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An intensional perspective on the semantic and pragmatic web

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Abstract: In recent years, there has been increasing interest in the pragmatic web as an extension of the semantic web. After preliminary sketches and initial ideas, more formal attempts at characterising and defining pragmatic aspects of the web have recently emerged. Although some amount of scientific research and a number of applications have appeared under the name of the pragmatic web, there is not yet a common agreement on what the pragmatic web should be and how it should be formalised. In this paper, we consider the pragmatic web to be an augmentation of the semantic web with virtual agents exploiting web content on behalf of human contractors.

Keywords: pragmatic web; semantic web; semantics; pragmatics; ontologies; intensional semantics; knowledge representation.

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1 Introduction

The web started as an information repository, a web of documents for human use with no particular structure except for untyped hyperlinks. Its rapid growth made it necessary to introduce virtual agents to aid in the search and processing of information. Virtual agents do not possess human capabilities with respect to analysing and understanding non-structured text. They are software programs whose ability is restricted to the analysis of formal structures. More efficient agent assistance thus calls for a formalisation of the web, which resulted in the vision of the semantic web (Berners-Lee et al., 2001).

The realisation of the semantic web now under way is based on the Internet Of Things (IOT)/Linked Data (LD) paradigm. In the context of the semantic web, the IOT stands for the idea of referring to ‘things of the world’ on the web by Universal Resource Identifiers (URIs). A URI comes as a URL (locator, dereferenceable URI) or URN (name). Technically, they both function as Ids, though one denotes the web-location or web-identifier of a resource and the other the name. LD, on the other hand, is a method of publishing loosely connected data. It builds upon standard web technologies, such as HTTP and URIs, but rather than using them to serve web pages for human readers, allow data from different sources to be connected and queried, thus enabling automated access to information (Bizer et al., 2008, 2009). A set of URIs representing objects, relations between them and information resources about them is an example of a domain of LD. The (typed) linking is realised by RDF triples (Subject, Predicate, Object) of which representative words might be related by definitions in an ontology. Their interpretation is based on the things in the world represented by the URIs. An agent possessing the language of the ontology is thus capable of investigating domains of LD and pick information resources requested by its contractor.

Pragmatics is rooted in the language-action perspective and refers to the dialogue between interlocutors. As Wittgenstein has pointed out, any notion of private language is meaningless (Wittgenstein, 1968). On the other hand, each person has his or her own frame of reference that influences their interpretation of the context of a dialogue and thereby the understanding of utterances presented by other persons. Normally, interlocutors are able to reach a common understanding through a number of steps that clarify meaning by referring to concrete examples, a process Wittgenstein calls a *language game*.

In the web setting, pragmatics concerns the dialogue between humans and virtual agents and the creators of websites via the sites. Unfortunately, the information resources they will encounter are expressed in relatively private languages. Though Wittgenstein only discussed the pragmatic aspects of language with respect to humans' use of natural language, his analysis also applies to virtual agents and their use of formal languages and the communication between human users and agents. The pragmatic web thus consists of the tools, like virtual agents, practices and theories describing why and how people put, retrieve and use information on the web; it is broadly speaking about social interaction via the web (Latour and Woolgar, 1986; Vermaas and Houkes, 2006; Kroes and Meijers, 2006; Baker, 2007; Pohjola, 2009; Sceele, 2005; Berners-Lee et al., 2001; Suchman, 1987; Ellison et al., 2007; Norman, 1999).

One aspect of the pragmatic web (de Moor et al., 2002; Allwood, 2008; Schoop et al., 2006) is to provide agents with the ability to learn new languages, i.e., to discover by playing a 'language game' how to translate between their language of origin and related languages of discourse. The aim of this paper is to follow up on this aspect and to present a method of automated translations between formal languages with overlapping domains of discourse.

