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glossaLAB: Co-Creating Interdisciplinary Knowledge

José María Díaz Nafría[1,2], Teresa Guarda[2,3], Mark Burgin[4], Wolfgang Hofkirchner[5], Rainer Zimmermann[5,6], Gerhard Chroust[2,5], Simone Belli[7]

[1] Madrid Open University, Madrid, Spain | jdian@unileon.es
[2] BITrum-Research Group, León, Spain
[3] Universidad Estatal Península de Santa Elena, Ecuador
[4] University of California, Los Angeles, CA, USA
[5] Institute for a Global Sustainable Information Society, Vienna, Austria
[6] Institute for Design Science, Munich, Germany
[7] Universidad Complutense de Madrid, Madrid, Spain

Abstract. The paper describes the glossaLAB international project as a contribution to confront the urgent need of knowledge integration frameworks, as required to face global challenges that overwhelm disciplinary knowledge capacity. Under this scope, glossaLAB is devised to make contributions in three main aspects of such endeavor: (i) development of a sound theoretical framework for the unification of knowledge, (ii) establishment of broadly accepted methodologies and tools to facilitate the integration of knowledge, (iii) development of assessment criteria for the qualification of interdisciplinarity undertakings. The paper discusses the main components of the project and the solutions adopted to achieve the intended objectives at three different levels: at the *technical level*, glossaLAB aims at developing a platform for knowledge integration based on the elucidation of concepts, metaphors, theories and problems, including a semantically-operative recompilation of valuable scattered encyclopedic contents devoted to two entangled transdisciplinary fields: the sciences of systems and information. At the *theoretical level*, the goal is reducing the redundancy of the conceptual system (defined in terms of "*intensional performance"* of the contents recompiled), and the elucidation of new concepts. Finally, at the *meta-theoretical level*, the project aims at assessing the knowledge integration achieved through the co-creation process based on (a) the diversity of the disciplines involved and (b) the integration properties of the conceptual network stablished through the elucidation process.

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Keywords: Knowledge Co-creation, Knowledge Integration, Systems Sciences, Information Studies, Interdisciplinarity, Transdisciplinarity.

1 The co-creation of knowledge in historical perspective. Problems and Challenges.

As a consequence of the constant development of information and communication technologies, the capacity to interact in an ever stretching milieu of data, information and knowledge producers offers a constantly evolving landscape of knowledge acquisition and creation, characterized by new possibilities and challenges.

In both ancient and modern perspectives, knowledge has been primarily seen as an individual activity. Indeed, it is the Platonic soul which acknowledges the eternal forms, and the Cartesian cogito which offer the first pillar of certainty. However, since the past century several views conceive knowledge as a social activity which is primarily carried out through social interaction [20]. In the case of the strong constructivist perspective, reality itself "is both revealed and concealed, created and destroyed by our [social] activities" [18, 2]. But even in the most classical tradition, in which the role of the individual plays the crucial part in the unveiling of reality, the importance of social interaction in the construction of knowledge has also been stressed throughout times. The Academy and the Lyceum, the medieval schools and universities, the Royal Society and the Republic of Letters, the Saint Simonians and the Positivist Schools, represent a few but highly relevant examples of institutionalized social relations for the development of knowledge in the most classical traditions. Therein, the communication, exchange and confrontation of ideas (as it happens for instance in the platonic dialectics) is fundamental to the creation of knowledge. Thus, it is possible to speak generally of co-creation of knowledge mediated by networks of knowledge agents, the same who develop the network of concepts used for the representation of reality (or, as the radical constructivist would rather state, the construction of reality) [7].

Yet the qualification of knowledge agents and relations (i.e. adequate interactions) in the process of justification of truthful believes is significantly different in each tradition.[1] In the historical development that leads to the constitution of positivism, it is the individual agent that follows the basic principles of the scientific method and adheres to the basics of her discipline who properly creates new knowledge in her domain and field of expertise. Here the assumption that our questioning of reality can be analytically broken down (which is in the core of modern epistemology since Descartes) provides a basic guiding for the structuring of knowledge networks: a treelike structure may suffice [7]. Aristotle himself provides a master guide to deploy the tree of knowledge through the posing of appropriate questioning: from the most general categories to the more specific ones, the endeavor of knowledge can be articulated in branches whose nodes are disconnected from other nodes at the same level [1, 15]. When the knower or a group of well-connected knowers end up, so to say, at the level of the leaves, it is possible to relink, in a synthetic effort, the parts which were previously divided in the analytical moment, grasping the tree in its full unity. This synthetic moment which was actually appreciated in the Cartesian epistemology [14], was unfeasible when the analytical mode was generalized from an individual researcher to science

