Perspectives in Knowledge Formalization for Scientific Collaborative Research: the case of Plastic pollution in the sea

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Abstract. Collaborative scientific research is based on sharing observations and resources. This implies some form of convergent cognition and mutual understanding, which is often not easy to achieve especially when researchers come from different disciplinary background, but also when they work in the same domain but live within different paradigms. To support and ease these activities, we propose to embed boundary objects into web based collaborative software. Boundary objects are artifacts, such as graphs, maps, software, abstract or concrete objects that being weakly structured in a common use, while strongly structured in individual use, facilitate communication between multiple social worlds. We report on how boundary objects can be implemented in a collaborative software by means of graphic maps derived from an ontology that at the same time formalize knowledge, allow implicit meaning to emerge from how data, information and communication is spontaneously organized by users, and link to controlled vocabularies widely recognized by the designated communities.

Keywords: collaborative research, knowledge formalization, boundary object, RDF, Plastics at sea.

1. Introduction

Current vision in knowledge formalization stems mainly from a machine-to-machine oriented approach. In that perspective, computers negotiate contents and process information to solve practical problems using categories and concepts linked to human thought. This is very effective, for example, when databases with different structures need to share data; in this case, data models are compared and mapped in order to find a bridge between the various environments while preserving the core set of the needed information. In our everyday life, we encounter examples of this, every time we buy something on the web or book a hotel or flight. This approach is generally called web semantics, in the sense that it has to deal with the meaning of concepts and categories, or ontology, since it formalizes the inner structure of reality.

A vast literature reminds us that “the world out there” cannot be easily reached, then attempts to understand and therefore formalize reality are generally

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unlikely to be effective. On the other hand, in capturing the meaning of a concept we often hit the very basic problem that different people use different connotations for the same term. "Nomina nuda tenemus" [15] and therefore meaning is in usage. Since the goal of this work is actually to delve into "human-to-human" collaboration in the sciences, which is a contingent and unstable process relying on agreements, we should probably swap the term semantics with the term pragmatics. Agreed concepts can be formalized, but often parts of them reside in opaque areas that resist to emergence and explicitation. We will describe the approach we took and the tools we are developing to address such problems.

2. Foundations of collaborative work in scientific research

2.1. Reasoning

Scientific reasoning lived a two-fold life in the last century. On one hand modern epistemology and sociology of science unveiled the many inconsistencies that the traditional scientific method is based on [32,5,17,20,27,12,14], on the other hand, researchers simply did not care and continued to apply the methods they were familiar with. These separate lives went along quite well, leaving philosophers in the academia and scientists in the lab until the necessity to use collaboratively scientific data, information and knowledge irrupted in the picture. Facing the increasing complexity of many scientific topics, researchers have preferred, in the past, to focus on narrow fields only. Specialization leads to the development of isolated knowledge niches, where concepts and language (in a word, culture) tend to speciate similarly to what happens with animals that develop different features when some kind of natural barrier keep communities separated. In fact, following Kuhn [25], researchers live within what he calls "paradigms". These are mental environments built upon backgrounds, traditions, practices and schools. They are wrapped around theories, supported by small communities, that defend their beliefs from falsification, changing, when needed, only peripheral and marginal hypotheses [26]. Soon cultures lose their overlap and, such as in the case of the Babel tower, people cannot understand each other anymore. Eventually, in different contexts, the same term gets divergent meanings. This is not acceptable anymore, since new scientific challenges need multidisciplinary approaches. This is particularly evident, for example, in the domain of environmental protection, where, disciplines such as Chemistry, Physics, Biology but also Economy and Sociology are often invoked at the same time. This subverted the classic vertical distribution of efforts in a team of researchers towards a more horizontal perspective where roles and responsibilities become interdependent and diffuse. To limit the above-mentioned issues and overcome possible misunderstanding induced by scientific cultures speciation, we advocate the need of some kind of explicit formalization of knowledge that, at the same time, could be able to preserve the necessary flexibility to cross different domains and backgrounds.

2.2. Forms of formalization (the many lives of formalization)

Knowledge can be formalized in many ways and to different depths. We suggest considering a progression in the row from explicit formalization to implicit representation, discussing three possible solutions.

