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# Chapter X

# Evaluation of Knowledge Integration through Knowledge Structures and Conceptual Networks

José María Díaz-Nafría[1], Mark Burgin[2], Blanca Rodriguez-Bravo

[1]*BITrum Research Group, C/ San Lorenzo 2, 24007 León, Spain*
*jdian@unileon.es*

[2]*Department of Mathematics, University of California, Los Angeles, California 90095-1555, mburgin@math.ucla.edu*

[3]*Facultad de Filosofía y Letras, Universidad de León, 24004 León, Spain*
*blanca.rodriguez@unileon.es*

The chapter addresses the general problem of assessing the integration of knowledge from different scientific disciplines joined in interdisciplinary settings and its specific application to the study of information. The method is based in the development of Interdisciplinary-Glossaries as tools for the elucidation of the network of concepts involved which also serve as proxies of the corresponding knowledge integration. We show the results obtained from the application of the network approach to a specific interdisciplinary-glossary devoted to the study of information. These results show the capacity of the methodology depicted to guide the future development of knowledge integration by the corresponding interdisciplinary or transdisciplinary teams, as well as to assess their integration achievements. However, the results described are rather qualitative with respect to the knowledge integration attainments. In order to offer a quantitative assessment, we propose an enhanced methodology in which each contribution and participant in the elucidation process is identified by the knowledge domains involved using a set of domains adapted from the higher categories of the Universal Decimal Classification. Such identification allows assessing the integration through a multidimensional perspective based on: (i) the diversity of the disciplines involved, measured in terms of Shannon Diversity Index, and (ii) The effective integration achieved through the meeting of different perspectives, measured through the analysis of both the semantic network of elucidated concepts and the network of participant researchers, in terms of the average minimal distance between any two nodes and the clustering coefficient, which are combined through the small-world-coefficient, σ.

## 1. Introduction

The disintegration of scientific knowledge has partially been a consequence of the intensification and widening of the scientific endeavour. Many specialized disciplines arose in the 18th century, in which the intensity required to address specific problems implied professional restraint to restricted areas of scientific knowledge [Porter, 2003]. This more specialized approach resulted in knowledge disintegration and fragmentation. Nevertheless, this was also an effect of the methodological principles with respect to the adequate means for the articulation of such endeavour, which in turn was based on strong ontological assumptions regarding the nature of reality. This approach is explicitly expressed in Descartes' second rule from the system of four rules that suffice to arrive "at a knowledge of all the things of which [our minds are] capable […]". Namely, the second rule instructs: "divide each of the difficulties […] into as many parts as possible, and as seemed requisite in order that it might be resolved in the best manner possible" [Descartes, 1952: pp. 46-47]. Indeed, if the complex reality faced by the scientist is difficult to understand as a whole, then its division into small parts allows arriving at a point where the isolated parts can be understood with relative ease. Descartes calls this approach "analysis" in opposition to "synthesis", reframing their original meanings as stated by Aristotle and praising the former as the sure means to achieve truths [Aristotle, Smith & Ross, 1908–1952]. The critical issue is not overlooking some essential relation between the parts separated in the analysis. Descartes do not offer a guide on how to preserve essential relations of the reality under the study in the division process. The method he depicts directly goes to a separate and distinct understanding of all parts of the wholes. It is assumed that reality, epistemologically reduced in such a way, is ontologically alike.

When this methodology was generalized from an individual researcher to science as a whole, the path to its division into specialized disciplines was the natural consequence, despite the concerns stated by a few, and in particular, by Leibniz concerns about breaching the necessary unity of science [Leibniz, 1996]. In the nineteenth and twentieth century, this division of science into separate disciplines grew to a much larger degree. However, the concerns on the mutilation of fundamental relations through the process of fragmentation of reality emerged since the second half of the twentieth century. 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 information theory, systems science, cybernetics, and the broad quest for interdisciplinarity belong to this trend [Frodeman *et al*, 2010; Díaz-Nafría and Salto-Alemany, 2011; Burgin and Hofkirchner, 2017].

The relevance of this concern can be also observed in the declarations and efforts devoted by international institutions, as UNESCO and OECD, since the 1970s to merging scientific disciplines into integrated frameworks. However, despite the national and international efforts to boost interdisciplinary research in the past decades, one of the fundamental barriers for its establishment has been the lack of assessment criteria of interdisciplinarity itself [Frodeman *et al*, 2010; DEA-FBA, 2008; EURAB, 2004]. This brought the scientific community to the following problems: How is it possible to measure the effort of merging more diverse knowledge? How is it possible to assess the quality of the knowledge integration achieved through interdisciplinary settings?

This "lack of appropriate quality criteria introduces a remarkable degree of uncertainty in the evaluation of interdisciplinary research" [Frodeman *et al*, 2010: p. 316] often causing research proposal assessment to be inefficient and disregard promising interdisciplinary research projects due to the mainly application of disciplinary criteria. For this reason, the development of assessment criteria has been one of the objectives marked by national and international research funding agencies [DEA-FBA, 2008; EURAB 2004]. This problem is addressed in our work, based on the study of knowledge structures and a network theoretical approach to knowledge co-creation specifically applied to the interdisciplinary study of information. This approach serves to embark upon a meta-theoretical inquiry of assessing the diversity and intensity of knowledge integration.

The chapter has the following structure: In Section 2, right after the Introduction, we elaborate a methodological base for knowledge integration and build a mathematical model of conceptual integration. According to methodology of science, concepts belong to the basic level of advanced knowledge systems. Naturally, they allow extended knowledge representation due to their intrinsic structure. That is why in Section 2.1, we give a brief description of knowledge structures representing big domains of reality. In Section 2.2, we show how these big knowledge structures are mapped onto conceptual systems.

In Section 3, we adopt a network perspective in order to map the dynamics of knowledge co-creation, particularly focusing on interdisciplinarity and its various levels. Based on this approach, we present in Section 4 a methodology to assess knowledge integration through interdisciplinary-glossaries as proxies of the integration achieved in interdisciplinary settings. In Section 4.2, we discuss the results of applying this methodology to an interdisciplinary-glossary in the field of information studies. In Section 5, we develop an improved methodology based on the evaluation of the discipline diversity and the intensity of knowledge integration observed in interdisciplinary glossaries. In the last section, we discuss the obtained results and possibilities of their more advanced applications and developments.

## 2. Structural perspective on knowledge integration

### 2.1. *Megalevel structures of knowledge*

Comprehensive knowledge systems about big domains of reality are called megalevel structures of knowledge [Burgin, 2017]. The most explored megalevel structures of knowledge are scientific theories, structures of which are studied in the methodology of science. Many researchers studied inner structures of scientific theories building their models, which are often called reconstructions, and testing their validity by application to existing scientific theories. The most popular is the *standard* (positivist) *model* (reconstruction) of a scientific theory, which utilizes means of logic representing a scientific theory as a system of propositions (cf., for example, [Suppe, 1999: pp. 16-24]). Another popular approach to description of the scientific theory structure is the *structuralist model* (reconstruction) of a scientific theory (cf., for example, [Balzer, *et al*, 1987]), which utilizes means of set theory representing a scientific theory as a system of models of the theory domain.

Some researchers treat scientific theories as devices for the formulating and resolving scientific problems. In this context, they model scientific theories by systems of statements and questions (problems) including (in some models) various forms of problem representation, rules and heuristics for resolving problems and utilizing erotetic logic for rigorous analysis of problems and problem-solving (cf., for example, [Garrison, 1988]). In his model, Thagard [1988] represented a scientific theory as a highly organized package of rules, concepts, and problem solutions.

