Towards a Pattern Science for the Semantic Web

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Abstract. With the web of data, the semantic web can be an empirical science. Two problems have to be dealt with. The *knowledge soup* problem is about semantic heterogeneity, and can be considered a difficult technical issue, which needs appropriate transformation and inferential pipelines that can help making sense of the different knowledge contexts. The *knowledge boundary* problem is at the core of empirical investigation over the semantic web: what are the meaningful units that constitute the research objects for the semantic web? This question touches many aspects of semantic web studies: data, schemata, representation and reasoning, interaction, linguistic grounding, etc.

Keywords: Knowledge patterns, Cognitive science, Frames, Contexts, Linked data,

1. Introduction

Linked data [BHBL09] are creating the web of data, which on its turn can be considered the bootstrapping of the semantic web. For the first time in the history of knowledge engineering, we have a large set of realistic data, created by large communities of practice, on which experiments can be performed, so that the semantic web can be founded as an empirical science, as a branch of web science [BHH+06].

An empirical science needs clear *research objects*, e.g. cells, proteins, or membranes are types of research objects in different branches of biology. Such research objects, which can typically change and evolve (within different time scales), need to be shared by a community working on them. The community should also develop a language that is at least partly shared by its members and that is appropriate to describe those research objects. Based on these basic resources, a science develops procedures for making *patterns* emerge out of the research objects.

Until few years ago, the research objects of the semantic web used to be extracted from mostly small or toy examples, which had not the coverage and form that one can expect from data emerging from the use of the web by people and organizations. That coverage and form now exist, and are sometimes wild, but this is probably what an empirical science should deal with. Currently the web of data, including datasets such as DBpedia, geographical and biological data, social network data, bibliographical, musical, and multimedia data, etc., as well as the data emerging from the use of RDFa, Microformats, etc., has eventually provided an empirical basis to the semantic web, and indirectly to knowledge engineering.
There are two main problems (presented in sections 1.1 and 1.2) for the identification, selection and construction of patterns from the empirical research objects of the semantic web. In section 2 we provide some scenarios that exemplify the knowledge boundary problem, and in section 3 we suggest a practical approach for making an empirical pattern science over the semantic web. Finally, we come back to the relation be-

tween the soup and the boundary problems, and discuss conclusion.

1.1. The knowledge soup problem

Several authors (e.g. [JHY^{+}10]) have pointed out that the research objects in the web of data are just data, and one should ask what is really "semantic" in them, besides the usage of certain knowledge-oriented syntaxes like RDF. This is a variation of a problem spotted by AI scientists years ago (e.g. [Sow06]), called the *knowledge soup* problem (section 1.1): since people maintain and encode heterogeneous knowledge, how can formal knowledge be derived from the soup of triplified data (this is also related to the "reengineering bottleneck", see Hoekstra in this special issue)?
The web of data is a knowledge soup because of the heterogeneous semantics of its datasets: real world facts (e.g. geo data), conceptual structures (e.g. thesauri, schemes), lexical and linguistic data (e.g. wordnets, triples inferred from NLP algorithms), social data about data (e.g. provenance and trust data), etc. The authors of [JHY^{+}10] envisages a situation where those datasets are formally represented, e.g. through the semantics that would derive from an alignment to DOLCE[1]. In that way (by means of appropriate reengineering practices) we can imagine that conceptual structures are represented as classes or properties, real world facts as individuals or assertional axioms, lexical data into annotations, etc. They also propose to remove the inconsistencies that can derive from the alignment.

1.2. The knowledge boundary problem

The second problem we have singled out is the *knowledge boundary* problem (section 1.2): how to establish the *boundary* of a set of triples that makes them meaningful, i.e. relevant in context, so that they constitute a knowledge pattern? and how the very different types of data (e.g. natural language processing data, RDFa, database tables, etc.) that are used by semantic web techniques contribute to carve out that boundary?
Patterns in general can be defined as *invariances across observed data or objects*. The patterns in the semantic web emerge from data, but we need to distinguish the symbolic patterns of mathematical pattern science [Gre96], as studied in data mining, complex systems, etc., from the knowledge patterns of a semantic web pattern science. Knowledge patterns are not only symbolic patterns: they also have an interpretation, be it formal, or cognitive. Such interpretation consists in the *meaning* of the pattern, e.g. a fact reported in news, a soccer event in a picture, an aggressive attitude in a sentence, a subtle plan revealed by the analysis of a set of documents. In practice, a meaningful pattern to be discovered in the web of data has to be *relevant in a certain context*; we need a notion of *boundary* for sets of triples that matter. How many semantic applications address relevance in context explicitly? How many of them succeed in achieving it, solving problems that matter to anyone?

