Dynamic interoperability
From ontology matching to cultural knowledge evolution

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Conclusion

- The logical approach to communication is very rigorous but rigid;
- Human communication evolve in a more flexible manner with built-in failure;
- It is possible to study this experimentally,
- and look for adapting it to our programmes.

The two approaches should be combined, not opposed.

Organisation of the talk

Classical part Alignment semantics and networks of ontologies

- Semantics and models theory [basics]
- Semantics of alignments and networks of ontologies [advanced]
- Revision in networks of ontologies [advanced]

Experimental part Cultural knowledge evolution

- This is not the way is works [basics]
- Cultural knowledge evolution [medium]

Exmo

- Computer-mediated exchanges of formalised knowledge (Échanges de connaissance formalisée médiatisés par ordinateur);
- Recognised by both in INRIA and LIG;
- Small team (three permanent researchers, 3 PhD students);
- **Semantic web – linked data**
- Focussed on Ontology matching.

The meaning problem = semantics

- Linguistics: what is the meaning of a natural language statement? Of a text?

  "The friends of my friends are my friends"

- Logics: what is the meaning of a formula?

$$\forall x, y, z, p(x, y) \wedge p(y, z) \Rightarrow p(x, z)$$

- Computer science: what is the meaning of a program?

```
knownfriends = {};
while knownfriends ≠ friends
do
    knownfriends = friends
    for each x, y, z
    if ⟨x, y⟩ ∈ knownfriends and ⟨y, z⟩ ∈ knownfriends
    do friends += ⟨x, z⟩
return friends
```


What could it mean?

Semantics and communication
Ontology matching
Semantics of ontology alignments
Revision in networks of ontologies
Not the way it works
Cultural knowledge evolution

```
From: drh@inria.fr
Subject: candidates on our open positions

...
Please note that, in the datasheet I sent you with my last
email, the colours of the rows have no particular meaning.
```


Symbolic representations

Semantics and communication
Ontology matching
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I still use symbolic representations!

- I do not pretend that they have an atomic reality in our brain
- I pretend that they are very practical to reason and to track errors (and this is very important)
- I pretend that they are very useful to communicate (D. Kayser: "I have never seen a naked concept without its dress of language")
- For instance, I learned a lot by reading books

And I will freely use the words "ontology", that will be no more than a logical theory.

Model theory

Semantics and communication
Ontology matching
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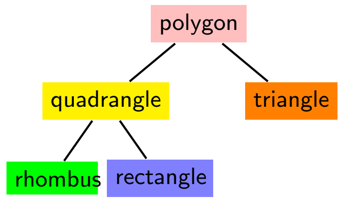
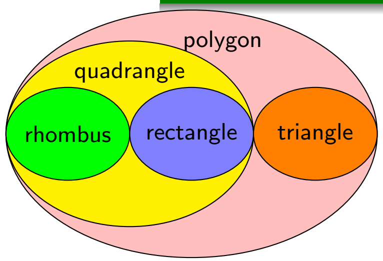
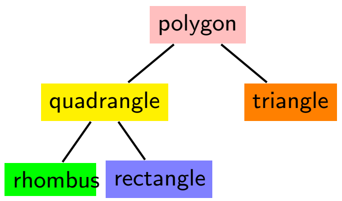


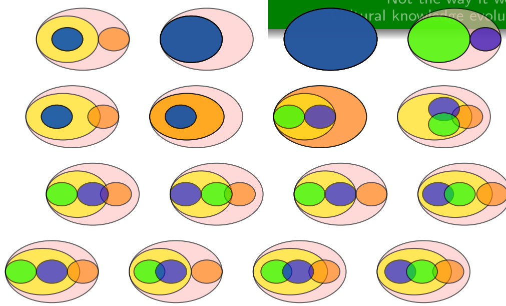


polygon ≥ quadrangle   polygon ≥ triangle

quadrangle ≥ rectangle   quadrangle ≥ rhombus

Model theory





polygon ≥ quadrangle   polygon ≥ triangle
quadrangle ≥ rectangle   quadrangle ≥ rhombus

Model theory

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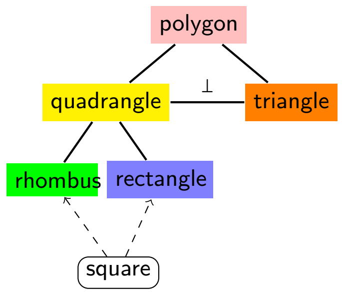

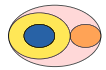

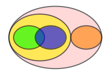

polygon ≥ quadrangle   polygon ≥ triangle
quadrangle ≥ rectangle   quadrangle ≥ rhombus
quadrangle⊥triangle   square ∈ rhombus ∧ rectangle

Model theory: summary

Semantics and communication
Ontology matching
Semantics of ontology alignments
Revision in networks of ontologies
Not the way it works
Cultural knowledge evolution

Interpretation map from the terms of the language to a domain of interpretation.

Satisfaction conditions for an assertion to be considered true.

Model (of a set of assertions): an interpretation satisfying all assertions

Consequence (of a set of assertions): an expression satisfied by all the models.

Consistency (of a set of assertions): there exists at least one model.

Completeness

Semantics and communication
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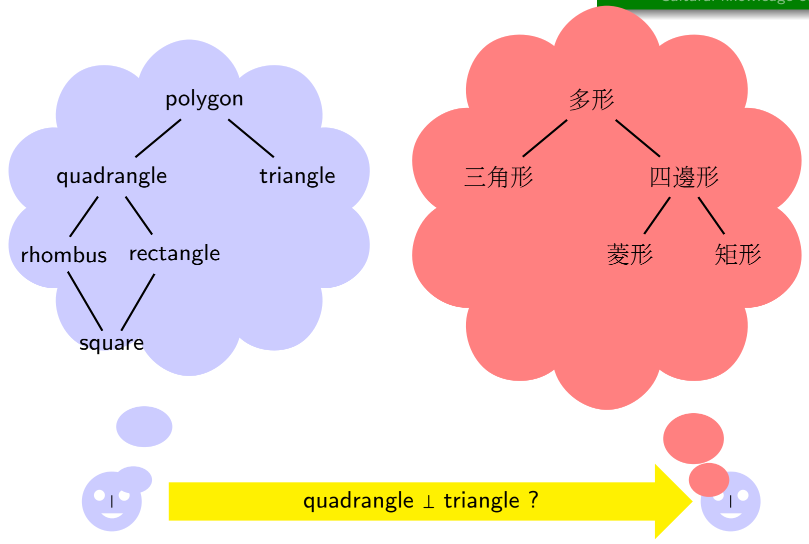
Language theory

Syntax
Langage
∋
axioms

Satisfaction rules ⊨ *consequences* Semantics	≡	inference rules + axioms' ⊢ *theorems* Deductive system
Model theory		Proof theory

Human communication: problem 2



Human communication: problem 2

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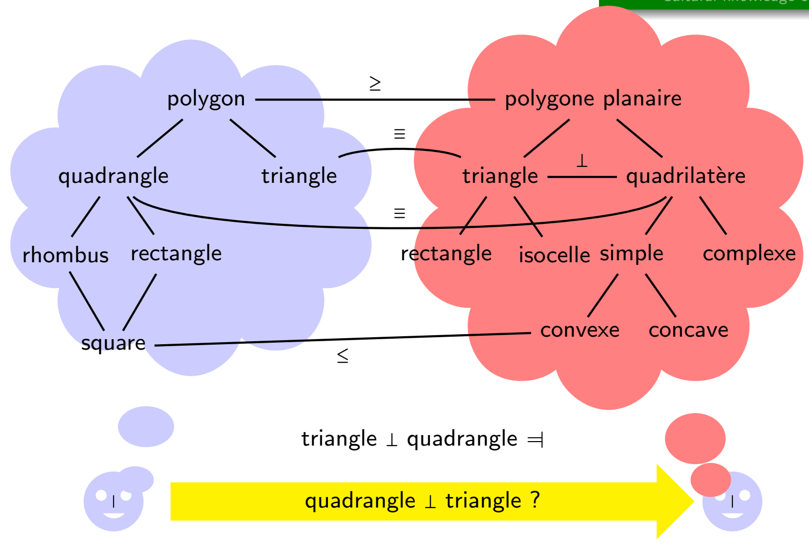
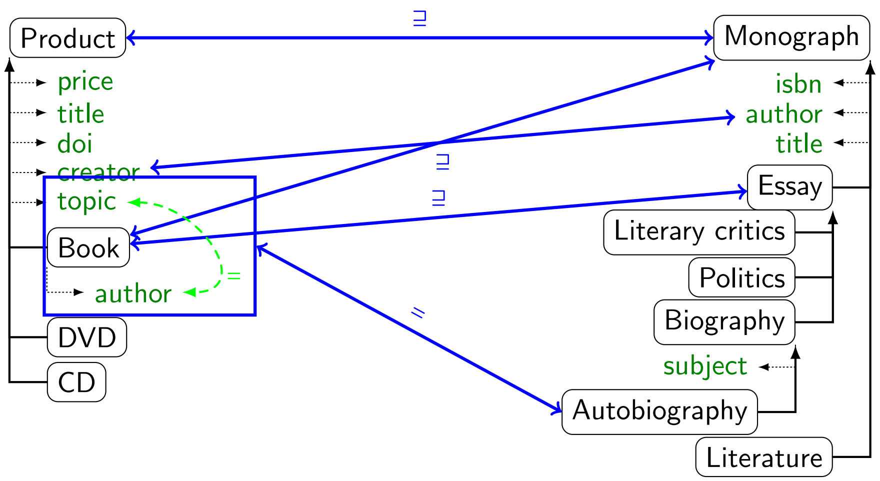
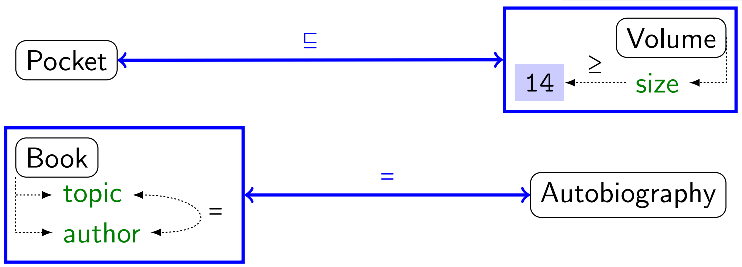