1. Ontologies.
2. Controlled vocabularies.
3. Data, information and knowledge stored into graph nodes.

Ontologies allow to specify a domain of knowledge. They allow computation and reasoning, and are, in fact, used in machine to machine semantics. A vast literature exists on the application of ontologies in scientific knowledge formalization, such as, to name a few: The Foundational Model of Anatomy [38] or the Gene Ontology [2]. In biology ontologies have been used extensively, for example, to perform cross-species comparison [37]

Being very strict, ontologies reach their limit when they try to describe something that cannot be made fully clear. Together with the above-mentioned issues related to scientific reasoning in general, in fact, a big problem in knowledge formalization, and in particular when human-to-human interaction is expected, is the fact that a considerable part of any knowledge simply cannot be made explicit, because it is embedded in practices or tools, so that a part of it will always remain obscure. Quoting Polany [31] "we know more than we can say", and therefore we know more than we can formalize. This is called "tacit knowledge".

The impact of paradigms and tacit knowledge on formalization depends on many factors, but in general, it can be said that, the more detailed the formalization, the more it will be prone to contrasting opinions and misunderstanding. This means that when reasoning, classification or computation is required the effects of paradigms and tacit knowledge will be relevant. On the contrary when concepts are described more generically, the effects of paradigms and tacit knowledge will have less impact because will be somehow dampen by usage. For example, considering the case of a spoon, even if it is not defined as made of wood or metal, it will remain a spoon since it will be used to eat a soup.

Controlled vocabularies organize knowledge in a less strict way. They can be structured, emphasizing relationships between and among concepts such as in the case of a thesaurus, or they can be un-structured such as in the case of a simple flat term lists. Their purpose is to provide terminologies to catalogs. What is relevant here is that they restrict the usage of a term upon a definition that should be authoritative. This means that either this is the product of the undebatable opinion of a worldwide renown scientific personality, or it should be the outcome of the convergence of a community. In the first case imposing a vision can induce disaffection in the proposed solution, a phenomenon called community melt-down. In the second case, as we said before, it is not trivial to achieve a convergence, since issues such as reasoning, practices, traditions and even economic interests tend to create barriers between and within communities. Now, even in the case when the relations between a term and others can be structured such as, for example narrow term/broader term etc., a term definition is based eventually on natural language. Notwithstanding the fact that the aim of a vocabulary is to be as clear as possible, natural language can effectively accommodate different opinions blurring the inconsistencies between different positions. Controlled vocabularies can then embed implicit meaning.

The third case we wanted to explore is that when knowledge formalization takes place as a graphic map where nodes/concepts are containers of knowledge in the form of data, diagrams, annotations and messages in general. Node names here are essentially labels of concepts/entities that are implicitly defined by what the node contains. In these cases, probably, it would be better to use the term representation, instead of the term formalization. Following Callender, and Cohen [7] representation is prone to omission and commission, where omission is the act of neglecting some possible causes among those that can explain a phenomenon and commission is the act of deliberate change brought to the network of possible causes and explanations of a phenomenon. Representation therefore can be considered a partial or skewed projection of knowledge formalization. Representation produce artifacts enabled to "store" knowledge. These artifacts can be images, models, graphs, workflows or even any verbal description. A very important characteristic that representation carries, is that its artifacts allow multiple interpretation at the same time. Each user can project on it his/her point of view and therefore see different things. For example, following Suchman [40] a map is a formal construction that can, but not necessarily does, control activities, as a traveler's map: "does not control the traveler's movements through the world," rather describes how to go from one place to another.

The assonance with representation in the arts, is not only casual then, but reasonable, as in the arts the role of the artist is central in shaping reality and the product of art is the vision of the artist, but at the same time art consumers are free to construct their experience upon what they perceive.

Likewise, representation is central also in education for its capacity to pack and transmit knowledge that resonate in learners. [11] highlights the symmetries between collaborative scientific research and learning, as they are both knowledge building processes in heterogeneous environments.

Experiences in knowledge formalization that follow this approach, have been reported, in several scientific disciplines and study cases, by [13,12,33,36].

2.3. The concept of Boundary object

In the late nineties, Star and Griesemer [39] introduced the concept of "Boundary object". This is an artifact that allows people from different cultures to interact effectively. The notion was developed in the area of ethnography, to explain why and how people from communities that have nothing in common, can eventually understand each other and work together. The idea was later applied to study communities of scientists, highlighting the need of such approach to understand scientific collaborative research. Boundary objects are weakly structured in a common use and become strongly structured in individual use. They contain sufficient details to be understood by one partner, although it is not necessary that he/she understands the context, in which the other partners use it. They are artifacts related to sets of information, conversations, interests, rules, or plans, and are at the center of communities of practices [14].

Boundary objects able to formalize/represent concepts, ideas, theories, processes and contexts, could be then the cornerstones of any modern collaborative research. How can a boundary object be implemented then?

