Ontology-based interaction design for social-ecological systems research

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Abstract. Contemporary social-ecological systems (SESs) research supports policy and decision-making to tackle sustainability issues and requires interdisciplinary and often multistakeholder synergy. Various frameworks have been developed to describe and understand SESs, each producing different kinds of data and knowledge. The resultant situation of information silos and lacking interoperability spurred our initial research towards an ontologically grounded SESs integrated conceptual model. This paper explores the deployment of that model and describes how ontology-based interactions can be used to clarify notions, align perspectives, negotiate terminologies and semantics in inter- and transdisciplinary collaboration settings. We present a practice of participatory sense-making for knowledge co-production using ontologies, discursive artefacts, game and play methods. Examples of interaction *scripts* are introduced, as are results from an exploratory workshop playtest which provide preliminary evidence of the potentials for ontology-based interactions and further developments in this field.

Keywords: Ontologies · Social-ecological systems · Interaction design.

1 Introduction

Understanding complex social-ecological systems (SESs) to support policy and decision-making requires a synergy between domain-specific knowledge and action in inter- and transdisciplinary settings. Collaboration, participation, and multi-perspective knowledge co-production are central to this endeavour [3,13] for which effective, unambiguous communication between scientists and stakeholders is required [13]. A variety of descriptive and explanatory frameworks have been proposed [3,4] which attempt to capture meanings and structure global and local understandings of SESs, and various engagement techniques have been developed to promote inclusive and equitable SESs analysis and transformation, for example dialogues, collective narratives, and participatory modelling [3,18]. Although these frameworks and activities share the goal of representing and explaining SESs towards sustainable management of human-nature interactions,

they produce knowledge following different worldviews, are often difficult to integrate or compare, and can be semantically vague, which hinders interoperability and cross-examination of research data and results [1,3].

In this paper and an accompanying workshop at the Research Challenges in Information Sciences 2024 Conference (see `https://humanfactorsinsemantics.net/RCIS2024.html`), we explore the potential of ontologies and ontology-based conceptual models to support participatory sense-making and knowledge co-production in sustainability research. The work revolves around an integrated conceptual model and emergent *Social Ecological SystemS ONtology* (SESsION) that bridge two well-known SESs frameworks, the social-ecological system framework (SESF) [11] and the ecosystem services (ESs) cascade [14] to clarify key SESs components and integrate them into a unified model using foundational ontologies and related ontological literature [1,2]. The ontology and integrated model, with their unambiguous semantics, ontological clarity and grounding in formal ontologies, align disparate SESs perspectives to support the understandability and comparability of research, and to facilitate data collection and interpretation.

The SESs integrated conceptual model and underlying ontological basis formalised in SESsION are intended for (i) domain experts to collectively map and express knowledge and support interoperability and comparability with other sustainability efforts, (ii) policy makers and broader communities of practice to access complex SESs knowledge and make sense of local social-ecological scenarios and sustainable management needs, and (iii) developers to design data structures and software alignments that facilitate FAIR datasets for modelling and comparative research. In order to achieve these uses, we define strategies to make sense *of the conceptual model* and render the complexity of SESs entities and relations understandable for researchers and stakeholders, to examine both general and place-based SESs scenarios *through the conceptual model*, and to *interrogate the model itself*, questioning its ontological assumptions and reflexively negotiating its meanings together with communities of knowledge engineers. We approach these tasks through the design of tangible cognitive artefacts [15,19] and development of participatory sense-making [7] *scripts* [10], using game and play interaction design techniques [16,20].

2 Social-ecological systems integrated perspective

SESs include *social* and *ecological* components, intertwined in complex feedback loops that are often challenging to understand and define [1,6]. Multiple frameworks have been proposed to capture SESs knowledge [4], and two that feature prominently in sustainability research literature are the SESF [11] and the ESs cascade [14]. The former is a product of political science and aims to define a common vocabulary for human-nature interactions and common-pool resource management, such as small-scale fisheries. The latter originated from environmental economics, focuses on nature's benefits to humans' well-being, and elaborates ecosystem services and products in terms of benefits and values,

such as food and pollination. These two frameworks apply different forms of analysis and produce different kinds of knowledge and data [3].

