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Concept maps to enable interdisciplinary research in cross-domain fusion

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Abstract

A sound basis for an interdisciplinary dialogue is highly important for cross-domain fusion (CDF) dealing with knowledge transfer between working groups situated in different research disciplines. In this paper, we present a literature-based concept map as one example to start an interdisciplinary dialogue between disciplines for the showcase of the concept "coast" and illustrate how such a concept map can be used to explicate various computer science challenges and provide inputs for CDF. We use the strengths of a concept map to display gathered knowledge and perspectives, and hence view the different disciplines have on "coast" and further highlight inter- and intra-categorical connections between several disciplines. With this example, we also want to point out the importance for the understanding of data originating from different disciplines and to raise awareness about the various methods and models that provide data and information for CDF approaches.

Motivation

Interdisciplinary research is at the heart of cross-domain fusion (CDF), which can be considered a new paradigm of scientific work. True interdisciplinary research is, however, a challenging endeavour with regard to, amongst other things, securing funding, publishing research results, transferring knowledge and communicating with each other. Complexity is added when research and infrastructure should serve various purposes, views and stakeholders – each equipped with different epistemological backgrounds, methods, research questions, etc. Hence, finding common ground and language on which research is based on is often time-consuming and considered troublesome [1, 2]. However, mutual understanding and 'a common language' have been identified as the most critical aspects of successful interdisciplinary collaborations [3] – therefore, it is also key for successful CDF. Also, in interdisciplinary research projects (as well as in any other research project) it is crucial to know the main goals and the steps to be taken to reach these goals. All collaborators, including the computer scientists as facilitators and designers of methods of and applications for CDF, should understand the (different) views on the research object, what aspects should or must be included, what methods will be used, etc., to outline the research needs as clearly as possible and independent of disciplinary terms and boundaries. One of the most prominent examples of interdisciplinary research is the effect of climate change on the coastal environment. It spans over and integrates disciplines such as atmospheric science and oceanography, biological consequences, economic interests, societal concerns, legal commitments, political action, as well as ethical implications [4].

As an interdisciplinary group, which is highly convinced by the visions of CDF for interdisciplinary research, we will present our approach to tackle the challenges of inter-

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disciplinary work, i.e., by preparing a concept map of the term "coast". We will explain our approach, present first results from our ongoing work and discuss what lessons can be learned to successfully deal with CDF. In particular, we will sketch the computer science challenges and inputs that can be developed with the help of jointly working and reflecting on such a concept map.

Concept maps for interdisciplinary research

We adapted the idea of concept maps [5] and mind maps [6] to collect, sort and sketch the views from various disciplines on a research object (a core concept) that they all work on. Such maps, in which central aspects are hierarchically or loosely connected via (un-)directed or (un-)defined relations, support representation of complex ideas, raise awareness about associated areas and foster understanding of key components of a concept. They also aid exchange among stakeholders. As a tool for organizing knowledge, concept maps provide an overview on the overarching picture as well as on the details of the constituent parts of a concept. Moreover, they can be used to highlight a lack of information and of interconnection. The interconnections between the different parts of the map are of key importance for CDF since they specify which views should be fused at which stage (level of detail) within the process from data to wisdom. In a visualized and schematized way, concept maps already embody what CDF aims to reach: the combination of multiple scientific views to gain a more comprehensive "super-view" on a research object. Due to their flexibility and expressiveness, concept maps have become established tools in, amongst others, learning, software engineering, and ontology development. For CDF, it is important that generic machine learning and data mining methods are developed that can be "parameterized" by these maps in such a way that the methods automatically know which concepts, views and stages are used as inputs rather than being picked and applied manually by a user.

For our concept map, we have chosen "coast" as the common research object and central concept. According to the United Nations Atlas of the Oceans, over 50% of the world's population lived within 200 km of a coastline in 2001 [7]. Moreover, in our interdisciplinary research team, we have found first anecdotal evidence on "coast" being a vital object of study in disciplines such as media science, political science, humanities, marine sciences including geology, geography or biology as well as theology, arts, architecture or computer science. The development of a concept map serves two major functions:

1. It raises awareness about the different concepts of "coast" across the various disciplines involved and fosters the understanding of different views on the research object "coast" (as already mentioned above).
2. It fosters the understanding of which kind of data is used for research on "coast" and, therefore, which kind of data infrastructure is required. Furthermore, it paves the way towards an analysis of requirements and expectations by increasing the transparency about data, methods and functions to be provided to serve all researchers and stakeholders that work on this research object.