All these and some other approaches were unified in the structure-nominative model or reconstruction of a scientific theory, which was the first methodological and mathematical model of comprehensive knowledge systems [Burgin & Kuznetsov, 1994]. As a result, other models of theoretical knowledge that describe inner structure of big knowledge systems, such as scientific theories, became subsystems of the *structure-nominative model* of scientific knowledge (a scientific theory) and all structures used in those models are either named sets or systems of named sets [Burgin, 2011]. For instance, the structuralist model of a scientific theory (cf., for example, [Balzer, et al, 1987]) is represented as the model-representing subsystem of the structure-nominative model, while the standard (positivist model) of a scientific theory (cf., for example, [Suppe, 1999]) is represented as the logic-linguistic subsystem of the structure-nominative model.

Later this model was extended and enriched in [Burgin, 2011] forming a higher step in modeling global knowledge. Now the most advanced is the *modal stratified bond model* of global knowledge elaborated in [Burgin, 2017], which comprises all other existing models of scientific knowledge systems and other big knowledge systems.

According to the modal stratified bond model, global knowledge expands in three dimensions – systemic, modal and hierarchical.

The ***modal dimension*** is based on modalities of knowledge:

(1) *Assertoric knowledge* consists of epistemic structures with implicit or explicit affirmation of being knowledge.
(2) *Hypothetic* or *heuristic knowledge* consists of epistemic structures with implicit or explicit supposition that they may be knowledge.
(3) *Erotetic knowledge* consists of epistemic structures that express lack of knowledge.

Logical propositions or statements, such as "The Sun is a star", are examples of assertoric units of knowledge. Beliefs with low extent of certainty, i.e., when they are not sufficiently grounded, are examples of hypothetic knowledge. Questions and problems are examples of erotetic knowledge.

Knowledge with different modalities forms strata in knowledge systems determining the **horizontal structure** of comprehensive knowledge systems.

The ***hierarchical dimension*** delineates three levels of global knowledge systems:

(1) The *componential level* consists of elements, parts and blocks from which systems from the attributive level are built. In some sense, the componential level is the substructural level of a global knowledge system.
(2) The *attributed level* reflects the static structure of global knowledge as a system constructed from elements, parts and blocks from the componential level.
(3) The *productive level* of global knowledge reflects the cognitive (dynamic) structure of global knowledge, containing means for knowledge acquisition, production and transmission.

Note that each of these three levels has its strata and sublevels. Levels in global knowledge systems determine the **vertical structure** of this system.

Three categories of knowledge form the ***systemic dimension*** of knowledge structuration:

(1) *Descriptive* knowledge (also called *declarative* knowledge or sometimes *propositional* knowledge) is knowledge about properties and relations of the objects of knowledge, e.g., “a swan is white”, or “three is larger than two”.

(2) *Representational* knowledge about an object is the set of representations of this object by knowledge structures, such as models and images, e.g., when Bob has an image of his friend Ann, this image is representational knowledge about Ann.

(3) *Operational* knowledge (also called procedural knowledge) consists of rules, procedures, algorithms, etc., and serves for organization of behavior of people and animals, for control of system functioning and for performing actions.

As we can see, knowledge about big domains is also big and diverse.[a] However, it is usually represented as conceptual systems called encyclopedia, encyclopedic dictionaries, thesauri and glossaria. This representation is based on conceptual integration of knowledge, which is formalized in the next section.

### 2.2. *Conceptual integration of knowledge*

Representation of knowledge structures by conceptual systems is a mapping $c$ of a knowledge structure (system) $\mathbf{K}$ into a conceptual system $\mathbf{C}$ and this mapping $c$: $\mathbf{K} \rightarrow \mathbf{C}$ is called a *conceptualization mapping* of knowledge $\mathbf{K}$. However, any mapping in a complete form is a named set [Burgin, 2011]. This gives us the following definition.

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[a] It is possible to read more about modeling global knowledge systems in the book [Burgin, 2017]

**Definition 2.1.** The named set (**K**, *c*, **C**) is called a *conceptualization* of knowledge **K** by the conceptual system **C**.

For instance, the general theory of information [Burgin, 2010] as a knowledge system **K** can be represented by the system **C** of concepts, which include such system concepts as information, principles of the general theory of information, infological system, statistical information theory, semantic information theory, algorithmic information theory, dynamic information theory, and so on. Whenever this is possible, the conceptual system **C** can be regarded as a *transdisciplinary setting* as we will refer to in Section 3.2.

**Definition 2.2.** When knowledge from different systems is mapped into one conceptual system it is called *conceptual knowledge integration*.

For instance, it is possible to take several information theories, e.g., statistical information theory, semantic information theory, algorithmic information theory and dynamic information theory (cf., [Burgin, 2010]), and conceptualize them using the same conceptual system **C**.

**Definition 2.3.** A *conceptual system* consists of concepts and relations between them.

When we abstract the conceptual system from its role of conceptualization of knowledge referred above (Def. 2.1), we can regard it as a network of concepts as we will do in the following sections.

There are three types of concepts in a conceptual system:

(1) *Systemic* (or *primary*) *concepts* form separate knowledge items and have descriptions (definitions).

(2) *Emphasized* (or *secondary*) *concepts* are concepts used in descriptions of systemic concepts and have descriptions (definitions).

(3) *Background* (or *tertiary*) *concepts* are concepts used in descriptions of systemic concepts and do not have descriptions (definitions).

To build a mathematical model of conceptual knowledge integration, we use the *representational model* of a concept introduced in [Burgin & Gorsky, 1991] and further developed in [Burgin, 2017]. Its surface structure is a specific kind of named sets or fundamental triads [Burgin, 2011]. It is presented in Figure 1, in which concept name can be one word, e.g., "information", an expression, e.g., "structural information in a computer", or a text, e.g., a set of postulates describing information as in [Burgin,2010].

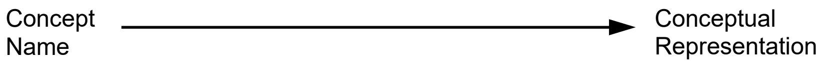


Fig. 1.The first specification rank of the *representational model* of a concept.

It is demonstrated that the representational model of a concept comprises all other models of a concept as a structure having higher level of abstraction [Burgin, 2017]. For instance, to get Frege's model of a concept [Frege, 1891; 1892; 1892a], it is possible to consider the components *Denotation* and *Sense* as the conceptual representative of the concept. In a similar way, to get Russell's model of a concept [Russell, 1905], it is possible to consider the components *Denotation* and *Meaning* as the conceptual representative of the concept.

Here we divide the conceptual representative into three parts – the domain, meaning and representation:

(1) The *concept domain* is the domain of reality described by the concept. It corresponds to the Denotation in the sense of Frege and Russell [Frege, 1891; 1892; Russell, 1905].

(2) The *meaning* of a concept C is knowledge about the concept domain $D_C$. This knowledge is called the *broad-spectrum concept knowledge*. All knowledge about the concept domain is called the *abundant domain knowledge*. Meaning corresponds to the Sense in the sense of Frege [Frege, 1892a].

(3) The *representation* of a concept C consists of different representations of knowledge about the concept domain $D_C$.

For instance, if the name of the concept is *information*, then an article about *information* in an encyclopedia or a dictionary is a representation of the concept *information*. This shows that one concept can have many representations, while the union of concept representations is also a representation of this concept.