The recognition in sustainability science of a growing need for data interoperability and integration of different knowledge sources, to improve the quality and speed of cohesive actions, inspired our initial efforts towards integration of SESs frameworks [1,2]. The semantic clarification of central SESF and ESs cascade elements was achieved through ontological analysis and conceptual alignment, adopting in particular the Unified Foundational Ontology (UFO) [8] and Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) [5]. The resultant integrated SESs conceptual model includes four elements from SESF, i.e. *resource*, *resource system*, *actor*, *governance*, and five from the ESs cascade, i.e. ecosystem *structure* and *function*, ecosystem *service*, *benefit* and *value*. For an in-depth read of the integrated perspective we redirect the reader to the original articles ([1,2]). The SESs integrated perspective's components, including the necessary elements for its ontological alignment and grounding, have been implemented and expanded in a computational ontology called SESsION, available for consultation, download, and reuse on GitHub.

3 Participation and the collective negotiation of meanings

Interdisciplinary research on complex, adaptive or evolving social-ecological [3] and socio-technical [9] systems frequently employ participatory practices that are rooted in action research (AR), a form of qualitative inquiry that proposes interpretative and collaborative methods to engage scientists and stakeholders in cycles of planning, action and reflection [3,9]. AR acknowledges multiple forms of exploratory and explanatory knowledge, and has engendered methods such as participatory rural appraisal (PRA) and knowledge co-production [3,12], user-centered and participatory design [9]. Central to these practices is the collective negotiation of terminologies and meanings, a "figuring things together" ([17] p. 55) wherein agreement is reached on which aspects of an investigative context are most relevant and how those concepts should be articulated and represented. The implications of such participatory sense-making [7] are that meanings emerge from, and are formed in collaborative activities [7,15], for example group- and participatory modelling [10,18] which allow for the *elaboration of existing knowledge* through creating model(s) of x, the enaction of which can facilitate the *co-creation of new knowledge* concerning x [7,10,18]. Collaboratively developed models and other representations, such as rich pictures and causal loops [18], serve as cognitive artefacts, the generation and use of which can, for example, align participants' emergent perspectives [7,15]. The materialities and discursive characteristics of designed things [19] subsequently foster pluralism and dialogue [20] as people coordinate their actions around, and through those artefacts.

The relations between artefacts, people and practices are linked with human intersubjectivity, language and collaboration (see [15,20]), and their recursive and co-constitutive configurations are nowhere more evident than in the familiar forms and social coordination of games and play [16]. Game techniques are widely

used in participatory research [3,18] and their unique entanglement of material and social worlds are evidenced by the physical arrangement of players around a gameboard, players' acknowledgement of that as a map of the game world, and of play-pieces as virtual representations of ourselves. Turn-taking, role-play and rules are all part of a social contract [16] that is entered upon agreeing to play a game, which signal and facilitate willingness to collaborate and the activation of intersubjective linkages at the core of communication [7,15].

4 Ontology-based interaction design: artefacts and scripts

Ontologies are renowned as tools for defining and representing explicit meanings that can be shared and used among communities, thus fostering interoperability. However, rendering ontologies and ontology-based conceptual models understandable and usable for scientists and stakeholders often requires some translation, especially for groups and individuals that are not familiar with abstractions and formalisation. Hence, we have developed an approach for participatory sense-making and knowledge co-production using ontology-based representations, which involves disassembling the information artefact/model into its constituent parts, such as elements, relations and rules, and creating tangible artefacts to represent each component. Subsequently, interaction *scripts* [10] are devised using game and play methods which support participants in (*a*) understanding the ontological concepts and commitments of the information artefact/model, and (*b*) collaboratively constructing meanings and interpreting research and design scenarios guided by the information artefact/model. Using the same game elements, scripts are developed for a third purpose, (*c*) the interrogation of ontological groundings of the information artefact/model itself, for example to corroborate the assumptions and ontological interpretations.