As such, the explication of the various disciplines' background knowledge and epistemologies on the research object lays the ground for CDF and research in computer science. It is indispensable preparatory work preceding further formalization, modelling and implementation, e.g. in terms of retrieval of data and information suitable for all disciplines with varying terminologies. The development and reflection of the map with all parties involved is key in interdisciplinary research and CDF. The concept map aids the process towards mutual understanding, since it is considered a more integrative and visual tool than glossaries or dictionaries that are rather flat representations of a knowledge domain.

From our experience with this map, we argue that in terms of CDF the interdisciplinary dialogue and reflection helped to emphasize what views are worth merging, which connections exist between and across views and on what level of detail input needs to be prepared and processed to arrive at a meaningful "super-view" on "coast". In the end, CDF has to mirror the core ideas of each discipline to allow for meaningful interdisciplinary research. Instead of just combining data, models and processes, CDF provides a bigger picture that is greater than the sum of its parts. Here, the role of computer science is to enable this in all phases of research and in the presentation of results. Moreover, the approach to CDF has to be flexible, as new disciplines and research questions may develop over time.

Development of a concept map

We applied an elaborated process for the development of the concept map and its reflection (see the process diagram in Fig. 1). Similarly to the approaches of thesaurus- or ontology-building [8], first we recorded occurrences of concepts and links between them via information we found in an extensive literature research and analysis. As such we followed an evidence-based approach outlining how the "coast" is actually researched in the various disciplines, i.e. how it is represented in publications. The goal was to diversify the content as much as possible and to include many different perspectives. A starting point was publications and references from the research group stemming

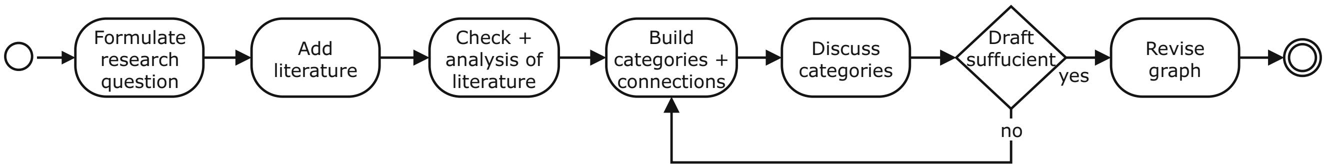

Fig. 1 The flow diagram for the development of the concept map

from geosciences, political sciences, computer sciences and humanities. From the papers' basic knowledge, use cases and keywords were extracted and used for further research as well as for mapping the landscape of concepts associated with "coast". Overlapping or recurring definitions from multiple disciplines indicated larger categories and broader concepts.

Hence, the second step comprised the summary and categorization of the information found and explication of relations between the categories. Sometimes connections are rather derived and built on the meta level of the literature. The links can result in one-sided and reciprocal relations. In this regard, special consideration were given to categories that describe, amongst others, what data and methods are used, where data stems from, who is concerned by the research object and what time span is considered.

A first draft of this map was discussed within the research group, and reflection revealed a need for adjustment of categories and the addition of missing links, categories or views (see the process in Fig. 1). After revision, a detailed concept map formed the basis for further deliberations and exchange with domain and computer science experts.

The method has some limitations; only a limited number of experts has provided initial literature, so the derived concept map might lack input of disciplines such as engineering, humanities or historical sciences, medicine and arts. Although securing precision of analysis, having only a single person conducting literature research and categorization, bias and uncertainty may have been introduced. Here, the value of using automatic methods to support and complement manual work should be integrated in future work.

