Origins of Collective Intelligence: Is there a Homology between Social Networks and Knowledge Structures?

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1. INTRODUCTION

In a fundamentally knowledge-driven society, it behooves us to develop processes that optimize the creation and distribution of knowledge structures. However, efforts to do so are bound to fail without a firm understanding of the sources of the knowledge structures themselves. As a result of the pioneering works of Lev Vygotsky and others, we seem to intuitively understand that knowledge is constructed in a social setting and transmitted through its network connections (Vygotsky 1985). Unfortunately, the fundamental understanding of how knowledge first arises in such social settings has so far eluded us. Moreover, once knowledge structures have arisen, how are they modified in a social network? Specifically, what role does transmission within a network have to play in the restructuring of the knowledge? Do qualitatively different social networks modify and transmit knowledge structures or information differently? What types of structures of social networks effectively serve to block the flow of knowledge and information? Additional questions related to how the dynamics of the social network impact the dynamics of change within the knowledge structures also remain unanswered.

2. DATA-DRIVEN APPROACHES AND THEIR POTENTIAL LIMITATION

Current work in the field of emergent collective intelligence is largely driven by a focus on sociological studies and multi-agent systems. Most sociological studies rely on a data-driven regression-based approach that makes use of relatively large-scale experiments to understand correlations between study parameters and measures of collective intelligence (Wolpert and Tumer 1998)(Malone, Laubacher, and Dellarocas 2009)(Woolley et al. 2009). On the other hand, studies in the domain of multi-agent systems largely focus on the effects of local rules or agent-based learning algorithms on the global system dynamics (Mataric 1990)(Heylighen 1998). Both approaches are essentially trying to determine patterns of information in large-scale networks – sociological studies focus on the collective intelligence aspect, while multi-agent system studies focus on the network.

Both approaches have their merits, but they also make some implicit assumptions that hold them back. For example, these studies may implicitly assume homogeneity of the agents, or assume perfect transfer of information from one agent to another. They may also assume an underlying heuristic – a rule of thumb that can consist of many different types of well-documented information types, such as algorithms, fragments, etc. (Page 2007). Being data-driven, these approaches do not approach the problem of collective intelligence and knowledge structures from a first-principles approach (Gower 1996). As a result, these approaches may not be sufficient to generate an overarching understanding of the generation of knowledge structures in a social setting. That said, these research studies will prove to be of immense importance in determining the accuracy of any proposed first-principles approach.

Fortunately, there already exists a potential candidate that can be used to develop a first-principles-based theory of knowledge structures and their dependence on social networks. In the following section, we explore these first principles and how to use them to understand the process of knowledge generation. The work is further extended to examine the homology between knowledge structures and the social networks that created them.

3. SOCIOLOGICAL FIRST-PRINCIPLES FOR GENERATING KNOWLEDGE STRUCTURES

In this paper, we build upon a potential first-principles candidate – Don Beck's work on societal evolution, known as Spiral Dynamics – to generate an understanding of the relationship between social networks and knowledge structures (Beck and Cowan 2013). Specifically, the set of canonical social structures proposed in Spiral Dynamics implicitly contains some fundamental information coherence properties of communication channels, as represented by de Waal's empathy pyramid (De Waal 2007). The set of social structures may then be used to create a canonical set of knowledge structures.

Our work seeks to answer the question: do social network structures correspond to knowledge structures, and if so, what is the nature of this homology (or mapping)? There is evidence to support a related hypothesis, known as Conway's law, which states 'the design of a system will map to the social system that created it' (Conway 1967). Empirical studies have proven the accuracy of Conway's Law (MacCormack, Baldwin, and Rusnak 2012). In a previous paper, one of the authors introduced the concept of the ***Intermediate Corollary***, which states that '*the design structure of a system maps to the knowledge structure of a system, which must then map to the social structure of the system that created it*' (Pezeshki and Kelley 2012). The implication of the Intermediate Corollary is that the social structure must map to knowledge structures, and by the same logic different social structures should uniquely map to and generate specific types of knowledge structures. Building on the idea of the Intermediate Corollary, one may also infer that the synergy in the knowledge structures must be generated by either presence or lack of duplex exchange inside the social structure. The level of duplex exchanges in a social network directly corresponds to the level of empathetic development within the same social structure. Finally, since empathy is a core neural function, it then becomes possible to map back this in a self-similar fashion to neurogenic development in agents in the social network.