Ontology matching



Expressive alignments (EDOAL)



$$\forall x, Pocket(x) \Leftarrow Volume(x) \wedge size(x,y) \wedge y \leq 14$$
$$\forall x, Book(x) \wedge author(x,y) \wedge topic(x,y) \equiv Autobiography(x)$$

Transformation and mediation


```
SELECT ?d
WHERE {?x rdf:type o:Book .
  ?x o:creator ?y .
  ?x o:topic ?y .
  ?y o:name "Bertrand Russell" .
  ?x o:doi ?d .}
```

```
SELECT ?i
WHERE { ?x rdf:type o':Autobiography .
 ?x o':author/o':name "Bertrand Russell" .
 ?x o':isbn ?i .}
```

mediator

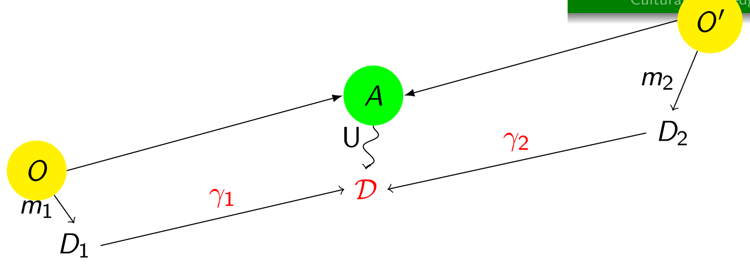
x.doi=http://dx.doi.org/10.1080/041522862X

x.isbn=041522862X

Alignment semantics

- Problem: two ontologies with independent semantics related by an object without semantics (the relation);
- Many semantics have been given to alignments;
- Solutions:
  - same domain,
  - disjoint domains,
  - relationships between domains
  - mapping to a common domain
- This presentation is on a generalised view of these semantics.

Alignment semantics

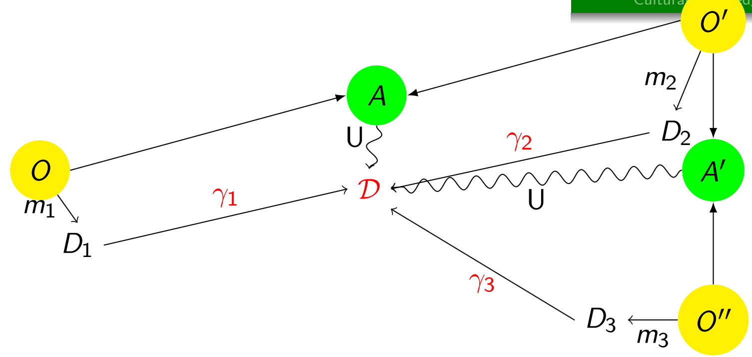


Definition (Satisfied correspondence)

$r(e, e')$ is satisfied for γ by two models m_1, m_2 de O, O' if and only if

$$m_1, m_2 \models_\gamma r(e, e') \text{ iff } \langle \gamma_1 \cdot m_1(e), \gamma_2 \cdot m_2(e') \rangle \in r^U$$

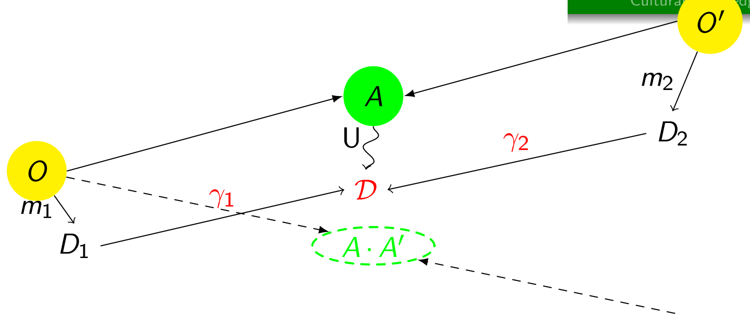
Alignment semantics



Definition (Model of a network of ontologies)

A model of a network of ontologies $\langle \Omega, \Lambda \rangle$ is a $n+1$-uple $\langle m_1 \dots m_n, \gamma \rangle \in \mathcal{M}(O_1) \times \dots \mathcal{M}(O_n) \times \Gamma$, such that $\forall O_i, O_j \in \Omega$, $\forall A \in \Lambda(O_i, O_j)$, $\forall \mu \in A$, $m_i, m_j \models_\gamma \mu$.

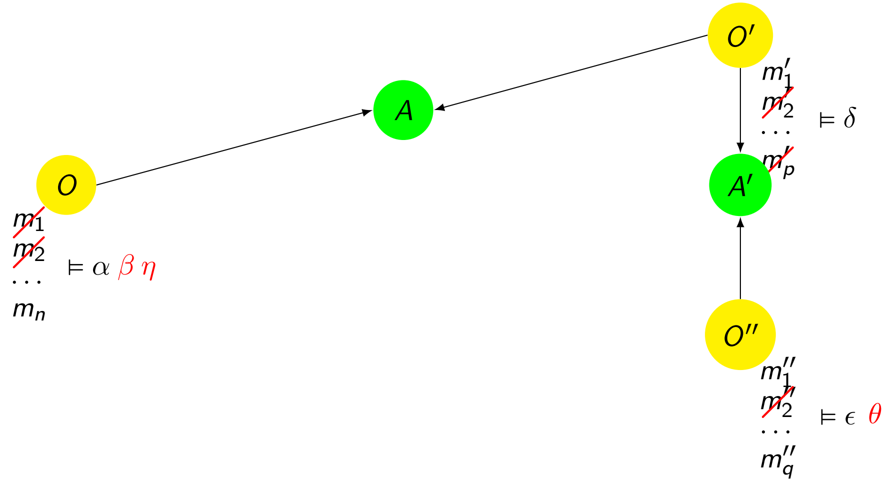
Alignment semantics



Definition (Entailed correspondence)

A correspondence μ between O_i and O_j is entailed by a network of ontologies $\langle \Omega, \Lambda \rangle$ iff for each model $\langle m_1 \dots m_n, \gamma \rangle \in \mathcal{M}(\langle \Omega, \Lambda \rangle)$, $m_i, m_j \models_\gamma \mu$

Alignments as model filters



Generalisation

- A model of a network of ontologies is a tuple of classical ontology models (one per ontologies)

\+ A set of constraints Δ on these models (before γ).

- Once $A \models_\Delta \mu$ has been defined, the semantics is defined.

Other concepts

From this simple basis, all classical logic definitions can be derived:

- models of aligned ontologies and networks of ontologies ($\mathcal{M}(\langle \Omega, \Lambda \rangle)$);
- consistency (having a model);
- consequences ($\models_{\Omega,\Lambda}$);
- what it means for a correspondence or an alignment to be consequence of an alignment.

