INRIA Project-team Exmo

Evaluation of Theme “Représentation et traitement des données et des connaissances”

October 2011 (last compilation: 5th October 2011)

Project-team acronym :	**EXMO**
Project-team title :	**Computer-mediated exchange of structured knowledge**
	Échanges de connaissance structurée médiatisés par ordinateur
Scientific leader :	**Jérôme Euzenat**
Research center :	**INRIA Grenoble Rhône-Alpes (Montbonnot)**
Common project-team with :	**LIG**
URL:	http://exmo.inrialpes.fr/

The last evaluation occured in November 2005. The current evaluation is supposed to run from January 2007 to October 2011.

1 Personnel

Personnel (November 2005)

	Misc.	INRIA	CNRS	University	**Total**
DR (1) / Professors		1			**1**
CR (2) / Assistant Professors		1			**1**
Permanent Engineers (3)					
Temporary Engineers (4)					
PhD Students	2	1		1	**4**
Post-Doc.		1			**1**
Total	**2**	**4**		**1**	**7**
External Collaborators					
Visitors (> 1 month)	1				

Personnel (October 2011)

	Misc.	INRIA	CNRS	University	**Total**
DR / Professors		1			**1**
CR / Assistant Professor				1	**1**
Permanent Engineer					
Temporary Engineer					
PhD Students		2			**2**
Post-Doc.		1			**1**
Total		**4**		**1**	**5**
External Collaborators				1	**1**
Visitors (> 1 month)					

(1) “Senior Research Scientist (Directeur de Recherche)” (2) “Junior Research Scientist (Chargé de Recherche)”
(3) “Civil servant (CNRS, INRIA, ...)” (4) “Associated with a contract (Ingénieur Expert or Ingénieur Associé)”

Changes in staff

DR / Professors CR / Assistant Professors	Misc.	INRIA	CNRS	University	total
Arrival				1	**1**
Leaving		1			**1**

Comment: Departure of Jean-François Baget to Montpellier / Arrival of Jérôme David.

Current composition of the project-team (October 2011):

- Jérôme Euzenat, DR2, INRIA
- Jérôme David, Assistant professor, U. Pierre Mendès-France, Grenoble
- Cássia Trojahn dos Santos, Post-doctoral researcher, INRIA (FP7 SEALS contract)
- Melisachew Wudage Chekol, PhD student, INRIA
- Zhengjie Fan, PhD student, INRIA (ANR Datalift contract)

Current position of former project-team members (including PhD students) during 2007-2011:

Exmo positions are within parentheses after the names.

- François Scharffe (post-doc), Assistant professor (permanent), U. Montpellier
- Chan Le Duc (post-doc), Assistant professor (permanent), U. Vincennes
- Giuseppe Pirró (post-doc), Assistant professor (medium term), FU. Bolzano
- Jason Jung (post-doc), Assistant professor (permanent), Yeungnam U., Gyeongsan (KR)
- Patrick Hoffmann (post-doc), ATER (short term assistant professor), U. Pau
- Jérôme Pierson (PhD), freelance trainer
- Antoine Zimmermann (PhD), Maître assistant associé (short term assistant professor) École nationale supérieure des mines de Saint-Étienne
- Faisal Alkhateeb (PhD), Assistant professor (permanent), Yarmouk U., Jordan
- Sébastien Laborie (PhD), Assistant professor (permanent), U. Pau

Last INRIA enlistments

- none during the period.

Team History

Exmo has been created as an INRIA project in 2003. It was a founding team of the LIG (Laboratoire d'informatique de Grenoble) in 2006.
The initial Exmo topic concerned interoperability on the web in its full generality. During our 2005 INRIA evaluation, this topic has been refocussed on "ontology matching and alignment".

2 Work progress

Our work belongs to the "Information, computation and communication everywhere" strategic priority of INRIA and more specially the "Web of knowledge and services".
On a local basis, Exmo is part of the "knowledge" scientific theme of the LIG and aims at contributing to its"ambient computing" objective .

2.1 Keywords

– knowledge representation, semantics of knowledge representation, ontologies,
– semantic web, content representation, context,
– knowledge transformation, ontology matching, ontology alignment, data interlinking, multimedia document adaptation, semiotics,
– RDF, RDF Path, OWL, SPARQL, PSPARQL, IDDL,
– Alignment API, Alignment server, OntoSim, Aroma, OLA

2.2 Context and overall goal of the project

Expressing formalised knowledge on a computer is useful, not especially for the need of the computer, but for communication. In future information systems, formalised knowledge will be massively exchanged. The goal of Exmo is the development of theoretical and software tools for enabling interoperability in formalised knowledge exchange. Exmo contributes to an emerging field called the semantic web which blends the communication capabilities of the web with knowledge representation.
There is no reason why knowledge expressed on the web should be in a single format or by reference to a single vocabulary (or ontology). In order to interoperate, the representations will have to be matched and transformed. Moreover, in the communication process computers can add value to their memory and medium role by formatting, filtering, classifying, consistency checking or generalising knowledge.
We currently build on our experience of alignments as representing the relationships between two ontologies on the semantic web. Ontology alignments express correspondences between entities in two ontologies. They allow for maximising sharing on the semantic web: various algorithms can produce alignments and various uses can be made of these alignments. Such alignments can be used for generating knowledge transformations (or any other kind of mediators) that will be used for interoperating. In order to guarantee properties of these transformations, we can consider the properties of alignments and generate transformations preserving them.
Our current roadmap focusses on the design of an alignment infrastructure and on the investigation of alignment properties (and especially semantic properties) when they are used for reconciling ontologies.
On a longer term, we want to explore "semiotic" properties, i.e., properties which concern the interpretation of the communicated representation by a human user. This goal should require an analysis of the extra-semantic rules that govern the choice of subsets of models.
Our work is naturally applied in several contexts: semantic peer-to-peer systems, dynamic document composition, interoperability in ambient computing, web service composition, semantic social networks and data interlinking. We also investigate more traditional topics such as distributed reasoning with heterogeneous ontologies and expressive query answering.

2.3 Objectives for the evaluation period

We reproduce below, the objectives which where available in our previous evaluation report. It has been slightly reduced of circumstantial comments.

2.3.1 Objective 1: Alignment infrastructure

The ontology alignment structure allows for maximizing sharing on the semantic web: various algorithms can produce alignments and various use can me made of these alignments.
We are working on an alignment infrastructure that can fulfill the needs of various applications (ontology merging for editors, message translation for agents, mediation for web services, query and peer-to-peer systems). The current alignment API is being extended in order to offer its services to these applications (through agent communication protocols and web service invocation) and generating or processing the various transformations required by the applications.
We currently investigate two practical applications of such an infrastructure:

- Matching context and needs in ambient computing requires such an infrastructure and would benefit sharing alignments on a large scale.
- Annotated resource sharing in peer-to-peer architecture requires to query peers with heterogeneous ontologies. The alignment service is used there to infer, edit and store the alignments and provide appropriate mediators for processing the queries. In this application, the alignment infrastructure is also used for building a "knowledge network" paralleling the social network of peers and enabling to expand it.

2.3.2 Objective 2: Alignments, transformations and properties

Such an alignment infrastructure is the occasion to adapt Exmo's objective of providing an environment guaranteeing properties of the transformations. Instead of directly considering the properties of transformations, we would consider those of alignments and generate transformations (or any other kind of mediators) from these alignments.
For that purpose, we are currently studying how alignment properties can be obtained by construction from the type of algorithm used for computing the alignment. We are also developing alignment composition operators that will be inserted in the alignment service. We will have to study how the transformation generators preserve these properties (and what distortion is introduced by these generators).
Another approach is the study of graph homomorphism-preserving transformations. Using the class of self-described logics, such transformations directly translate into consequence-preserving transformations on formulas. These transformations are thus an adequate tool to align ontologies written in different languages belonging to that class.

2.3.3 Objective 3: Other research

In the meantime, we continue to investigate some particular interesting problems on which we can still progress:

- the design and development of efficient alignment algorithms;
- the design of semantically grounded alternative to precision and recall for comparing ontology alignments;
- the design of inference and transformation techniques based on graph homomorphism;
- the semantic (and rhetoric) adaptation of multimedia documents.

Evolution

In the following, we treat the three objectives mentioned above in three different sections. We have changed their order and name: "Alignment, transformations and properties" becomes "Alignment foundations" and comes first.In addition, we introduce an intermediary "Application section", covering the Application part of "Objective 1" above, because we consider them as important.