The scripts include (i) a *name* that frames the engagement, and basic instructions for (ii) setting the *stage* (iii) participants' *roles*, (iv) necessary *props* and (v) procedures or *rules*. Most scripts require a **Mediator** who introduces the activity and initial engagements, and **Players** who actively engage in the interactive activities. Additional roles such as a **Recorder** who takes notes and **Data Entry** who enters data into a tablet spreadsheet may be required. **Spectators** include any observers who are not (yet) engaged in an active role; input from spectators is encouraged, and they can become players at any time. **Props** created for these scripts include tangible artefacts derived from the ontology or ontology-based conceptual model, such as a large print of the model, henceforth called the big model map, laminated concept cards and relations tabs, four magnified model snippets called model zooms, scenario illustrations and other graphic elements, a whiteboard, stickynotes, writing materials, a tablet computer, digital camera and a spreadsheet app.

In the following we introduce three example ontology-based interaction scripts for participatory sense-making and knowledge co-production in sustainability research using the SESs integrated conceptual model. Fig. 1 depicts a sample of the props (left) and their use during playtest interactions (right).

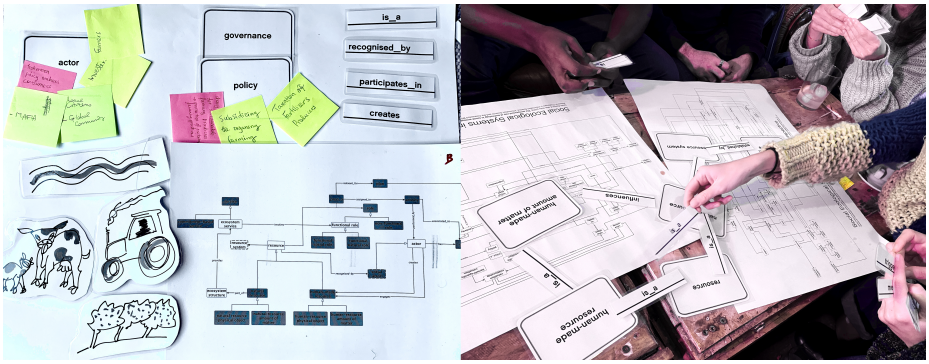

Fig. 1: Sample of SESs props (left), **Relation-Slap!** script test (right).

Relation-Slap! is a script for participants to gain an initial understanding of the model, its elements and their relationships to others. The interaction is inspired by a Japanese card game called Menko, in which players slam cards on top of each other in a defined playspace. Props for this activity include the big model map, four model zooms, concept cards and relations tabs. Players sit on the floor or stand at a table around the big model map, with the model zooms at hand. Roles in this script are Mediator and Players, and the activity proceeds as follows:

- Distribute relations tags among players (e.g. *is a*, *participates*);
- Shuffle and place the big concept cards in the center;
- The Mediator acts as dealer and turns over the top card one by one;
- Each player must "slap!" their relationship tabs between relevant concepts;
- Move the concept cards around to create model snippets;
- Turn-taking may or may not be necessary;
- First player to properly place all of their relationship tabs wins.

Scenario Zoom is a script for domain experts and/or stakeholders to investigate SESs scenarios. Artefacts needed for this activity include scenario illustrations, model zooms, tablet, and spreadsheet, big model map, concept cards, stickynotes and writing materials. Participants sit or stand around a table with the scenario illustration as a game board; the big model map is on hand and model zooms arranged like place mats. Roles include Mediator, Players, Recorder and Data entry, and the activity unfolds as follows:

- Mediator draws from the stack of large concept cards (e.g. *resource*, *ecosystem service*, *governance*, *decisions*);
- Players articulate the concept card and its relations referring to model zooms;
- Players write on stickynotes and attach to relevant concept cards;
- Data Entrist adds information to a spreadsheet on the tablet;
- Iterate for 15 minutes, after which a collective narrative for sustainable policy is produced and written down by the Recorder.

Negotiating commitments is a meta-script to analyze the ontology and conceptual model, which uses the big model map, concept cards, whiteboard, markers and digital camera. The whiteboard is placed flat and participants sit or stand around it, with big model map on hand for reference. No Mediator is required; Players and Recorder do as follows:

- Concept cards are distributed among players;
- Taking turns, place and discus entity cards on the whiteboard;
- Draw lines, arrows and named relations;
- Players take turns to query the ontological commitments, analysis, and alignment with existing ontologies, e.g. "do the relations all make sense?", "How to reconcile the DOLCE ontological commitments?";
- Players reflect upon the understandability and (re)usability of the model, drawing proposed changes on the whiteboard;
- Recorder takes notes and photos of proposed changes and justifications.