We propose to integrate all the three types of formalization mentioned above. In detail we propose to use: an ontology as a backbone, presenting to end users a graph that represents (omitting and committing) the ontology in order to help reducing the cognitive overload, and providing links between graph nodes/terms/concepts to controlled vocabularies. In addition, each node of the graph will then act as a container of information providing to the node itself implicit meaning from its usage.

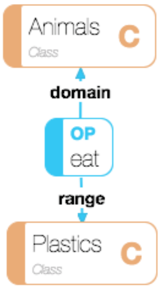

Fig. 1 Graph of a triplet, where Animals is the subject, plastics is the object and eat is the predicate

3. Implementing Boundary objects

3.1. Representing ontologies as a map

Ontologies can be built and shared using the Resource Description Framework (RDF). RDF inner structure is based on triples, that are statements that express the relationship between a subject and an object by means of a predicate. Triples can be plotted in a graph. For instance, such as in the example of Figure 1, the class “Animals” is the domain on which the predicate “eat” applies, while the class “Plastics” indicate the range to which the predicate “eat” applies.

Nodes in the graph can stand for anything: word objects, ideas or even something that does not exists such as in the triple: “Nihilism shot the sheriff” (generated with the nonsense generator, http://nonsense.x2d.org). They can be seen as labels to concepts that receive meaning from the relations with other entities, from the possibility to append a definition to the term, and in general from the use made of them. And in this sense, they match the aim of boundary objects. Collaborative work insists on some topic that refers to a domain of knowledge that can be represented by means of an ontology. The corresponding graph/map can be pretty complex but at the same time is very useful to understand exactly where the user is. In order to reduce cognitive overload, it is possible to subset the overall graph into smaller RDF graphs, which allows also to produce context-specific or community-specific views. In the example of Figure 2 it is proposed to have a simpler subset of the ontology (upper box) that graphs the expression: “DegradationFactors degrades Plastics”. This considers only part of the phenomenon. If we enter further into details, the graph shows what types of plastics can enter in the process (lower part of the graph in figure 2). For some users such detail is not useful and can be hidden while for other users this can be important.

All these graphs share the same ontology but depending on the situation subsets of it can be shown or not.

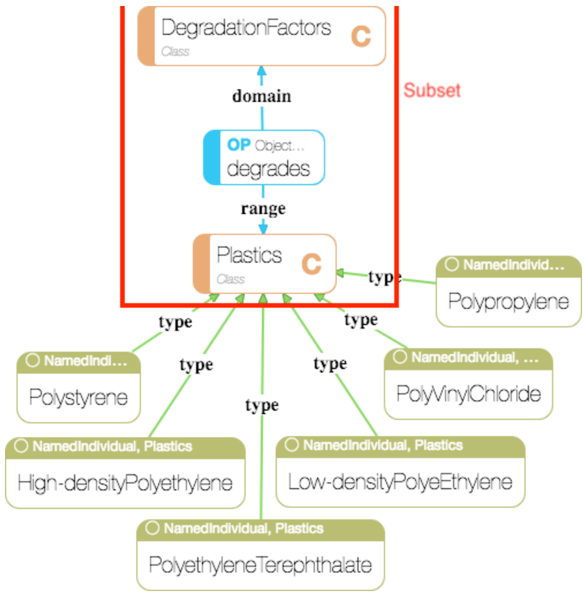

Fig. 2 Context dependent subsetting of an ontology

The ontology provides, then, a common space for different points of views and contexts. When this approach is implemented the resulting system meets the flexibility criteria required to create a boundary object and will be therefore eligible to support human-to-human collaborative work.

3.2. Linking nodes to human-defined natural language definitions

Nodes can also be defined by linking them to a controlled vocabulary, where a human readable definition can be located. If this, on one hand, can sound very convenient, at the same time, as a consequence of what said above, can revert to be problematic. In fact, for human readable definitions to be effective, they should be the result of an agreement within a community. Since multiple, possibly contrasting, visions should be forced in a single definition, this typically results in very generic descriptions that are supposed to satisfy everyone and eventually satisfy no one.

Notwithstanding this in the case study proposed here, we made every effort to embed as many controlled terms/concept/nodes definition as possible. Sources for such definition of course cannot be ourselves but need to be well recognized vocabulary