Dual consequences and closures

Definition (ω-consequence)

An assertion ϕ is the ω-consequence of an ontology o_i in a network of ontologies $\langle \Omega, \Lambda \rangle$ iff

$$\forall \langle m_1, \ldots m_n, \Delta \rangle \in \mathcal{M}(\langle \Omega, \Lambda \rangle), m_i \models \phi$$

We note the set of ω-consequences as $Cn^{\omega}_{\Omega,\Lambda}(o)$

Definition (α-consequence)

A correspondence μ between two ontologies o_i and o_j is an α-consequence of a network of ontologies $\langle \Omega, \Lambda \rangle$ iff

$$\forall \langle m_1 \ldots m_n, \Delta \rangle \in \mathcal{M}(\langle \Omega, \Lambda \rangle), m_i, m_j \models_{\Delta} \mu$$

We note the set of α-consequences as $Cn^{\alpha}_{\Omega,\Lambda}(o, o')$

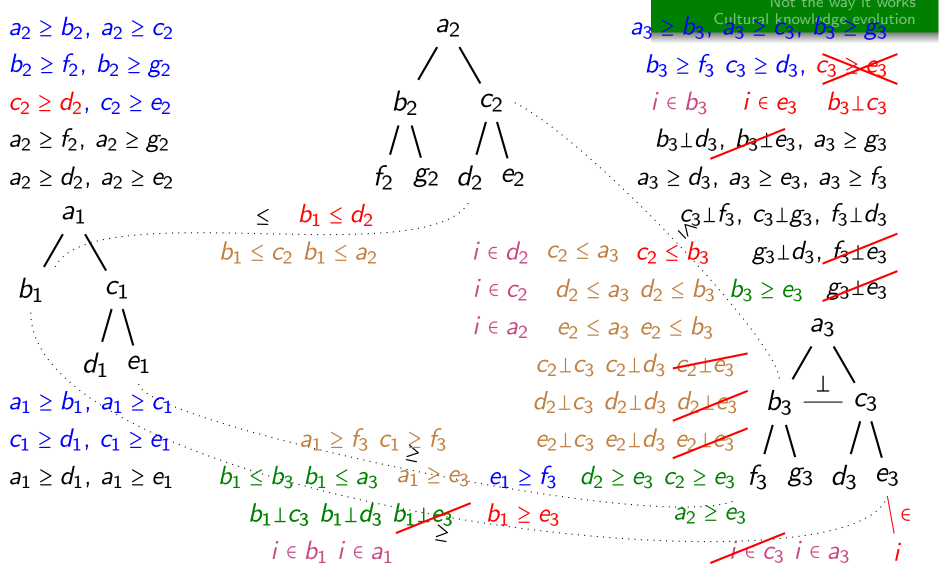
$$Cn(\langle \Omega, \Lambda \rangle) = \langle \{Cn^{\omega}_{\Omega,\Lambda}(o)\}_{o \in \Omega}, Cn^{\alpha}_{\Omega,\Lambda}(\Lambda(o, o'))_{o,o' \in \Omega} \rangle$$

Motivations

- We are working with networks of aligned ontologies
- with a constant flow of new information (and an evolving world)
- Changes in one ontology may have long range consequences
- which affect any alignment or ontology in the network
- The network may become inconsistent

How to deal with this?

Inconsistency in a network of ontologies



Approaches

- Local repair of ontologies [Lambrix] or alignments [Meilicke]
- Constrained revision in ontologies [Flouris] or aligned ontologies [Qi]

Let study this under the full fledged revision principles
Three approaches:

- Reduce everything to a known logic + apply revision;
- Combine local revision operators;
- We will remain in the middle.

Revision principles (AGM)

Cn: deductive closure; K sets of beliefs; ϕ: a formula; $K + \phi = Cn(K \cup \{\phi\})$

- $\dot{+}1$ (closure) The result is deductively closed: $K \dot{+} \phi$ is always a theory
- $\dot{+}2$ (success) The new formula should be believed: $\phi \in K \dot{+} \phi$;
- $\dot{+}3$ (vacuity) If the formula is compatible with current beliefs, then simply add it: $\neg\phi \notin Cn(K)$, then $K \dot{+} \phi = K + \phi$
- $\dot{+}4$ (consistency) Revision should not bring inconsistency: if $\neg\phi \notin Cn(\varnothing)$, then $K \dot{+} \phi$ is consistent
- $\dot{+}5$ (extensionality) Revision should be semantically neutral: if $Cn(\phi) = Cn(\psi)$, then $K \dot{+} \phi = K \dot{+} \psi$
- $\dot{+}6$ Revision plays well with retraction: $(K \dot{+} \phi) \cap K = K \dot{-} \neg\phi$
- $\dot{+}7$ (superexpansion) $K \dot{+} (\phi \wedge \psi) \subseteq (K \dot{+} \phi) + \psi$
- $\dot{+}8$ (subexpansion) If $\neg\psi \notin K \dot{+} \phi$, then $(K \dot{+} \phi) + \psi \subseteq K \dot{+} (\phi \wedge \psi)$

Revision principles (reformulation)

Cn: deductive closure; K sets of beliefs; ϕ: a formula; $K + \phi = Cn(K \cup \{\phi\})$

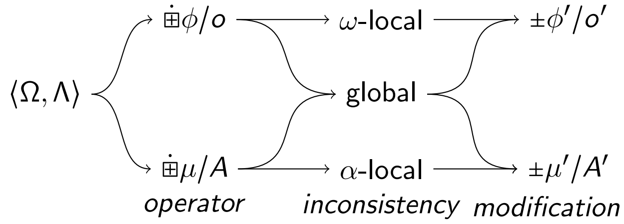
- $\dot{+}1$ (closure) The result is deductively closed: $K \dot{+} \phi \supseteq Cn(K \dot{+} \phi)$
- $\dot{+}2$ (success) The new formula must be believed: $\phi \in K \dot{+} \phi$, or $K \models \phi$
- $\dot{+}3$ (inclusion) It should not provide more knowledge than the mere addition of the formula: $K \dot{+} \phi \subseteq K + \phi$
- $\dot{+}4$ (vacuity) If the formula is compatible with current beliefs, then simply add it: If $K + \phi$ is consistent, then $K \dot{+} \phi \supseteq K + \phi$
- $\dot{+}5$ (consistency) Revision should not bring inconsistency: If $K \dot{+} \phi$ is inconsistent, then ϕ is inconsistent
- $\dot{+}6$ (extensionality) Revision should be semantically neutral: If $\phi \equiv \psi$, then $K \dot{+} \phi \equiv K \dot{+} \psi$

Revision of a network of ontologies

- Starting from a network of ontologies $\langle \Omega, \Lambda \rangle$;
- Adding an assertion ϕ to ontology o or a correspondence μ to alignment A;
- (Ignoring ontology/alignment addition/deletion;)
- What should be the resulting network of ontology $\langle \Omega, \Lambda \rangle \dot{\boxplus} \phi / o$ or $\langle \Omega, \Lambda \rangle \dot{\boxplus} \mu / A$?
- In particular, when the addition makes the network inconsistent.

We will base our revision on a semantics for networks of ontologies

In summary



Revision principles for ontologies

$o + \phi = Cn(o \cup \{\phi\})$

- $\dot{+}$1/closure The result is deductively closed: $o\dot{+}\phi \supseteq Cn(o\dot{+}\phi)$
- $\dot{+}$2/success The new formula should be believed: $\phi \in o\dot{+}\phi$
- $\dot{+}$3/inclusion It should not provide more knowledge than the mere addition of the formula: $o\dot{+}\phi \subseteq o + \phi$
- $\dot{+}$4/vacuity If the formula is compatible with current beliefs, then simply add it: If $o + \phi$ is consistent, then $o + \phi \subseteq o\dot{+}\phi$
- $\dot{+}$5/consistency Revision should not bring inconsistency: If $o\dot{+}\phi$ is inconsistent, then ϕ is inconsistent
- $\dot{+}$6/extensionality Revision should be semantically neutral: If $\phi \equiv \psi$, then $o\dot{+}\phi \equiv o\dot{+}\psi$

Revision principles for alignments

$A + \mu = Cn^{\alpha}_{\{o,o'\},\{A\cup\{\mu\}\}}(A)$

- $\dot{+}$1 (closure) The result is deductively closed: $A\dot{\oplus}\mu \supseteq Cn^{\alpha}_{\{o,o'\},\{A\dot{\oplus}\mu\}}(o,o')$
- $\dot{+}$2 (success) The new formula should be believed: $\mu \in A\dot{\oplus}\mu$, i.e., $A\dot{\oplus}\mu \models \mu$
- $\dot{+}$3 (inclusion) It should not provide more knowledge than the mere addition of the formula: $A\dot{\oplus}\mu \subseteq A + \mu$
- $\dot{+}$4 (vacuity) If the formula is compatible with current beliefs, then simply add it: If $A + \mu$ consistent, then $A\dot{\oplus}\mu \subseteq A + \mu$
- $\dot{+}$5 (consistency) Revision should not bring inconsistency: If $A\dot{\oplus}\mu$ inconsistent, then μ is inconsistent
- $\dot{+}$6 (extensionality) Revision should be semantically neutral: If $\mu \equiv \nu$ then $A\dot{\oplus}\mu \equiv A\dot{\oplus}\nu$