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[1] In the case computer science, Millo and Lipon offers an interesting discussion about the social process involved in the justification of belief, particularly with respect to mathematics [32].

as a whole, as it particularly happened in the 18th century. The path to the division of science into specialized disciplines was the natural consequence, despite the concerns stated by a few, and in particular, by Leibniz' caveat against breaching the necessary unity of science [15]. From the network perspective, the tree-like-structured disciplines started to be further apart, reducing the interaction among them. In the nineteenth and twentieth century, this division of science into separate disciplines grew to a much larger degree as the positivist tree of knowledge keep on growing.

1.1 Knowledge co-creation in network perspective

The network perspective offers a suitable framework to analyze the problem of co-creation and integration of knowledge, as some of the authors have argued elsewhere [9, 10]. To this purpose, it suffices to draw on the abstract network, which is just comprised of a set of nodes and links [3, 8]. Indeed, the definition of *conceptual systems,* provided in another contribution to this volume [4], as a set of concepts and relations between them, is actually a network theoretical definition. However, as suggested above, the network perspective enables us to map not only the network of concepts (fig. 1.a), but also the networks of knowledge agents (fig. 1.b) as two sides of the same coin. This can be better seen for knowledge within a given discipline.

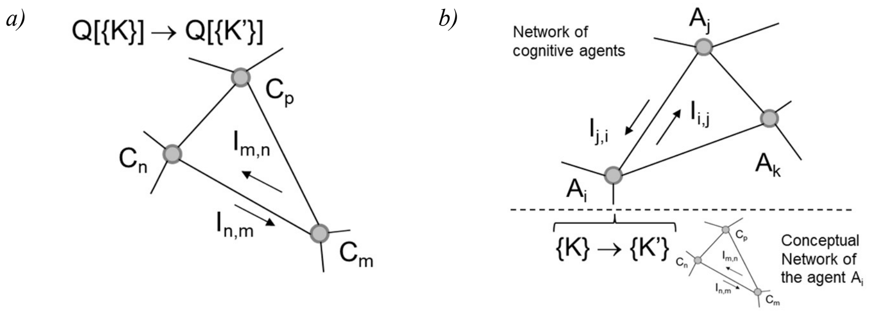

Fig. 1. Dynamics of the conceptual network evolving as: a) passive network of concepts; b) active network of interacting peers.

The dynamics of disciplinary knowledge correspond to the evolution of the *conceptual network* and, at the same time, the evolution of the interaction among the scientist whose joint undertaking corresponds to the continuous process of falsification, verification, and theoretical re-structuration [28]. Therefore, the knowledge of a discipline and its evolution can also be expressed by means of the communicative interaction among scientists, which can be mapped by an actor network [8]. The conceptual network is internalized by every peer, though in a slightly differ way. At the same time, the conceptual network as a whole can be taken as the one comprising the predicative relations supported by the community. A parallel representation of the passive network of concepts, on the left, and the active network of agents (peers), on the right, is represented in fig.1. The (individualized) conceptual networks, mostly shared by all peers, is represented at the lower part of the agent network. K→K' represents the evolution of individual knowledge, while Q{K}→Q{K} represents the evolution of knowledge qualified by the scientific community. The situation is different when we step out of a single discipline.

1.2 The challenge of reconciling scientific disciplines

As referred above, the process of fragmentation of the scientific enterprise derived from the epistemological groundings of modernity had as a consequence that the tree-like-structured disciplines started to be further apart. Hence, the interaction among disciplines and their respective conceptual networks was gradually reduced.

The concerns regarding the consequent mutilation of fundamental relations through the process of fragmentation of the reality under-study emerged since the second half of the twentieth century [21]. Appeals for reunification of science arose in different arenas caused by the necessity to address the fundamental complexity of the reality and the problems to be solved. The emergence of systems science, cybernetics, information theory, and the broad quest for interdisciplinarity belong to this trend [19, 3].

The relevance of this concern can also be observed in the pleas made by international institutions, as UNESCO and OECD, since the 1970s to merge scientific disciplines into integrated frameworks. However, despite the national and international endeavours to boost interdisciplinary research in the past decades, several barriers have significantly blocked its establishment. According to several studies, the most relevant barriers correspond to the lack of: (i) appropriate theoretical frameworks, (ii) broadly accepted methodologies and (iii) assessment criteria for interdisciplinarity [19, 6, 15]. As shown below, these constitute the main problems addressed by glossaLAB project.