At the same time, in a conceptual system, the meaning of a concept is also formed by the description (definition) of this concept in the considered conceptual system. These descriptions and definitions represent the components of the ample knowledge in the same way as a map represents the corresponding terrain. This situation is represented by the *contraction conceptual diagram* (1), in which $p$ is a knowledge projection.

$$\begin{tikzcd}
 & \text{Broad-spectrum Concept Knowledge} \arrow[d, "q"] \\
\text{Concept Name} \arrow[ur] \arrow[r] & \text{Conceptual Description/Definition}
\end{tikzcd} \tag{1}$$

Taking a conceptual system **C** and combining all diagrams of the form (1) corresponding to the systemic concepts from **C**, we obtain the broad-spectrum knowledge BK as the union of all broad-spectrum concept knowledge items of all systemic concepts from **C** forming the *conceptualization diagram* (2), which is a named set (BK, $p$, **C**) in general and a fiber bundle with the projection $p$ in particular.

$$\begin{tikzcd}
\text{Broad-spectrum Knowledge (BK)} \arrow[d, "p"] \\
\text{Conceptual System } (\mathbf{C})
\end{tikzcd} \tag{2}$$

This diagram represents a *conceptualization* of the broad-spectrum knowledge BK by the conceptual system **C**.

Conceptual systems are often represented by conceptual networks, which show explicit connections and ties between concepts from the system. Connections and ties between concepts consist of connections and ties between elements and components of these concepts.

When we wish to stress the dynamical aspects of the conceptual system (for instance, in case of the theoretical transformations on which Kuhn or Lakatos were primarily focused [Kuhn, 1970], [Lakatos, 1978]) these can rather be seen as networks abstracting the functional role in the conceptualization of knowledge, as we mentioned above. For these conceptual networks, there is another named set worth considering: the *nominalization named set* (CN, $r$, NN) represented by Diagram (3) characterized by the projection $r$ is related to conceptual networks. Namely, any conceptual network is usually represented by a nominal network, which represents connections between system concepts forming a network of concept names.

$$\begin{tikzcd}
\text{Conceptual Network (CN)} \arrow[d, "r"] \\
\text{Nominal Network (NN)}
\end{tikzcd} \tag{3}$$

In an ideal situation in which a conceptual systems **C** offers an effective transdisciplinary setting capable to map different broad-spectrum concept knowledge, the corresponding conceptual knowledge integration is represented by the *conceptual integration diagram* (4).

$$\begin{tikzcd}
\mathrm{BK}_1 \arrow[dr, "p_1"'] & \mathrm{BK}_2 \arrow[d, "p_2"] & \mathrm{BK}_3 \arrow[dl, "p_3"] \\
& \text{Conceptual System } (\mathbf{C}) &
\end{tikzcd} \tag{4}$$

Mathematically conceptual knowledge integration is represented by the union of conceptualization. As each conceptualization is a named set, properties of named sets [Burgin, 2011] allow us to find different features of conceptualizations. However, in an intermediate situation in which the mapping of several knowledge structures **K** into a single conceptual system **C** cannot be fully accomplished, the network perspective, as represented by the aforementioned conceptual networks and nominal networks, offers a good foothold to assess knowledge integration as we will see in the following sections.

## 3. Network perspective

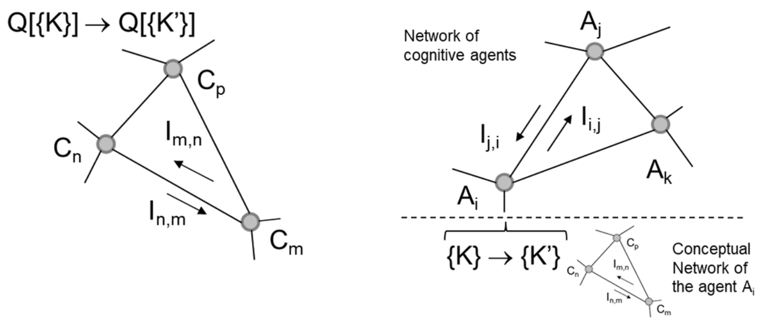
An abstract network, composed of nodes and links, can be used, as mentioned above, as an appropriate framework for knowledge creation and integration using disciplinary and interdisciplinary scientific methodology [Barabasi, 2003; Díaz-Nafría, 2017]. Definition 2.3 of conceptual systems was actually a network theoretical definition, but the network perspective enables us to deal as well with networks of knowledge agents.

### 3.1. *Networks of disciplinary knowledge*

At the level of disciplinary science, the knowledge of a discipline can be characterized through its conceptual network, composed by concepts and semantic links among concepts [Hempel, 1952] [Kuhn, 1970] [Loose, 2001]. These semantic links correspond to predicative relations through which the discipline expresses its knowledge–continuously evolving–and the open problems addressed. The dynamics of this knowledge correspond to the evolution of the conceptual network. Such dynamics are the consequence of the joint undertakings within the scientific discipline, corresponding to the continuous processes of verification, falsification and theoretical re-framing, in which the scientists are immersed [Lakatos, 1978]. These processes involve, at the same time, communication among scientists of their own findings, proposals, assessments, criticism and approbation, which are communicated using the **conceptual network** of the discipline.

The scientific knowledge of a discipline and its evolution is also expressed through this communicative interaction among scientists, which can be mapped through an **actor network** [Díaz-Nafría, 2017]. Here, the nodes correspond to scientists and the links to communication between peers. While the conceptual network is passive (requires active agents to perform effective interactions), the actor network is clearly active (the nodes are active by themselves).

Each scientist internalizes the conceptual network of the discipline in a way that can be slightly different to the one held by other scientists, while the conceptual network of the discipline as a whole can be understood as the one corresponding to the predicative relations that are endorsed by the community. Figure 2 represents both the passive network of concepts (on the left) and the active one of agents who holds their own (individualized) conceptual networks, which are mostly shared by all peers (on the right). In the conceptual network (Fig.2.a), the interaction among concepts, $I_{n,m}$, corresponds to some sort of predicative relation between concepts pairs, for instance, “message” and “meaning” connected as: message HAS meaning, or according to other perspective, message OFFERS meaning. Indeed, due to the strong semantic connection between these two concepts, it happens that, independently from the specific predicative relation, they frequently appear together in the utterances of the scientist working in the field of communication theory. The centrality of a concept in the whole network or in a conceptual cluster corresponds to its relevance in the articulation of the scientific statements. In the actor network (Fig. 2.b), the network centrality of an author, either global or local, represents her capacity to drive the scientific discourse in the corresponding community. As a consequence, the knowledge creation of such an author, symbolized as {K} → {K’}, has a higher weight in the evolution of qualified disciplinary knowledge than other authors, symbolized as Q{K} → Q{K’}.



*a)* *b)*

Fig. 2. Conceptual network as: a) passive network of concepts evolving through scientific inquiry and communication; b) network of interacting agents (scientists who have their own conceptual network {K} evolving through scientific communication).

The systematic relation among the nodes of the network enables the mapping of the objects and problems that such discipline is focused on. The concepts have thus not an isolated absolute value; this is rather gained in virtue of the capacity of the whole. At the same time, each concept enables that a knowledge domain can better approach a specific part of the reality it strives to gather (or provides an operational capacity to the other concepts in such endeavour). If a node is really worth, when it is taken away, the whole network loses its ability to address its field of interest: the network separates (partially or globally) from the reality and problems that it is attempting to map. These are problems of a scientific domain operating by its own.

### 3.2. *Interdisciplinary knowledge*

Different problems arise when various scientific disciplines need to join their knowledge with the purpose of addressing a complex issue which none of the isolated disciplines is capable to cope with by its own capacity (for instance, the understanding of the information phenomena across the different levels of reality, from the physical to the social aspects). As referred to in Section 2, in the ideal situation knowledge integration can be achieved as represented in diagram (4), but this is not feasible in many cases, or at least the conceptual network is not prepared yet for such integration. However, the nominal network, as it happens with natural language, enables the communication about different aspects of the problems under study despite of polysemy. In other terms, the conceptual network held by agents, as depicted in Fig.2.b may differ in a significant way for certain concepts if these agents are from different disciplines.