The method is based on an intensional formal semantics (Aaberge, 2009, 2010), i.e., a semantics that conceives the structure of the language to be determined via the conceptual model of the domain. The reason is the advantages of applying intensional rather than extensional interpretations (Tarski, 1983): intensional interpretations

- convey more information than extensional ones, which implies that
  - extensional interpretations can be derived from intensional interpretations
  - intensional interpretations cannot be derived from extensional interpretations
- define a canonical metalanguage in which
  - the complete syntactic and semantic content of the language can be expressed
  - a closed set of truth conditions can be formulated thus avoiding the generation of an infinite hierarchy of languages
- apply directly to a domain structured as a directed graph as is the case for a set of LD

The paper is organised as follows: we start by giving a short exposition of the main elements of a formal language, mainly to introduce necessary terminology, then the web of documents is metaphorically described and the Semantic Web introduced in terms of Linked Open Data. Finally, we present the methodology for automated translations before making concluding remarks.

2 Language, metalanguage and ontologies

A language has a vocabulary and it is characterised by properties that are referred to as syntax, semantics and pragmatics. The syntax decides what are to be accepted as well-formed sentences, i.e., valid juxtapositions of words from the vocabulary. The semantics is a theory on how meaning of words is tied to external objects and activities, and the pragmatics is the study on how the situations or contexts of human communication contribute to meaning. It is worthwhile to notice that these properties are not independent. Thus, the meaning of a sentence is determined by the meaning of the words composing it (names, predicates and logical constants) provided it is well formed, i.e., an interpretation of a language is an interpretation of its vocabulary. Sentences that are not well formed are meaningless.

There are two ways of representing meaning formally, referred to as *extensional* and *intensional*. The extensional meaning (bedeutung) of a predicate is given by a set of objects (referents). This set is called the *extension* of the predicate. The meaning of a predicate that stands for a kind of relation is the class of all ordered pairs that satisfy the relation, etc. Extensional semantic conceives the structure of the domain to be imposed by the structure of language. Thus, an extensional interpretation is represented by a map from the vocabulary to a conceptual model of the domain pictured as the set consisting of the individuals of the domain, subsets of individuals, sets of ordered pairs of individuals, etc. The interpretation map being a bijection (one-to-one and onto) maps a name to an individual and a predicate to its extension.

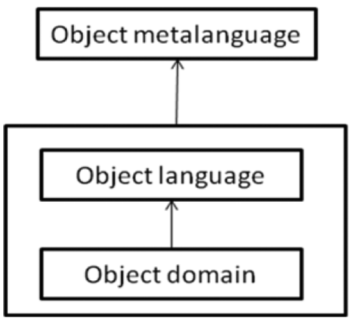
Intensional[1] semantics is based on a conceptual model that conceives the domain as consisting of individual objects with properties and relations, pictured as a directed graph. The individuals are represented by nodes and the relations by arrows (edges). An intensional interpretation is then represented by maps from the domain to the vocabulary of the language: a bijection that maps the individuals (or relations) to names and *observables* that maps individuals (or relations) to predicates. In this case, it is thus the structure of the domain that determines the structure of language.

Observables are identified by mutual exclusion of properties. Two properties that cannot simultaneously be possessed by an individual are represented by predicates belonging to the range of the same observable; an individual cannot at the same time be red and green, colour is, therefore, an observable. It maps an individual to the predicate representing its colour. Other observables are weight, position in space, temperature, etc. An observable represents a kind of measurements and is associated with an operational definition exhibiting a standard of measure, laws on which the measuring device is based and rules of application of the measuring device. For example, the measurement of the colour of an individual consists in holding a colour chart representing the standard of measure for the colours against the individual. If the mental pictures that the observer gets of the colour of the individual and the colour marked red on the colour chart coincide, then red is taken to denote the result of the measurement.