As discussed in [9], the situation is actually different in the various trends to integrate scientific knowledge. According to UNESCO's classification [21], there is a gradation of theoretical integration that goes from the mere juxtaposition of disciplines in *multi-disciplinary* settings, whose conceptual networks stay apart from each other, to *trans-disciplinary* setting which "assumes conceptual unification between disciplines" and the sharing of a consistent conceptual network at a higher level of abstraction, as it is the case of systems science. The diverse situations in between correspond to *interdisciplinarity* of different degree.

The network perspective (and Fig.1 in particular) can also be applied to represent the case of interdisciplinarity. To this end, we can add a level of abstraction in the network of agents, taking as an agent one entire discipline. In this case, the conceptual network among disciplines is more heterogeneous than among disciplinary peers. However, if a good transdisciplinary setting is achieved, the corresponding conceptual network will be of a higher level of abstraction. The communication between disciplines (agents) will be mostly done using the more abstract conceptual network, while disciplinary concepts are used within the cluster of peers (abstracted as a single agent).

In intermediate situations, most of the communication will be done within the clusters of peers, while the interaction between clusters will be less dense and less consistent. The lack of interdisciplinary understanding among interacting disciplines results in the relative disconnection among the corresponding clusters. The structural properties of the conceptual system reveal, as we will see in sec.3, its capacity to integrate knowledge. In sum, the network representations of knowledge systems and communities can be used as a proxy for the qualification of the integration of knowledge in interdisciplinary settings.

2 Project glossaLAB: background and objectives

GlossaLAB project stems from several endeavours to provide a more robust toehold to the unification of knowledge through the strengthening of the *general studies of systems and information*. These fields offer in themselves a broad framework for the unification of knowledge in virtue of the conceptual abstraction of systems, information and related concepts with respect to the nature of the reality involved (which can be of physical, biological, social, technological or symbolic nature) [25]. However, the development of disciplines within the broader field of information and systems has resulted in the deployment of conceptual networks and perspectives which are not fully consistent (*ibidem*).

As it was essayed in the encyclopaedic projects which conforms the background of glossaLAB project, the establishment of good foundations for the integration of knowledge implies tackling, on the one hand, the challenge to reduce the distance within the network of related knowledge agents, on the other, the distance within the network of concepts. Just two sides of the same problem [9, 25].

More specifically the **goal** of the project is stated as "the development of an interactive open platform for conceptual elucidation and its application to the interdisciplinary co-creation, learning, dissemination and assessment of the knowledge underpinning interdisciplinary frameworks (in particular, the general study of systems and information). This development comprises: at the *technical level*, the semantically interoperable recompilation of valuable scattered encyclopedic contents; at the *theoretical level*, the reduction of conceptual redundancy (defined in terms of "*intensional performance*" of the contents recompiled) and the further elucidation of concepts; and at the *meta-theoretical level*, the assessment of knowledge integration based on diversity and conceptual network integration". The solutions adopted at these three levels will be shown in sec.3.

2.1 Facilitating the co-creation of knowledge

The way to achieve project objectives takes the form of developing the *Encyclopaedia of Systems Science & Cybernetics Online* (ESSCO) using the corpus of the *International Encyclopedia of Systems and Cybernetics* [16], the *Principia Cybernetica* [21] and *glossariumBITri* [10]. Among the methodological groundings it is worth mentioning the concept of *interdisciplinary-glossaries* developed within BITrum project as elucidation tools devoted to the clarification of concepts, methods, theories and problems in interdisciplinary settings, which at the same time are used as proxies for the evaluation of the related knowledge integration [9].

Underneath ESSCO, glossaLAB is also devised to host other focused *interdisciplinary-glossaries* devoted to specific research and innovation projects and frameworks. A subsidiary integration of these interdisciplinary-glossaries implies that those articles sufficient general as to become of general interest for the study of information and system can escalate to the level of ESSCO.

According to the aforementioned complementarity between the conceptual network and the agent network, the purpose of strengthening the capacity of systems science for the integration of knowledge implies not only analyzing and fortifying the network of concepts, but also the network of agents. Therefore, one of the dimensions of the projects concerns the development of communication and impact mechanisms linked to the glossaLAB platform for knowledge co-creation.