2.4 Alignment foundations (Objective 2)

Objective 2 has been split in three different sub-objectives: Alignment semantics, Alignment languages and algebra and Ontology distances. The graph homomorphism part of alignments has been abandoned due to the departure of Jean-François Baget to Montpellier.
Starting from the initial objective, the work has evolved from trying to infer properties of alignments from algorithms to **alignment semantics**. The main reason for this is that most of the matchers do not offer clear properties to work on. When dealing with alignments, it is important, both for generating them and for using them to know their interpretation. This is even more important when users are dealing with a whole network of ontologies related by alignments. Such a structure composed of a set of ontologies, interconnected with ontology alignments is called a network of ontologies. A legitimate question is: given the semantics of these ontologies, what are the consequences of a network of ontologies? Instead, having a clear alignment semantics allows to define alignment composition with various level of dependency with respect to the ontology language semantics.
Sharing alignments across the web requires a language to express them. We have been developing the Alignment format for exchanging alignments across applications which is widely used inside and outside Exmo. Although this format is freely extensible, it is only able to express simple alignments between ontologies. So, we have investigated enhanced **alignment languages** and especially the use of algebra of relations in alignments.
There are many reasons for measuring a **distance between ontologies**. In particular, it is useful to know quickly if two ontologies are close or remote before deciding to match them. To that extent, a distance between ontologies must be efficiently computable. We have also investigated distances between ontologies as they are a central component of ontology matchers. We showed that such distances may also be based on alignments and alignment properties.

2.4.1 Personnel

Alignment semantics Antoine Zimmermann, Jérôme Euzenat

Alignment languages and algebra Jérôme Euzenat, Antoine Zimmermann, François Scharffe

Ontology distances Jérôme David, Jérôme Euzenat, Giuseppe Pirró, Ondřej Šváb-Zamazal

2.4.2 Project-team positioning

Alignment semantics The semantics of networks of ontologies were so far provided with distributed description logic (U. Trento, L. Serafini) or $\mathcal{E}$-connections (U. Liverpool, O. Kutz, F. Wolter, M. Zakharyaschev, C. Lutz). We have provided our own semantics that, we think, is more intuitive. One of its benefits is to treat alignments as independent from ontologies. Hence, classical ontology languages do not need to be modified and this allows for accommodating heterogeneous languages. We offered (in 2006) a comparison with some of these approaches on the standpoint of composition[1].

[1] A. Zimmermann, J., Euzenat, Three semantics for distributed systems and their relations with alignment composition, Proc. 5th ISWC, Athens (GA US), *LNCS* 4273:16–29, 2006

Alignment languages and algebra There is no direct competition on independent alignment languages. Our format is used by most ontology matching systems, even when this is not their native format. A comparable vocabulary is SKOS mapping which is restricted to thesauri correspondences and comes with no semantic. Even in this context, our format is used by Mondeca and VU Amsterdam (A. Isaac). EDOAL is developed jointly with François Scharffe (U. Montpellier). It is new and has not been used much so far. Its main competition is the direct use of a description logic for expressing alignments, this would help reusing reasoners but would not allow to express transformations.

Ontology distances The work on ontology distance is developed in collaboration with Open university and Prague University of Economics. There is more work developed on ontology distances, in particular in Karlsruhe (A. Mädche, M. Ehrig). The work on alignment space distances is original although P. Cudré-Mauroux developed related concepts in his PhD (EPFL).

2.4.3 Scientific achievements

Alignment semantics

So far, alignments have been given a semantics only related to a precise logical framework, e.g., first-order logic. We aimed at an alignment semantics in which alignments are considered as first-class entities, independently from the ontology semantics. For that purpose, we have defined a parameterised family of model-theoretic semantics for alignments and knowledge-based networks of ontologies [16]. This semantics is parameterised by the interpretation of the set of relations it uses and relies transparently on the semantics of the ontologies (which is only supposed to define the consequence relation). This means that the models of an alignment or a network of ontologies are defined in function of the models of the local ontologies, even when different ontologies are written in different languages.
The composition of alignments within a network of ontologies can be defined syntactically and semantically [16] (and the syntactic procedure is usually incomplete: composition is only an approximation). It is, in particular, possible to define reasoning in a network of ontologies based on alignments alone, i.e., without resorting to the ontologies. This can be useful in systems like agent or peer-to-peer systems in which the ontologies are unknown or as an approximation technique, e.g., for checking consistency.
We have further used this semantics with the notion of α-consequences which are those correspondences which are satisfied by all models of a network of ontologies [37]. This has allowed to develop a semantic version of precision and recall (§2.5.3) and can be used for testing the consistency of an alignment, or for preprocessing a distributed set of alignments through the computation of its compositional, symmetric and union closure.

Alignment languages and algebra

In order to offer a format which is both expressive and independent from concrete ontology languages we developed the Expressive and Declarative Ontology Alignment Language [77]. It is mostly an expressive description logic language to which the declaration of data transformation are added. The high expressivity of the language allows for expressing complex alignments even if the ontology languages are not themselves expressive. The language independence guarantees that we can define expressive alignments between any languages and provides a declarative definition of the alignments which will be usable in various manners, e.g., ontology merging or data translation. We provided a model theoretic semantics for the language which relies upon the semantics of aligned ontologies while remaining independent from their details.

We also have proposed to use algebra of binary relations instead of the generally used ad hoc relations. Algebras of relations allow for combining relations, that which is useful for combining alignments themselves. Our first motivation for using them was to be able to express uncertainty in relations between ontology entities, but we have shown that algebras of binary relations are a natural way to represent disjunctions of relations, to aggregate matcher results, and to compute composition and granularity change [38]. They are an adequate tool for expressing more precisely composition operations.

Ontology distances

We investigated two families of ontology distances: ontology-space measures relying on the content of ontologies and alignment space measures which rely on alignments between ontologies.
For the ontology-space measures, we have studied constraints applying to such them and reviewed several possible ontology distances. Then, we evaluated experimentally some of them [34]. We have carried out experiments on 12 measures in the ontology space against 111 ontologies. This allowed us to identify a triple-based distance of our own, associated with a minimum weight maximal graph matching, as the most accurate measure, but measures based on the vector space model of information retrieval as the most efficient measures. Since then, we introduced new similarity measures across ontology entities combining symbolic features (specialisation relation and characteristics) and information theoretic content of concepts [53]. We showed that these measures are comparable or improve on previously available ones on standard tests [52].
In the context of alignment-space, we investigate the design of distance and defined both path-based and coverage-based measures [36]. Path-based measures only consider the existence of a path of alignments between ontologies while coverage-bath measures are more precise in the sense that they are defined on the ratio of elements of the ontology which are covered by an alignment. This is useful in the context of semantic peer-to-peer systems for securing the coverage of query rewriting. These measures have been compared to ontology-space measures. Although not strongly correlated with the best measures, the coverage-based measures provide results comparable to these. Moreover, in addition to not depend on the ontology content, they have proved to be reasonably robust to errors in the alignments especially if individual correspondences are missing. This work has been implemented and disseminated in the OntoSim library (§3.2).

2.4.4 Collaborations and external support

Alignment semantics Part of this work has been carried out in the framework of the Knowledge web network of excellence (see §4) and has benefited from discussions with Luciano Serafini (U. Trento), Markus Krötzsch and Pascal Hitzler (U. Karlsruhe).

Alignment languages and algebra This work has also started within Knowledge web. It was carried out in cooperation with F. Scharffe (Innsbruck U.). It has been continued with François during his post-doctoral stay in the team.

Ontology distances This work has been carried out in cooperation with Open university (Mathieu d'Aquin and Carlo Aloca) in the context of the NeOn project (see §4) and Prague University of Economics (Ondřej Šváb-Zamazal) in a context of a PhD visit.

2.4.5 Self-assessment and perspectives

Among the contributions not mentioned above, we have written, with Pavel Shvaiko, the reference book concerning ontology matching and alignment [1]. Although it is not a specific scientific contribution, it has contributed to define the field.

Alignment semantics This semantics is a major asset of the team which is widely used in many of our other activities (distance, algebra, evaluation measures, modules). We plan to study further what an agent aware of this semantics can do for deciding what it must believe. We also plan to use this semantics, if not to improve it, in future studies of alignment composition and revision.

Alignment language and algebra Although the work on expressive language did not seem to be followed by many at its beginning, the interest seems to have sprung this year. We had contact with several groups working with (Southampton) or interested in EDOAL (Humboltd project). We plan to further develop this language in the context of data interlinking (see §5.2).

Ontology distances We have acquired a strong position in ontology distances, both by our coverage of many measures and by the introduction of new measures. Another category of measures, named agreement and disagreement, has come up and we plan to investigate them and use them for assessing the quality of alignments (see §5.2).