Subsumption between networks of ontologies

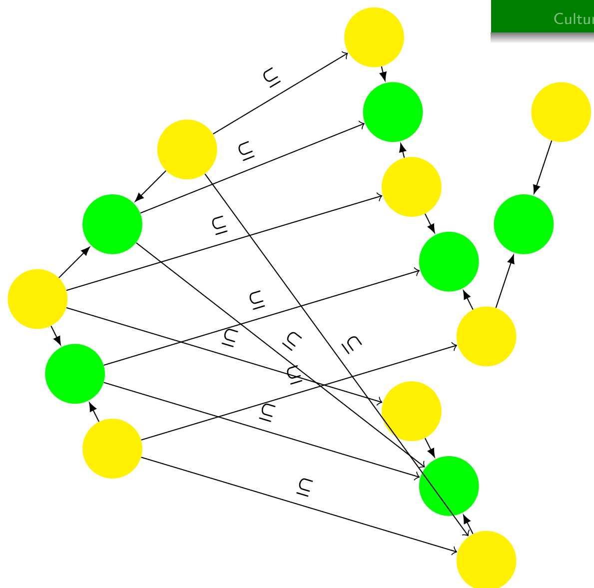
Definition (Normalised network of ontologies)

A network of ontologies $\langle\Omega,\Lambda\rangle$ is said normalised if and only if for any two ontologies o and o', $|\Lambda(o,o')| = 1$.

Definition (Syntactic subsumption between networks of ontologies)

Given two networks of ontologies, $\langle\Omega,\Lambda\rangle$ and $\langle\Omega',\Lambda'\rangle$, $\langle\Omega,\Lambda\rangle$ is syntactically subsumed by $\langle\Omega',\Lambda'\rangle$, denoted by $\langle\Omega,\Lambda\rangle \sqsubseteq \langle\Omega',\Lambda'\rangle$, iff $\exists\langle h,k\rangle$, a pair of morphisms: $h:\Omega \longrightarrow \Omega'$ and $k:\Lambda \longrightarrow \Lambda'$ such that $\forall o \in \Omega$, $\exists h(o) \in \Omega'$ and $o \subseteq h(o)$ and $\forall A \in \Lambda(o,o')$, $\exists k(A) \in \Lambda'(h(o),h(o'))$ and $A \subseteq k(A)$.

Illustration



Revision postulates for networks/ontologies

$$\langle\Omega,\Lambda\rangle \boxplus \phi/o = Cn(\langle\Omega - \{o\} \cup \{o+\phi\}, \Lambda\rangle)$$

- $\dot{\boxplus}$1 (closure) $\langle\Omega,\Lambda\rangle\dot{\boxplus}\phi/o \sqsupseteq Cn(\langle\Omega,\Lambda\rangle\dot{\boxplus}\phi/o)$
- $\dot{\boxplus}$2 (success) $\phi \in Cn^{\omega}_{\langle\Omega,\Lambda\rangle\dot{\boxplus}\phi/o}(o)$;
- $\dot{\boxplus}$3 (inclusion) $\langle\Omega,\Lambda\rangle\dot{\boxplus}\phi/o \sqsubseteq \langle\Omega,\Lambda\rangle \boxplus \phi/o$
- $\dot{\boxplus}$4 (vacuity) If $\langle\Omega,\Lambda\rangle \boxplus \phi/o$ consistent, then $\langle\Omega,\Lambda\rangle\dot{\boxplus}\phi/o \sqsupseteq \langle\Omega,\Lambda\rangle \boxplus \phi/o$;
- $\dot{\boxplus}$5 (consistency) If $\langle\Omega,\Lambda\rangle\dot{\boxplus}\phi/o$ inconsistent, then ϕ is inconsistent
- $\dot{\boxplus}$6 (extensionality) If $\phi \equiv \psi$, then $\langle\Omega,\Lambda\rangle\dot{\boxplus}\phi/o \equiv \langle\Omega,\Lambda\rangle\dot{\boxplus}\psi/o$

Revision postulates for networks/alignments

$$\langle\Omega,\Lambda\rangle \boxplus \mu/A = Cn(\langle\Omega, \Lambda - \{A\} \cup \{A+\mu\}\rangle)$$

- $\dot{\boxplus}$1 (closure) $\langle\Omega,\Lambda\rangle\dot{\boxplus}\mu/A \sqsupseteq Cn(\langle\Omega,\Lambda\rangle\dot{\boxplus}\mu/A)$;
- $\dot{\boxplus}$2 (success) $\mu \in Cn^{\alpha}_{\langle\Omega,\Lambda\rangle\dot{\boxplus}\mu/A}(o,o')$ with o and o' the ontologies aligned by A, i.e., $\langle\Omega,\Lambda\rangle\dot{\boxplus}\mu/A \models \mu$;
- $\dot{\boxplus}$3 (inclusion) $\langle\Omega,\Lambda\rangle\dot{\boxplus}\mu/A \sqsubseteq \langle\Omega,\Lambda\rangle \boxplus \mu/A$;
- $\dot{\boxplus}$4 (vacuity) If $\langle\Omega,\Lambda\rangle \boxplus \mu/A$ consistent, then $\langle\Omega,\Lambda\rangle\dot{\boxplus}\mu/A \sqsupseteq \langle\Omega,\Lambda\rangle \boxplus \mu/A$;
- $\dot{\boxplus}$5 (consistency) If $\langle\Omega,\Lambda\rangle\dot{\boxplus}\mu/A$ inconsistent, then μ is inconsistent;
- $\dot{\boxplus}$6 (extensionality) If $\mu \equiv \nu$, then $\langle\Omega,\Lambda\rangle\dot{\boxplus}\mu/A \equiv \langle\Omega,\Lambda\rangle\dot{\boxplus}\nu/A$;

Revision postulates for networks

In both cases, the principles are the same as for the local postulates:

- $\dot{\boxplus}$1 (closure) The revised network is closed (this is plain revision);
- $\dot{\boxplus}$2 (success) The new axiom or correspondence is consequence of the network after revision;
- $\dot{\boxplus}$3 (inclusion) The consequences of the revision cannot extend beyond those of the addition;
- $\dot{\boxplus}$4 (vacuity) They will reach the result of the addition unless this bring inconsistency;
- $\dot{\boxplus}$5 (consistency) The only reason why the result of revision may be inconsistent, is because the new axiom or correspondence is itself inconsistent;
- $\dot{\boxplus}$6 (extensionality) Revision is syntax independent.

Network revision generalises ontology/alignment revision

Theorem

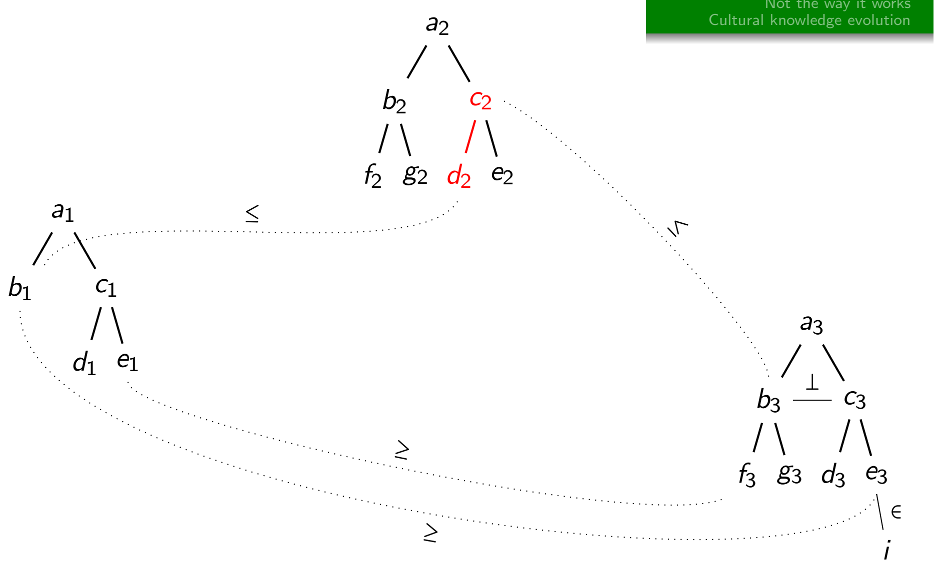
If $\dot{+}$ satisfies $\dot{+}$1-6, then $\langle\{o\},\varnothing\rangle\dot{\boxplus}\phi/o = Cn(\langle\{o\dot{+}\phi\},\varnothing\rangle)$ satisfies $\dot{\boxplus}$1-6.