Despite the differences between disciplinary and interdisciplinary research, the network model shown in Fig.2 serves also to represent the case of interdisciplinarity. Considering the aforementioned relative homogeneity of a discipline with respect to the conceptual network of the parts, we can add a level of abstraction in the actor network by taking a whole discipline as a unitary agent. Here the conceptual or the nominal network among interdisciplinary agents (disciplines) is not as homogeneous as it was in the disciplinary agent network (individuals). Indeed, it is usually significantly different containing common and specific terms. The tendency to articulate scientific statements with disciplinary concepts results in disciplinary clusters within the whole conceptual network. The lack of interdisciplinary understanding among some disciplines results in the relative disconnection among the corresponding clusters.

An important problem regarding knowledge integration concerns different predicative relations established between concepts which are common to different disciplines. These dissimilar predicative relations correspond ultimately to different network structures involving the same concept names. Particularly if well-established predicative relations are incompatible between disciplines, they will correspond to irreducible positions.[b] In other cases, equivalent predicative relations are established using apparently different concepts. Here, a syntactic reduction is possible and represents a positive advance in the effective integration of knowledge, increasing the *intensional performance* of the conceptual network, understood as the capacity to refer larger reality and knowledge with lesser theoretical terms.

In the endeavour of merging a set of disciplines, we can achieve different levels of integration. UNESCO distinguishes the following levels, organized from lesser to higher integration degree: multi-, pluri-, cross-, inter- and trans-disciplinarity [Hainaut, 1986]. At the lowest level, the *multidisciplinarity* represents a simple juxtaposition of disciplines (i.e. they solve by their own the issues they are entrusted with). Therefore, the conceptual network of the domains involved do not interact significantly. Nothing needs to be changed in their respective conceptual network to address the problems tackled. However, *transdisciplinarity*, at the highest integration level, "assumes conceptual unification between disciplines" [*ibid*: p. 9]. In other words, the conceptual network of the disciplines involved blends into a unified operative framework, what we called in Definition 2.2 "Conceptual Knowledge Integration". In between, interdisciplinarity embraces coordination and cross-communication among participant disciplines, but "the total impact of the quantitative and

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[b] Two interesting irreducible positions of this kind are the objectivist vs constructivist stances with regard to the relation between *information* (IN), *knowledge* (K) and *imagination* (IM), as discussed in detail in [Díaz-Nafría, Pérez-Montoro 2011a, 2011b; Díaz-Nafría & Zimmermann, 2013]. According to Dretske, who in a significant extent is reframing the classical stance of the *tabula-rasa* in the context of digital communication, K is just caused by IN, whereas in the constructivist stance the former cannot be caused by IN alone but rather with the necessary interplay of IM. This corresponds to different structures: in Dretske's account there is a causal link between KN and IN that suffices; whereas in the constructivist's account this link is conditional to the matching of IM. The former structure is a pair, the latter a triangle, and the links between nodes are qualitatively different.

qualitative elements is not strong enough to establish a [unified framework,] a new discipline" [*ibidem*]. From the perspective of the conceptual network, the common concepts (for instance, 'communication', 'message' or 'data' in the general study of information) often establish different relations with the rest of the combined conceptual network because the different value of the node (term/concept) at each domain. From each perspective, the phenomena mostly focused on is different as well as its interpretation with respect to the underlying reality.

Because of the lack of integration provided by multidisciplinarity, the international panel of experts, convened by the UNESCO in 1985, excluded it as a level of effective knowledge integration, and agreed to consider just three interdisciplinary levels:

(1) *pluridisciplinarity* where the disciplines are just brought together without adding new contacts,
(2) *interdisciplinarity* where there is a good knowledge of each other's concepts between the discipline concerned, and
(3) *transdisciplinarity* where the conceptual unification is achieved [*ibidem*].

Hence, while levels (1) and (3) represent the extremes, level (2) occupies a broad space in-between. In the following section, we offer a methodology to assess the interdisciplinary level, i.e., the effective distance to (1) or (3), which can also be put in terms of the effective attainment in the integration of knowledge. The given approach uses *interdisciplinary glossaries*, which are devised as tools to facilitate both knowledge integration in interdisciplinary settings and the meta-theoretical assessment of the integration achieved. The results of this approach applied to the interdisciplinary study of information using an interdisciplinary-glossary are shown and discussed in Section 4, while in the light of such results, an enhanced methodology is presented in Section 5.

## 4. Methodology to advance and assess knowledge integration

### 4.1. *Interdisciplinary glossaries as tools for the integration of knowledge and the evaluation of the integration achieved*

The concept of *interdisciplinary glossary* (ID-G) differs significantly from usual glossaries elaborated from single disciplinary perspectives. Normal glossaries aim at elucidating what is meant by the terminology used in a specific work or in a discipline, while ID-G aim at bringing together the different understandings of terms from the summoning of various disciplinary perspectives [Díaz-Nafría *et al*, 2016; Lattuca, 2003]. Normal glossaries thus exhibit strong consistency since there are not contentious views claiming different understandings for the concept names. As represented in diagram (3), the nominal network is directly related to a specific conceptual network. On the contrary, ID-G highlight the different accounts that can be encountered in interdisciplinary settings for the joint network of concept names and, at the same time, they contribute to the joint effort of building-up a transdisciplinary understanding in a situation in which diagram (4) cannot be fully achieved. In this endeavour of conceptual unification, the process itself can drive to find that there are some irreducible understandings that are worth considering different in order to preserve the consistency and integrity of the respective theories, as discussed above (s. Note b).

According to this approach, an interdisciplinary glossary of concepts devoted to foster the integration of knowledge in the general study of information, called *glossariumBITri* (gB), has been developed since 2009 with the support of an international interdisciplinary network of scientists. It has been conceived as a tool for the conceptual and theoretical elucidation in the study of information with the purpose of embracing the most relevant viewpoints concerning information, relying on a board of experts coming from a wide variety of knowledge fields. From a *theoretical viewpoint*, gB aims to shorten the distances among the different viewpoints and increasing the linkages; while from a *meta-theoretical viewpoint* aims to assess the accomplishment of such integration. In other terms, gB serves as a proxy of the knowledge integration achieved by the interdisciplinary study of information; thus assessing the interdisciplinary degree in a manner that can be generalised in other knowledge integration undertakings. This generalisation has been indeed proposed in the context of the PRIMER initiative which is aimed to foster interdisciplinary research capacities, and is supported by the scholar network that includes the one that backs up the gB [PRIMER, 2018].

### 4.2. *Network approach to assess knowledge integration trough interdisciplinary-glossaries*

According to the abovementioned characterisation of the interdisciplinary dialogue, the evaluation of the interdisciplinarity degree or knowledge integration is based on the scrutiny of the structural properties of the interdisciplinary glossary's semantic network. To this purpose, the semantic network structure is derived from the meaning relations stablished by the authors in their own writings devoted to the elucidation of the conceptual network [Drieger, 2013; Díaz, 2017]. In so far as the sentence formed by the author implies a unit of sense, the mere syntactic co-occurrence of words (grouped in sets of derivative words) in the space of a sentence stablishes a semantic linkage that can be explored in terms of the frequency of such links [Jakson&Trochim, 2002]. For instance, if we observe a high repetition in the co-occurrence of "complexity" and "algorithmic", on the one hand; or "message" and "meaning", on the other, is due to the semantic proximity of the co-occurring terms; in one case because of equivalence relation, in the other, because of consequence relation. In short, the greater or lesser occurrence of terms and links between terms have facilitated the examination of the relevance of different categories and the semantic connection between them from the perspective of the interdisciplinary research network.