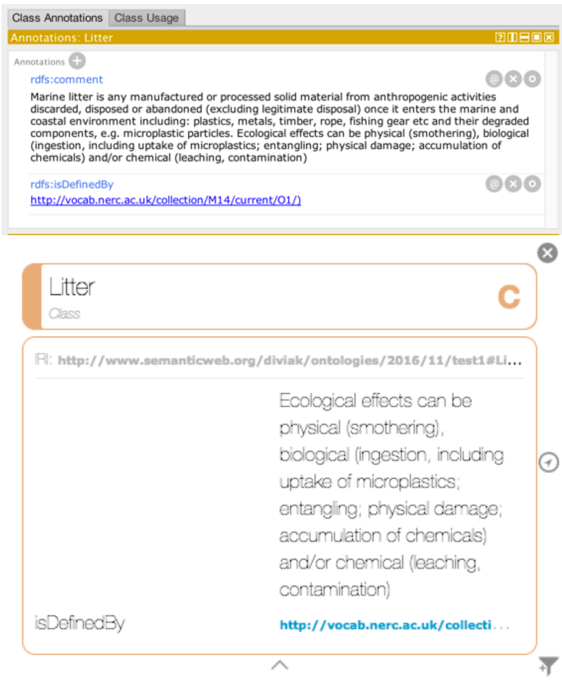

Fig. 3 (top) Entering term definition and URL in Protégé. (bottom) Term definition and URL in a graph node

servers that aggregate large communities of practices. Details on the references we used are mentioned later. Term definitions can be entered as rdfs:comment while URLs, that is where the on-line definitions can found, can be entered in the rdfs:isDefinedBy element of the nodes of the ontology.

3.3. Bypassing explicitation

Together with the definitions provided by the predicates associated with a node, and the possible definitions provided by a controlled vocabulary, nodes can be defined implicitly by their usage if we gather within them the data, information and knowledge that define them. This can be achieved if a data management system and a communication service is integrated with the graph so that every node collects everything that could be associated with it. The end user, then, selecting a node on the graph, will be able to access files, data or messages that pertain to that specific entity. Previous experiences in using graphs as boundary objects in collaborative research can be found in [14,12].

The easiest way to gather information into the nodes and therefore implicitly define them from their usage, is to let the users upload files and send messages from within the nodes themselves. In a way, initially, nodes are empty containers that later acquire signification upon the activities of the users. All the prototypes cited before were based on this approach, and in those cases the structure of the map was purely graphical and no computation was devised. On the contrary, switching to RDF would allow the introduction of some interesting possibilities such as easier ways to query/redistribute information across nodes/classes and reasoning.

3.4. COLLA

COLLA is a web-based collaborative tool developed to gather data information and knowledge to support collaborative scientific research. The central tenet of the portal has been that end users are enabled to navigate a graph/map that represents the structure of a collaborative work. Each project has its own map. Following the pragmatic approach described in [14], the nodes of the graph are just labels for concepts that are defined by what they contain. Within each node, partners can upload files, documents or scientific data (Figure 4 top) and refer to them within COLLA's messaging system (Figure 4 bottom). The latter is a very simple tool that allows to write, send messages to all the other partners enrolled in the project and organize the discussion in threads. Messages are not only kept within the portal but also sent via e-mail with a specific format of the subject e-mail field, that allows partners to easily sort them on their mailer application. In addition, the message text contains a "magic link" (a Web link containing several parameters and keys to log in automatically) that allows the user to be driven inside the discussion thread directly from his mailing system, without the need to log-in or search any topic.