2.5 Alignment infrastructure (Objective 1)

Objective 1 is split in two parts. This section deals with providing component of infrastructure based on alignments for the semantic web. These components use the results of objective 2 (§2.4). The second part is described in the next section: Applications.
We develop since 2003 an API for ontology alignment manipulation and storage whose goal is to become a key element in the semantic web infrastructure. We present the development of an **Alignment server** and the continuous support and improvement of the Alignment API. These are tools for expressing storing and manipulating alignments according to the principles developed in §2.4.3. They are used in our following developments as well as by many other teams around the world.
One such development, is a system for **reasoning with networks of ontologies**. There are very few distributed reasoners, we have developed one of those based on the semantics that we have defined. The semantics of networks of aligned ontologies defines the consequences of such a network. A reasoner should compute such consequences when needed or, alternatively, test the consistency of the network. The reasoner that we have developed has the advantage of processing the alignments independently of the local provers: it reuses reasoners for single ontologies. This provides flexibility, but is computationally expensive.
Finally, we have been involved since 2004 in the **evaluation of ontology matching**. We have created and still lead the Ontology Alignment Envaluation Initiative (OAEI)[2]. For that purpose, we developed tools based on the Alignment API for processing these evaluations. This covers evaluation measures, test generators as well as full evaluation processing within the SEALS European project. New evaluation measures based on the semantics of Objective 2 have also been investigated.

2.5.1 Personnel

Alignment API and server Chan Le Duc, Jérôme Euzenat, Jérôme David, Cássia Trojahn dos Santos
Reasoning with networks of ontologies Chan Le Duc, Antoine Zimmermann
Evaluation Cássia Trojahn dos Santos, Jérôme Euzenat, Jérôme David

[2] http://oaei.ontologymatching.org

2.5.2 Project-team positioning

Alignment API and server The main system comparable to the Alignment server is the bioportal developed at Stanford (N. Noy) based on Protégé. This system is only available as a service and is not specifically targeted on alignments: it is an integrated server for both ontologies and alignments. Cupboard developed at Open U. (M. d'Aquin) is complementary since it does not cover alignments (which are provided by our server). VU Amsterdam (A. Isaac) developed an alignment server for SKOS thesauri in the cultural heritage domain. The system took (acknowledged) inspiration from our Alignment format. However, it also remains an internal development.

Reasoning with networks of ontologies There have been reasoners for networked ontologies based on DDL both from Trento U. (Drago, L. Serafini,) and Mannheim U. (A. Schlicht, H. Stuckenschmidt). So, the semantics of these systems is different which requires each node to develop a specific distributed reasoning, while IDDL does not alter native reasoners.

Evaluation Matcher evaluation is a collaborative task carried out by volunteers from many institutions (the main ones being: Mannheim U., Prague U., VU Amsterdam, U. Trento). There is no effort to compare with OAEI as a campaign. Concerning the developments we have launched SEALS which is devoted to semantic technology evaluation on the model of OAEI. In SEALS, collaborate closely with Mannheim U. (H. Stuckenschmidt, C. Meilicke). Concerning tools, LIRMM (Z. Bellasehne) developed a testing environment for database schema matchers. Finally, C. Meilicke (Mannheim U.) implemented our semantic precision and recall measure and proposed an alternative coherence measure for matchers.

2.5.3 Scientific achievements

Alignment API and server

The Alignment API [18] is a library form manipulating ontology alignments. It implements the work described in foundations, in particular we offer support for the EDOAL language, allow alignment manipulation, offers various evaluation measures. It is connected to the main ontology libraries (OWL API, SKOS API, JENA) through a common interface. It is able to output simple alignments in many different formats and to transform SPARQL queries.
On top of it, the Alignment server[3] aims at sharing alignments over the web. It offers the opportunity to run matchers embedded in the system, to manipulate alignments, to store them permanently. The server can be accessed through HTML, REST and SOAP web service interfaces and FIPA ACL through JADE. It has been embedded in the WebContent platform and the Cupboard system. A NeOn toolkit plug-in allows to use it from the NeOn toolkit.

Reasoning with networks of ontologies

In order to effectively reason on networks of ontologies, we introduced a new kind of distributed logics, namely Integrated Distributed Description Logics (IDDL), where ontologies are represented as description logic knowledge bases and alignments assert cross-ontology concept/role subsumptions or disjunctions, or cross-ontology instance membership. In particular, this formalism is adapted for reasoning with OWL ontologies aligned by automatic ontology matching tools. The semantics of the logic is the one we introduced (see §2.4.3).
The difference between IDDL [64] and the existing formalisms is that (i) IDDL focuses on alignments by considering them as independent pieces of knowledge, (ii) IDDL does not make any

[3] http://aserv.inrialpes.fr for a test server

expressiveness assumption on formalisms used in ontologies, beyond $\mathcal{ALC}$, except for decidability, (iii) IDDL supports distributed reasoning, i.e., all local computing for ontologies can be independently performed by local reasoners.
We have developed an algorithm for consistency checking in IDDL [65]. The procedure is correct and complete when the correspondences which appear in the alignments only assert cross-ontology subsumption of concepts or roles, or cross-ontology disjointness of concepts. The complexity class of consistency checking is at least NP but depends on the complexity of local reasoners.
This algorithm has beed implemented and a preliminary version of the IDDL reasoner (see §3.2). First experiments with the prototype show that it answers quickly on several real life cases.

Evaluation

Since 2004, we run the Ontology Alignment Evaluation Initiative (OAEI) which organises evaluation campaigns for assessing the degree of achievement of actual ontology matching algorithms [103; 93; 101; 102]. In 2010, 15 different teams entered the evaluation which consisted of 6 different tasks. OAEI has always been a very successful and lively event with new matchers and new tasks entering each year [19].
On the research side, we have pursued our investigations on generalising precision and recall. We have developed semantic precision and recall measures [37] based on the semantics of alignments (see §2.4.3). It can work with any semantics given a definition of α-consequences. Unfortunately these measures are difficult to compute fairly in extreme cases, hence we have analysed its limits and we proposed two new sets of evaluation measures [35]. The first one is a semantic extension of relaxed precision and recall. The second one consists of bounding the alignment space to make ideal semantic precision and recall applicable. We are currently working at combining semantic precision and recall with relaxed precision and recall that we had previously developed.
Within the SEALS project, we work at making evaluations as automatic as possible [62]. The SEALS platform is now able to register matchers packaged in a specific way and to execute a particular evaluation scripts. We have implemented a test generator and performed extensive tests which showed the robustness of evaluations run so far [54].

2.5.4 Collaborations and external support

Alignment API and server The Alignment API and server receive external contributions from time to time, but it is mostly the work of our team. The development of the server benefited from the NeOn FP6 project and the ANR WebContent project. In both projects, it has been integrated in developed platforms (The NeOn toolkit and Cupboard on one side, and the WebContent platform on the other).

Resoning with networks of ontologies was an internal project, partly supported by NeOn.

Evaluation started with the knowledge web network of excellence (see §4) and the success of OAEI has been instrumental in the definition of the SEALS project (see §4). It is mostly developed in cooperation with Mannheim U. (H. Stuckenschmidt, C. Meilicke), U. Trento (P. Shvaiko), and Praha university of economics (O. Svab-Zamazal).

2.5.5 Self-assessment and perspectives

Alignment API and server The Alignment API is used by many systems developing alignments. We have identified more than 30 independent developments reported in a publication[4]. The

[4] See http://alignapi.gforge.inria.fr/impl.html.

API has been integrated in the Mondeca thesaurus management environment (ITM) for dealing with alignments (see §3.3).

We are currently reengineering our Alignment API (see §3.2) in order to ground it on the expressive languages and algebra and to demonstrate their benefits. We want to use them in reasoners and in systems for processing alignments.

Resoning with networks of ontologies Reasoners for networks of ontologies, either distributed or centralised, are tremendously useful and necessary. We need them, to some extent, in every work which involves our alignment semantics. They can be used in semantic peer-to-peer networks. Developing a reasoner requires very specialised knowledge and promises to be particularly expensive computationally. Moreover, the two main proponent of IDDL reasoner have left the team, so this is a track that we do not plan to follow.

Evaluation The success of the evaluation activity does not decrease. This work is continued in the framework of the SEALS European project. We will also complete our work on alternative evaluation measures.

2.6 Applications

We do not only develop tools for the semantic web infrastructure but we try to apply them in specific contexts in order to show their relevance. Objective 1 initially mentioned two application domains that we report separately here:

Semantic social networks Social networks are simply the graph between people along social relations (usually denoting that they know each others). We consider semantic social networks in which people use ontologies for describing their relations or semantic peer-to-peer systems in which they use ontologies for describing resources that they share. When the ontologies are different, communicating between peers require alignments. We have explored the use of networks of ontologies and distance measures in these networks (as defined in §2.4.3) in order to identify potential similarities between peers. We have also developed a model of trust among peers allowing to identify potentially faulty correspondences within a network of ontologies.