Theorem

If $\dot{\oplus}$ satisfies $\dot{\oplus}$1-6, then $\langle\{o,o'\},\{A\}\rangle\dot{\boxplus}\mu/A = Cn(\langle\{o,o'\},\{A\dot{\oplus}\mu\}\rangle)$, such that A is an alignment between o and o', satisfies $\dot{\boxplus}$1-6.

It is tempting to try the other way around.

Local revision is not sufficient



Partial meet revision (AGM)

Partial meet revision is defined by:

$$K\dot{\oplus}\phi = \bigcap\gamma(K\top\phi) + \phi$$

such that:

- $K\top\phi = \{K' \subseteq K; \mathcal{M}(K'+\phi) \neq \varnothing \text{ and } \forall K''; K' \subset K'' \subseteq K, \mathcal{M}(K''+\phi) = \varnothing\}$
- γ is a selection function ($\gamma(X) \subseteq X$) such that if $K\top\phi \neq \varnothing$, then $\gamma(K\top\phi) \neq \varnothing$

Maximal subnetworks of ontologies

Definition (Maximal consistent subnetworks of ontologies)

$$\begin{aligned}\langle\Omega,\Lambda\rangle \mathbin{\top\!\!\top} \phi/o = \{&\langle\Omega',\Lambda'\rangle \sqsubseteq \langle\Omega,\Lambda\rangle; \mathcal{M}(\langle\Omega',\Lambda'\rangle \boxplus \phi/o) \neq \varnothing, \text{ and}\\ &\forall\langle\Omega'',\Lambda''\rangle; \langle\Omega',\Lambda'\rangle \sqsubset \langle\Omega'',\Lambda''\rangle \sqsubseteq \langle\Omega,\Lambda\rangle,\\ &\mathcal{M}(\langle\Omega'',\Lambda''\rangle \boxplus \phi/o) = \varnothing\}\end{aligned}$$

$$\begin{aligned}\langle\Omega,\Lambda\rangle \mathbin{\top\!\!\top} \mu/A = \{&\langle\Omega',\Lambda'\rangle \sqsubseteq \langle\Omega,\Lambda\rangle; \mathcal{M}(\langle\Omega',\Lambda'\rangle \boxplus \mu/A) \neq \varnothing, \text{ and}\\ &\forall\langle\Omega'',\Lambda''\rangle; \langle\Omega',\Lambda'\rangle \sqsubset \langle\Omega'',\Lambda''\rangle \sqsubseteq \langle\Omega,\Lambda\rangle,\\ &\mathcal{M}(\langle\Omega'',\Lambda''\rangle \boxplus \mu/A) = \varnothing\}\end{aligned}$$

Meet of networks of ontologies

- In principle, one can define $\sqcap$ from $\sqsubseteq$;
- But $\sqsubseteq$ is defined up to homomorphisms because there is no way to anchor an ontology to another
- Then $\sqcap$ does not necessarily exists, nor being unique
- Fortunately, $\sqcap$ does not have to be applied to random subsumees, but to maximal consistent subnetworks.

Fibred meet

Fortunately, we are dealing with a special case in which all the network to be met are subnetwork of a particular network.

Definition (Fibred meet of networks of ontologies)

Given an initial network of ontologies $\langle\Omega,\Lambda\rangle$ and a finite set of networks of ontologies, $\{\langle\Omega_i,\Lambda_i\rangle\}_{i\in I}$, such that $\exists\langle h_i,k_i\rangle_{i\in I}$, pairs of one-to-one morphisms: $h_i:\Omega_i\longrightarrow\Omega$ and $k_i:\Lambda_i\longrightarrow\Lambda$ with $\forall A\in\Lambda(o,o')$, $k_i(A)\in\Lambda(h_i(o),h_i(o'))$, the fibred meet of $\{\langle\Omega_i,\Lambda_i\rangle\}_{i\in I}$ with respect to $\langle\Omega,\Lambda\rangle$ is

$$\overline{\prod_{i\in I}}\langle\Omega_i,\Lambda_i\rangle = \langle\{\bigcap_{i\in I} h_i^{-1}(o)\}_{o\in\Omega}, \{\bigcap_{i\in I} k_i^{-1}(A)\}_{A\in\Lambda}\rangle$$

In fact, this fibred meet is a pull back in the (syntactic) category of network of ontologies.

Partial meet revision for networks of ontologies

Definition (Partial meet revision operators for networks of ontologies)

$$\langle\Omega,\Lambda\rangle\dot{\boxplus}\phi/o = \dot{\sqcap}\gamma(\langle\Omega,\Lambda\rangle \mathbin{\top\!\!\top} \phi/o)\boxplus\phi/o$$

and

$$\langle\Omega,\Lambda\rangle\dot{\boxplus}\mu/A = \dot{\sqcap}\gamma(\langle\Omega,\Lambda\rangle \mathbin{\top\!\!\top} \mu/A)\boxplus\mu/A$$

Revision results

- A revision framework can be fully defined for networks of ontologies;
- We have done it with a general semantics of networks;
- Revision in networks of ontologies cannot be reduced to revising locally;
- It is possible to define partial meet revision operators;
- This requires network of ontology algebra defined "up to isomorphism";
- Networks of ontologies offer opportunity to guide revision preferences.

Temporary conclusion

We have investigated interoperability by defining:

- ontologies (logics);
- alignments (as logical axioms as well);
- revision operators, just in case the world would not be regular (and why would it be?).

- This is nice;
- This is difficult;
- This is not the way it works.

People achieve communication through trials and errors.

Engineering approach

Define communication protocol

Define message syntax

← Implement protocol

Implement protocol →

It works

Semantics and communication
Ontology matching
Semantics of ontology alignments
Revision in networks of ontologies
Not the way it works
Cultural knowledge evolution

Engineering approach

§ & % $!

Adaptation capacity has been lost

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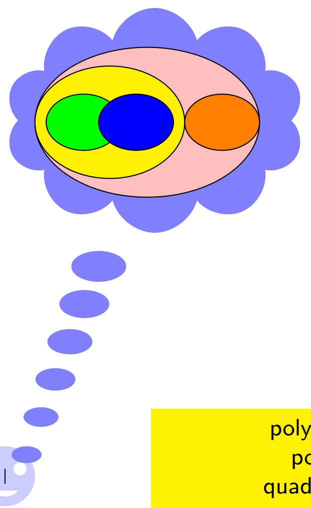
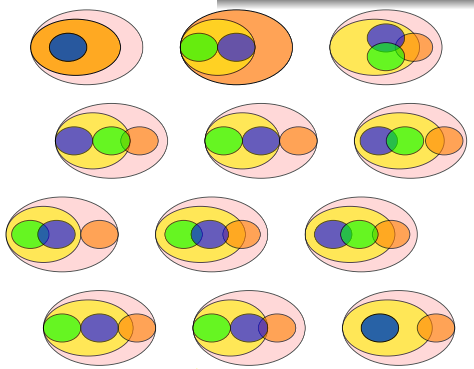
Communication with computers





polygon $\geq$ quadrangle
polygon $\geq$ triangle
quadrangle $\geq$ rectangle
quadrangle $\geq$ rhombus