Because the connections are stablished between concept names we are actually representing the nominal network referred to in Section 2.2, whose relation to the conceptual network was represented in Diagram (3). The formation of nominal networks through the elucidation process of the ID-G under study with "small-world" or "scale-free" characteristic structures (whose pertinence has been analysed and proven) enables the identification of both the categories effectively used in the generic articulation of utterances, and the grouping of verbal categories circumscribed by the dealing with specific issues, for instance, “complexity” [Barabasi, 2002; Díaz-Nafría, 2017].

According to this characterisation, the semantic network analysis has been structured in the following phases:

(1) Text refinement, getting rid of those elements not corresponding to (textually) expressed utterances for which a meaningful syntactic-semantic treatment could not be performed.

(2) Quantitative analysis of the texts by means of the application of computational linguistics “KH Coder” which enables the analysis of the co-occurrence network, i.e, the semantic network in terms of the semantic links observed in the texts through the adjacency distance in sentences [Higuchi, 2016; Anzai & Matsuzawa, 2013].

(3) Iterative process of relevant terms refinement according to its significance for the analysed issues which enables reviewing the aprioristic categorisation.

(4) Co-occurrence mapping extraction of the semantic networks derived from the conceptual elucidation of the interdisciplinary-glossary.

## 5. Results of glossariumBITri’s network analysis

The methodology presented above to assess the *interdisciplinary level* (sec.4) has been applied to the aforementioned interdisciplinary-glossary devoted to the conceptual elucidation of “concepts, metaphors, theories and problems concerning information” as crystallized in the *glossariumBITri* edition of 2016 [Díaz-Nafría et al, 2016].

### 5.1. *Characteristic structure of glossariumBITri’s nominal network*

The result shown in figure 3 illustrates a relevant characteristic of the glossarium-BITri: the statistical degree distribution of the semantic network exhibits the properties of the free-scale networks. This means that the subsidiarity properties discussed in [Díaz-Nafría 2017] can be applied to glossariumBITri's semantic network.

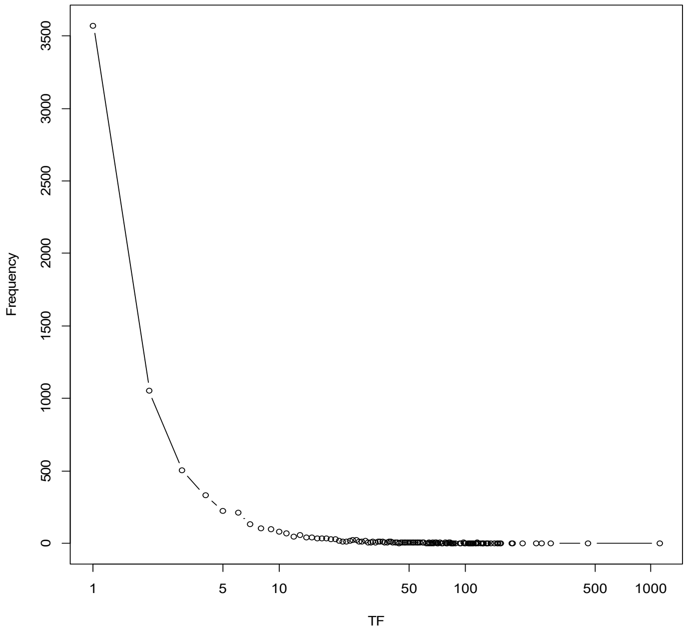

Fig. 3. Distribution of the frequency of word occurrence in the glossariumBITri 2016 edition. The statistic parameters denote that the semantic network is of the type small-world and free-scale.

The recursive character of the corresponding structure entails a disciplinary clustering of issues which, at the same time, are well connected semantically to the rest of the network. The statistics of the semantic distances observed in the network, and the study of the clustering offers an innovative methodological road to strengthen the interdisciplinary study of information. Moreover, it can be generalised to the measurement of scientific integration through the use of interdisciplinary glossaries applied to a given scientific context as a proxy of the knowledge integration achieved.

## 5.2. *Co-ocurrence Networks*

Figures 4, 5 and 6 shows the results of the gloossariumBITri's semantic network analysis. Each term/concept is represented by a node whose size is proportional to its occurrence frequency, while the thickness of links among terms is proportional to the co-occurrence frequency of the corresponding terms in the sentences of the whole text. Only the terms and links whose frequency surpasses the thresholds indicated in the figure caption are visible. At the same time, the result of the analysis of term clusters determined by intermediation distances is represented using different colours (terms with the same colour are at distances below a threshold).

### 5.2.1. *Co-occurrence network of the 130 most frequent terms*

As we can observe in Fig. 3 (in which the 130 most frequent terms are represented), "information" is the most dominant term, as it could be expected. Under this nuclear term we can find other outstanding terms: theory, communication, knowledge, use, concept. They reflect, on the one hand, the general objective of the glossariumBITri (concept, theory), on the other, a significant weight of theoretical terms as communication, knowledge, and use. We can also observe 4 important clusters, corresponding to domains with capacity to concentrate some specific aspects that have experience a deeper development. In addition, we only find two dominant authors, Shannon and Kolmogorov (at 11 and 2:30 respectively, in clock position). However, while Shannon appears at a relatively central position and with a high degree of interconnectedness with the rest of the network, Kolmogorov is located at the central position of a cluster (between 2 and 4 in clock position) which is less connected and is more peripheral, linked to important theoretical terms as algorithm, complexity, object and other more mathematically oriented terms as fuzzy, set, function, etc (around 4). This cluster corresponds to one of the theoretical domains which has been incorporated in the 2016 glossariumBITri edition. Its relative disconnection with other relevant terms points to the need to devote efforts in developing missing links in order to achieve a more integrated elucidation.

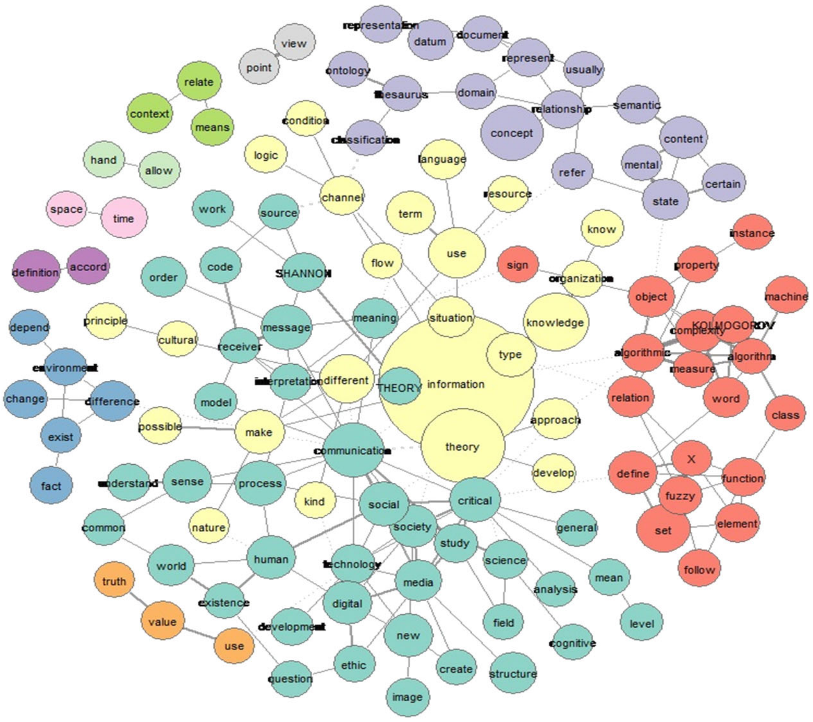

Fig. 4. glossariumBITri's Co-occurrence network. Term frequency occurrence > 50; Number of nodes (words-concepts): 130 most frequent ones; *Colours*: semantic clusters determined by intermediation measurements. Adverbial and prepositional categories are excluded.