The concept map "coast"

The preliminary concept map on "coast" is shown in Fig 2. We describe how to read this map by using the political science view as an example. By doing so we consider the human's perspective in orange colouring, the corresponding categories *Political science* and *Economy* in the orange circles and the corresponding sub-categories within the white boxes. It becomes apparent that there is a strong focus on the study of human interaction with the coast, and more specifically on regulations of human activities with regard to the coast. This encompasses, for example, the analysis of the perception and behaviour of one specific type of (often collective) actor, such as non-governmental organizations or refugees. Moreover, political science literature analyzes how and why people establish political authority over maritime waters, for example, due to geostrategic reasons or to foster a sustainable use of and interaction with coastal regions (UN Sustainable Development Goals, SDGs), and what socio-political consequences of political actions are. This is frequently done by analyzing textual documents or oral discourses, legal and political regulations, regimes and narrations, media as well as further cultural products. So the analysis may, for instance, be dedicated to differing interpretations of the concepts of Blue Economy by various governmental actors, international organizations and NGOs [9]. The interpretations are gathered through content analysis of policy documents and so-called grey literature and aims at figuring out consensual narratives as well as contestations in order to be able to draw conclusion on the impact of these contestations on the legitimacy of the Blue Economy concept.

As mentioned in Sect. 3, within the course of the literature analysis connections between the formed categories were found. In Fig. 3, these relations are demonstrated with arrows, both one- and two-sided, to give a deeper look into the levels of connection and synergy effects.

The development process revealed interesting insights that highlighted the challenges of interdisciplinary research, spurred discussion among the research group (as expected) and that will well serve as requirements for CDF:

1. Patterns appeared: Two major epistemological approaches to "coast" were revealed, i.e. nature's and the human's perspectives. Nature's perspective (see Fig. 2, green colouring) joins all areas that focus on nature and the environment and that have a factual, rational or theoretical approach to research. Here, metadata is recorded and made available for other categories, on which their understanding and the processing of the coast is based. The human's perspective (see Fig. 2, orange colouring) provides a view of the coast, which is partly self-centred and anthropogenic and usually gathered through the analysis of narratives. This perspective focuses on how humans see and interpret the coast and what benefits and normative attribution it has for them.