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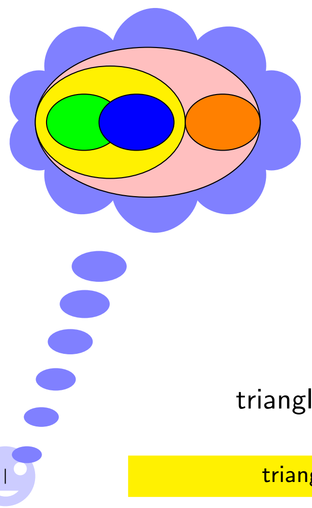
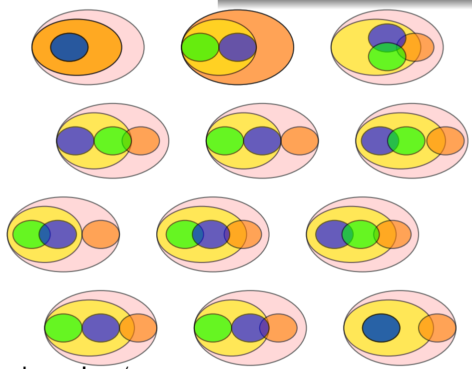




triangle $\perp$ quadrangle $\not\models$

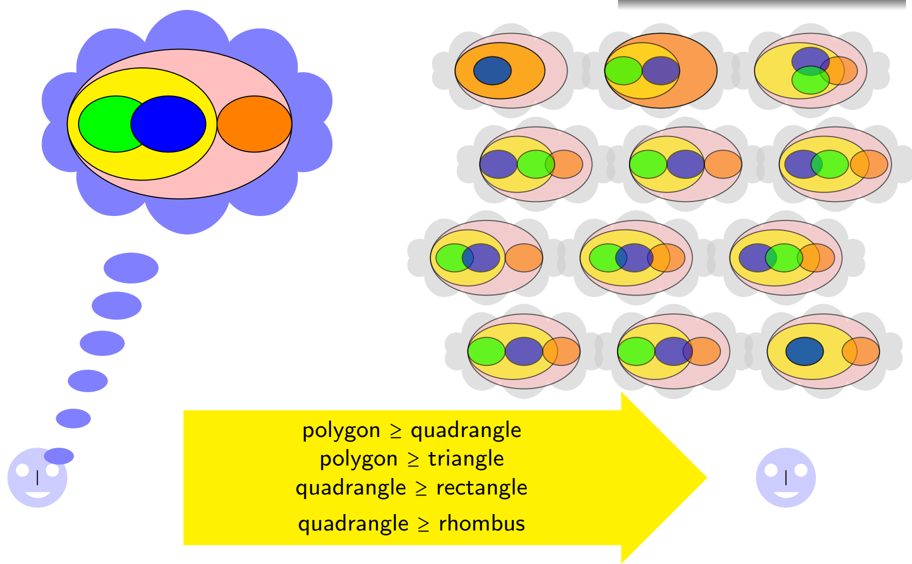
triangle $\perp$ quadrangle ?

Model theory is not precise enough

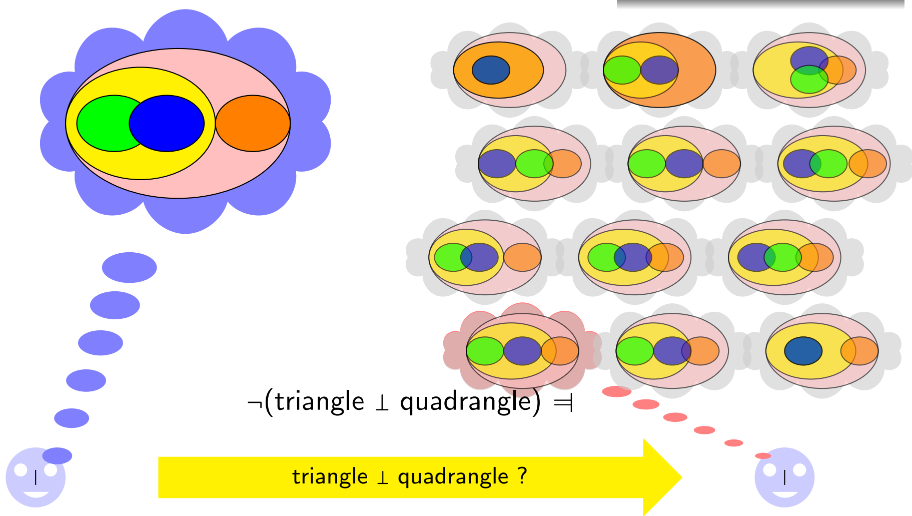
- If someone has a privilegied interpretation of a set of expressions, this must be a model.
- Then any inference on the language is coherent with this interpretation: it concerns what is true in all models.
- However, if one wants to stick to this models, axioms have to be added.

- From a mathematical standpoint, this raises a representation problem
- From an informatic standpoint: this raises problems of expressiveness and size
- From a human standpoint: it is just not the way it works

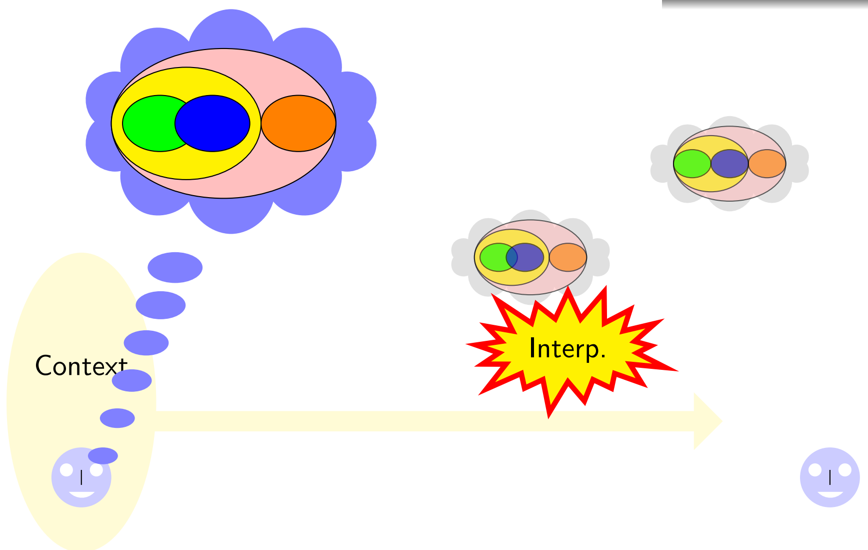
Human communication: problem 1



Human communication: problem 1



Human communication: problem 1



What is context?

Add more axioms!

Other ways of providing context exists:

- DRT, RST, Dialogue schemes, Interaction protocols;
- Schemas and scripts;
- Alignments, themselves put an ontology in the context of another

This is still adding more axioms.

Another way

- Context has been studied in many fields (semantics, semiotics, hermeneutics, rethorics, pragmatics)
- Answers given by such fields all resorts to defining a priori a contextualisation mechnanism;
- Human communication does not work this way;
- It fails!
- It is able to detect failure and to recover by adaptation;
- This is a way we want to explore.

Cultural evolution

Comes from anthropology (and population genetics)

Culture may be many things:

- fashion;
- étiquette;
- food;
- know-how for creating tools;
- religions;
- language.

- It is shared by a population;
- It has a function;
- it is transmited (from generation to generation but not exclusively)
- it is subject to selection.

Note that everything above is observable.

Is culture a topic for computer science?

- Nature $\neq$ Culture
- Nature $\approx$ Science

M. Derex, M.-P. Beugin, B. Godelle, M. Raymond, Experimental evidence for the influence of group size on cultural complexity, *Nature* 503:389–391, 2013

This has been applied successfully to natural language by Luc Steels and colleagues.

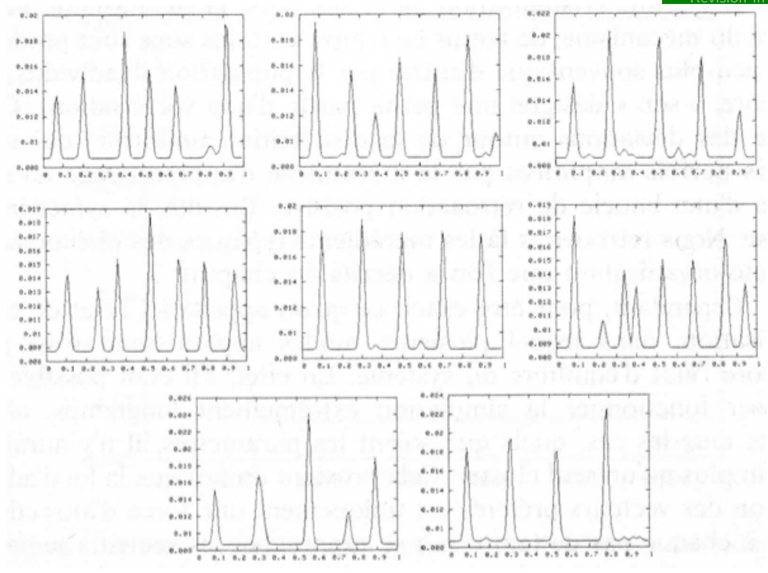
Experiment #1: Autoorganisation of vocalisation systems [Oudeyer 2013]

- A set of mobile robots (2–50)
- able to emit and perceive sounds (vowels)
- short range
- equiped with a neural network system to integrate perceived sounds and control emission (“anthropomorph” simulation)

→ their emission will be influenced by those of their neighbours

- Starting by emitting sounds along a uniform or random distribution.