The intensional meaning (sinn) of the predicates is provided by the operational definitions. An extensional interpretation can be defined from an intensional one. The inverse image of a value (predicate) of an observable, i.e., the set of all individuals that is mapped to the same predicate by the observable is the extension of the predicate. The opposite is, however, not the case. Intensional interpretations cannot be constructed from extensional ones. The reason for this asymmetry is that intensional interpretations contain more information than extensional ones.

Given a language, there exists a canonical metalanguage whose domain is constituted by the domain of the language and its domain (as shown in Figure 1).

Figure 1 Language and its domain



The structure of the domain is determined by the instances of the maps of the commutative diagrams that express semantic relations and is thus a canonically given directed graph. This choice of domain for the metalanguage, constructed to describe the semantic relations between domain and language, differs from the Tarskian kind of domain, which is constituted by the language. The Tarskian metalanguage also contains a copy of the language. The definition of Tarskian truth conditions, exemplified by "'snow is white' if and only if snow is white", thus generates an infinite hierarchy of languages (Tarski, 1944).

The vocabulary of a language is for practical reasons much richer than is strictly needed for its expressibility. This extra richness can be made explicit by the formulation of an *ontology*, i.e., supplement the vocabulary with a set of

- axioms
- intensional definitions
- extensional definitions.

An axiom is an implicit definition that relates the *primary terms* of the vocabulary of the object language. The axioms picture structural properties of the domain and express restrictions on the possible meaning of predicates. The *intensional* and *extensional* definitions are terminological. They define secondary predicates that serve to facilitate the discourse from the primary terms,[2] e.g., instead of having to repeat the properties that an individual must possess to be of a certain kind a terminological definition will introduce a predicate to denote the kind. An intensional definition of a predicate (definiendum) is thus the conjunction of atomic sentences (definientia) stating which properties that an individual must possess for the predicate to apply. When the meaning of the definientia is given, the definition explains the meaning of definiendum. An extensional definition of a predicate, on the other hand, is simply the list of the names of the individuals that constitute its extension. When the individuals referred to are known, the extension of the predicate representing its meaning is given. From an intensional definition of a predicate, an extensional one can be derived; the extension of the predicate is the class of individuals that satisfies definientia in the intensional definition. It follows that the interpretation of the vocabulary is determined by the interpretation of the primary vocabulary, which consist of the names and some predicates.

3 Intensional formal language

3.1 Object language

Let $L_D(N \cup V, P)$ stand for the object language for a domain D. N denotes the set of names of individuals and relations, V the set of variables and P is the set of unary predicates and binary predicates. The names of the individuals are given by a map[3] ν,

$$v : D \to N; d \to \mathrm{v}(d)$$
$$d_s r d_t \mapsto v(d_s r d_t)$$

that to an individual d or relation $d_s r d_t$ in the domain D associates the name n by $\nu(d) = n$ or $\nu(d_s r d_t) = (n_s, n_t)$ where n_s and n_t are the names of the individuals that constitutes source d_s and target d_t of the relation, respectively. We will consider interpretations where ν is a bijection; then, by convention, there is a unique name for every individual (or relation) and there is exactly the same number of names and systems.

Each observable δ determines an atomic fact about an individual $d \in$ D or relation $r \in$ D by

$$\delta_1 : D \to P; d \mapsto \delta_1(d)$$
$$\delta_2 : D \to P; d_s r d_t \mapsto \delta_2(d_s r d_t).$$

For each δ, there exists a unique map π defined by the condition of commutativity of the diagram

$$\begin{array}{ccc} & \pi & \\ N & \to & P \\ \uparrow v & \nearrow \delta & \\ D & & \end{array} \qquad (1)$$

The diagram relates the simulation of measurements determining atomic facts assigning properties to an individual (or relation to a pair of individuals) and the formulation of an atomic sentence expressing such a fact by the juxtaposition of names and predicates, e.g., the sentence pn where n is the name of the individual d and p the predicate referring to a property of d expresses a fact about d iff, for $\nu(d) = n$ and $\delta(d) = p$. $\pi(\nu(d)) = \delta(d)$ is, therefore, a truth condition. It equates a proposition about the system d with a statement of the result of a measurement on d with respect to the observable δ.

