \quad ext_i^*(c) \subset ext_j^*(d)
\]

\[
R = \{\perp\} \quad \text{iff} \quad ext_i^*(c) \cap ext_j^*(d) = \emptyset
\]

\[
R = \{\emptyset\} \quad \text{iff} \quad \text{none of the above holds}
\]
• if there is no direct experience: priors are based on alignments
Computation of Trust

• if there is no direct experience: priors are based on alignments

• provided that $\text{ext}_j^t(d) \subseteq \text{ext}_j^*(d)$
Computation of Trust

• if there is no direct experience: priors are based on alignments

• provided that $ext_t^j(d) \subseteq ext^*_j(d)$

if $R$ is ‘$=$’ or ‘$>$’ then $p(ext^*_i(c)|ext^t_j(d)) = 1$

if $R$ is ‘$\bot$’ then $p(ext^*_i(c)|ext^t_j(d)) = 0$

if $R$ is ‘$<$’ or ‘$\triangleright$’ then $p(ext^*_i(c)|ext^t_j(d)) \in [0, 1]$
Computation of Trust

- if there is no direct experience: priors are based on alignments
Computation of Trust

- if there is no direct experience: priors are based on alignments

\[ \langle c, \{\perp\}, d \rangle \quad \langle c, \{<\}, d \rangle \text{ or } \langle c, \{\emptyset\}, d \rangle \quad \langle c, \{=\}, d \rangle \text{ or } \langle c, \{>\}, d \rangle \]
Computation of Trust

• if there is no direct experience: priors are based on alignments
Computation of Trust

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• if $R$ is not a singleton, relations are taken equiprobable
• if there is no direct experience: priors are based on alignments
Computation of Trust

- if there is no direct experience: priors are based on alignments
Use of Trust
• peer $P_i$ will query peer $P_{j_0}$ through the class $d_{j_0}$ if

$$E(T^t(P_i, P_{j_0}, \langle c, d_{j_0} \rangle)) = \max\{E(T^t(P_i, P_j, \langle c, d_j \rangle))\}$$
• if peer $P_i$ receives $B = ext^t_j(d)$ as an answer to the query “$c(X)$” then $B$ will be (partly) added to $A = ext^t_i(c)$
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• the set $B$ is partitioned into three subsets
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$$B = ext^t_j(d) = B^+_\text{aut} \uplus B^-\text{aut} \uplus B^-\text{aut}$$
Update of Probabilistic Populated Ontologies

- if peer $P_i$ receives $B = ext^t_j(d)$ as an answer to the query “$c(X)$”
  then $B$ will be (partly) added to $A = ext^t_i(c)$

- the set $B$ is partitioned into three subsets

$$B = ext^t_j(d) = B^+_\text{aut} \uplus B^-_{\text{aut}} \uplus B_{\text{aut}}$$

then $B_{\text{aut}}$ is included with a probability degree based on the previous sampling
• if peer $P_i$ receives $B = ext^t_j(d)$ as an answer to the query "c(X)"
  then $B$ will be (partly) added to $A = ext^t_i(c)$

• the set $B$ is partitioned into three subsets

$$B = ext^t_j(d) = B^+_{aut} \cup B^-_{aut} \cup B^\bot_{aut}$$

then $B^\bot_{aut}$ is included with a probability degree based on the
previous sampling

• it has to be included to any superclass of $c$
Experimentation
Experimentation

• research questions:
Experimentation

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  • do trust values converge as more queries are sent and answers received?
Experimentation

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  • do trust values converge as more queries are sent and answers received?

  • is there any gain in query-answering performance -measured in precision and recall- when peers make use of trust?
Experimentation

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  - do trust values converge as more queries are sent and answers received?
  - is there any gain in query-answering performance -measured in precision and recall- when peers make use of trust?
    - for this we compared the use of trust with a naive strategy
Experimentation

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• do trust values converge as more queries are sent and answers received?

• is there any gain in query-answering performance -measured in precision and recall- when peers make use of trust?

• for this we compared the use of trust with a naive strategy

• precision and recall are defined by

\[ P(n) = \frac{|ext^*_i(c) \cap ext^n_i(c)|}{|ext^n_i(c)|} \quad R(n) = \frac{|ext^*_i(c) \cap ext^n_i(c)|}{|ext^*_i(c)|} \]
Experimental Setting
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• generation of a network of 20 peers with a small-world topology
Experimental Setting

- generation of a network of 20 peers with a small-world topology
- reference and initial populated ontologies:
Experimental Setting

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• reference and initial populated ontologies:
  • the same ontological schema (64 classes)
Experimental Setting

- generation of a network of 20 peers with a small-world topology
- reference and initial populated ontologies:
  - the same ontological schema (64 classes)
  - distribution of a set of instances among the peers (6000 instances) using a Zipfian distribution so that the ontological axioms are fulfilled
Experimental Setting

• generation of a network of 20 peers with a small-world topology

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  • the same ontological schema (64 classes)
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• reference and initial alignments:
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  • reference alignments computed from the reference populated ontologies
Experimental Setting

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- reference and initial populated ontologies:
  - the same ontological schema (64 classes)
  - distribution of a set of instances among the peers (6000 instances) using a Zipfian distribution so that the ontological axioms are fulfilled
- reference and initial alignments:
  - reference alignments computed from the reference populated ontologies
  - initial alignments computed by randomly declining the reference ones (precision and recall equal to 0.6)
Execution and Evaluation
Execution and Evaluation

- 15 peers and 25 classes were randomly chosen
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- 100 simulations
Execution and Evaluation

- 15 peers and 25 classes were randomly chosen
- 100 simulations
  - the maximum number of oracle calls was 40
Execution and Evaluation

• 15 peers and 25 classes were randomly chosen
• 100 simulations
  • the maximum number of oracle calls was 40
  • the trust threshold to accept an answer was 0.6
Experimental Results: Convergence

The graph shows the convergence of different rounds (q1 to q10) plotted against the Delta value on the y-axis and Round on the x-axis. The data points indicate a decrease in Delta as the rounds progress, suggesting a convergent trend.
Experimental Results: Precision

![Precision Chart]

Tuesday, October 25, 2011
Experimental Results: Recall
Conclusions and Further Work

• trust mechanism
  • convergence of trust values
  • gain in query-answering performance (precision and recall)

• by-product: probabilistic populated ontologies

• trust versus alignment: “two sides of the same coin”

• future work
  • more expressive ontology and query languages
  • witness information