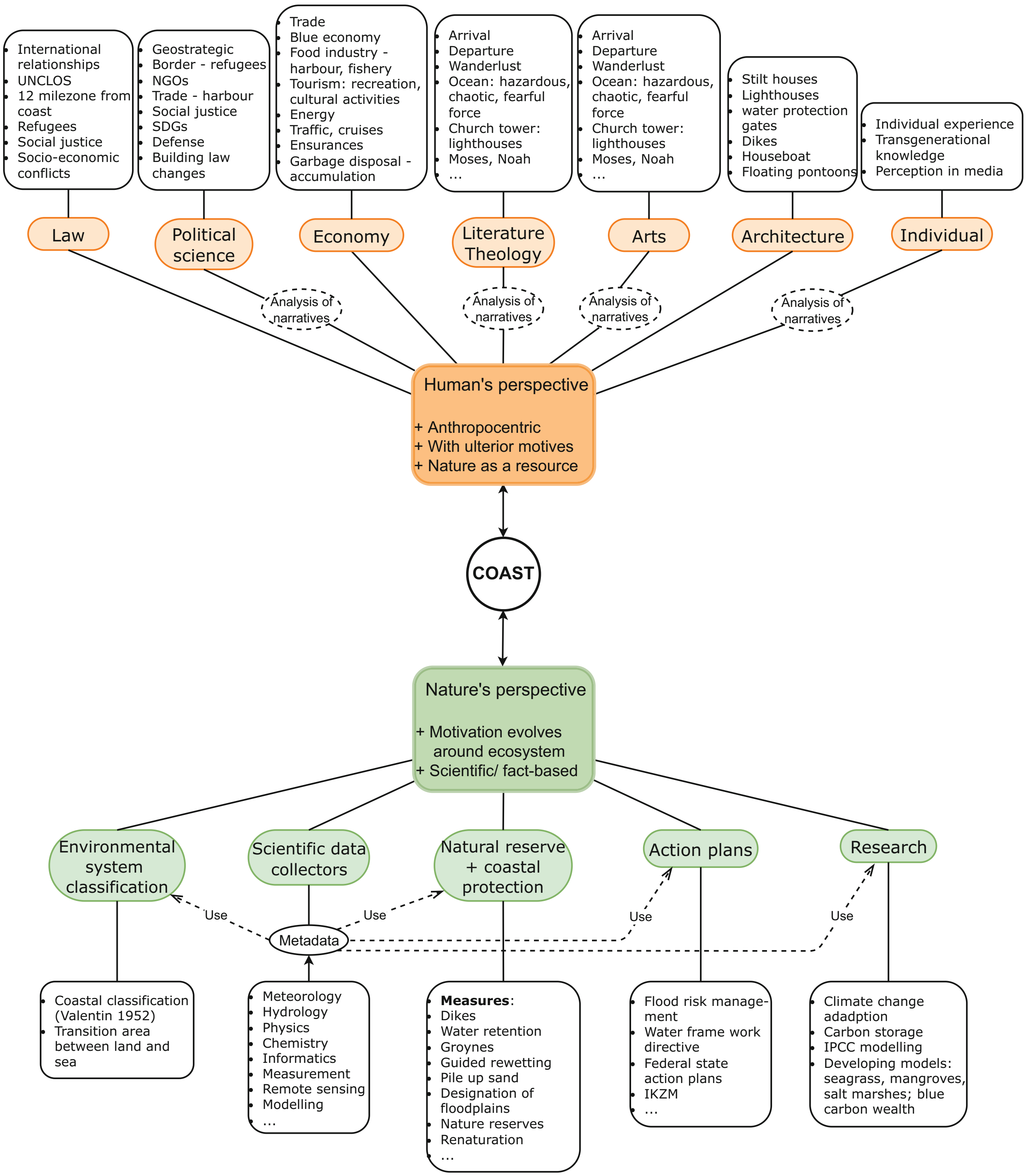

Fig. 2 Preliminary concept map for "coast". *Middle:* nature's perspective and the human's perspective in *orange* and in *green colouring*, respectively; branching out are the categories in *coloured circles* and sub-categories in *white boxes*

2. Interdisciplinarity increases complexity: Although it was possible to form broad categories (e.g. "action plans", see Fig. 2), the different disciplines, views of the coast, different data analysis, etc., have led to a great variety of relationships and connections between and within categories but also as an effect of one generic term on the other and vice versa.

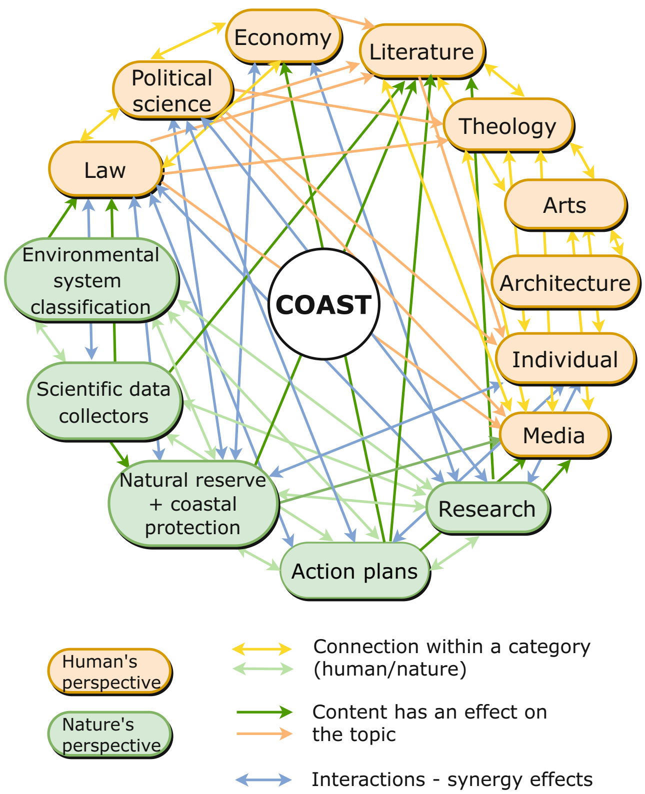

Fig. 3 Connections between main categories: Connections within the categories and between the human's and nature's perspective; direction of actions, interactions and synergy effects are displayed with *colour-coded arrows*

3. Complex relationships between categories: The literature analysis revealed that links between categories can result in one-sided and reciprocal relations to reflect mutual synergies and dependencies (see the arrows in Fig. 3). The influence among the main categories also show an impact from one category to the other. But, each category can also be semantically independent with only a limited amount of connections across categories (reflecting a more disciplinary view on the topic).