5 Preliminary results

A playtest of **Relation-slap!** and **Scenario Zoom** was enacted in a local cafe with a group (n=5) of post-graduate level sustainability researchers. **Negotiating commitments** was not tested as it requires specific ontology engineering expertise. The authors briefly introduced the SESs integrated model and SESsION ontology, then shared the role of Mediator for the exercises, which took roughly an hour and a half each, after which participants were asked for feedback in the round. Handwritten notes were taken and transcribed post-engagement, with additional insights drawn from researchers' discussions and observations of participants' body language and interactions. These texts were examined using discourse analysis, yet due to the small number of participants in a singular engagement, the following insights must be regarded as preliminary.

Signs of alignment between participants can be found by attending to dialogic syntax and resonances in particular, the repetition of utterances and re-elaboration of ideas during the interactions, which signify emergent intersubjectivity [7,20]. One example is the use of the term "lost" by several participants when describing initial engagement with model complexity; another instance of resonance is their elaboration of the concept "seeing". One participant referred to the model print as a map, stating that with it, "We can see where we are going..." A second suggested, "It's good to have the [scenario] image, so people can see..." and a third shared that Relation-slap! was "...interesting, to get a glimpse of how ontologies work..." These examples offer evidence that participants are engaging with each other's perspectives, and more significantly, articulating how ontology and model can potentially serve as cognitive artefacts, to navigate complexity as an unfamiliar space, and to gain insights from different perspectives.

The discursive dispositions of the artefacts and game interactions were noticeable as the group engaged in animated discussions; they commented and disputed each other's actions while actively rearranging the cards and relations

tabs. During Relation-slap! participants reflexively noted the connection between placing the relations and speaking out their intended logic. One even asked if that articulation was a "rule"; another stated, "I think everyone who put the card must explain the card. I placed my last card and there was no discussion, so I started to have doubt in my mind if it was correct." This hints of acceptance that individual contributions could only validated by the group. Participants' body language also provided testimony of enacted social cognition [7]; for example, in arranging the artefacts several times players touched the same card at once and then debated possibilities until agreeing upon the proper configuration. One participant spoke of a plurality that was made possible through the exercises "...maybe we have different opinions. Why? I explain this connection (gesturing to the cards), but another player can explain in a different way."

The social coordination on display can be attributed to well-known aspects of engaging in games as socially structured play, and the positive feedback may simply reflect the novelty effect, as participants had not previously encountered such ontology-based interactions. However it was clear that the ontology was also playing a role in the group's emergent worldview. For example, in the scenario exercise, without prompting, participants decided for *organisation* as a *social actor* as per the model, and debated whether *governance* is a *social actor*, or a *role* played by an *organisation*. This spontaneous alignment with the ontological commitments, through an embodied engagement between participants, artefacts and dialogue offers encouraging signs that ontology and interaction design were functioning as coordinating enablers [15].

6 Conclusions and future works

This paper presents exploratory research traversing the fields of ontology, conceptual modelling, interaction design and sustainability. It describes a process of transforming an integrated SESs conceptual model and its underlying ontological ground into tangible cognitive artefacts and game and play interactions for engaging groups of scientists and stakeholders in knowledge co-production. Several scripts for participatory sense-making are presented for examining the integrated model components, and for investigating sustainability scenarios. Initial playtest results suggest that ontology-based representations can guide participatory sense-making and knowledge co-production, and that game and play methods can prove useful in the fields of conceptual modelling and applied ontology. A hands-on workshop is planned for RCIS 2024 to share and practice these techniques; future works will include refining the emergent SESsION ontology and elaborating an ontology-based interaction design with different groups.

Acknowledgements This research is supported by the Basque Government IKUR program Supercomputing and Artificial Intelligence (HPC/AI), the María de Maeztu Excellence Unit 2023-2027 (CEX2021-001201-M) funded by MCIN/AEI /10.13039/501100011033.

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