Figure 2 offers an overview of the project as a whole, highlighting the flow of content from the corpus to the glossaLAB platform and from here to other dissemination pathways.

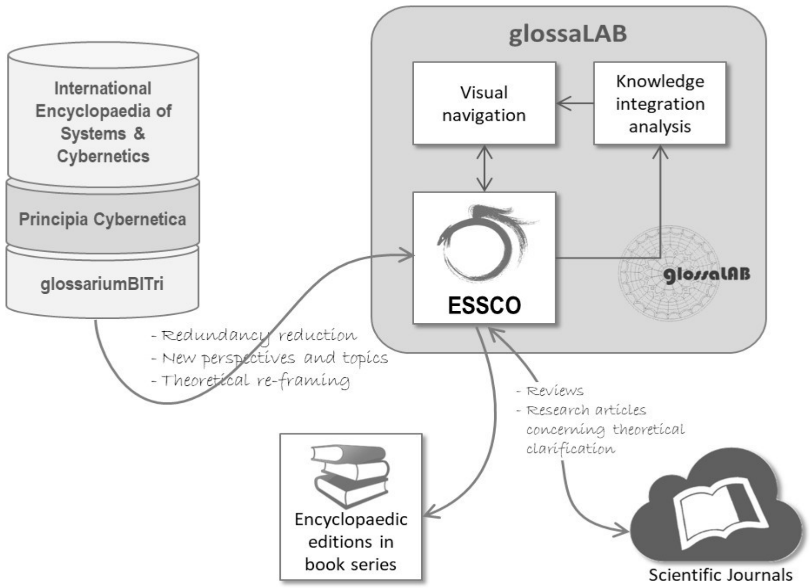

Fig. 2. Overview of glossaLAB project as regards ESSCO's development and content flow.

3 glossaLAB: a three-dimensional endeavor

3.1 Technical level: Integrating scientific networking

Network technologies facilitate encompassing the participation of the scientific community in the theoretical venture envisaged, keeping quality control and avoiding the multiplication of unnecessary redundant terminology. To this purpose, MediaWiki technology offers a panoply of tools and applications that enable the development of an editorial policy for *ESSCO*, driven to the achievement of high quality standards and its subsequent acknowledgement by the scientific community at large. At the same time, MediaWiki framework offers a wide set of open resources in constant evolution which facilitate the development of visualization and semantic navigation tools based on the same network approach that is used at the theoretical and metatheoretical levels (s. figure 2, shadowed area). This specific target is intended to increase the utility, outreach and impact of *ESSCO,* which, as discussed above, is fundamental for the achievement of project's general objective. The currently ongoing development for the actualization of the glossariumBITri interactive platform [11] using MediaWiki technology, started in a previous project, offers a toehold for the development of glossaLAB platform.