Relevance for cross-domain fusion and computer science

So far, the development and the reflection of the concept map has been a high-level, conceptual exercise to increase understanding between researchers of different disciplines. It also supported sketching out the disciplinary requirements for research on "coast", e.g. regarding the different methods mostly used, origin of data or the use of models, and along with it raising awareness about the heterogeneity of data and information feeding CDF. We argue, however, that the development of a concept map is a valuable prerequisite to enable effective CDF and the nucleus for the introduction of computer science methods and research. In the following, we will therefore highlight some areas of interest to computer science that we believe to be fruitful avenues for further investigation and research towards CDF:

- The demand for mapping between terminologies and views is steadily rising, mainly due to the availability of digital data and the demand to combine and/or modularize the same data for different purposes. One of the consequences of comparing the languages of different disciplines on the basis of an empiric selection is that such a selection reduces the range of possible meanings and links between languages, i.e. it is always limited. Coming from a single discipline, the semantic analysis based on such a selection may be somewhat coarse grained or, to some extent, even misleading. The most important gain, however, is that it offers an operationalization of meaning across disciplines [10]. The comparison of discipline-specific terms is an important exercise involving correspondence between conceptual and operational domains and, therefore, is a prerequisite for cross-domain research. Moreover, concept mapping offers a solid method for establishing content validity. This may be a difficult and time-consuming task but may suggest *a priori* hypotheses and can provide a strong basis for building the evidence of validity for a wide range of applications [11].
- The concept map needs to be extended by several layers of knowledge – specific to CDF and that allows for proper modelling such that it can be explored by data analysis methods – including:
  - A layer that models explicit background knowledge at any level of detail, e.g. differential equation systems about climate systems, an economic model describing the interplay of different economic views (see Fig. 2), etc. This background knowledge may be integrated into the data analysis methods that perform the CDF.
  - A layer that models constraints that need to be respected by CDF methods. Such constraints might include technical aspects surrounding the analysis, e.g. that a data source is gathered by a sensor with very limited resource constraints, and a corresponding CDF method should use edge computing techniques, or ethical constraints like privacy [12].
  - A layer that models the types of relations between categories and the types of categories to explicate whether relations are (un-)directed, or whether or not links and nodes have weights, etc. Also, the use of graph-theoretical models need to be evaluated here.
- The concept maps display background knowledge that needs to be explored during CDF. Thus, new methods are needed to explore this knowledge during the fusion,

e.g. for schema mapping, for shrinking down the search space of search methods, and for guiding learning methods towards specific patterns (as it is already done partly by machine learning methods using knowledge graphs, see e.g. [13], etc.

- CDF will leverage complex analysis processes and workflows that may be interactively guided by a user but may also be assembled automatically. In the latter case, concept maps will be the guidance that specifies what should be fused but also what can be fused. For example, the map may reveal that a particular data source is qualitative and may only be merged with other qualitative views. Another possible scenario is that a given view requires a specific privacy level, so an analysis involving this view needs to guarantee this privacy level.
- Finally, the concept map can be seen as a separate view on its own that could be analyzed for patterns that are of potential interest for CDF. In this sense, the concept map may be interpreted as a (heterogeneous) information network, and the challenge is to find interesting and relevant patterns in this network.

Conclusion

In order to successfully investigate complex problems via CDF all disciplines involved have to communicate and collaborate to create a common understanding and to learn from each other's perspectives and views. As mentioned in the opening article of this issue, there are already sophisticated tools to merge different views. However, as we have shown by providing a concept map for "coast" knowledge about and understanding of the kinds and types of data, models and methods that have been used by the various disciplines are crucial for successful fusion. Besides discussing further research avenues with domain experts and computer scientists we aim at developing further maps for concepts that are critical for CDF such as "model", "data" or "metadata" by using a more diverse set of methods. We also plan to explore automated methods for the generation of concept maps.

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