Ambient computing In an ambient computing environment, the environment itself is the interface between services and users. Using context information coming from sensors, location technologies and aggregation services, applications adapt their run time behaviour to the context in which users evolve, e.g., physical location, social or hierarchical position, current tasks as well as related information. These applications have to deal with the dynamic integration in the environment of new elements (users or devices), and the environment has to provide context information to newly designed applications. We have proposed to use alignments to interpret information provided by various such devices. Applications take advantage of an Alignment server (as described in §2.5.3) to retrieve dynamically necessary alignments. We have studied and developed such a dynamic context management system for ambient applications. We have further developed client software for mobile devices.

2.6.1 Personnel

Semantic social networks Jérôme Euzenat, Jason Jung, Jérôme David, Manuel Atencia, Giuseppe Pirró

Ambient computing Jérôme Pierson, Jérôme Euzenat, Jason Jung

2.6.2 Project-team positioning

Semantic social networks There is much interest in some form of semantic social networks. In particular in Edelweiss (Sophia-Antipolis) or in DERI (Galway). However, they usually assume a central ontology and no alignment while we base our work on alignments. On this topic we collaborate with Yeungnam U. (J. Jung). On semantic peer-to-peer systems, we collaborate closely with our LIG colleagues from Hadas (M.-C. Rousset, M. Atencia) as well as Zenith (Montpellier) within the ANR DataRing project. There has been much work on social network analysis for finding central people in a network or connecting efficiently an individual to another, but to our knowledge, none based on ontology distance. The same thing occurs for trust in semantic peer-to-peer systems: we do not know of any group for which takes alignments into account for computing trust.

Ambient computing Ontologies are a common need in ambient computing: each application now has some. Our specific point is on insisting that these ontologies are different and they will not converge, hence a mechanism for relating them is necessary and ontology alignments are exactly what is needed. So, we are rather evangelising (even if we concretely worked with Orange Labs), than competing.

2.6.3 Scientific achievements

Semantic social networks

We introduced the notion of semantic social networks in order to describe networks embedding not only relations between people, but also the ontologies that people use. These ontologies can be used, for instance, in order to annotate resources such as documents, pictures, etc. We proposed an organisation for semantic social networks in three layers: social layer, ontology layer and concept layer [44]. Each layer features a network based on different relations.
People in the social network are related to the ontologies they use, and ontologies are related to the concepts they use and they define. However, it may be useful to be able to infer relations between people from the relations between concepts and ontologies. This has the advantage of providing potential proximity relations for people who do not even know each others. Such techniques can be useful for finding people to which it will be easier to forward a query or group of homogeneous people who will be more prone to design a consensus ontology [45]. We proposed some propagation rules as well as measures for computing network analysis.
In a semantic peer-to-peer network, peers may use different ontologies and rely on alignments between them for translating queries [22]. Alignments may be incorrect or incomplete and generate flawed translations, leading to unsatisfactory answers. We have designed a trust mechanism that assigns trust representing the probability that a peer will provide a satisfactory answer to a specific query through a specific alignment. In order to compute trust, we exploit both alignments and peers' direct experience, and perform Bayesian inference. We have implemented our technique and conducted an evaluation. Experimental results showed that trust values converge as more queries are sent and answers received and accuracy of answers increases [29].

Ambient computing

We have designed an architecture in which context information is distributed in the environment. Each device or service implements a context management component in charge of maintaining its local context. It can communicate with other context management components: some of them are context information producers, some of them are context information consumers and some of them are both. We have defined a simple protocol to allow a consumer to identify and determine the right producer for the information it needs. Context management components express their context

information using an OWL ontology and exchange RDF triples with each other. The openness of ontology description languages makes possible the extension of context descriptions and ontology matching helps dealing with independently developed ontologies. Thus, this architecture allows for introducing new components and new applications without interrupting what is working [20].
We have developed a library to build the distributed context management system. It provides support for most operations of context management, i.e., searching, broadcasting and updating context information. The Alignment server (see §2.5.3), for which a JADE plug-in for communicating with agents has been developed, is used in our distributed context management system. It allows the context information manager component to find correspondences between various ontologies with which it is confronted and thus to match application needs in terms of context information with the information provided by the other devices.
We have built a complete easily deployable ambient home environment. Our infrastructure manages context information flows from sensors and web services to application and a dynamic service composition infrastructure. We demonstrated it through the composition of a set of potentially interchangeable sensors and actuators [15]. We are applying the same approach to mobile environments for which we have deployed a stripped down version of the Alignment API [97].

2.6.4 Collaborations and external support

Semantic social networks The work on using ontology distance to assess peer proximity in social networks is carried out with Yeungnam U. (J. Jung) in the context of a PHC STAR project (see §4). The work on probabilistic trust in semantic peer-to-peer systems is developed in collaboration with our LIG colleagues from Hadas (M.-C. Rousset, M. Atencia) as well as Zenith (Montpellier) within the ANR DataRing project.

Ambient computing This work has been developed in collaboration with France Telecom R&D (now Orange Labs, F. Ramparany).

2.6.5 Self-assessment and perspectives

In both cases, we did not reach the impact that we wanted in these projects. For that purpose, we would like to participate in large targeted projects in either ambient computing or mobile computing.

Semantic social networks The experiments that we run on semantic social networks were not particularly conclusives. Although, this could certainly be improved, we do not have enough resources for investing in extensive experiments. The work on semantic peer-to-peer systems is providing promising results. Moreover, it is easier to experiment and could be directly used for improving alignments, so we will certainly continue it after DataRing.

Ambient computing We think that the issue of ontology heterogeneity in ambient and mobile computing applications will develop during the years to come. We plan to integrate the proposal that we have made in a broader context involving user intervention. In particular, we think that such applications should not be restricted to work in a particular well identified context, but should be continuously kept in order in uncontrolled contexts (this is typically the case for mobile applications). So we plan to push on experimenting and improving our heterogeneous context framework (see §5.2).

2.7 Other research (Objective 3)

This pot-pourri "objective" was made of topics closely related to Exmo's activities, but not necessary standing as main objectives in their own rights. It has been mostly achieved. We report below on three main threads:

Constrained Path RDF Although RDF itself can be used as a query language for an RDF knowledge base (using RDF entailment), the need for added expressivity in queries has led to the definition of the SPARQL query language. SPARQL queries are defined on top of graph patterns that are basically RDF (and more precisely GRDF) graphs. Another way to query RDF graphs is to query for paths expressed by regular expressions holding between nodes (the former allows for full graph branching and cycling as queries, the latter allows for undefined lengths of paths). However, some queries that can be expressed in one approach cannot be expressed in the other: a query whose homomorphic image in the database is not a path cannot be expressed by a regular expression, while RDF semantics is not meant to express paths of unknown length. We have worked at reconciling both approaches.

Alignment argumentation When two independently developed agents want to interact they may not share the same ontologies. In order to reconcile their ontologies, they can take advantage of an alignment service which will provide alignments for the two ontologies. But if the obtained alignment does not suit both parties, it is necessary for these parties, if they want to interact, to negotiate the meaning of terms, or, more modestly, to negotiate the correspondences in alignments. We have investigated the design of ontology matching systems or alignment aggregators based on argumentation theory, i.e., the exchange of arguments and counter-arguments for or against correspondences and the identification of acceptable alignments.

Multimedia document adaptation When a multimedia document is played on platforms with limited resources, e.g., a mobile phone that can only display one image at a time or an interactive display without keyboard, it is necessary to adapt the document to the target device. In order to assess the meaning of adaptation, we have defined a semantic approach, which considers a model of a multimedia document as one of its potential executions (an execution satisfying its specification). In a first approximation, adaptation reduces the set of models of a specification by selecting those satisfying the adaptation constraints. Adapting amounts to finding this subset of models or, when it is empty, finding a compatible execution as close as possible to the initial execution.

There were other tracks in our initial objectives:

– graph-homomorphism transformations has been discontinued after the departure of Jean-François Baget;
– semantic precision and recall has been covered in §2.5.3;
– design of efficient matchers has been frozen due to lack of resources (however, this partially covers the continuous improvement of the Aroma matcher and the development of argument-based matchers).

2.7.1 Personnel

Constrained Path RDF Faisal Alkhateeb, Jean-François Baget, Jérôme Euzenat, Melisachew Wudage Chekol

Alignment argumentation Jérôme Euzenat, Loredana Laera, Cássia Trojahn dos Santos

Multimedia document adaptation Sébastien Laborie, Faisal Alkhateeb, Jérôme Euzenat

2.7.2 Project-team positioning

Constrained Path RDF The work on path-based query language for RDF is related to the work of other INRIA teams, since this work was initiated by Jean-François Baget when he was with Exmo, although it does not seems that Graphik is pursuing this work. It is also related to the work around Corese developed in Edelweiss. Indeed, Corese implements a query engine over RDF, based on conceptual graphs, which incorporates paths. Our main competitors on RDF query languages are J. Perez and C. Guttierez (U. Chile), though, we have different languages (PSPARQL is an extension of SPARQL, nSPARQL is a drastic restriction of it, with no selection and not even all SPARQL graph patterns). It is likely that path graph patterns will be included in the next SPARQL recommendation.