2. Some Scenarios and their Requirements

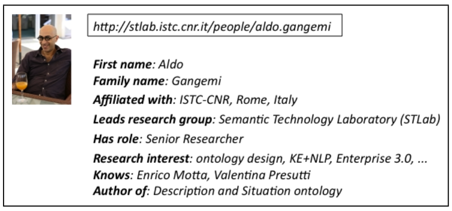
Being meaningful is usually associated with relevance in context, i.e. having a clear boundary in order to matter to someone.
In this section, we exemplify this concept and highlight the importance to have a semantic web able to recognize, handle, and exploit such boundaries.
For example, consider an application that leverages the web of data to provide information on some topic. Tools of this sort, like Sig.ma[2] already exist. The information that Sig.ma or similar tools can collect, *mesh up*, and serve is much easier to consume than the typical results of a traditional search engine like Google. This is due to the form of information handled: data as opposed to documents.Nevertheless, to establish which of the retrieved data are relevant in the context that matters to the user is still an issue. For example, consider the situation of searching information about a person e.g. Aldo Gangemi, who teaches as tutor in a school for researchers. Figure 1 shows the difference between all data that are collected from the web of data, and those that are relevant for the specific purpose. Figure 1(a) shows the data collected about "Aldo Gangemi": it can be noticed that such data contain information about Aldo's favorite music, civil status, political views, hobbies, etc., which are not relevant for his role of tutor at the school. Among all such information only those depicted in Figure 1(b) would solicit some interest in this context. Notice that the selection of relevant information impacts at both the level of properties and the level of property values e.g. in

[1] http://www.ontologydesignpatterns.org/ont/dul/DUL.owl

[2] http://sig.ma/

this context it could be relevant to provide the information that Enrico Motta, who is a researcher, is in Aldo's contact network, while it is less important to mention that the network includes Aldo's mother. How could relevance boundaries for this context be identified? Another clarifying example is the situation of a

(a) Data about Aldo Gangemi collected and meshed up from the web of data.



(b) Relevant data about Aldo Gangemi as tutor, collected and meshed up from the web of data.

Fig. 1. The difference between data about Aldo Gangemi collected and meshed up from the web of data, and the selection on such data of what is relevant for a specific context i.e. looking for information about the tutor of a school for researchers.

query aimed at identifying a more complex entity than a person. Consider the situation of a talk involving a discussion about two politicians belonging to different periods. In this case the application should be able to extract and interpret relevan knowledge by exploring the relationships that hold between the two politicians. One such application is RelFinder[3], a tool based on the web of data that extracts and visualizes relationships between objects in datasets, and to make these relationships interactively explorable. Figure 2 depicts a fragment of the result produced by RelFinder for "Benito Mussolini" and "Silvio Berlusconi". Despite the extent of the data about the two politicians available on the web of data, the similarity between them that RelFinder discovers is shallow and somehow irrelevant to most people. For example, it emerges that the two men have been both Prime Minister of Italy but the relevant knowledge that would matter to the user in this context would be the possible similarity of approaches that they followed, and the attitude that they have shown during their respective careers. Hence, the issue is still how to establish what are the boundaries that identify the relevant knowledge for a specific context. It is even clearer to understand the issue, and its

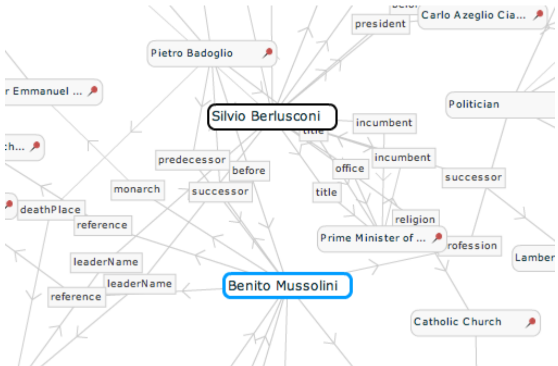


Fig. 2. Relations between Benito Mussolini and Silvio Berlusconi extracted from the web of data by the RelFinder application.