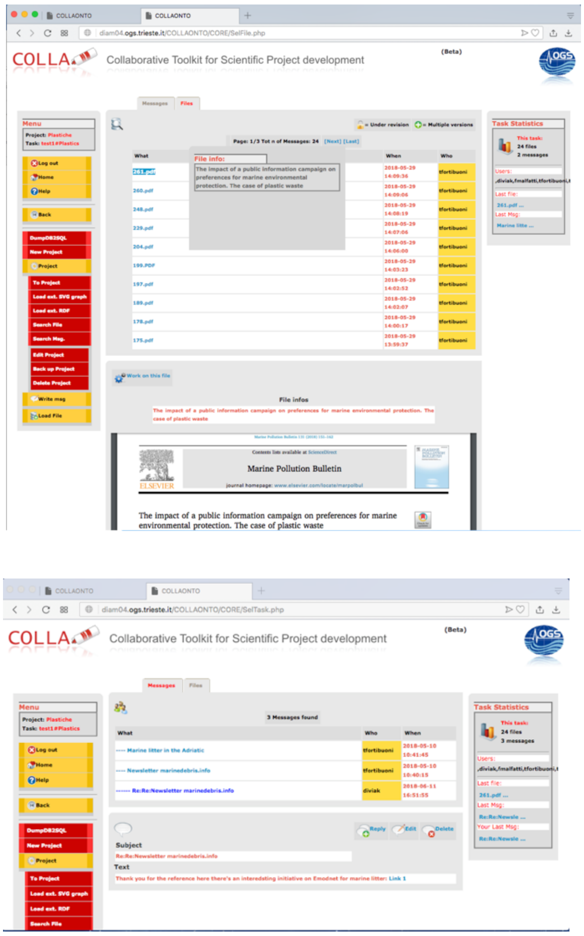

Figure 4 (top) COLLA files repository/visualization and (bottom) messaging tools

3.5. Integration of Ontodia in COLLA

Ontodia API has been integrated in COLLA so that it is possible to directly upload an RDF file and create and configure automatically a collaborative space. RDF files are produced externally generally using Protégé (https://protege.stanford.edu/). Classes, Instances and Properties are associated to nodes such as are data repositories and messaging threads. This is done using Apache Jena Fuseki (https://jena.apache.org/) which is a SPARQL endpoint that supports SPARQL 1.1 protocol and the SPARQL Graph Store protocol.

The system is deployed as a java web-application (WAR archive) into the web servlet container Tomcat (http://tomcat.apache.org). The Fuseki web application offers a SPARQL endpoint and an intuitive web interface to manage (query and update) the triples store configured for it. Fuseki is integrated to use TDB (transaction triple store) and also single RDF files.

Ontologies are uploaded in COLLA through a specific uploading service that creates for each node a discussion space using an ID which name is the node URI itself; the ID is used to load the COLLA topic-oriented discussion page. Once this is done the RDF is made available to Fuseki copying it into the Fuseki space and updating the Fuseki configuration using a specific service definition; this allows the service name to be used in the URL endpoint in order to point to the wished ontology.

Eventually, the Javascript Ontodia libraries are loaded directly into the web page from the Ontodia site, and the HTML page is extended in order to use Ontodia API to create a new workspace (Figure 5) using the endpoint customized for the specific (2 previous steps) project in use; in particular, further to the API to initialize the workspace, the API to import the ontology can be used as is for loading the remote ontology objects with no graph plotted or adding a previously saved Ontodia graph internal status (in JSON format) in order to initialize the workspace with remote ontology objects and the saved graph plotted.

A graph can be built/plot selecting the needed nodes, from a list, and dragging them to a central graph canvas (Figure5a). Automatically all properties are drawn among nodes, showing the predicates and classes that link and add meaning to them (Figure 5b and c). Clicking on the node an URL is shown that can be used to navigate to the files and messages repository (Figure 5d). Following such web links it is possible to re-use the previous COLLA e-mail based message notification system.

Multiple graphs can be designed within the same project (subsets of the overall ontology).