Alignment argumentation Alignment argumentation was initially developed in collaboration with U. of Liverpool with L. Laera. Cássia Trojahn dos Santos further developed this approach while she was working at Evora and VU Amsterdam. Now Cássia joined Exmo and we have further collaborated with Liverpool on this topic.

Multimedia document adaptation This is a joint work with the WAM team (N. Layaïda), it was a follow-up on a former collaboration with Nabil. The main competitors on that type of topic are CWI Amsterdam (L. Rutledge) who investigated rhetorical guide for adapting while our work is based on a semantic view of the document structure (or execution). Related work has been developed at LIRIS (M. Saïd-Hacid, S. Benbernous).

2.7.3 Scientific achievements

Constrained Path RDF as a query language for RDF and RDFS

To benefit from both SPARQL and path queries, we have defined PRDF, for Path RDF [17; 13], an extension of RDF that encompasses regular expressions over relations as labels to the arcs of RDF graphs. PRDF can characterise paths of arbitrary length in a query, e.g., "does there exist a trip from town A to town B using only trains and buses?". In addition, we have extended these PRDF graphs so that they allow for expressing constraints on the nodes, e.g., "Moreover, one of these connections must provide a wireless connection". To express these constraints, we propose an extension of PRDF, called CPRDF (for Constrained Path RDF [26]).
For these two extensions of RDF, we have provided an abstract syntax and an extension of RDF semantics. We characterise query answering (the query is a PRDF or a CPRDF graph, the knowledge base is an RDF graph) as a particular case of PRDF or CPRDF entailment that can be computed using some kind of graph homomorphism. Query answering thus remains an NP-hard problem in all these languages. Finally, we use these PRDF or CPRDF graphs as graph patterns in SPARQL, defining the PSPARQL and CPSPARQL extensions of that query language. We provide the necessary algorithms for computing the answer set to a given PSPARQL or CPSPARQL query and we have implemented them (see §3.2).
We have also proposed a new approach for evaluating queries over a core fragment of RDFS [13]. This approach mainly relies on rewriting any (CP)SPARQL query q into a semantically equivalent CPSPARQL query q' such that the evaluation of q' over an RDF graph G is equivalent to the evaluation of q over the RDFS closure of G. The efficiency of evaluating queries using this approach has been demonstrated through the use of the Lehigh University Benchmark[5] for generating RDFS graphs.
Finaly, we have proposed to use PSPARQL as a basis for a new language for processing alignments [40; 74]. More precisely, we have proposed that for processing expressive alignments generated

[5] http://swat.cse.lehigh.edu/projects/lubm/

by patterns [56] or EDOAL (see §2.4.3), we needed a mix of the rule language SPARQL++ and PSPARQL.

Argumentation over ontology alignments

We have introduced a novel argumentation framework for arguing for and against correspondences found in alignments [49]. This framework is based on previous work on argumentation in multi-agent systems, and especially value-based argumentation, but adapts it to the specific case of arguing about alignments and correspondences. It provides a first typology of arguments that can be applied to correspondences between ontology entities (based on the way the correspondences have been obtained). A preference relation among arguments can be defined with regard to this typology. This relation can be different from agent to agent so that they do not all prefer the same arguments. We have used classical multi-agent argumentation theory in order to characterise what is an acceptable argument for an agent as well as the preferred extensions (of a set of arguments) for a set of agents having different preference relations. We also designed an argumentation protocol for reaching these preferred extensions. We provide strategies for evaluating arguments during the unfolding of the negotiation dialogue. We summarise the state of the art and open issues in [25].
Argumentation does not account for consistency. Hence, the preferred extension may well be inconsistent. We have explored ways to avoid this by involving consistency checking after and within the argumentation process (by recording inconsistency causes as nogood arguments). However, although checking consistency or arguing improves the quality of alignments, their combination does not improve on these results [61].

Semantic adaptation of multimedia documents

We instantiated our approach on semantic adaptation for the SMIL 2.0 language, by adapting SMIL documents in the temporal, spatial, hypermedia dimensions and mixing them [?].
We have extended our adaptation approach [24] with the capability to suppress multimedia objects [46]. For example, a profile may indicate that only a few multimedia objects are allowed in a presentation. When multimedia objects are removed, we forced the adapted document to satisfy properties such as presentation contiguity. We have considered media adaptation Instead of removing multimedia objects [48]. For that purpose, we propose to adapt media items by replacing incompatible media items by others found on the web. The adapted media items must convey the same message as the original ones, while satisfying the target profile. We have presented a possible architecture to implement this and we have shown that search engines can already do it to a limited extent. Nonetheless, some results are unsatisfactory because media annotations lack semantics, are partial and are heterogeneous. Hence, we have proposed to use semantic web technologies, such as RDF descriptions, ontologies, ontology merging and matching, in order to select better alternatives, thus improving this adaptation framework.
We have also considered the use of the author discourse in the context of semantic adaptation [14]. We have shown that specifying some rhetorical relations between multimedia objects, such as “examplified”, may in turn identify implicit spatio-temporal relations between these objects. Hence, using the author discourse structure guides the adaptation process by providing adapted documents which are as close as possible from either the explicit document composition or the author discourse structure.

2.7.4 Collaborations and external support

Constrained Path RDF benefited from a small support from Knowledge web. New work, in collaboration with WAM is supported by an INRIA PhD grant.

Alignment argumentation This work has been developed in collaboration with the U. of Liverpool (L. Laera, V. Tamma, T. Bench-Capon) supported by Knowledge web. Cássia Trojahn dos Santos has been supported by an INRIA post-doctoral grant.

Multimedia document adaptation This work has been made in collaboration with N. Layaïda (WAM).

2.7.5 Self-assessment and perspectives

Constrained Path RDF This work has been ahead of the development of SPARQL. There is currently a new W3C working group considering extensions of the current SPARQL language. Among these extensions, as a "to be added if time permits" feature is the addition of regular paths and this work is among its inspiration. We do not plan to invest more on query languages and rather to use those implementing the standards for processing alignments. We are however pursuing related work on static analysis of path languages for RDF and, in particular PSPARQL, in collaboration with WAM [33].

Alignment argumentation Using argumentation for alignment aggregation is an interesting idea, especially in the context of multi-agent systems. However, this is not the silver bullet for matching ontologies. We do not plan to pursue it intensively.

Multimedia document adaptation The work on multimedia document adaptation is currently stopped due to lack of forces and focussing the team on alignments. There are, however, interesting perspective in designing adapters closer to the semantics of documents.

This third objective can now be transformed into a proper objective of Exmo: we currently see a convergence in the context of data interlinking, i.e., finding new links in linked data. We are currently considering these issues in the context of the Datalift project (see §4). Indeed, interlinking data requires manipulating SPARQL queries and we would like to generate such queries from alignments. This requires expressive alignments because heterogeneity in linked data encompasses both ontology and data values. This query generation process from expressive ontologies for data interlinking raises interesting issues that we plan to consider (see §5.2).

3 Knowledge dissemination

3.1 Publications

	2007	2008	2009	2010	2011	Total
PhD Thesis		3	1			4
H.D.R (*)						
Journal		1	1		3	5
Conference proceedings (**)	8	8	5	10	6	37
Book chapter		2	1		2+1	6
Book (written)	1					1
Book (edited)	4	3	2	2	+1	12
Patent						
General audience papers		1			1	2
Technical report	2	1			2	5
Deliverable	4	2	2	4	1	13

(*) HDR Habilitation à diriger des Recherches

(**) Conference with a program committee

Main journals:

– Journal of web semantics [17]
– Journal on data semantics [19]
– Semantic web journal [18]
– Artificial intelligence
– Journal of artificial intelligence research

Main conferences:

– International Semantic Web Conference (ISWC, ≈20%) [34; 38; 36; 52; 29]
– European Semantic Web Conference (ESWC, ≈18%) [44; 50]
– International conference on Autonomous Agents and Multiagent Systems (AAMAS, 23%) [49]
– Knowledge Representation and Reasoning (KR)
– International Joint Conference on Artificial Intelligence (IJCAI, 15%) [37]

Selected publications:

[1] J. Euzenat and P. Shvaiko. *Ontology matching*. Springer-Verlag, Heidelberg (DE), 2007.