importance for the semantic web, if we consider that a key goal of the semantic web is to drastically decrease the cognitive load of humans when performing some task by delegating it to smart software agents. Consider the situation of a user that plans to arrange a holiday trip to San Francisco. In order to solve this task the user considers personal preferences e.g. on hotels, personal past traveling experiences, working calendar, available budget, etc., and compares them to what can be extracted from the information gathered from the web. A common task like this requires a significant amount of time, and cognitive effort. Additionally, the capability of identifying relevant contextual information in order to produce e.g. trip arrangement proposals, is key for enabling automatic support that goes beyond information or data retrieval.

The current semantic web and its frontline web of data branch are far from enabling support for tasks like this, although it enables the interpretation and consumption of data in the form of knowledge. We need a new paradigm, which enables a move from representing knowledge in general to shaping knowledge to be represented for a certain task, i.e. meaningfully.

[3]http://relfinder.semanticweb.org/

3. Frames and Knowledge Patterns

A research paradigm for the semantic web should include at least two key foundational, interleaving aspects: (i) a *unit of meaning* for the semantic web, more complex and effective than scattered classes or properties (binary relations), and (ii) a multidimensional context model.
We believe that the unit of meaning of the semantic web should be the *knowledge pattern*, a special name for *frames* [Min75,BFL98] in the semantic web, and that a formal context model should address the distinction between four dimensions i.e. descriptive, informational, situational, and social, besides the formal dimension.

3.1. Frames

A frame is a pattern whose intuition goes back to the notion of *schema* by [Bar32][4]. Many-flavoured varieties of schemata or frames have been proposed later by [Pia67], [Fil68], [Min75], [Bar99], [GM03a], [CTP00], etc. The intended meaning of a frame across the different theories can be summarized as "a structure that is used to organize our knowledge, as well as for interpreting, processing or anticipating information".
Different theories highlight the static vs. dynamic behavior of frames, their adaptability, or even people's ability to create them on the fly. Some older studies cast doubts on their role in e.g. scene recognition [BMR82], but besides the huge positive literature in linguistics and cognitive science, recent biological evidence seems to be quite convincing for considering them more than a philosophically-fascinating hypothesis. For example, [AZWRI06] found a clear congruence between activations of visually presented actions and of actions described by literal phrases. These results suggest a key role of mirror neuron areas in the re-enactment of sensory-motor representations during conceptual processing of actions invoked by linguistic stimuli. These findings support *embodied semantics* hypotheses, in which frames are the core unit of meaning, as event-oriented, embodied structures that abstract basic sensory-motor competences acquired by cognitive agents (see [Gan10] for an overview of embodied semantics applied to ontologies).
Marvin Minsky [Min75] introduced frames into computer science, claiming that "*there would be large advantages in having mechanisms that could use these same structures both for thinking and for communicating*". This means that the cognitive notion of a frame should have *counterparts* into the computational world. [Min75] exemplified counterparts in the form of modeling, programming, and interaction schemata. That was very successful, since the frame metaphor has been used as a formal schema in frame logics (frames involving closed world assumption) and description logics (concepts); as a design structure in object oriented design (classes); as an interaction design pattern in human-computer interaction (templates), etc. Therefore, a cognitive frame is an embodied structure that can be *partly represented* with constructs from languages with different formal semantics: as a polymorphic intensional relation, as a F-Logic frame, as an OWL class, etc.
However, the cognitive origin and motivation of Minsky's proposal were abandoned during the evolution of knowledge representation and engineering, because other scientific problems, such as complexity and formal semantic foundations, overruled the original agenda, which demanded a lot on the *design* side rather than on representation and reasoning. We believe it is time to resurrect that agenda.
Based on the above considerations, we suggest the usage of frames as the primary research objects over the semantic web, as opposed to simple concepts or binary relations, and we call them *knowledge patterns*. Such notion must be pragmatic and provide a meaning unit that acts as a "hub" between requirements for semantic applications, reusable ontologies, data to be queried, patterns in indexed texts, interaction patterns for semantic data, etc. The benefits of knowledge patterns can be several: easier ontology design, advanced exploration, extraction, and lenses over data, query patterns, rich linguistic grounding of ontologies for hybrid applications, etc.[5] In the next section, we briefly present a model of the different aspects (data, linguistic, interaction, etc.) of a knowledge pattern as revealed in the complex semiotic activity of cognitive agents, which can be addressed by semantic web research.