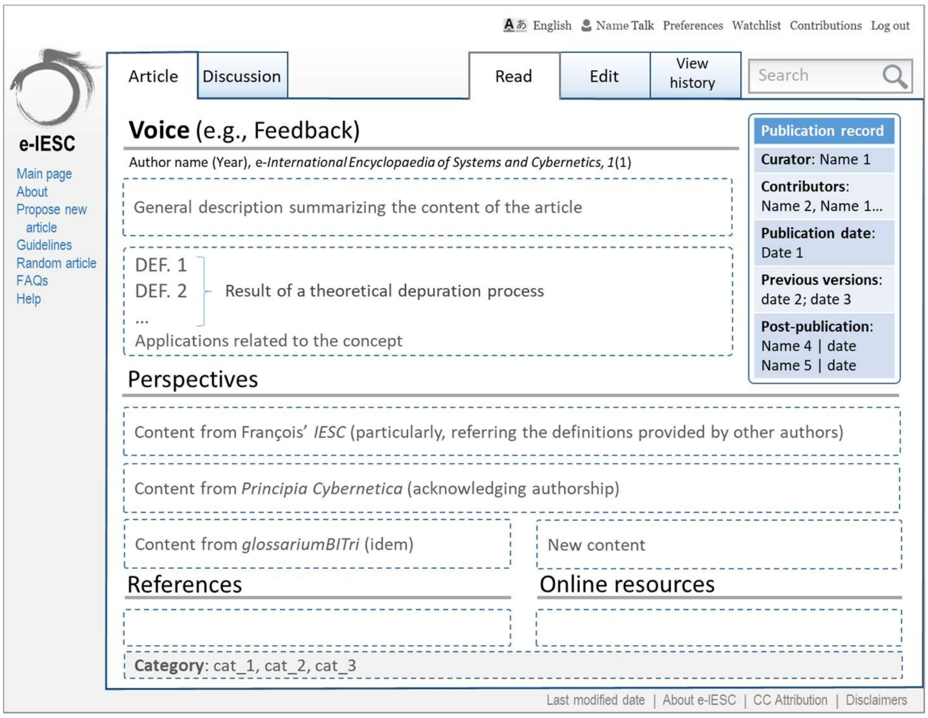

Fig. 3. Layout of a generic article page indicating content sources

The current design follows a number of blue-prints for an article page, homepage, index pages, submission form, etc., devised in accordance with the objectives at the theoretical and meta-theoretical levels (secs. 3.2 and 3.3). Figure 3 shows the blue-print of an article page for *ESSCO,* indicating for instance where the different contents come from. The publication record shown on the upper right side of the article summarizes the edition, curation and review process that the article has gone through. The upper tabs give access to the discussion (peer-review records) and edition history.

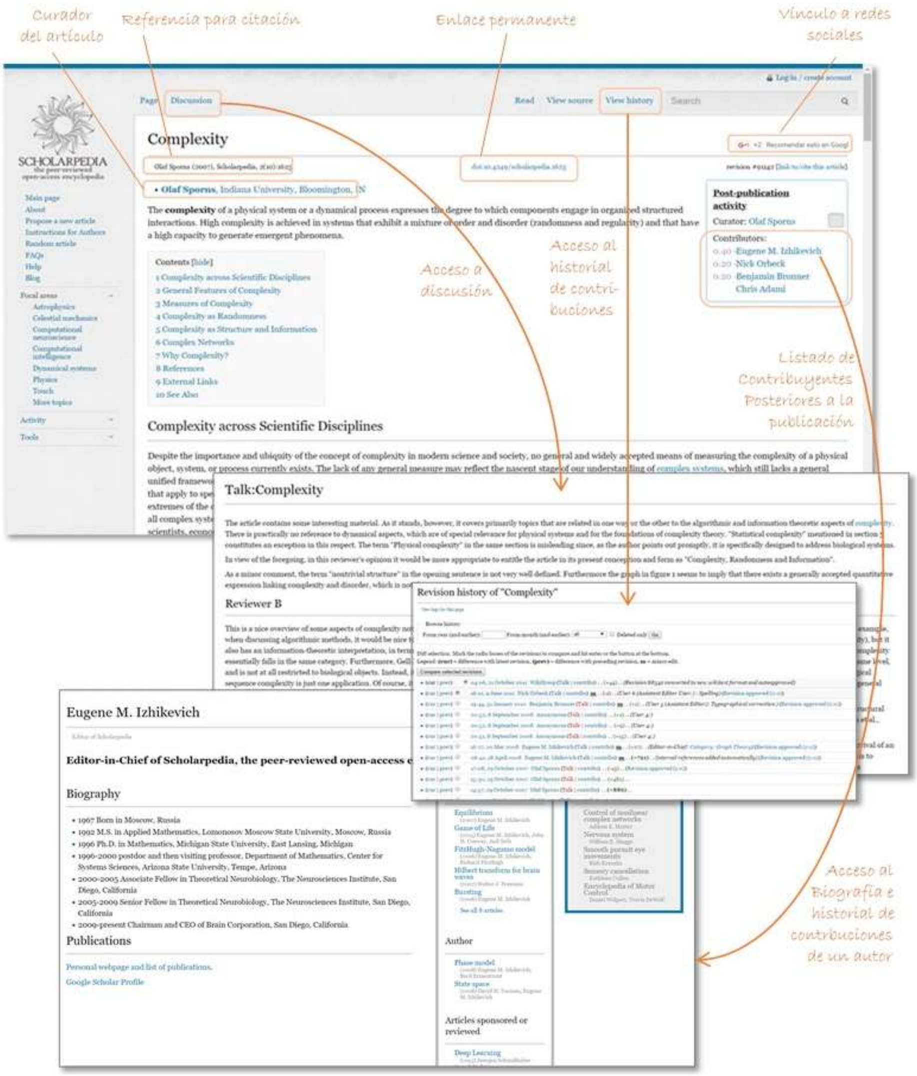

Fig. 4. Layout and functionality of article components in Scholarpedia.