[17] F. Alkhateeb, J. Baget, and J. Euzenat. Extending SPARQL with regular expression patterns (for querying RDF). *Journal of web semantics*, 7(2):57–73, 2009.

[18] J. David, J. Euzenat, F. Scharffe, and C. Trojahn dos Santos. The alignment API 4.0. *Semantic web journal*, 2(1):3–10, 2011.

[36] J. David, J. Euzenat, and O. Sváb-Zamazal. Ontology similarity in the alignment space. In *Proc. 9th international semantic web conference (ISWC), Shanghai (CN)*, pages 129–144, 2010.

[37] J. Euzenat. Semantic precision and recall for ontology alignment evaluation. In *Proc. 20th International Joint Conference on Artificial Intelligence (IJCAI), Hyderabad (IN)*, pages 348–353, 2007.

3.2 Software

	A	SO	SM	EM	SDL	OC DA-CD-MS-TPM	loc
Alignment API	3up5	4	4	4	4	4	22k
OntoSim	2	4	3up4	3up4	4	4	7k
Aroma	2	4	3	3	4	4	4k
PSPARQL	1	4	2	1	4	4	
IDDL	1	4	1	1	4	4	

Alignment API and server, Software library and toolbox, the Alignment API and server is composed of a format for expressing alignments, an API for manipulating (generating, parsing, rendering, trimming, evaluating) these alignments, a library implementing this API and a server for sharing and storing alignments on the web. This API provides a high level of interoperability between systems providing and requiring alignments. It has been adopted by many developments around the world, both by team implementing matchers and teams manipulating them, and is used in the Ontology Alignment Evaluation Initiative. It is distributed since 2003 under the LGPL license and current version is 4.2. http://alignapi.gforge.inria.fr.

OntoSim OntoSim is an API dedicated to the computation of distances between ontologies and ontology entities. It constrains all ontology-space and alignment-space measures proposed in [34] and [36]. It also provides measures used for matching ontologies and supports the development of new measures. In particular, it provides methods for aggregating similarity matrices. It also comes with a set of distances (string, objects, collections). It is written in JAVA, distributed since 2009 under the LGPL license and current version is 2.2. http://ontosim.gforge.inria.fr.

Aroma AROMA is an ontology matcher made of an association rule discovery algorithm and several string-based similarities. This algorithm has the originality to produce both equivalence and subsumption correspondences. It has the advantages to run fast and to scale to large ontologies (several thousands of concepts). It has been integrated in the ITM commercial software developed by Mondeca. AROMA is written in JAVA, distributed since 2009 under the LGPL license and current version is 1.1. http://aroma.gforge.inria.fr.

PSPARQL Query evaluator, This query evaluator can parse SPARQL, PSPARQL and CPSPARQL queries, parse RDF documents written in the Turtle language, evaluate the query and then return the answer set. It is a research prototype showing the possibility of implementing the PSPARQL and CPSPARQL languages that we designed. It can serve as a reference implementation. License: Cecill-B. http://exmo.inrialpes.fr/software/psparql.

IDDL Reasoner, The IDDL Reasoner is a theorem prover in the distributed description logic IDDL [92]. It takes as input a network of ontologies and can decide if it is consistent; it can also decide if a correspondence is a consequence. It is a research prototype demonstrating our work on IDDL. http://iddl.gforge.inria.fr/

Research Infrastructure

NeOn toolkit: http://www.neon-toolkit.org/ is an extensible ontology editor created by the NeOn project. Exmo provides the Alignment plug-in based on the Alignment API and server for the NeOn toolkit. It has been used both inside and outside of the project.

WebContent platform: http://www.webcontent-project.org/ is a software platform integrating tools necessary to exploit the semantic web for market watch. Exmo provides the ontology alignment service of the WebContent platform based on the Alignment API and server.

3.3 Valorization and technology transfert

The software that we develop is distributed under open source licenses. This allowed some success in the many adopters of these software.
In terms of technology transfer, we collaborated with the Mondeca company to develop a Terminology Alignment Environment on top of their terminology management system (ITM). For that purpose the Alignment API and part of its implementation has been embedded in ITM by Mondeca. The projects also embedded within the environment a version of our Aroma matcher specifically tuned for matching thesauri. This projects gave us the opportunity to tests our tools on large multilingual thesauri and to develop specific strategies (yet unpublished).
Meaning Engines is a start-up company founded by François Scharffe and other partners whose goal is to use the web of data principles for integrating product catalogs. It plans to use the result of our work on automated link detection based on ontology alignments.

Consulting Activities

– Consulting visitor for the EDGAR project, ISEP, Porto (PT), Jérôme Euzenat, 2008;

3.4 Teaching

Supervision of educational programs

- Jérôme Euzenat: coordinator of option "intelligence artificielle" of Master research program 2nd year (M2R) Mathematics and informatics (UJF & INPG, 2005-2007);
- Jérôme Euzenat: coordinator of option "web intelligence" of Master research program 2nd year (M2R) Mathematics and informatics (UJF & INPG, 2007-2008);
- Jérôme Euzenat: coordinator, with Éric Gaussier, of option "artificial intelligence and the web" of Master research program 2nd year (M2R) Mathematics and informatics (UJF & INPG, 2008-2011);
- Jérôme David: coordinator, with Julie Dugdale, of option "Web, Informatique et Connaissance" of Master "Ingénierie de la Cognition, de la Création, et des Apprentissages" (UPMF & UJF & INPG, 2011-);

Jérôme Euzenat has been member of the ad hoc committee on the future of computer science research master (UJF-INP) in 2007.

Teaching

When indicating a year span, it means that we have been involved in each academic year of this year span.

Name	Course title (short)	Level	Institution	Hours (eqTD)	Academic Years
Jérôme Euzenat, Jean-François Baget	Connaissance, web, sémantique	M2R MI	UJF-INPG	24	2006-2007
Jérôme Euzenat	Ontology matching	advanced	UPMadrid	10	2007-2008
Jérôme Euzenat	Ontology matching	advanced	summer school	4	2007, 2008, 2009, 2011
Jérôme Euzenat	Web sémantique	M2R MI	UJF-INPG	9	2008-2009, 2009-2010, 2010-2011
Jérôme David	Plate-formes de développement Web	M2 DCISS & ICPS	UPMF	30	2008-2009, 2009-2010, 2010-2011
Jérôme David	Développement Web mobile	M2 DCISS & ICPS	UPMF	30	2008-2009, 2009-2010, 2010-2011
Jérôme David	Interfaces Homme-Machine	M2 DCISS & ICPS	UPMF	30	2008-2009, 2009-2010, 2010-2011
Jérôme David	Outils Informatique	L1 socio.	UPMF	2*24	2008-2009, 2009-2010, 2010-2011

Jérôme David	Bases de données relationnelles	L2 MIASS	UPMF	55	2008-2009, 2009-2010, 2010-2011
Jérôme David	Développement mobile - streaming	Lpro MIAM	UPMF IUT2	20	2008-2009
Jérôme David	Développement mobile	Lpro MIAM	UPMF IUT2	25	2009-2010, 2010-2011
Jérôme David	Introduction à Java	Lpro ESSIG	UPMF IUT2	24	2010-2011

3.5 General Audience Actions

- Paper in *IEEE Intelligent systems* [74],
- Paper in the *Bulletin de l'AFIA* about the semantic web [73],
- Talk on *Semantic web technologies for document management (Technologies du web sémantique pour la gestion documentaire)* at the IN'Tech technology watch club, Montbonnot (4/12/2008),
- Talk on *Improved access to EU content through thesaurus matching* at the OPOCE Eurovoc Workshop, Luxembourg (LU) (18/11/2010),
- Talk on *Interlinking the web of data: challenges and solutions* at the 5th Semantic days, Oslo (NO),(9/06/2011)

3.6 Visibility

Managment of Scientific Organisations

- *Semantic Web Science Association* (steering committee for the ISWC conference series), Jérôme Euzenat is founding member, 2001-;
- *Steering committee of the LMO conference series*, Jérôme Euzenat, 2004-;
- *European Academy for Semantic web Education* (EASE), Jérôme Euzenat has been member of the "Scientific advisory board" and a founding member, 2006-2009;
- *Scientific Steering Committee of the "European Semantic Web Conference Series*, Jérôme Euzenat, 2006-2008;

Editorial Boards

- *Journal of web semantics*, Jérôme Euzenat, 2004-
- *Journal on data semantics*, Jérôme Euzenat, 2004-
- *Semantic web journal*, Jérôme Euzenat, 2011-