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[4]The genealogy of Bartlett's schemata goes back to Kant's distinction between objects of perception and their interpretation by an agent, and the need to postulate background schemata that enable interpretation over pure perception.

[5]Some of them have been experimentally demonstrated [BPGD10].

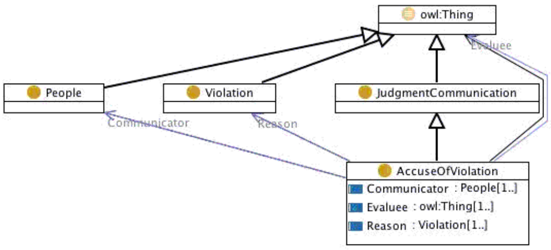

Fig. 3. An OWL content pattern learnt from a text corpus, based on a FrameNet frame and machine learning techniques. It models the relevant entities participating in an accuse of violation, a special case of the *judgement communication* frame in FrameNet [BFL98], learnt as described in [CGG+09].

3.2. *A research framework for knowledge patterns*

Over the semantic web, agents and reasoners should be able to discover and/or recognize knowledge patterns (KP), and reason on them. Examples of KP representations that are already reused within the semantic web are mentioned in Section 3.3. A KP derived from a FrameNet [BFL98] frame is depicted in Figure 3[6], while a native semantic web KP (a content pattern[7]) is depicted in Figure 4. Currently, technology and languages allow us to find occurrences of KPs that we already know. For example, we can use SPARQL for querying the linked data cloud in order to find occurrences of the KP depicted in Figure 4. However, how to discover new meaningful KPs is still an open issue. How to decide a boundary within the giant graph of LOD? What topology should be adopted? How to hybridize different data? While some of these questions are left to more extensive work, and for the joy of the semantic web community, the following proposal provides a unified model for describing the different aspects of an empirical research for KPs over the semantic web. A KP can be modeled as a polymorphic relation that takes arguments from a number of *façades*, as depicted in Figure 5. A façade represents a type of knowledge that can be associated with a frame, and can be used to motivate, test, discover, and use it. We use an elementary KP that models "persons with a role in a research group" for exemplifying some typical façades of a KP.

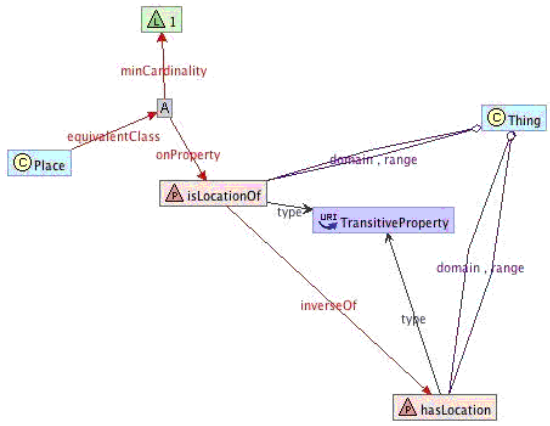

Fig. 4. An OWL content pattern from http://www.ontologydesignpatterns.org (ODP), manually defined. It models places, their characteristics, and the relationships between them e.g. the transitive property `hasLocation`.