Experiment #1: Results [Oudeyer 2013]



Experiment #1: Results

- Robots stabilises on a small number of vowels (3–7)
- The spectrum is the same for all robots involved in the same experiments
- Across experiments, spectra and numbers may vary
- still with a small set of distinct modes.

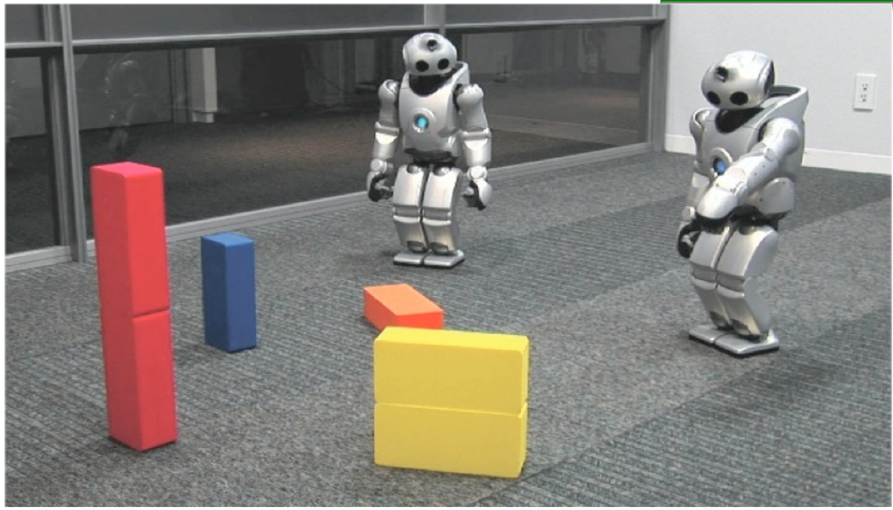
Some criticisms

- What about consonents?
- No real communication;
- Little (symbolic) knowledge representation.

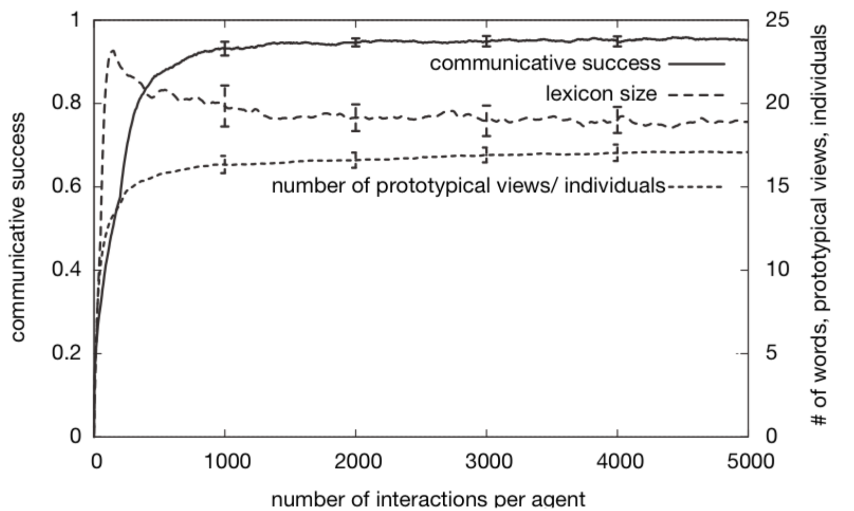
Experiment #2: Rules of the situated naming game [Steels 2012]

1. A robot tells the name of an (randomly chosen) object (if it has no name a new one is created)
2. The other robot must identify the object and designate the object
3. The first robot perceives what is shown and nods if it corresponds to his name (SUCCESS)
4. Otherwise (FAILURE), he points at the actual object
5. The second robot records the outcome of the game

Experiment #2: Steels movie



Experiment #2: Results [Steels 2012]



Experiment #2: Results

- Robots converge towards a common names for objects in the environments.
- They converge faster if they can exchange their lexicons.

General rules for language games

Environment Content of the environment

Population Kind and type of the population

Initialisation Initial situation

Games Rules played in each game

Success When communication has occurred

Failure When it did not

Repair strategy What actions for improving the situation after a failure

Synchronisation (or alignment): exchange of state by agents

Success measure usually #success/#game played

Secondary measures often a parsimony measure

External comparison comparison with other approaches

Synchronisation or alignment

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Cultural knowledge evolution

A supplementary modality named "alignment" (and that I will name synchronisation) is introduced:

- It consist for agents of sharing their current state, e.g., lexicon,
- . . . as we would do with a dictionary.
- This speeds up convergence
- This integrates in the same experimental protocol:
  - learning by immitation, and
  - learning by reading.

Embodiement

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- These experiments are strongly grounded on physical reality
- They implement perception-action cycles
- This establishes common experience to robots
- which contributes to symbol grounding.

Some criticisms

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- Not really evolutionist, subjects select their "culture".
- This models would predicts that all natural language converge;
- However, diversity is an important component of evolution.
- How can this be?

Towards cultural knowledge evolution

I started to apply this types of protocols to knowledge:

- Considering knowledge representations as culture
- instead of communication mechanisms
- Still preserving logical techniques (based on model theory)
- Trying to preserve the heterogeneity of representations.

Difficulties:

- Knowledge is not an observable
- It is difficult to tell if it is shared (culture)
- It has to be indirectly observed.

Cultural alignment repair

- Take alignments as culture (not necessarily ontologies):
- Have agents try to communicate using available alignments;
- Let them repair them on the fly.

Exp. #4: Knowledge game setting

Environment populated by objects characterised by n dimensions: ■, ▲, □, △, ■, ▲, □, △.

Population n agents with their own representations (ontologies)

Initialisation randomly generated alignments between their representations

Game an agent draws randomly an object and ask to another (randomly selected) agent to which class the object belongs. The former agent uses the alignments for determining to which class the entity belongs in his own ontology.

Success the resulting class subsumes the class of the object

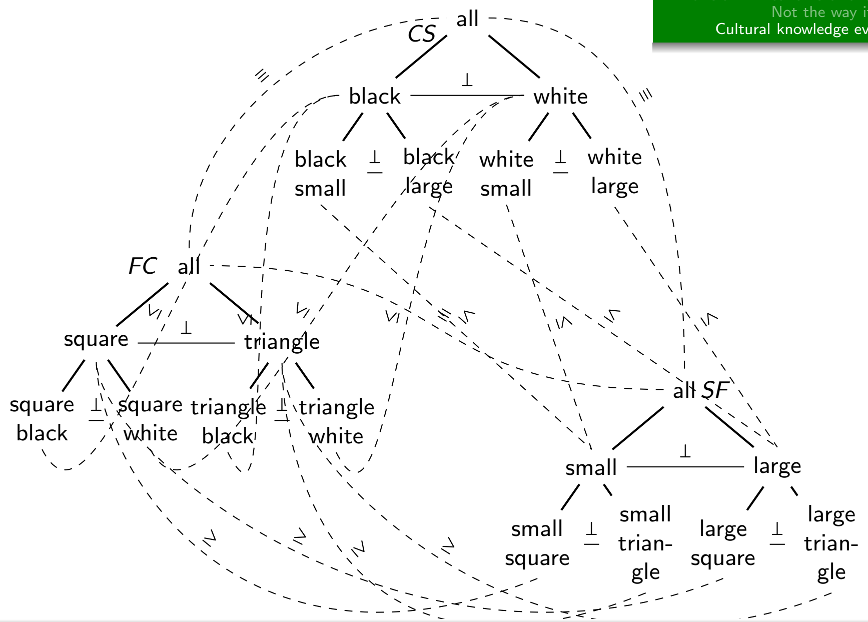
Failure the class is disjoint (exclusive)

Repair (a) suppress the correspondence; (b) weaken correspondences; (c) add entailed non falsified correspondences

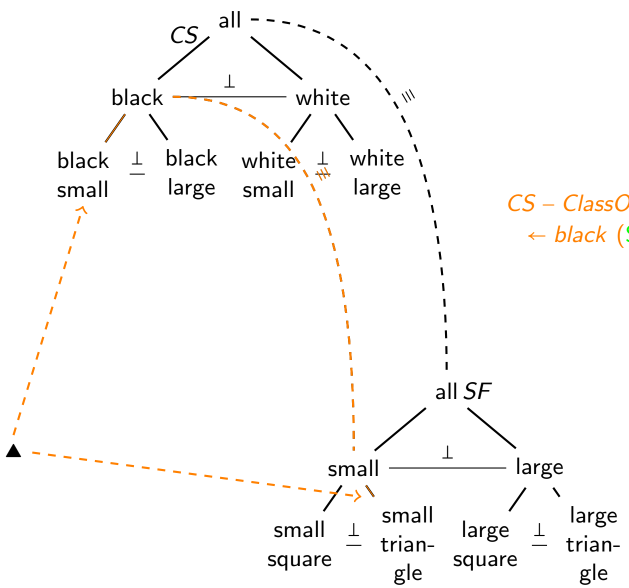
Secondary measure (Semantic) F-measure

External evaluation Compare to Alcomo, LogMap

Ontology network



Game examples



CS – ClassOf(▲)? → *SF*
← *black* (SUCCESS)