3.2 Metalanguage

The metalanguage for the object language is denoted $L_{M_D}(G, Q)$ where the domain M_D consists of: the set of diagrams (1) and with wffs as isolated nodes; $G = L_D(N \cup V, P)$, the names[4] of the nodes (individuals, names, predicates and wffs) and relations (arrows $\mathrm{d} \mapsto \mathrm{n}$, etc., in equation (1)), and Q the predicates of the metalanguage.

The naming map η is identity on the nodes of M_D and maps arrows to the ordered 2-tuples constituted by the names of its source and target, e.g.,

$$h{:}M_D \to G;(d(n) = p) \to h(d(n) = p) = (n,p). \qquad (2)$$

(Meta-) observables can be defined that simulate the determination of atomic facts about an element of the domain G:

$$\alpha : M_D \to Q; m \mapsto \alpha(m). \qquad (3)$$

Predicates of the metalanguage are Individual, Property, Type, Class, Name, Relation, KindOfRelation and Sent (for sentence) that express syntactic properties of the elements of its domain, NameOf (νOf) and δOf that express semantic relations and πOf facts.

The commutativity condition (1) is expressed by axioms (one for each observable $\delta = \pi \circ \nu$)

$$\forall_d \exists_n \exists_p \left(\begin{pmatrix} \text{Individual}(d) \wedge \text{Name}(n) \wedge \text{Class}(p) \\ \wedge \text{NameOf}(n,d) \wedge \pi\,\text{Of}(p,n) \end{pmatrix} \Leftrightarrow \delta\,\text{Of}(p,d) \right).$$

The related truth conditions are

$$\begin{pmatrix} \text{Individual}(d) \wedge \text{Name}(n) \wedge \text{Class}(p) \\ \wedge \text{NameOf}(n,d) \wedge \delta\,\text{Of}(p,d) \end{pmatrix} \Leftrightarrow \mathrm{T}\, pn. \qquad (4)$$

Thus, a true atomic sentence pn about d is expressed by

$$\begin{array}{l} \text{Individual}(d) \wedge \text{Name}(n) \wedge \text{Class}(p) \\ \wedge \text{NameOf}(n,d) \wedge \pi\,\text{Of}(p,n) \end{array} \qquad (5)$$

in the metalanguage.

This shows that the translation of the conceptual content of the true object language sentence pn to the metalanguage is πOf(p, n), e.g., the sentence 'n is red' to "red is the colour of n".

Reasoning takes place in the metalanguage, on the basis of the ontology formulated in the object language, by means of deduction rules like modus ponens,

$$\text{Sent}(h_1) \wedge \text{Sent}(h_2) \wedge \left(Th_1 \wedge T\left(h_1 \Rightarrow h_1\right)\right) \Rightarrow Th_2.$$

It depends solely on the syntactic structure of the object language sentences, not on their meaning. Deductions will not be discussed in this paper.

The rules for the language L_D are formulated in the metalanguage L_{M_D}. We have, for example,

atomic sentence:

Name(h_1) $\wedge$ Class(h_2) $\Rightarrow$ Sent($h_2 h_1$)

conjunction:

Sent(h_1) $\wedge$ Sent(h_2) $\Rightarrow$ Sent ($h_1 \wedge h_1$)

negation: Sent(h) $\Rightarrow$ Sent ($\neg h$).