Figure 4 describes in detail the parts of an article page of a Scholarpedia's article that has been taken as a model for the *ESSCO* lay-out in virtue of the parallelism between their respective editorial policies and the scientific quality and impact of Scholarpedia's articles, which are indexed as a regular journal articles [23]. In a large extent, the functionality is derived from MediaWiki open-source components customized to glossaLAB objectives, while some Scholarpedia's components have also been taken as a model, and often as code source, for the development of the platform. In addition, visual navigation tools based on semantic network analysis and representation (using the approach shown in the following sections) are currently under development.

3.2 Theoretical level: Leveraging a rich legacy

The work that has been carried out over decades for the development of the *International Encyclopedia of Systems and Cybernetics* (directed by Charles François) [17] as well as the *Principia Cybernetica* [22] and *glossariumBITri* [10], represents an excellent platform to fulfil the theoretical purposes of the project. Charles François' enthusiasm, dedication and work quality constitutes an invaluable legacy capable to show the insight variety and penetration of the systems science community. Such a sweeping compilation of perspectives, understandings and theoretical frameworks, requires, within the scope of the project, being properly disseminated and actualized in order to encompass the on-going research. Thus, the theoretical target of the project concerns the effort to: (i) eliminate the redundancy usually observed in the varied usage of scientific terminology, (ii) incorporate new concepts, perspectives, theoretical frameworks and research topics, (iii) reframe the network of concepts and focus theories in the simplest possible way.

Targets (i) and (iii) can be rephrased in terms of the increase of ***intensional performance***

Definition 3.1. *intensional performance* is the capacity of a conceptual system **C** to refer a knowledge field **K**. The larger the relation between the extensions of **K** and **C** the larger the intentional performance of **C**.

Definition 3.2. The *relative intensional performance* of a set of definitions (reframed) with respect to an original set is the relation between the number of definition in the original set with respect to the second, provided that **K** is preserved.

Thus, the intensional performance is better if a smaller set of definitions captures the same internal content as the original set.

In order to obtain guidance to increase performance at the theoretical level, a metatheory of knowledge systems, as addressed in sec.3.3, offers a cornerstone. To this end, a formal theory for the analysis and representation of knowledge integration is being developed [4, 9]. Its relevance, applied to the field of systems science was highlighted by Klir [25]: "The comparison of individual conceptual frameworks used in individual approaches to general systems theory appears to be very difficult. A meta-theory must be used to decide whether one concept is identical to, is different from, or is a proper subset of a concept drawn from another theory."

Figure 2 illustrates the theoretical undertaking in the passage from the contents of the original corpora into *ESSCO*. An editorial team is committed to this work assisted by a scientific council. At the same time, this team is in charge of leveraging the participation of the systems science community and the proper integration of the new contributions into *ESSCO*.

Strengthening the Agent Network. As a measure to ensure participation of the scientific community (the counterpart of the fortification of the conceptual network), the contents of *ESSCO* (in continuous development) are linked to other dissemination and exploitation pathways (see fig.2 lower part), in particular, to scientific journals, encyclopedic editions, and scientific social networks [34]. In addition, a stakeholder engagement strategy contributes to leverage both scientific contributions from the community and dissemination of results.

3.3 Metatheoretical level: Assessing knowledge integration

Using and advancing the methodology developed for the glossariumBITri [10, 9], glossaLAB aims at escorting this knowledge integration with the assessment of its performance (s. top right corner of figure 2). Just this achievement, concerning the qualification of knowledge integration, is considered by international institutions in charge of regional and global scientific policies as a necessary condition to strengthen the position of interdisciplinary and transdisciplinary research [15, 16, 12, 14, 6].

The activity at this level is of two types: (i) the development of formal approaches to represent and analyze knowledge conceptualization and integration [4, 9], (ii) the application of these approaches to assess the achievements of knowledge integration at the theoretical level using the contents of the elucidation platform as proxies of the conceptual network [9].

Interdisciplinary-glossary as proxy of knowledge networks. In order to obtain a network of concepts corresponding to the theoretical framework already clarified, we follow a simple idea: the semantic network structure is derived from the meaning relations stablished by the authors in their own texts dedicated to the clarification of the conceptual network [12, 9].