Organisation of Conferences and Workshops

- *Asian semantic web conference*, Jérôme Euzenat, general chair, 2008;
- *Context and ontologies* workshop, Jérôme Euzenat, 2007, 2008;
- *Ontology matching* workshop, Jérôme Euzenat, 2007, 2008, 2009, 2010, 2011;
- *Ontology Alignment Evaluation Initiative*, Jérôme Euzenat, 2007, 2008, 2009, 2010, 2011;
- Atelier *Passage à l'échelle des techniques de découverte de correspondances*, Jérôme Euzenat, 2007;
- Atelier *Intelligence artificielle et web intelligence*, Jérôme Euzenat, 2007;
- *Plate-forme AFIA*, Faisal Alkhteeb, Sébastien Laborie, Antoine Zimmermann, 2007;

Program committee members (conferences only)

- *International conference on knowledge engineering and knowledge management (EKAW)*, Jérôme Euzenat, co-programme chair, 2008;
- *International Semantic Web Conference (ISWC)*, Jérôme Euzenat, 2007, 2008, 2009, 2011; Jérôme David, 2009; Cássia Trojahn dos Santos, 2009, 2011;
- *International Joint Conference on Artificial Intelligence (IJCAI)*, Jérôme Euzenat, 2009, 2011;
- *European Semantic Web Conference (ESWC)*, Jérôme Euzenat, 2007, 2008;
- *European Conference on Artificial Intelligence (ECAI)*, Jérôme Euzenat, 2010;
- *Worldwide Web Conference (WWW)*, Jérôme Euzenat, 2009, 2010, 2011, 2012;
- *(US) National conference on AI (AAAI)*, "AI and the web" track, Jérôme Euzenat, 2007, 2008, 2011;
- *International conference on Mobile Web Information Systems (MobiWIS)*, Jérôme David, 2011;
- *International Conference on Conceptual Modeling (ER)*, Jérôme Euzenat, 2008, 2011;
- *ACM conference on Knowledge capture (KCap)*, Jérôme Euzenat, 2011;
- *Formal Ontologies for Information Systems (FOIS)*, Jérôme Euzenat, 2008, 2010, 2012;
- *International and Interdisciplinary Conference on Modeling and Using Context (Context)*, Jérôme Euzenat, 2011;
- *International Conference on Artificial Intelligence: Methodology, Systems, Applications (AIMSA)*, Jérôme Euzenat, 2008;
- *International conference on knowledge engineering and knowledge management (EKAW)*, Jérôme Euzenat, 2010;
- *Brazilian Symposium in Information and Human Languages Technology (STIL)*, Cássia Trojahn dos Santos, 2011;
- *Reconnaissance des Formes et Intelligence Artificielle (RFIA)*, Jérôme Euzenat, 2008, 2010;
- *Langages et Modèles à Objets (LMO)*, Jérôme Euzenat, 2008;

International expertise

- *Evaluator for FP7 European projects, DG INFSOMEDIA*, Jérôme Euzenat, 2011;
- *Panelist in the European Commission Knowledge and content research unit FP7 brainstorming meeting (Luxembourg, LU)*, Jérôme Euzenat, 2009;
- *Expert on WWTF (AT) grant applications*, Jérôme Euzenat, 2008;
- *Expert for ISF (IL) grant applications*, Jérôme David, 2009;
- *Expert on NWO (NL) grant applications*, Jérôme Euzenat, 2009;
- *Expert on SNSF (CH) grant applications*, Jérôme Euzenat, 2010;
- *Expert on FCT (PT) grant applications*, Jérôme Euzenat, 2011;
- *Expert on SFI (EI) grant applications*, Jérôme Euzenat, 2011.

National expertise

- *AERES visiting committee for LORIA and INRIA Lorraine*, Jérôme Euzenat, 2008;
- *Expert on OSEO industry grant applications (FR)*, Jérôme Euzenat, 2008;
- *Evaluator on ANR CONTINT grant applications*, Jérôme David, 2009;
- *Evaluator on ANR Verso grant applications*, Jérôme Euzenat, 2010
- *Recruitment committee Université de Pau* professor position 510, Jérôme Euzenat, 2009; *Recruitment committee of University of Rennes 1* for the assistant professor position 27MCF1058, *of Grenoble-INP* for the assistant professor position 27MCF674, Jérôme Euzenat, 2010

4 External Funding

<table>
<tr><td>(k euros)</td><td>2007</td><td>2008</td><td>2009</td><td>2010</td><td>2011</td></tr>
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<tr><td>ARC†</td><td colspan="5"></td></tr>
<tr><td>LSIA‡</td><td colspan="5"></td></tr>
<tr><td colspan="6">National initiatives</td></tr>
<tr><td>ANR WebContent</td><td>15</td><td>15</td><td>15</td><td colspan="2"></td></tr>
<tr><td>ANR DataRing</td><td colspan="2"></td><td colspan="3">travel (LIG)</td></tr>
<tr><td>ANR Datalift</td><td colspan="3"></td><td>36</td><td>36</td></tr>
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<tr><td colspan="6">European projects</td></tr>
<tr><td>FP6 Knowledge web</td><td>70</td><td>70</td><td colspan="3"></td></tr>
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<tr><td>FP7 SEALS</td><td colspan="2"></td><td>55</td><td>110</td><td>110</td></tr>
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<tr><td>OntoCompo</td><td></td><td colspan="3">travel</td><td></td></tr>
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<tr><td colspan="6">Industrial contracts</td></tr>
<tr><td>Mondeca/OPOCE</td><td colspan="3"></td><td>40</td><td></td></tr>
<tr><td colspan="6">Scholarships</td></tr>
<tr><td>PhD *</td><td colspan="2"></td><td>.5</td><td>1</td><td>1</td></tr>
<tr><td>Post Doc*</td><td colspan="2"></td><td>1</td><td>.5</td><td></td></tr>
<tr><td>AI+</td><td colspan="5"></td></tr>
<tr><td>ODL#</td><td colspan="5"></td></tr>
<tr><td>Total</td><td>175</td><td>175</td><td>160+1.5</td><td>186+1.5</td><td>146+1</td></tr>
</table>

† INRIA Cooperative Research Initiatives

‡ Large-scale Initiative Actions

∗ other than those supported by one of the above projects

+ junior engineer supported by INRIA

engineer supported by INRIA

The funding has been estimated roughly from the grant amounts and length of projects. A more detailed distribution would not provide more information while being more difficult to collect (and not less questionable). We do not request additional funding (dotation) from INRIA or another partner (to be safe: less than 2kEuros/year all partners included). A further rough estimate shows that $\frac{2}{3}$ of this money is spend for hiring post-doc, PhD students and other interns, $\frac{2}{9}$ is dedicated to travelling and $\frac{1}{9}$ to computer equipment.

National initiatives

WebContent (ANR-RNTL, 2006-2009). Project partners involve INRIA Gemo (now Leo), LIG Hadas, CEA, EADS, coordinated by CEA. The project is dedicated to the development of an open platform for exploiting semantic web technologies in searching and managing information; We are more specifically in charge of subtask 3.2 dealing with ontology matching. We are integrating the Alignment server and new matching algorithms to the WebContent platform. http://www.webcontent.fr/

DataRing (ANR, 2009-2011). Project partners involve LIRMM, Telecom ParisTech, INRIA Zenith and LIG Hadas/Exmo. DataRing investigates peer-to-peer data sharing for online communities. We are concerned with the issue of trust in such systems. http://www.lina.univ-nantes.fr/projets/DataRing/.

Datalift (ANR-Contint, 2010-2013). This project led by INRIA/Exmo involves 7 partners: INRIA (Exmo and Edelweiss), LIRMM, Eurecom, IGN, INSEE, Mondeca, Atos and Fing. The goal of the project is to develop a platform to publish and interlink datasets on the Web of data. Datalift will both publish datasets coming from a network of partners and data providers and propose a set of tools for easing the data publication process http://www.datalift.org.

European projects

Knowledge web (FP6 NoE 2004-2008, FP6-507482) Network of excellence on the semantic web. There were 19 partners led by the university of Innsbruck (AT). Among the INRIA partners were Acacia (now Edelweiss) and Orpailleur. Exmo was leader of the Heterogeneity work package and served as vice-scientific director (Jérôme Euzenat). This network has structured semantic web research in Europe and for our concern driven the work on ontology matching. http://knowledgeweb.semanticweb.org/

NeOn (Networked ontologies, FP6 IP IST, 2006-2010), 14 partners coordinated by Open university (UK). NeOn is dedicated to the development of an environment covering the whole lifecycle of networked ontologies. Exmo is working on the alignment support aspect of netwoked ontologies. We provided our Alignment server and various means to use it (NeOn toolkit plug-in and Cupboard integration) and we investigated context-based matching and distributed reasoning. http://www.neon-project.org

SEALS (Semantic evaluation at large scale, FP6 Infrastructure, 2009-2012), 10 partners coordinated by Universidad Politecnica de Madrid (ES). SEALS develops a lasting reference infrastructure for semantic technology evaluation and organises the continuous evaluation of semantic technologies at a large scale via public world-wide evaluation campaigns. Exmo is in charge of the Ontology matching evaluation work-package and Jérôme Euzenat is vice-project coordinator. http://www.seals-project.eu

Associated teams and other international projects

STAR (Ontology distances for semantic social networks, PHC STAR, 2009-2011). The project is a cooperation between Exmo and Yeungnam university (Gyeungsan, South Korea) for designing ontology distances that can be used for computing measures in semantic social networks.