- *Vocabulary*: a set of terms that can be structured with informal relations, for example, for a KP about researchers, the following set of terms could be activated: {Person, Role, ResearchInterest, ResearchGroup, Name}
- *Formal representation*: axioms that provide a formal semantics to the vocabulary. For example (in OWL):
  $\texttt{Person} \sqsubseteq \exists\texttt{hasRole.Role} \wedge$
  $\exists\texttt{hasTopic.ResearchInterest} \wedge$
  $\exists\texttt{memberOf.ResearchGroup} \wedge$
  $=1\texttt{hasName.Name}$
- *Inferential structure*: rules that can be applied to infer new knowledge from the formal representation of the KP, e.g.:
  `similarInterest(?p1 ?p2) ←`
  `hasTopic(?p1 ?i), hasTopic(?p2 ?i)`
- *Use case*: requirements addressed by the KP. They can be expressed in various forms e.g. including one or more competency questions [GF94]; in our lead example a competency question could be: *What phd students from a research group have a certain research interest?*
- *Data* that can be used to populate an ontology whose schema is a formal representation for the KP
- *Linguistic grounding*: textual data that express the meaning of the KP, e.g.: *The AST group has developed significantly in the last year. Professor João spawned AST interests from theoretical work on strong AI to applications by making an agreement with the WQP software engineering lab*
- *Interaction structure*: mappings between elements in the formal representation of a KP, and in-

[6] A comprehensive discussion on how to transform linguistic frames to knowledge patterns, and how to enrich them is [CGG+09]

[7] See http://www.ontologydesignpatterns.org and [PG08] for more details on content and other ontology patterns.

terface or interaction primitives, e.g.: `Person` ≈ `Static container`, `Role` ≈ `Container features (color, size)`, `Research group` ≈ `Drop down list`, `Research interest` ≈ `Static container`, `Relation` ≈ `Link | Containment`
- *Relations* to other KPs, e.g.: `hasComponent {personrole, collection, topic}`
- *Annotations*: provenance data, comments, tags, and other informal descriptions not yet covered by any existing façade.

In an empirical research perspective, the different façades provide research objects, which can be RDF triples in the formal and data façades, texts to be indexed or parsed, data in different formats that can be reengineered according to specific needs, etc. Each of them is the result of a particular approach for representing our knowledge. For example, evidence of an known KP, or the discovery of a new one can be the result of machine learning techniques applied to large corpora (cf. [CGG+09]), of defining RDF named graphs, of reengineering existing data models or structures, or of the harvesting of formalized ontologies.
The KP framework presented here is an invitation to start empirical work for a knowledge pattern science that has cognitive objects as primary research objects (see also Raubal and Adams in this special issue), and that provides a unifying framework to all diverse approach for representing knowledge. Although it is reasonable to envision an implementation of the KP framework, semantic web research can take advantage

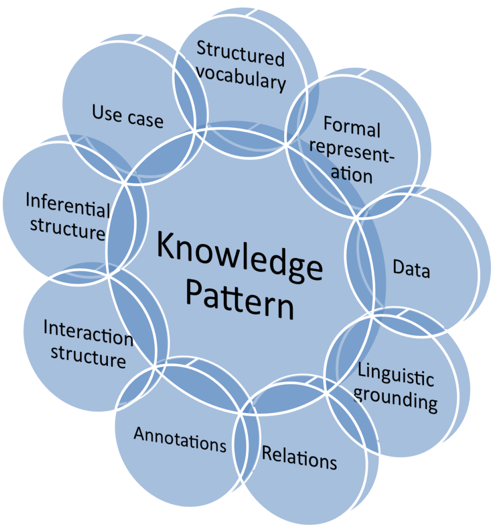

Fig. 5. The façades of a knowledge pattern.

from it as a research model, and individual KPs can be used for annotating results of data integration, pattern discovery or detection, etc., and eventually to make them converge for specific projects or applications.

3.3. Partial realizations of knowledge patterns

Existing projects that (partially) realize the KP research model include: the Component Library [CP97] encoded in the KM language, which realizes the vocabulary and formal façades; the FrameNet project [BFL98], which realizes the vocabulary and linguistic grounding façades; Microformats, which realize the data and vocabulary façades; the Ontology Design Patterns project, which includes several types of design patterns: content patterns (realizing the use case, vocabulary and formal façades) [PG08], logical patterns (realizing types of formal façades), reengineering patterns (targeting good practices in mapping vocabulary to formal façades, or formal to formal), etc. Ontology design patterns also highlight some similarities between frames and "design patterns" as employed in software engineering [GHJV95].
Besides projects that explicitly address frames or patterns, we remark that a lot of semantic web research and applications already implicitly address the typical data involved in some KP façades. The difference is that they lack of explicit use of KPs as research objects, therefore the patterns that eventually emerge in e.g. representation and reasoning, data reengineering, linked data, etc. do not necessarily address cognitively meaningful structures. Moreover, those heterogeneous patterns are usually disconnected from each other. In such situations, KPs can play the role of "attractors" for the diverse patterns: linguistic, data, axiom schemata, reasoning-oriented, etc. by providing a unified research model that support integration between those diverse, although complimentary results.