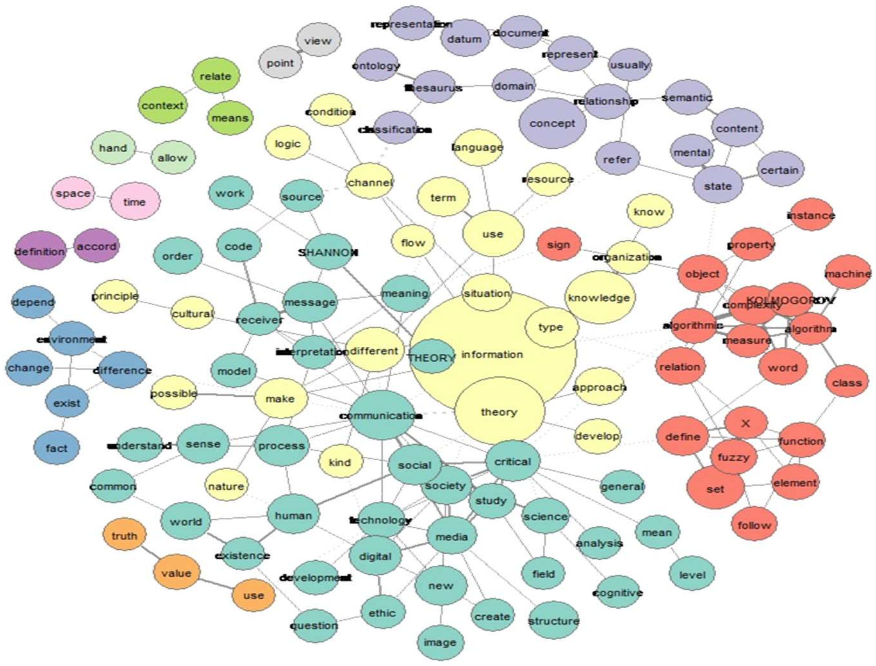

Fig. 5. Co-occurrence network of glossariumBITri edition of 2016 [11]. Term frequency > 50 (130 most frequent concept-words); Most frequent links (thickness proportional to frequency); Colors: semantic clusters determined by intermediation measurements.

In so far as an author's sentence implies a unit of sense, the syntactic co-occurrence of words (properly arranged in groups of derivative words) in the space of a sentence stablishes a semantic association to be explored in terms of link frequency [25]. For instance, if we observe a high co-occurrence degree between "link" and "connection", on the one hand; or "feedback" and "regulation", on the other, this is derived from the semantic proximity between these terms. In the first case, due to a relation of equivalence, in the other, due to a causal relation. In brief, the occurrence of terms and links enables the examination of the relevance of different categories and their semantic connection. Figure 5 shows the co-occurrence network corresponding to the glossarium-BITri edition of 2016, filtered to relatively high frequency of terms and links (for more details about how to derive this network and the analysis of results derived from the network cf. [9,10]). Besides the application to the assessment of knowledge integration, discussed in the referred literature, other applications of the co-occurrence networks, worth considering for future work, concerns the retrieval of definition statements in corpora [26] or the detection of semantic similarity [23].

Bi-dimensional assessment of knowledge integration. So far we have addressed the problem of assessing how far an interdisciplinary knowledge network is from the extremes of multidisciplinarity and transdisciplinarity. However, we have dismissed the relevance of the amplitude of the knowledge that is being integrated, i.e., the number and diversity of the disciplines convened. To bridge this gap, the qualification of knowledge integration concerns a double assessment:

- The **diversity of the contributing disciplines** (the more disciplines contributing the more diverse the knowledge integrated), and
- The **integration effectively achieved** through the collaboration of disciplines (the integration is weak if each discipline handles different aspects separately; the integration is sound if the theoretical constructs gets to merge into a general understanding of all the concept domain).

A. Discipline Diversity Index. To the purpose of evaluating this diversity, we draw on the Universal Decimal Classification (UDC) which has the virtue of covering all knowledge fields y a broadly accepted categorization of disciplines. But in order to apply it, we need first determining the granularity level in the distinction of disciplines. In a first approximation, this can be carried out determining the number of relevant UDC digits used to distinguish the knowledge areas involved in a particular research [30, 37, 39]. However an adaptive implementation of the UDC categories need to be introduced in our categorisation of *Knowledge Domains* (KD): (i) some UDC categories should be disregarded, for example, the ones not related to knowledge but to document typologies, (ii) some categories are scaled from a lower granularity level because of their relevance for the subject field, and (iii) some category groups have to be merged since correspond to different aspects of the same knowledge, for example, applied and theoretical.