Finally, it is possible to observe in the greenish-blue cluster (between 4 and 11 in clock position) a particularly well cohesive group, composed by the terms: society, media, technology, communication, critic. Here we observe the weight of a theoretical framework developed in depth, namely the *critical theory of information*, which is mainly focused on human, social and political aspects of information technologies. It is worth mentioning that the article "critical theory of information" is the most read article in the interactive-glossariumBITri as determined by Internet traffic analytics.

### 5.2.2. *Co-occurrence network of the 58 most frequent terms*

Figure 4 corresponds to the same co-occurrence network in which only the 58 most frequent terms (nodes) are visualized (with a frequency over 75) and the 100 most frequent co-occurrences (links). According to the clustering analysis, the largest cluster is again the one that has been significantly cemented by the *critical theory of information* (between 7 and 10 in clock position). At the same time, the well cohesive cluster of terms related to algorithmic information theory and the General Theory of Information (between 4 and 5) seems to be mostly connected to another cluster (blue). It can be noted that the red cluster of Fig. 3 originates from the convergence of the cluster composed by set, function, and other terms that was extensively developed in the previous glossariumBITri edition (e.g. fuzzy logic) (Fig.3, between 4 and 5 o'clock). In both figure 3 and 4, it is interestingly possible to observe the presence of Bateson's conceptual approach to information, stated in the famous formula: "*information* is a *difference* that *makes* a *difference*" (Bateson, 1979), which over time has gained most general support among the multifarious community of information studies. As we can see, this conception establishes relevant links to "environment" which reflect the concern spread along the community of information studies to go beyond the de-contextualisation which is inherent to Shannon's perspective (Díaz-Nafría 2010, 2011).

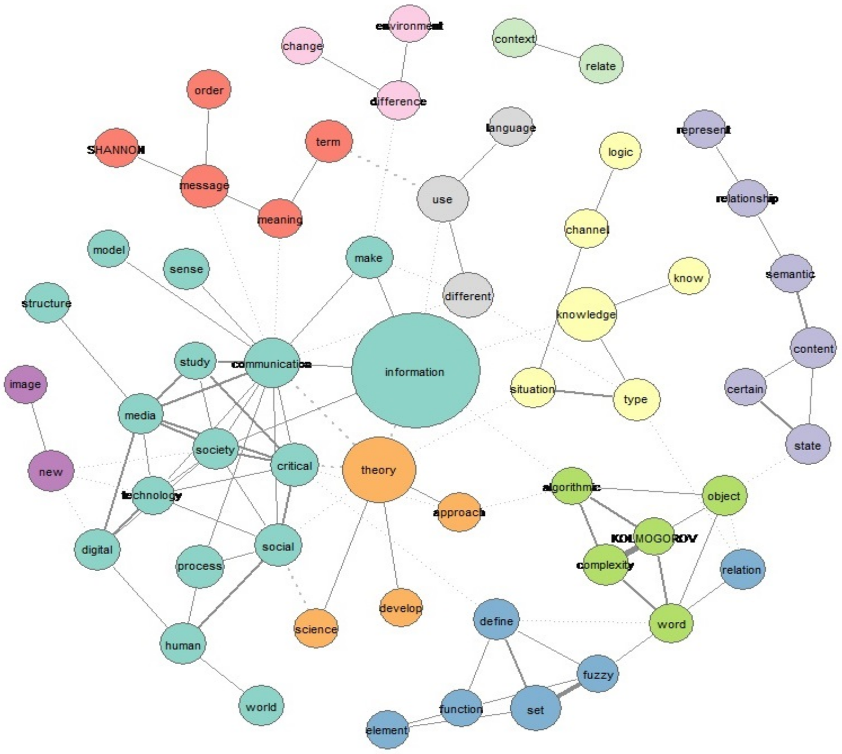

Fig. 5. glossariumBITri's co-occurrence network. Term frequency occurrence > 75; Number of nodes (words-concepts): 100 most frequent ones; *Colours*: semantic clusters determined by intermediation measurements. Adverbial and prepositional categories are excluded.

### 5.2.3. *Co-occurrence network of the 6 most frequent terms*

Figure 5 corresponds to a further refinement of the previous co-occurrence network including only the 6 most frequent terms (nodes) and the 100 most frequent co-occurrence (links), which in the figure are reduced to the 15 existing among the 6 visualised terms. We observe here the 4 heaviest conceptual terms (information, communication, knowledge and use) upon which the rest of the conceptual elucidation is articulated, as well as two meta-theoretical terms (theory and concept) which manifest the very goal of the gB itself. It is also worth mentioning at this level the strong link between communication and use, what shows that the gB effectively accomplishes the objective of giving account of the pragmatic aspects that was missing in the Mathematical Theory of Communication from which Shannon forged the scientific concept of information.

From the inspection of the three co-occurrence networks, a remarkable void can be noted, pointing to a direction of further development and improvement of the gB: the need to stress the more specific and broader consideration of metaphors. In a network structural perspective, the benefit of metaphors relies on their capacity to reduce average distances in the whole conceptual network as discussed by Díaz-Nafría [2017; Sigman and Cecci 2003].

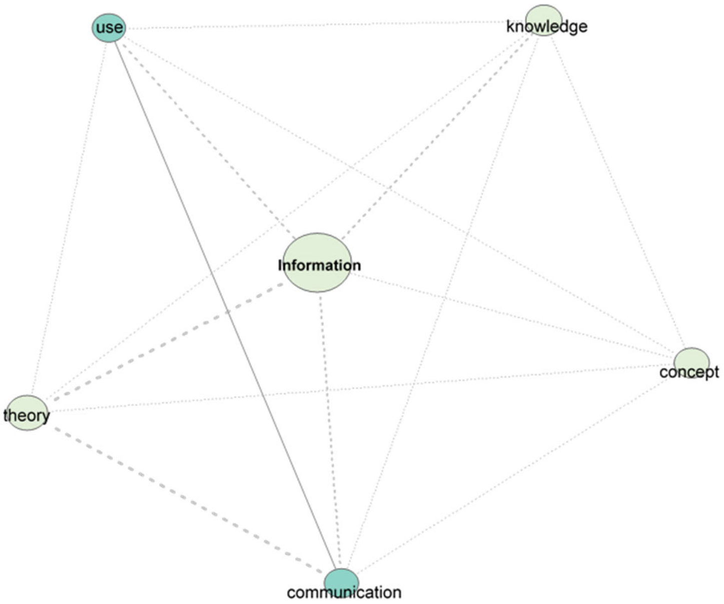

Fig. 6. glossariumBITri's co-occurrence network. Term frequency occurrence > 200; Number of nodes (words-concepts): 6 most frequent ones; Number of links: 100 most frequent; *Colours*: semantic clusters determined by intermediation measurements.