3.3 Ontology language

The sentences of L_{M_D} are uniquely expressible in a N3 representation by blocks of RDF triples.[5] Thus, (5) translates to

ml:d owl:Type owl:Individual
ol:n owl:Type ml:Name
ol:p owl:Type owl:Class (6)
ol:n ml:NameOf ml:d
ol:p ml: πOf ol:n

and

$$
\begin{aligned}
&\text{ml:}d_s rd_t \text{ owl:Type ml:Relation} \\
&\text{ol:}(n_s, n_t) \text{ owl:Type ml:Name} \\
&\text{ol:}p^2 \text{ owl:Type owl:Property} \\
&\text{ol:}(n_s, n_t) \text{ ml:NameOf ml:}d_s rd_t \\
&\text{ol:}p^2 \text{ ml:}\pi\text{Of ol:}(n_s, n_t)
\end{aligned}
\tag{7}
$$

is a translation of a corresponding sentence involving a relation. The prefixes ol, ml and owl refer to the object language, metalanguage and OWL namespaces, respectively. The triples of the kind

ml:*d* owl:Type owl: Individual

ol:*n* owl:Type ml: Name

ol:*p* owl:Type owl: Class

ol:*n* ml:NameOf ml: *d*

are sentences in the ontology language that express the syntactic role of the terms of the vocabulary.

The triples

ol: *p* ml: πOf ol: *n*

ol: p^2 ml: πOf ol (n_s, n_t)

are sentences in the ontology language that describe properties and relations of the individual referred to by the URI d_s.

The domain is represented by triples of the kind

ml: d_s owl: Type owl:Individual

ml: d_t owl: Type owl:Individual

ml: *r* owl: Type ml:KindOfRelation

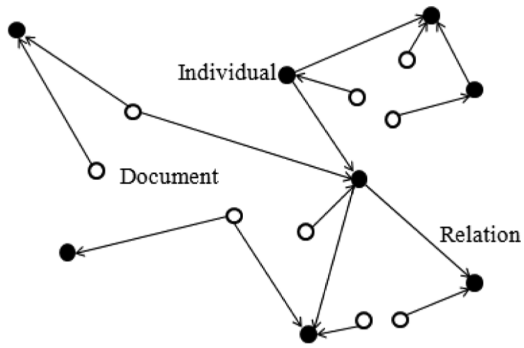
ml: d_s ml: *r* ml: d_t

are sentences in the metalanguage that express relations between individuals, i.e., they link the descriptions of the individuals of the domain. In fact, to each URI for an individual there is 'attached' an index card by a mechanism of redirection that contain a description of the individual. The index card for an individual d is constituted by the set of blocks like (6) being translations of equation (5), which satisfies equation (4). The individuals of the object domain are thus described as bundles of properties.

4 Learning vocabularies

The environment of an agent is the web of LD. It can be conceived as a directed graph (Figure 2) with two kinds of nodes, URIs representing individual things in the world and URLs representing information resources (documents) about the things, and arrows representing relations. To each URI representing an individual is 'attached', by a mechanism of redirection, an index card describing the individual in the ontology language. Between documents and individuals, there is only one kind of relation, 'About'.

Figure 2 A directed graph



The web of LD can be considered as a mosaic of interlinked domains, each with a particular description language. But published LD might be reused in third-party applications that combine information resources from a priori different domains, e.g., public transport schedules, points of interest and geographic information (geolocations and geonames). They will select appropriate domains, define new URIs related to the old ones by 'SameAs' to realise a representation of the domain accommodated to their needs and construct description languages (ontologies) to serve the purpose of the applications. An appropriate selection of information resources will be connected to the individuals. An agent prospecting the web of LD for particular information resources on behalf of a contractor will then have to investigate overlapping domains described in different languages. To do so, he must know at least one of the description languages and learn the others.

An agent can be said to know a language L_{D_1} if he is endowed with the canonical metalanguage $L_{M_{D_1}}$. He then possesses knowledge of the complete syntactic and semantic of content of L_{D_1}. In fact, the syntactic structure of sentences in L_{D_1}, and the semantic relations are described and the true sentences formulated in $L_{M_{D_1}}$. From the semantic relations, the extensions of the predicates can be derived.