Taking N as the number of considered KD, the diversity of participating disciplines is determined using *Shannon Diversity Index* weighted by the maximal value of diversity, which is attained by an equal participation of all the KD, that is $\log_2 N$. After normalization, the diversity index of an equalized participation of all the KD is 1, while for a single participant KD is 0. In general, the more KD and the more equal the participation, the index is closer to 1.

Definition 3.3. Calling p_i the frequency of occurrence of a contribution from the KD i the *diversity index* is:

$$DI = \frac{1}{\log_2 N} \sum_{i=1}^{N} p_i \log_2\left(1/p_i\right) \tag{1}$$

For the application to ESSCO, a selection of 67 KD have been selected from the UDC, corresponding in most of the cases to 2 digits of UDC code (about 7 per UDC group). Table 1 shows the first 10 categories selected corresponding to the first UDC group (the whole list has been published in [14]).

Table 1. Knowledge Domain Categories selected for the classification of contributions.

i	Knowledge Domain (EN)	UDC code	Additional UDC fields covered by domain i + **Clarifications**
0	**Generalities. Science and Knowledge. Organisation. Information. Documentation**	**0**	**# types/group: 10**
00	Science and knowledge in general	001	
01	Documentation and Writing systems	002/003	
02	Computer science	004	
03	Management (including Knowledge management)	005	Do not confuse with 658 (business management)
04	Standardisation	006	
05	Activity and organizing. Control theory generally (systems science)	007	Do not confuse with the technical domain "Automatic Control" 681.5
06	Communication theory generally (incl. Information theory)	007	Do not confuse with the technical domain "Telecommunication and telecontrol" 654
07	Civilization. Culture	008	
08	Librarianship	02	01 + 03 + 05 + 07 / 09 01: bibliographies | 03: reference works | 05: serial publicat. | 07: newspapers | 08: polygraphed | 09: manuscripts
09	Organisations of a general nature	06	
⋮	⋮	⋮	

For the practical application of the normalized domain categories, each contribution (e.g. article of the encyclopedia) identifies the domain categories that best fits the knowledge area which supports the knowledge represented in the contribution. As regards the *agent network* each peer is identified by the domain categories matching her expertise. This identification also serves to the organization of the peer-review process and other communication and dissemination activities.

B. Integration of Disciplines. As discussed in section 1, the structural properties of the conceptual network and of the actor network revels the integration capacity of the interdisciplinary setting at stake. A co-occurrence network derived from the elucidation corpus, as the one represented in fig.5, enables the assessment of integration properties (as shown in [9, 10]). To this purpose we use both quantitative and qualitative assessment. Regarding **quantitative assessment**, a good integrated conceptual network exhibits at a time, as discussed in sec.1.2 and [9]: low *average minimal distance* (between any two concept-words) and relatively high *clustering* (for an effective referencing of

the concept domain, which can be smaller if the size of the network size is small). Thus, high *clustering coefficient*, C, and low *average minimal distance*, L, provides an indication of integration reached. Indeed, its ratio compared with the equivalent ratio for random networks correspond to the *small-world coefficient* which reflects the two factors contributing to the increase integration: $\sigma = {C}/{C_{rand}} \cdot {L_{rand}}/{L}$ which is used to measure knowledge integration.
In addition, the network analysis enables the **qualitative** identification of integration issues (as discussed in [9] for the case of glossariumBITri). This assessment provides specific and valuable guidance for the forward planning of the theoretical work.

4 Conclusions

In section 1, we have presented the background problem addressed by glossaLAB project, namely, the fragmentation of knowledge derived from the epistemological grounding of modernity and the extension of the scientific enterprise. We have analyzed this problem using a network perspective applied to the levels of the conceptual network and the actor network in order to characterize the structural properties of poor and sound knowledge integration. In sec. 2, we observed that project objectives focus on three big challenges: (i) the development of a sound theoretical framework for the unification of knowledge, (ii) the establishment of broadly accepted methodologies and tools to facilitate the integration of knowledge, (iii) the development of assessment criteria for the qualification of knowledge integration. In sec. 3, we have seen the means adopted to address these challenges. To cope with (i), the project draws on systems sciences, which have been proven to provide a sound platform for the integration of knowledge in general, but requires overcoming differences between sub-disciplines, which is done departing from sound corpora. To cope with (ii), the project draws on well experienced methodologies derived from systems science, the interdisciplinary-glossaries developed in the past for similar endeavors, and technical solutions applied to numerous projects on knowledge co-creation. And finally to cope with (iii), a novel methodology to assess knowledge integration is devised, based on sound theoretical underpinnings.

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