OntoCompo (cooperation FACEPE-INRIA, 2008-2011) designs modular ontology models and software support. It involves Exmo and partners at Universidade Federal de Pernambuco and Universidade Federal de Santa Catarina.

Cameleon (Collaborative and Automatic Methods for the Multilingualisation of Lexica and Ontologies; cooperation CAPES-COFECUB, 2010-2014) involves LIG/Getalp-Exmo and the Universidade Federal de Rio Grande do Sul. We are more especially interested in multilingual matching in this project.

Industrial contracts

Mondeca/OPOCE contract (2010-2011) Exmo has been subcontractor of the Mondeca company in a project for the OPOCE (the office for the official publications of the european union) which aimed at developing a matching environment for thesauri. Exmo's role has been the integration of the Alignment API technology within Mondeca's thesaurus edition environment and the development and evaluation of new matchers adapted to thesauri matching.

Other funding,

Web Intelligence (Région Rhône-Alpes grant, 2006-2008-2011) Regional research network involving seven Rhône-Alpes laboratories working on Web and artificial intelligence led by LIRIS and École nationale des mines de Saint-Étienne. http://www.web-intelligence-rhone-alpes.org/

5 Objectives for the next four years

5.1 Self-Assessment

We think that Exmo has been successful in shaping the field and leading the work on ontology matching these past years. We have written the reference book on the topic [1], we organise the well-attended OAEI evaluation campaigns, we have papers at the best conferences on the topic (ISWC, IJCAI, AAMAS, ESWC), and we develop software which is well used. We also have good papers out of the field of ontology matching (SPARQL, ambient computing, document adaptation). Globally the team, of only two permanent people, is well regarded and the PhD students that we have trained have reached a good visibility.
We are involved in large European projects (Knowledge web, NeOn, SEALS) and ANR project (Datalift). This strategy, beside providing resources, allows us to collaborate with very good teams in mid term projects. This also helps to involve our students on the international scene. The constraints and burden associated with such projects are real, but so far, so good.
We faced difficulties for finding adequate people at all levels (PhD students, post-doctoral researchers, professors). At the moment, it is far easier for us to hire post-doctoral students than permanent people or PhD students. This is a problem because good post-doctoral fellow tend to quickly find more permanent position that we do not succeed to offer them.
We have enough topics to address during the next four years to employ a few more members. However, the effort must apply to permanent positions and doctoral students, before post-doctoral researchers. Doing otherwise would threaten the viability of the project.

5.2 Perspectives for the research team

Exmo aims at building on its strengths in order to increase its contribution and impact to the field of ontology matching and alignment and the semantic web at large. For that purpose, we propose to organise our work of the next years in three lines which extends the current objectives:

Alignment foundations

On the foundation side, our ambition is to consider three specific topics:

Semantic of network of ontologies Our goal is to develop further the semantics of networks of ontologies. In particular, we aim at considering two research directions: (i) using the semantics for defining what a peer in a peer-to-peer system can know depending on the initial knowledge of the peers, the query language used and the alignment language considered, and (ii) developing the principles of revision in network of ontologies, i.e., what happens when a new correspondence or an ontology modification makes the network inconsistent.

Algebraic manipulation of alignments We currently have a view of alignment composition based either on the full semantics of network of ontologies or a "naïve" view of relations. The use of algebras of relations offers a formal intermediate position. Hence we want to fully define the possible operations on alignments, including composition, reasoning and combining alignments.

Distances between ontologies Until now our work has been limited to alignments only composed of equivalence correspondences. By taking advantage of our works on algebraic manipulation of alignments and semantic evaluation measures, we want to propose computable generalisations of our alignment space measures able to capture more precise relations. We also plan to investigate agreement and disagreement between ontologies proposed by M. d'Aquin. We want to reconsider them in order to reintroduce alignments at the core of the measures and replace the currently syntactic compatibility comparison by more semantic ones, e.g., entailment and consistency as well as weaker notions such as entailment through composition and integrity constraints. This should also provide the opportunity to compare the measures with C. Meilicke's coherence measure (based on the semantics of ontologies). We plan to experiment with these measures in matchers.

Alignment infrastructure

As usual, we want to push the theoretical work within the semantic web infrastructure in order to support applications and to improve our support to alignment management [23].

API improvement We aim at integrating all results of the first objective within the Alignment API (and OntoSim for the last item). This will require two major redesigns: integrating algebras of relations at the core of the API, and integrating better reasoning mechanisms within the API. Under the pressure of application using it (see Applications and Objective 3), we will certainly make EDOAL evolve.

Alignment services for ambient computing We will further improve the Alignment server and mobile library so that applications could use them easily In particular, we want to better integrate SPARQL query generation and manipulation from EDOAL to support mobile and peer-to-peer systems (see Objective 3).

Evaluation of matchers The work on matching evaluation shall continue through SEALS and OAEI. OAEI is constantly evolving: as matcher capabilities evolve, new modalities are introduced (multilingual matching, non equivalence alignments). Two years ago, we have introduced evaluation of instance matching (aiming at linked data), but there is place to more consensual improvement in this matter. We are also working on automatic generation of new test sets allowing to generate network of aligned ontologies by applying both alterations and transformations on a source ontology. This will allow us to more precisely parameterise the hardness of tests to generate.

Exploitation and data interlinking

The third objective is consolidated into one precise direction relying on previous developments. Its goal is to help using alignment in applications and especially in application to linked data [55].

We are planning to apply and extend our expertise in ontology matching to linked data co-reference resolution, i.e. for determining whether different URIs refer to the same entity.
So far, the development of transformations has only been carried out on simple (URI-to-URI) alignments. There are applications in which such alignments are not sufficient. We already knew it for semantic web services, but this is now clear for data interlinking. We are already experiencing this in the context of the Datalift project and colleagues in Southampton are using EDOAL for that exact same purpose. To be used in data interlinking, alignments must be expressive and a language such as EDOAL is needed. Moreover, SPARQL is the common language for processing data. Hence, we need to provide adapted EDOAL to SPARQL transformations that can be used for extracting data and eventually generating links [60]. These same manipulation techniques may be used for extending the type of semantic peer-to-peer systems that we are currently able to consider.
This raises various interesting issues for alignment manipulation. The first natural issue is to guarantee that the EDOAL to SPARQL transformation will indeed extract the described set or to characterise what approximations have been made. For instance, if data is extracted for applying a link generation algorithm, it may not matter if more data is extracted. Another issue is related to minimality: if several correspondences may apply to the same piece of data, it should be guaranteed that their application link the same object. This type of problem has been investigated in database schema mapping. It is also related to the problem of confluence in rewriting systems (we want that the order of the transformations does not influence the result).
In order to treat this problem in full, it is necessary to deal with query or correspondence comparison. We are currently investigating the static analysis of RDF manipulation in cooperation with the WAM team [33].
This work will be partly developed in the context of the ANR Datalift project and more precisely with U. Montpellier (F. Scharffe).

Other issues

Better matchers. We would like to build better matchers investigating several paths among which context-based matching in which the matcher takes advantage of resources external to the ontologies, reasoning about alignments for improving them, multilingual thesauri matching [63], and pattern-based matchers in which matching patterns are used for guiding matching [56]. This could be based on our existing OLA and Aroma matchers.
However, this can only be achieved if substantial resources are dedicated to these tasks. As long as such resources are not available, we cannot plan to develop these aspects.
Applications. On the application side, the semantic web is slowly making progress. We would like to contribute to the adoption and dissemination of semantic web technology more broadly. In fact, we would like to deliver it in everybody's pocket. For that purpose, we are planning to curve Exmo's trajectory towards ambient and mobile applications [43] that we have already considered (see §2.6.3).
This would happily be achieved through an appropriate European project. We have had marks of interest from the field of ambient intelligence for energy efficient buildings [99], so this may be a context in which to develop this work.

This should keep us busy for the next four years. After this, we expect that the most challenging problems to be considered will revolve around the dynamics of networks of ontologies (how they preserve coherence while evolving).

6 Bibliography of the project-team

Most of our papers are available at ftp://ftp.inrialpes.fr/pub/exmo/.

6.1 Books and Monographs

Monographs

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Book editing

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6.3 Articles in referred journals and book chapters

Journals

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