To learn a new language L_{D_2} he must compare the semantic content of its vocabulary with the vocabulary of his own language. This means to identify names and predicates that carry the same meaning in the two languages. The ontology limits the part of the vocabulary that has to be analysed semantically to achieve a translation to the primary vocabulary, i.e., the names and the primary predicates.

The predicate NameOf is at present not standardised. However, it is feasible to identify the symbols serving as names and determine the individuals they are representing and to establish a translation of names. The names of two individuals (URIs) related by 'SameAs' represent the same individual. If the domains are not coinciding, he will add new names to the vocabulary.

The extension of a predicate p is the set of all individuals to which the predicate applies (5):

$$\operatorname{ext}(p) = \left\{ \begin{array}{l} d|\text{Individual}(d) \wedge \text{Name}(n) \wedge \text{Class}(p) \\ \wedge \text{NameOf}(n,d) \wedge \pi\text{Of}(p,n) \end{array} \right\}.$$

The extensions of the secondary predicates are obtained from the extensions of the primary predicates via the intensional and extensional definitions.

To identify predicates with the same meaning, one has to compare their extensions. The precision of a translation will then depend on the relative size of the intersection between the domains measured by[6] $E = \#D_1 \cap D_2/\#D_1 \cup D_2$ where the relation 'SameAs' is used to identify equals. The possible accuracy increases with the size of the quotient.

For each pair of predicates $\varepsilon(p_1, p_2) = \#\text{ext}(p_1) \cup \text{ext}(p_2)$ $\text{ext}(p_1) \cap \text{ext}(p_2)$ is a measure of concurrence of meaning. The rule is then to take as the p_2 for which $\varepsilon(p_1, p_2)$ is maximum as the translation of p_1.The probability that this is the correct translation is $\varepsilon(p_1, p_2) \cdot E$. The probability makes it possible to introduce an acceptance threshold.

Given a translation of the primary vocabulary of L_{D_2} the ontology of L_{D_2} can be expressed in the language L_{D_1}. The correctness of the translation depends on the mutual consistency of the two ontologies. Consistency checks are, therefore, tests of correctness of translations.

5 Conclusions

The aim of this paper has been twofold, to characterise certain fundamental features of the semantic and pragmatic web and to propose a methodology for automated translations between formal object languages. The methodology is based on intensional formal semantics for which the interpretation is represented by a set of maps from the domain to the vocabulary. This choice has two important consequences: (1) the conceptual model of the domain is described as a directed graph; (2) there exists a canonical metalanguage whose domain of discourse is the set of instances of the commutative diagrams constructed from the interpretation maps, and thus also possesses a directed graph structure. Sentences in the metalanguage can be formulated in the N3 syntax in a vocabulary that extends OWL. This language seems well adapted to describe Linked Open Data and thus become a natural representation language for the semantic web. Its increased richness can be exploited to identify whether words belonging to different languages with overlapping domains of discourse have the same meaning and thus establish translations. In summary, the pragmatic web can be related to the semantic web in two ways, by helping to decrease inherent context reliance of the semantic web and by helping to make it a more natural and flexible medium for communication.

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Notes

[1]Intensional should not be confused with intentional. An *intensional* interpretation gives the sense of a predicate referring to a property of an individual by specifying the necessary and sufficient conditions that determine whether the individual possesses the property. On the other hand, *intentional* applies to purposeful actions.

[2]Or rather, all terminological definitions can be expressed by means of the primary terms.

[3]We use standard mathematical notation $\rightarrow$ denotes a map and $\mapsto$ the value of the map for a given argument.

[4]We apply the convention that the string of symbols representing a node or a relation serves as its name. This is justified by the fact that a sentence embodies a syntactic form and expresses a proposition. The proposition belongs to the language and the syntactic form to the metalanguage. Since the sentences of the language are only mentioned and not used in the metalanguage the convention does not lead to problems. The advantage of the convention is not to lead to an infinite regress.

[5]We refer to the corresponding representation language as the ontology language.

[6]# is used for cardinal number.