3.4. Knowledge patterns and multidimensional contexts in the soup

As mentioned in section 1.1, data on the web is affected by the knowledge soup problem, and needs to be cleaned up when making advanced reasoning on it. The solution proposed by [JHY+10] is to align it to foundational ontologies, and perform inconsistency debugging. While data cleaning through alignment to foundational ontologies can be feasible and desirable to some extent, the removal of inconsistencies can be hardly sustainable. It would require the removal of triples that express possible relevant knowledge, hence distorting the original intentions of data curators. Rather than removing them, we might want to live with inconsistencies by isolating them when a consistent reasoning pipeline is needed.

The choice of a foundational ontology is key in this process as it heavily impacts on the effects of reasoning. In order to make such choice effective two key aspects have to be addressed.

Task. The coverage and axiomatic complexity of the foundational ontology should be tailored to the task at hand, and alternative solutions may co-exist. E.g. reasoning on sequence-related axioms (temporal, spatial, scheduling) is different from reasoning on participation-related axioms (events, situations). Using all of them at the same time is not mandatory. Using a unique ontology for all of them is not mandatory either. Knowledge patterns such as ontology design patterns [PG08] are a blessing for this criterion, since they can be used to plug and play with manageable subsets of axioms and aligned data, which are related to relevant use cases.

Context. The data in the soup implicitly assume different domains of interpretation, or "contexts": e.g. WordNet datasets live in an informational (linguistic) domain of discourse, FOAF profiles live in a social context, most DBpedia and geographic datasets come from a situational domain (they are bare "facts"), a lot of DBpedia and biological data are about conceptual entities, etc. To make sense of these data, formal semantics alone is not enough. We need something that supports multidimensional interpretations of data linked across different, sometimes logically incompatible contexts: descriptive (or conceptual) context, informational context, situational context, social context, and formal context.

Based on the above reasons, some of the types and axioms of the foundational ontology should cover the knowledge contexts that make up the soup, typically individuals, facts, concepts, information objects, and social metadata.

The research on KPs exemplifies the typical contexts that are mixed up in the soup. The vocabulary, linguistic grounding, formal representation, and definition-oriented annotation façades of a KP contain data that exemplify the *descriptive context* of knowledge; the linguistic grounding façade exemplifies the *informational context*; the interaction façade and provenance annotations exemplify the *social context*; the data façade exemplifies the *situational context*; the formal and inferential façades exemplify the *formal context*.

A foundational ontology that formally represents such different contexts is the "Constructive Description and Situation" (c.DnS) [GM03b,Gan08]. It leaves it open the choice about controversial distinctions such as objects and events vs. three-dimensional entities, qualities vs. values, etc., which are typically fixed by most upper-level and foundational ontologies. The basic machinery of c.DnS involves a strict separation of the domains for the different context types, and includes appropriate relations between contexts of the same or different type. Several content ontology design patterns encode parts of c.DnS for its use within the KP paradigm. For space reasons, we redirect the reader to the cited literature for further details.

4. Conclusion

In this paper we argue that the semantic web can be an empirical science based on a new paradigm built upon two foundational aspects: (i) the *knowledge pattern* as a unit of meaning for the semantic web, and (ii) a multidimensional context model able to capture its descriptive, informational, situational, social, and formal characters. The current situation is that only triples and named graphs on one side, and large or complicated ontology schemata on the other side, are de facto research objects: in neither case they are close to the way knowledge is contextually relevant for people. We have suggested *knowledge patterns* (KPs) as a primary research object to focus on. KPs both reflect the intuition of frames on the semantic web and provide the structure needed for representing the different context dimensions.

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[8]http://stlab.istc.cnr.it

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