## 6. Enhanced Methodology to Qualify Knowledge Integration in Conceptual Networks

The previous results exhibit the capacity of the network approach to qualify interdisciplinarity within the broad margin left by the UNESCO's classification (referred to in Section 3), i.e. how far apart is from transdisciplinarity. However, this approach has not addressed how diverse the integration of knowledge is with respect to scientific knowledge in general. In addition, it provides a rather qualitative assessment that hinders the possibility of an objective evaluation. To fill the gap, building upon the network approach, we propose–for future development–the assessment of the quality of the knowledge integration, based on two general aspects:

- The **diversity of the disciplines involved** (the more disciplines the larger the integrated knowledge), and
- The **effective integration** achieved through the meeting of different perspectives (if each discipline treats separately different aspects, the integration will be weak; if the theoretical construct gets to be merged into a general understanding of the involved phenomena, the integration will be strong)

### 6.1. *Discipline Diversity Index*

In the first place, the granularity level in the distinction of disciplines have to be determined. This can be done, in a first approximation, by fixing the number of relevant digits of the Universal Decimal Classification (UDC) used to distinguish the knowledge areas involved in a particular research [McIlwaine, 2007; Slavic, 2011; UDC Consortium, 2017]. Though the UDC offers a good and well-accepted coverage of knowledge in general, an adaptive implementation need to be introduced in the categorisation of *Knowledge Domains* (KD): (i) some UDC categories have to be disregarded (for instance those which are not related to knowledge but to document types), (ii) other categories should be ascended from a lower granularity level in virtue of its relevance for the problems under study, and (iii) some category groups should be merged because they represent different aspects of the same knowledge, for instance, theoretical and applied.

Assuming the number of relevant KD is $N$, the diversity of participating disciplines can be determined through Shannon Diversity Index weighted by the maximal diversity achieved through a similar participation of the $N$ KD, i.e. $\log_2 N$. By that means, if the $N$ KD are homogenously distributed (i.e. they contribute equally –situation of maximal diversity) the index will be 1; and 0 in case that only one KD is contributing. Generally, the more KD are contributing in a more distributed way, the index will be closer to 1.

**Definition 5.1.** Calling $p_i$ the frequency of occurrence of a contribution from the $i^{\text{th}}$ KD (or probability that a contribution taken at random belongs to such a discipline), the *diversity index* will be:

$$ID = \frac{1}{\log_2 N} \sum_{i=1}^{N} p_i \log_2\left({}^{1}\!/_{p_i}\right) \qquad (5)$$

For the purpose of evaluating the performance of the knowledge integration achieved in glossariumBITri, a selection of 67 knowledge domain categories ($N$=67) have been selected from the UDC (mostly corresponding to just 2 digits of the CDU, ca. 7 per UDC group), agreed by glossariumBITri's editorial board on the basis of a discussion held in summer 2017 according to the adaptation referred to above. This number of differentiated knowledge domains is deemed sufficiently large to provide a satisfactory approximation of the diversity index, at the same time that is not excessively specific as to make its application too complex. Table 1 shows the categories selected and its correspondence within the UDC framework.

For its application, each contribution (entry) to the glossariumBITri needs to be identified, among other descriptors, by the domain categories that best fits the knowledge area supporting the contribution. For peer-review purposes the scientific board will also be identified by domain categories corresponding to the fields of expertise. This will ensure a good correspondence of the contributions to the knowledge domains, therefore the real support provided from disciplinary expertise to the interdisciplinary elucidation.

In a dynamical perspective, the comparison among consecutive knowledge integration assessments over time will facilitate the visualisation of the knowledge coverage evolution in the related inter- and transdisciplinary elucidation. Simultaneously, it will provide strategic guidance to the clarification needs to be covered through: (i) the strengthening of specific knowledge domains, (ii) the launching of discussions on new concepts or topics that required a deeper consideration, etc.

Table 1. Knowledge Domain Categories selected for glossariumBITri content classification.

| **i** | **Knowledge Domains** | **UDC code** | Additional UDC 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 657 (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 | 01 + 03 + 05 + 07 / 09 |
| 08 | Librarianship | 02 | |
| 09 | Organisations of a general nature | 06 | |
| **I** | **Philosophy** | **1** | **# types/group: 7** |
| 10 | Nature and role of philosophy | 101 | |
| 11 | General and Specific Metaphysics | 11/12 | Includes general metaphysics (ontology; philosophy of nature), and specific metaphysics (causality, necessity, liberty, teleology, etc) |
| 12 | Special Metaphysics (causality, necessity, liberty, teleology…) | 12 | |
| 13 | Philosophy of mind | 13 | |

| i | **Knowledge Domains** | **UDC code** | Additional UDC covered by domain i + **Clarifications** |
|---|---|---|---|
| 14 | Philosophical systems and point of views | 14 | |
| 15 | Logics. Epistemology | 16 | |
| 16 | Moral philosophy. Ethics | 17 | |
| **II** | **Religion. Theology** | **2** | **# types/group: 2** |
| 20 | Theory, philosophy, nature and manifestation of religion | 2-1/2-9 | |
| 21 | Religious systems. Religions and faiths | 21/29 | |
| **IV** | **Social Sciences** | **3** | **# types/group: 11** |
| 40 | Methodology of SS. Social questions | 30 | |
| 41 | Statistics as science | 311 | |
| 42 | Demographics. Sociology | 314/316 | |
| 43 | Politics | 32 | |
| 44 | Economics | 33 | |
| 45 | Law | 34 | |
| 46 | Public administration | 35 | |
| 47 | Safeguarding necessities of life | 36 | |
| 48 | Education | 37 | |
| 49 | Cultural anthropology | 39 | |
| 40 | Psychology | 159.9 | Moved from group 1, as it appears in UDC |
| **V** | **Natural Sciences. Mathematics** | **5** | **# types/group: 10** |
| 50 | Environmental studies | 50 | |
| 51 | Mathematics | 51 | |
| 52 | Astronomy | 52 | |
| 53 | Physics | 53 | |
| 54 | Chemistry. Minerology | 54 | |
| 55 | Earth Science | 55 | |
| 56 | Palaeontology | 56 | |
| 57 | Biological sciences in general | 57 | |
| 58 | Botany | 58 | |
| 59 | Zoology | 59 | |
| **VI** | **Applied Sciences. Engineering** | **6** | **# types/group: 13** |
| 60 | Biotechnology | 60 | |
| 61 | Medical sciences | 61 | |
| 62 | Engineering. Technology in general | 62 | |
| 63 | Agriculture and related sciences and techniques. Forestry. Farming | 63 | |
| 64 | Home economics. Domestic science | 64 | |
| 65 | Telecommunication and telecontrol | 654 | |
| 66 | Postal and transport industries and services | 656 | |
| 67 | Business management. Accountability | 657/658 | |
| 68 | Graphic industries. Informative work. Public relations | 655+659 | |
| 69 | Chemical technology | 66 | |

| i | Knowledge Domains | UDC code | Additional UDC covered by domain i + **Clarifications** |
|---|---|---|---|
| 6A | Various industries, trades and crafts (excl. automatic control) | 67/68 | It groups UDC 67 (materials) and ~ for assembled articles (UDC 68), except 681.5 |
| 6B | Automatic control technology. Intelligent technology | 681.5 | Separated from "various industries…" (UDC 68) |
| 6C | Building trade, materials, procedures | 69 | |
| **VII** | **The arts. Recreation** | **7** | **# types/group: 6** |
| 70 | Physical, regional, town, country planning | 71 | |
| 71 | Architecture | 72 | |
| 72 | Plastic and graphic arts | 73/76 | 73: Plastic art<br>74: drawing design<br>75: painting<br>76: graphic art |
| 73 | Photography | 77 | |
| 74 | Music | 78 | |
| 75 | Recreation. Theatre. Cinema. Gaming | 79 | |
| **VIII** | **Language. Linguistics. Literature** | **8** | **# types/group: 3** |
| 80 | General questions relating to linguistics and literature | 80 | |
| 81 | Linguistics and languages | 81 | |
| 82 | Literature | 82 | |
| **IX** | **Geography. Biography. History** | **9** | **# types/group: 5** |
| 90 | Archaeology. Cultural remains. Area studies | 90 | |
| 91 | Geography | 91 | |
| 92 | Bibliographical studies | 92 | |
| 93 | Science of history and historiography | 93 | |
| 94 | History | 94 | |
| **i** | **# knowledge domains:** | **67** | **E[# types/group]: 7.4** |