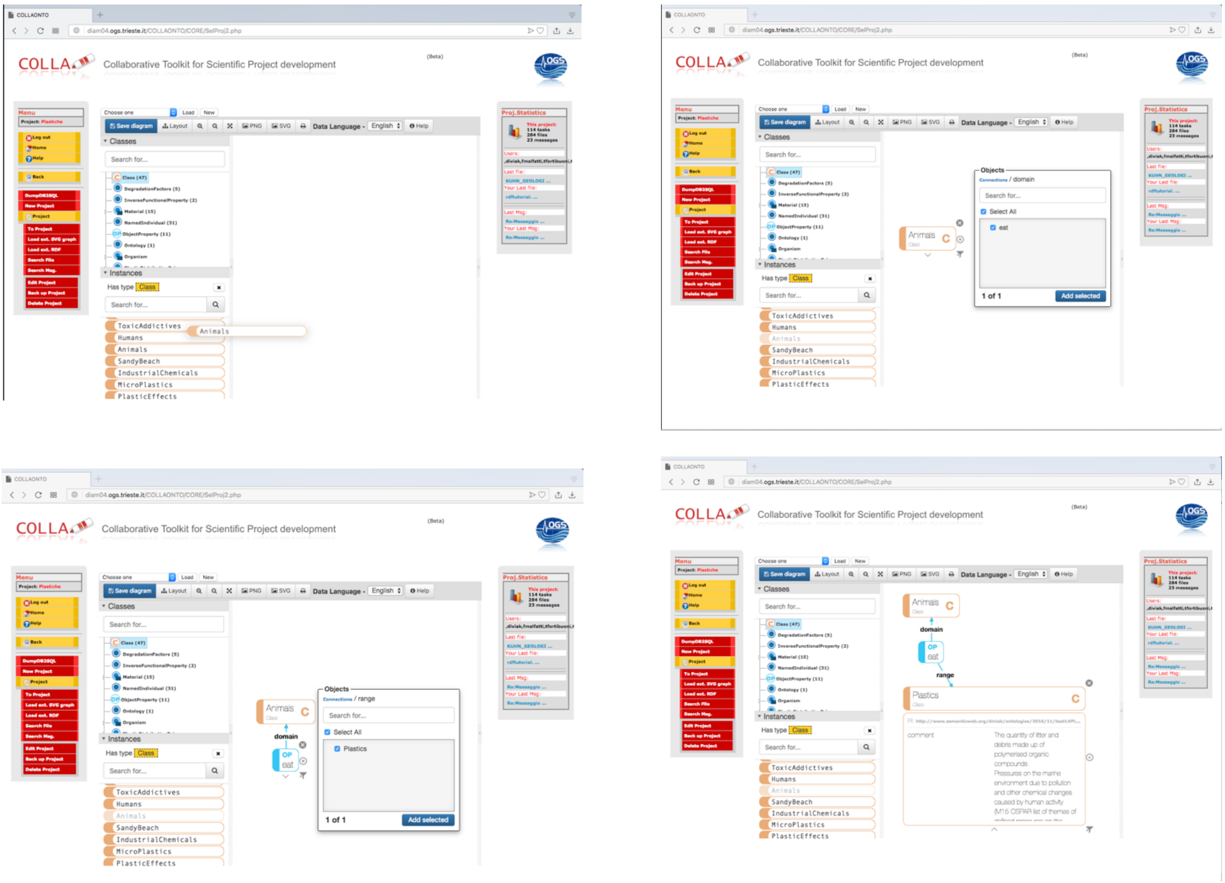

Figure 5 Building a graph in COLLA out of the uploaded ontology: (a) classes are drag and dropped on the canvas and (b) relations to the other classes or properties can immediately be seen and (c) added to the graph. Multiple graphs can be built out of the same ontology to distinguish context specific workspaces, while each node retain the same information across them(d).

Each of them can refer to a different or overlapping set of nodes so that eventually the links to the repositories and messaging facility will be the same. However, the map shown and the relations/predicates that will describe the nodes in such graphs can be different. This could be important if we try to provide different maps to different contexts while retaining the overall mass of information.

A simple application can be, for example, to provide detailed maps for experts that will discuss a very specific topic while less detailed maps for those who need just a quick overview.

4. Case study

4.1. The issue of plastics

Plastics are synthetic organic polymers invented approximately 110 years ago that are now almost omnipresent in every aspect of our lives (e.g. clothing, food, buildings, appliances, communication, transportation, medicine, etc.). Plastics contamination in the marine environment was first reported in the 1970s [24,6], less than two decades after the rise of commercial plastics production. Originally considered harmless, evidence is accumulating on the threats associated with plastic pollution, particularly in the oceans where breakdown of plastics is slow, effects on wildlife are grave, and removal is hard [44].

