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Collapse and reorganization patterns of social knowledge representation in evolving semantic networks

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ABSTRACT

This study introduces semantic network analysis of natural language processing in collective social settings. It utilizes the spreading-activation theory of human long-term memories from social psychology to extract information and graph-theoretic linguistic approximations supporting rational propositional inference and formalisms. Using an empirical case study we demonstrate the process of extracting linguistic concepts from data and training a Hopfield artificial neural network for semantic network classification. We further develop an agent-based computational model of network evolution in order to study the processes and patterns of collective semantic knowledge representation, introducing incidents of collapses in central network structures. Large ensembles of simulation replication experiments are conducted and the resulted networks are analyzed using a variety of estimation techniques. We show how collective social structure emerges from simple interactions among semantic categories. Our findings provide evidence of the significance of collapse and reorganization effects in the structure of collective social knowledge; the statistical importance of the within-factor interactions in network evolution, and; stochastic exploration of whole parameter spaces in large ensembles of simulation runs can reveal important self-organizing aspects of the system's behavior. The last session discusses the results and revisits the issues of generative semantic inference and the semantic networks as inferential formalisms in guiding self-organizing systemic complexity.

1. Introduction and rationale

1.1. Semantic networks and collective knowledge representation

Semantic networks present coherent and cohesive structures for knowledge representation (KR) and qualitative data mining tasks. Although often encountered as complex ontological hierarchies following strict rules of object inheritance [21,101], their most efficient and information-theoretic symbolism is their graph-theoretic representation as patterns of interconnected nodes (vertexes) and links (arcs). In such symbolic form, semantic networks encode a wide variety of semantic relationships, including linguistic approximations of knowledge and different types and scales of connectivity over complex hierarchical structures of subsumptional entities [20,62].

Semantic expressions can introduce knowledge approximations (also known as isomorphisms) to logic-based, rational propositional inference or formalisms [39,75]. According to Quillian [72], semantic networks based on linguistic assertions form an abstraction theory of the structure of the human long-term memory, able to embody knowledge as a computational

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model of mind. The spreading-activation theory of semantic processing [8,9,26] studies the effects of priming in semantic memory via associative semantic networks of interconnected relationships. These associations are stored and recalled in memory altogether (retention–activation process). Semantic networks of memory processing have recently contributed to a new approach to learning theory, namely the connectivism as a learning theory [82]. Connectivism focuses on the understanding of how informal learning patterns and associations (as complex adaptive systems) help people utilize and connect learning and knowledge rather than information itself. In their graph-theoretic properties, semantic networks are proven to follow scale-free distributions [12,73], and found to be strongly related to weak social ties in social networks of interactions [43,59].

In this paper, we will provide an evidence-based framework that goes beyond the construction of semantic networks from natural language knowledge representation [38,99], attempting to explore their evolution and their patterns of resilience and reorganization over a series of simulation-based experimentation techniques. A brief overview of the participatory and bottom-up empirical construction of semantic networks for a case study will be provided, and the use of Hopfield-type Artificial Neural Networks for training and extracting spreading-activation thresholds will be explored. Hopfield ANNs present a type of recurrent NNs with simple neurons and no hidden layers [17,52]. They utilize dynamic computation of auto-associative semantic rules in connecting synaptic nodes in the network and symbolize content-addressable memory systems with binary threshold units. The iterative nature of semantic memory processing [48,92] and retrieval in Hopfield Semantic Nets allows for finding a lower "energy" level for the network that self-organizes spreading-activation network patterns over knowledge hierarchies. The paper will showcase how semantic processing in semantic memory priming and retention, modeled using Hopfield-type ANNs allows for efficient and correct knowledge approximation and ontological representation of dynamics in human cognitive processing [see, for example, 4,11]. It will also demonstrate how human memory self-organization of semantic patterns improves informal learning and decision-making.

In terms of their social science context, the semantic representation discussed in this paper elicits collective social understanding of contextual relationships. In other words, the emergence of collective social structure as a function of how closely related are the mental models of individuals as members of the community or the social system under study. In this way, our approach to semantic network construction deviates from traditional cognitive approaches to knowledge representation. The strength of the semantic associations measured in our study depends on the degree to which such associations are widely shared by other individuals in the community. The more semantic concepts are shared by more members, the more they function at the collective social level of inference [38,81].

Sawyer [78] argues that traditional theories of emergence and the structural patterns from widely accepted system theories of complexity such as the chaos theory and the away-from-equilibrium dissipative structures of Prigogine [68,69] are hard to fit into the sociological and sociocultural realities of social emergence. He argues that the internal interactions among the components of the social system itself (e.g., individuals, institutions, social collective structures and norms) are far more significant from their perspective "sociobiological inflows" [78]. He also raises the importance of computational social science techniques on the study of macro-sociological phenomena and social mechanisms as a form of "social explanation" [77]. A growing number of articles in the relevant literature illuminate the high added value of adopting and exploring computational methods in social, cognitive and psychological sciences [23,35,76,86]. Computational social science methods, techniques and experimentation allow the study of complexity, adaptation and emergence in social systems ranging from the individual to the collective level of inference. Parallel advances in computational algorithms and artificial intelligence methodologies have provided an ever-expanding toolbox for computational social scientists in their attempts to study and explain highly complex patterns of social interactions (e.g., [61,71,80,94,97,100]). The volatile and subjective nature of human judgments, attitudes, dispositions and behaviors, coupled with the deep uncertainties and incomplete information characterizing the flows of real-world phenomena and their social and natural environments brings forth often implausible challenges for computational social scientists. It is not simply enough to describe "how" complexity in social systemic interactions emerges, but requires theoretical and evidence-based empirical arguments attempting to address "why" these complexity patterns emerge from social interactions, as well as for which scale prevalence of social inference (i.e., cognitive, individual, collective). Exploring the *micro-to-macro* links has been the "holy grail" of social science for the last few decades [32,35,44].

Patterns of collapse and reorganization in social systems can emerge and persist in parallel in a society at different scales of social inference. For example, at the same time income inequality between the top 20% of the richest and the bottom 20% of the poorest in the US population has increased noticeably both in absolute numbers and in its global rankings, economic growth at the collective level and investment levels in monetary terms has risen considerably [89,93]. Under the social science context, from the perspective of the increasing number of individuals falling under the poverty line in US their individual social experience could be characterized as a social collapse. On the other hand, from the perspective of the top global companies as collective organizations, their collective social experience is characterized as reorganization. Both of these social realities (individual and collective organizational) coexist in parallel social realities and form a part of a social *holon*, forming complex *holarchies*, the latter terms borrowed those terms from Lovelock's and Margulis's *Gaia* hypothesis [60].

1.2. Related work and structure of the study

The empirical research findings from studying collective social processes, including collective knowledge representation flows, suggest that the transition from the individual to collective structure emerges alongside with the emergence of