### 6.2. *Integration of Disciplines*

Even when the meeting of very diverse knowledge (as assessed through the methodology depicted above) has been achieved, it can be the case that its theoretical constructs do not merge at all in the explanation of the phenomena concerned, and instead each discipline devote itself to refer a different aspect of the object or problem under study. In such a case the integration would be null. In the extremely opposite case, all the theoretical constructs from each discipline involved are interrelated in the explanation of the phenomena concerned. In the latter case the network distance between any two nodes of the whole network of concept names is expected to be short and the clustering low, while in the former case the average distance is expected to be large, particularly if many disciplines are involved, and the clustering high.

This density of semantic relation can be analysed in terms of the structural properties of the semantic network obtained through the development of an *interdisciplinary glossary* (ID-G) as described in Sections 4 and 5. Such network, as shown above, is constituted by the interconnectedness of theoretical terms established through the corresponding elucidation process.

The identification of knowledge domains, referred to in the previous section, enables the visualisation (within the semantic network analysis) of the specific domain support to different parts of the network of concepts. At the same time, the identification of contributors and reviewers in the analysis of the interacting network of scientists will enable the identification of relevant interactions among researchers and the corresponding knowledge domains as discussed in Section 3 (s. Fig.2.b). Such *actor network analysis* can serve as an additional mapping of the disciplinary interactions.

### 6.2.1. *Quantitative assessment of conceptual integration*

Following the methodology described above, it is possible to derive a quantitative assessment of the knowledge integration achieved. The study of the minimal average distance between any two words provides a measure of the integration achieved. In the case of natural language, taken an extended vocabulary of 66,000 words, Sigman and Cecci [2002] determined that the *average minimal distance* between any two words was around 7. However, when the knowledge is not well integrated, the distances increase at the same time that disconnected clusters can be identified. Thus, high *clustering coefficient* and low *average minimal distance* offer a characteristic of the integration achieved. Indeed, its ratio compared with the equivalent ratio for random networks, provides the *small-world coefficient* in which both values are combined with the dependency that directly contribute to increase integration:

$$\sigma = \frac{C/C_{rand}}{L/L_{rand}} \qquad (6)$$

Using the small-world coefficient we can evaluate, with a single parameter, whether the network satisfy or not the condition of a small-world network $\sigma>1$ and how well integrated it is [Telesford, 2011].

### 6.2.2. *Qualitative assessment of knowledge integration*

The network analysis, as the one described in section 4.1, facilitates a qualitative evaluation, distinguishing specific theoretical clusters that are not well integrated, fields or concepts that are misrepresented, etc. This evaluation provides guidance for the further development of the research concerned in the same vein as the discussion of results shown in section 5 (e.g., what disciplines need to be strengthened, what dialogue should be open up, etc.).

## 7. Discussion and conclusions

In Section 2, we have provided a broad view for the structural properties of knowledge integration, presenting first an overview of knowledge in general according to the *modal stratified bond model* [Burgin 2017]. We then provided a formalisation for *conceptual integration of knowledge* that can be applied to knowledge representation in conceptual systems as glossaries, thesauri and encyclopaedias, as considered in Sections 4 to 6. As we observed in Section 2.2, a possible way to interpret conceptual systems is through networks of concepts (Definition 2.3) and it was this approach to which we dedicated the rest of this Chapter. However, the structure of conceptual systems can be explored in much more detail. For instance, we depicted the ideal situation of having a conceptual system capable to merge different knowledge systems (Diagram 4). This is indeed the maximal knowledge integration we labelled as “transdisciplinarity” in Section 3.1 (using UNESCO’s categorisation [Hainaut, 1986]), but we did not provide a means to measure how far we are from this situation when we are merging knowledge through interdisciplinary settings. In [Burgin

2017], several metrics and methodologies are proposed that can be used to address this issue, and this is certainly a rich vein for further inquiry. Nonetheless, the network approach offers a breadth of possibilities to analyse knowledge integration in interdisciplinary undertakings, and even some paths to evaluate whether the integration of knowledge is approaching to the ideal situation labelled by transdisciplinarity.

The methodologies described in section 3 and 4, and the results discussed in section 5 show the interest of the ID-glossaries in combination with the network analysis as a promising approach to qualify knowledge integration and interdisciplinarity through the study of conceptual networks. In Section 3.2 we discussed the importance of developing means to qualify interdisciplinarity, as the performance in the attainment of knowledge integration, for the underpinning of interdisciplinarity and transdisciplinarity within the global endeavor of science, i.e. at a meta-theoretical level. To this purpose, the network approach offers a simple metric consisting in link distances. In Sections 4 and 5, we showed that the benefit is not only meta-theoretical, it also constitutes a useful tool in the advancement of knowledge integration, as we indicated in several places of our discussion of results from the semantic networks analysis performed on the glossariumBITri (s. Section 5.2). This capacity will be even stronger if the network analysis is performed over time to facilitate a comparative assessment of the evolution of the knowledge integration achieved through consecutive glossariumBITri editions. It is expected that this approach will serve to guide the theoretical work with additional capacity.

The possibility to use this approach to the assessment of educational processes has been discussed by one of the authors, showing its ability to detect the development of soft skills for which formal education is practically blind [Díez-Gutierrez, Díaz-Nafría, 2018]. Its application to the development of knowledge integration skills, as intended in the abovementioned PRIMER initiative (2018), is straightforward derived from the methodology and results discussed herewith.

Nevertheless, the approach, on which the results presented in Section 5 is based, do not provide a quantitative evaluation, which prevents an objective assessment. To circumvent this limitation, the enhanced methodology proposed in section 6 fills the gap with a bi-dimensional measure in which both the diversity of disciplines and the effective integration of conceptual networks is measured at the same time. An ongoing international project devoted to the enhancement of the glossariumBITri and the creation of an *Encyclopaedia of Systems and Cybernetics Online* (ESSCO) is currently applying the described categorization of knowledge domains to deploy the described approach. In addition, other methodologies to assess knowledge integration exploring further structural properties, as referred above, are also envisaged.

Summarizing, knowledge integration is the very purpose of interdisciplinary and transdisciplinary undertakings, where the latter constitutes a rather ideal situation in which conceptual unification is feasible. The complex structure of knowledge systems responds to their capacity to articulate knowledge in the confrontation of problems and the description, representation and modelling of reality. The analysis of conceptual networks offers a simple and powerful way to scrutinise structural properties of knowledge which is in the process of integration; while interdisciplinary glossaries offer the way to represent and co-create knowledge with a two-fold purpose: at the theoretical level, the increase of *intensional performance* (or reduction of conceptual redundancy) and the further elucidation of concepts; at the meta-theoretical level, the assessment of knowledge integration based on diversity and conceptual network integration. They can be applied to the integration of knowledge in the context of focalised problems, or in the larger context of developing interdisciplinary and transdisciplinary settings.

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