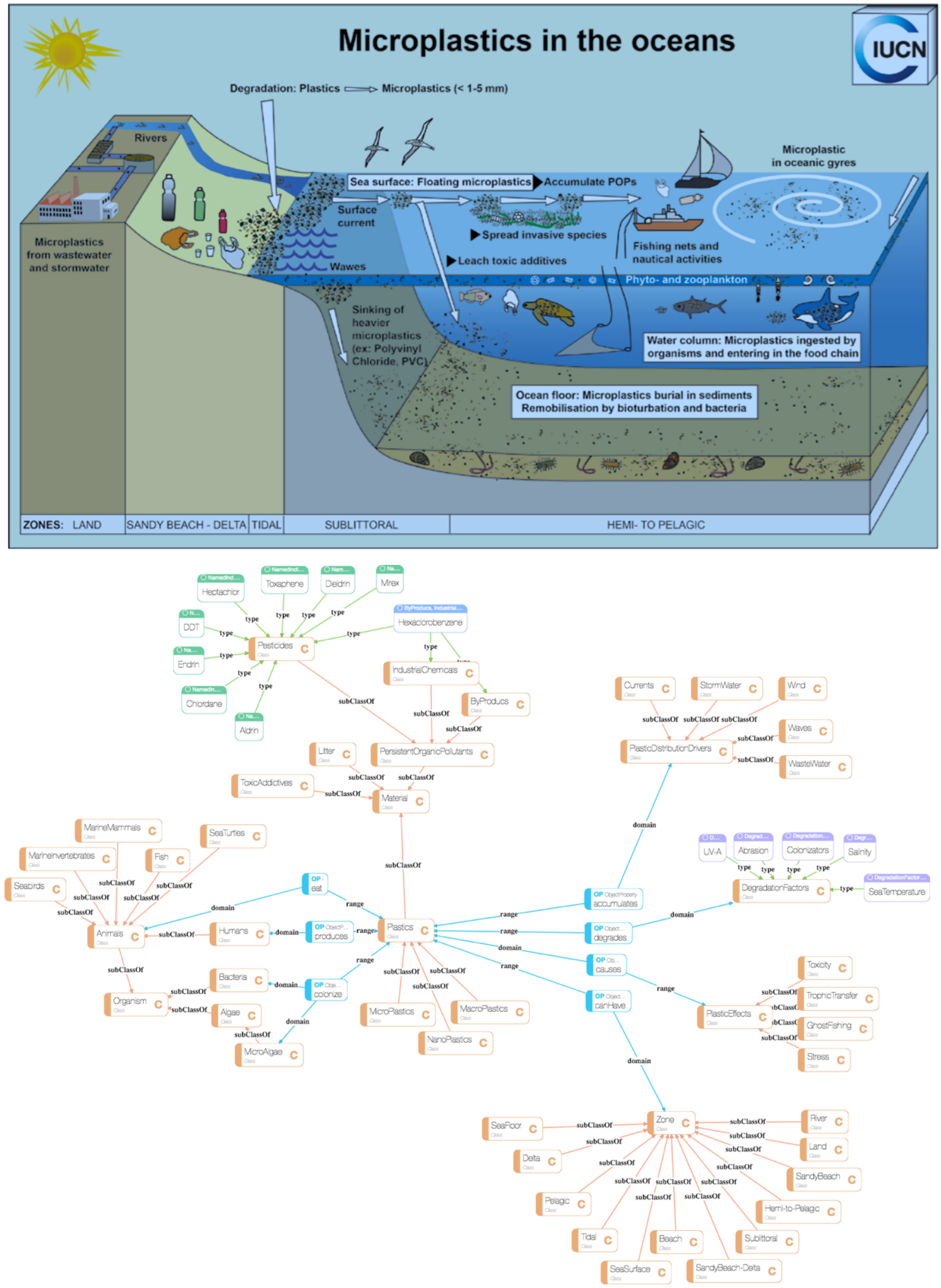

Fig. 6 Microplastics in the oceans: conceptual model from Thevenon et al., 2014 (top panel) used in building the ontology graph (bottom panel)

Conventional plastics do not easily biodegrade in the marine environment due to their high molecular weight and lack of natural analogues and may just disintegrate physically due to salinity, temperature, UV exposure and biological alteration [19]. However, in the oceans (in particular in the deeper waters), these processes are very slow because mechanical and photolytic forces are greatly diminished [43]. Most plastic polymers have inherently low toxicity due to their insolubility in water and because they are biochemically inert. However, all plastics are made of monomer chemicals (e.g. styrene or vinyl chloride) and additives that are toxic and carcinogenic [10,34].

Toxic additives are used to change material properties in desired ways, and include flame retardants, plasticizers that modulate texture, colouring agents and antimicrobials. These substances may present health risks for marine organisms and humans through the consumption of seafood [34].

Some plastic items are lighter than seawater and thus can travel long distances before sinking [8], whereas others are heavier and directly sink to the bottom [18] Thus, plastics can be found floating on the sea surface [16], deposited on beaches, or sank on the seafloor.

Plastics can be classified by size class: nanoplastics (< 1 μm), microplastics (1 μm–5 mm), and macroplastics (> 5 mm). Microplastics can be produced as such (primary microplastics), for example as plastic pellets and microbeads in facewash and toothpaste, or via mechanical breakdown of larger plastic items (secondary microplastics).Microplastics are colonized by marine microbes [46], can adsorb and vehiculate pollutants (e.g. Persistent Organic Pollutants – POPs; [4]) and can be eaten by marine organisms (from plankton to marine mammals, see a review in [18]) and transferred to higher trophic levels and ultimately also humans. Also macroplastics pose a direct risk to marine organisms (seabirds, fish, sea turtles, marine invertebrates, marine mammals), mainly through entanglement and ingestion. Toxic effects of plastics on marine species are less commonly demonstrated than entanglement and ingestion [18], even if experimental studies demonstrated toxicological impacts from these materials [34].

4.2. An ontology for plastics at sea

The figure from Thevenon [42] (Figure 6 top panel), has offered the perfect example to develop an ontology for plastics in the ocean (Figure 6 bottom panel). Humans are producing plastics, that derive from the petrol industry. There are different kind of plastics for instance: polyvinyl chloride, polyethylene terephthalate, polypropylene, polystyrene, low-density polyethylene. These enter the aquatic environments directly or via the wastewater and the riverine runoff water systems. Once the plastics reach the ocean it can be washed on shore or continue drifting in the high seas. According to the prevailing winds and currents plastics can accumulate in specific areas of the ocean (gyres). At the same time, plastics is altered and degraded by UV, salinity, temperature and biology (e.g. biofilm formation). Plastic can become smaller in size thus becoming an integral part of the pelagic food web. According to the chemical structure and of its age, plastics can sink at the bottom of the ocean thus affecting also the benthic food web. Consequently, plastics affect all biota living on land, in the river, on the tidal zone, in the sublittoral and hemi-to-pelagic zones. Plastic presence has been detected in all the oceans, from the surface to the deep sea of both populated and remote areas. Plastics can accumulate POPs (POP, persistent organic pollutants), spread invasive species that are attached to the plastic fragments and can leach out toxic chemicals. Tourism, fishing (e.g. clogging of the fishing net) and nautical activities (e.g. propeller clog) are also affected beside ecosystem health and human health.