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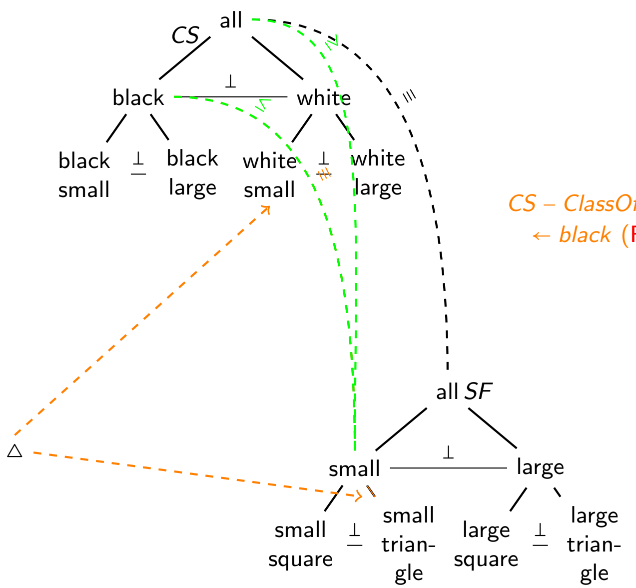
Game examples



CS – ClassOf(△)? → *SF*
← *black* (FAILURE)

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Experimental questions

1. Does the process converge?
2. What is the effect of repair modalities?
3. How does this compare to baselines?
4. Does it scale?

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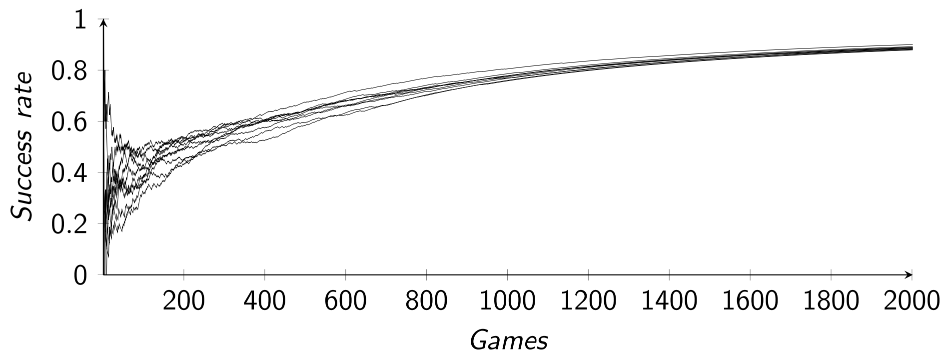
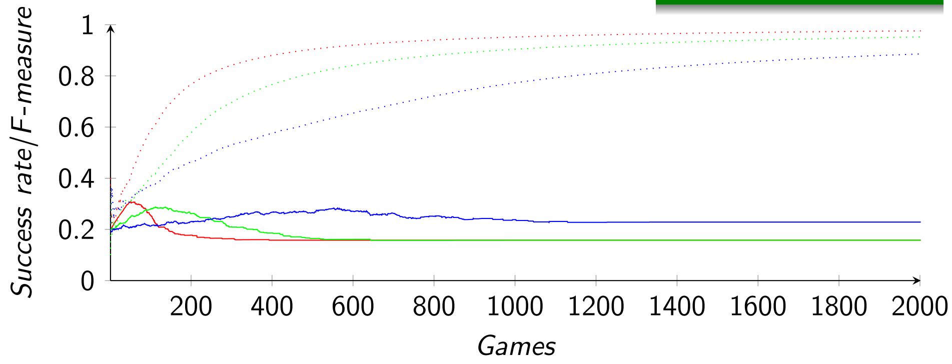
Convergence



modality=add; #agents=4; #games=2000; #runs=1

Modalities



modality=del,repl,add; #agents=4; #games=2000; #runs=10

del success rate; del F-measure; repl success rate; repl F-measure; add success rate; add F-measure

Modalities and baselines

Modality	Size	Success rate	Incoherence degree	Semantic F-measure	Syntactic F-measure	Convergence
reference	70	-	0.0	1.0	1.0	-
initial	54	-	[0.46-0.49]	0.20	(0.20)	-
delete	6	0.98	0.0	0.16	(0.16)	400
replace	6	0.95	0.0	0.16	(0.16)	1000
add	12.7	0.89	0.0	0.23	(0.16)	1330
Alcomo	25.5	-	0.0	0.26	(0.14)	-
LogMap	36.5	-	0.0	0.26	(0.14)	-

modality=del,repl,add; #agents=4; #games=2000; #runs=10

Scalability

	# correspondences					Incoherence				F-measure				
# agents	Reference	Initial	LogMap	Alcomo	Final	Initial	LogMap	Alcomo	Final	Initial	LogMap	Alcomo	Final	Convergence
3	15	15	12	10.3	3	0.31	0.	0.	0.	0.32	0.35	0.36	0.33	300
4	70	54	36.7	28.4	12.4	0.47	0.	0.	0.	0.20	0.24	0.25	0.21	1670
5	250	170	94.7	71.7	47.4	0.58	0.	0.	0.	0.11	0.18	0.17	0.24	5400
6	783	495	234	182	224	0.63	0.	0.	0.	0.06	0.12	0.11	0.14	10.000+

modality=add; #agents=3,4,5,6; #games=10000; #runs=10

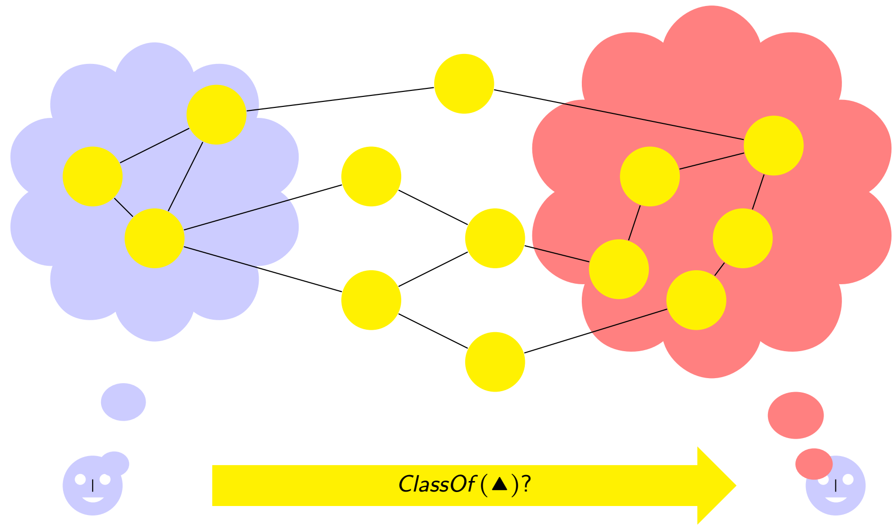
Problem solving vs. survival

- The number of games for converging (reaching perfect communication) grows fast (with *n*);
- Indeed the probability of finding, at random, the last failure is really low;
- It is possible to produce an algorithm that converges faster:
- But this is not the problem
- Their goal is not to solve a problem, but to live
- How many more do you think it will take you to reach perfect communication with your closest relatives?

Refinements (future work)

- Comparing this approach with revision (a supervised learning technique);
- Considering the whole network of alignments, and not just one alignment;
- Learning ontologies and alignments;
- Changing the environment;
- Considering agents having each their own network of ontologies;
- Having toxic objects which kills the agent in case of misidentification:
- Allowing agents to adopt each others ontologies.

Considering agents having each their own network of ontologies



Summary

- HETEROGENEITY is here to stay;
- ONTOLOGY ALIGNMENT is a capable tool to cope with heterogeneity;
- it can be provided with MODEL THEORETIC SEMANTICS;
- which supports REVISION operators for dealing with inconsistency;

However, this is not flexible enough to deal with changes.

- CULTURAL EVOLUTION techniques may be used to converge to a common understanding.

Conclusion

- The logical approach to communication is very rigorous but rigid;
- Human communication evolve in a more flexible manner with built-in failure;
- It is possible to study this experimentally,
- and look for adapting it to our programmes.

The two approaches should be combined, not opposed.

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