The implications of this train of logic are potentially very powerful. First, one realizes that certain types of social structures may only generate specific types of desirable (or non-desirable) knowledge structures. Second, and perhaps more importantly, it implies that certain types of social structures may only be able to understand and process specific types of knowledge structures and not others. This second statement raises major questions about our understanding of how information and knowledge propagates across social networks.

From a qualitative perspective, the authors have cross-referenced social structures from Spiral Dynamics to the knowledge structures that might create. This mapping is included in Figure 1. In the right column, the authors show how these canonical knowledge structures can be mapped to understandings of thermodynamics and material phase change. These concepts allow a cognitive bridge for the development of mathematical models that can predict how information moves in societies, as well as when conditions are sufficient to create societal phase change.

	Value Meme	Knowledge Structure	Example/Physical Analog	
Second tier value-memes	Bodhisattva (Coral)	Reflective and Selfless Feedback Loop-Based Heuristics	Evolving Mixed Turbulent Flow with Feedback Loops	Independently Generated, Trust-Based, Data-Driven Evolved Empathy Relationships
	Global Holistic (Turquoise)	Reflective/Feedback Loop-Based Heuristics Based on Connected Group Reflection and Integration	The Dynamics of the Internet/Fully Mixed Turbulent Flow with Large Scale Structures	
	Global Systemic (Yellow)	Reflective/Feedback Loop-Based Heuristics Based on Personal Reflection	Zen Buddhism/Feedback Loop Nonlinear System/Chaotic Motion	
	Communitarian (Green)	Multiple, Integrated Scaffolded Heuristics	OpenIDEO/Multi-constituent, mixing flow with entrained solids	
	Performance/Goal-Based (Orange)	Fixed Scaffolded Heuristics	Waterfall Design Process/Turbulent to Laminar Transition Flow with entrained solids from lower modes	Trust Boundary
First tier value-memes	Legalistic/Absolutistic (Blue)	Rules, Determinate Processes, Created by a Group, Applied Across a Group	Professional Code of Ethics/Fully Developed, Crystalline Fractal Structure with transformed elements	Externally Defined, Low Empathy Belief-Based Relationships
	Authoritarian/Egocentric	Knowledge Fragments, Decided on by an Authority	Modulus of Elasticity/Beginning of Crystalline Structure with regular self-similar patterns	
	Tribal/Magical (Purple)	Indeterminate Short Time Stories, based on Deep Long Time Narratives	Creation Myth/Amorphous Solid	
	Survival (Beige)	Knowledge Fragments, Short Time, Small Spatial Scale	"Where's the water cooler?"/Single Particle	

Fig. 1. Canonical knowledge structures. Every value-meme above contains partial representations of all lower value-memes. Colors from Don Beck's Symbolic Dynamics (Beck and Cowan 2013).

From a quantitative perspective, the authors also examine the network structure of the real-world social systems and the associated network structure of the knowledge units. For this part of the study, the authors use Wikipedia datasets from Stanford's SNAP Large Network Dataset Collection (Leskovec and Krevl 2014). This dataset includes the complete Wikipedia edit history up to January 2008. Within a specific Wikipedia category, the authors examine the social network in terms of the number of instances when a user edits a 'talk' page, and the knowledge structure in terms of the cross-references to additional 'main' namespaces that contain other Wikipedia articles. Together, these data allow us to use graph networks to model the social and knowledge structures, respectively. We then examine the Betti numbers for various weighted filtrations of the social as well as the knowledge networks (Horak, Maletic, and Rajkovic 2008). Betti numbers are used to differentiate between different topological spaces (graph networks) by studying the inherent connectivity of simplicial complexes. As a quantitative measure, Betti numbers provide more information than scalar values, such as betweenness centrality or mean degree, that are traditionally used in network theory. The final quantitative comparison between social and knowledge structure networks is performed by analyzing the trends in Betti numbers as a function of the weight threshold (ranging from 0 to 1) in the graph networks.

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