In building the ontology we started from the central element: plastic. Then we defined the type of plastic materials, the plastic size distribution that can be found in the ocean and its associated entry points. Furthermore, we identified the degradation pathways once the plastic is in the ocean and how the plastic interacts with biology and its effect on maritime activities.

Regarding the issue of linking terms/nodes to human-defined natural language definitions, in the case of plastics at sea we used the NERC-BODC Vocabulary server (https://www.bodc.ac.uk/resources/products/web_services/vocab/). Content governance of the vocabularies is very important and is done by a combined SeaDataNet (https://www.seadatanet.org) and MarineXML Vocabulary Content Governance Group (https://www.iode.org/index.php?option=com_content&view=article&id=21&Itemid=60), moderated by BODC, and including experts from many international groups.

4.3. Discussion

To test the capabilities of the developed system we built a knowledge-base on the issue of plastics in the ocean to foster collaborative research on this emerging societal challenge. We built a multidisciplinary vivid team to populate the nodes with relevant literature, linked data and message exchanges.

After a first evaluation of the system, users identified and reported several strong points together with some limitations.

Among the positive aspects, users confirmed the usefulness of having a single but flexible and constantly updated space where all information can be located. They highlighted the importance of having a graphic map that routes them in finding the information they need, which confirmed that the perspective we are adopting fits our purpose.

It seems also that the community is strengthened by the fact of having a single space to identify with, and we expect that this can result in easier convergence of ideas within a team/community.

Among limitations that have been reported, the fact that the current implementation does not provide any connection to social media such as Facebook, Twitter, WhatsApp and the like. Something that is requested, but currently is not available, is a search facility that can be run across nodes. And in this direction another serious issue reported by users is the fact that it is very difficult, currently, to move data and information across nodes.

5. Future Work

COLLA is a constantly evolving project that needs to confront with emerging technologies and leverage new opportunities in proofing its core idea of using a graph as a boundary object to ease collaboration among scientists. Limitations to the current version have been identified and we are already working to address them.

Among the new features that we'd like to introduce in COLLA, we find very interesting the possibility to suggest, to users working in a node, contents from neighbor nodes, a practice known as "recommending" or as commonly can be found in e-commerce the classic "you might be also interested in.." web link. Following Airoldi [1], Recommender systems co-construct social imaginary and shape cultures, we are committed to find a recommendation mechanism that will not bias researchers activity, this, possibly, could become another mean to help communities converge on shared meaning and understanding.

Another feature we would like to introduce in COLLA is text extraction. This essentially will mean to extract metadata and text contents from the multiple types of files uploaded by users in the system. After text extraction, terms/keywords could be compared with those listed in a controlled vocabulary in order to tag documents. This would allow to make a huge leap forward since there will be no more the need to upload files in specific nodes but it will be the system to organize itself autonomously upon the terms used in the ontology, albeit this could introduce other forms of bias in the system. This will also solve a serious problem of the current system, that is the difficulty to move contents across nodes.

From a non-technical point of view, we would like to extend the communities of practice that, so far, used the system, to include different stakeholders such as marine biologists, chemists, oceanographers, fishery managers, policy makers and educators.

6. Conclusions

The main objective of this work was to introduce ontology-based knowledge formalization as a boundary object to ease collaborative work in scientific research. This is recognized to be particularly important when multidisciplinary work is envisaged.

Previous work already pointed the issues and needs of such cases and highlighted on one hand the limitations of collaborative systems based on pure graphical concept maps, and on the other hand, the difficulties of controlled vocabularies in being authoritative across multiple domains.

We demonstrated that the situation can be improved considerably by integrating all 3 types of knowledge formalization in a single collaborative space and namely: (I) a backbone graphic map based on an ontology where users can find nodes that (II) act as containers of information and provide (III) links between terms and controlled vocabularies.

We are confident that our collaborative environment approach can complement effectively e-Research: a new perspective where the life of researchers will be augmented through on-line interaction, communities and knowledge.

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