Future Directions in Network Science: Integrating Top-Down and Bottom-Up Approaches

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Abstract

Although the majority of researchers in the field of network science continue to rely on a top-down research process, the weaknesses of that approach are beginning to become apparent. As a result, some researchers in the field are transitioning into a bottom-up approach. This, too, has its weaknesses. This paper proposes a new framework for research in network science that utilizes a combination of top-down and bottom-up approaches in order to reduce the risk of failure.

Introduction

Network science has recently emerged as a powerful way to understand the impact of social structure on a wide variety of social and organizational properties. It has been used to research everything from the network structure of the Internet[3] to the effect of network structure on human performance in economic games[5].

Several examples of network science can be found in the 2007 Network Science Workshop at the US Military Academy. Much of the current research in network science is concerned with human social systems. These systems are extremely complex and relatively poorly understood. Much of the existing work operates under a top-down approach, using intuition to guide the subdivision of the entire system into subtopics(e.g. cooperation & teamwork[7], communication[1], etc.).

One of the problems being encountered is that even though each individual sub-problem is less complex than the whole system, the individual components are still extremely complicated. This is the basic risk with the top-down approach. This paper proposes a new framework for research in network science that attempts to reduce the risks and difficulties currently being caused by the top-down approach.

Background

Top-down design focuses on taking the high-level goal and decomposing it into smaller and smaller units.[10] Built into this idea is the belief that it is easier to solve the smaller sub-problems than it is to approach the top-level problem. Top-down design is closely related to the 'blackbox' mentality of cybernetics. It has been applied in a wide variety of domains, including computer science, nanotechnology, psychology, political organization, and ecology.

One of the main weaknesses of the top-down approach is that the smaller sub-problems may be almost as hard or harder to solve as the original problem. For example, top-down designs in psychology often follow from intuitive or 'just-so' reasoning. Consider Sally. We want to study how Sally finds a flower. The first thing that researchers following a top-down process would do is to break this down into subcomponents. Sally wants a flower. Sally thinks about what a flower looks like. She compares this with the objects she sees around her. When she finds something that matches her idea of a flower, she takes it. Instead of trying to study the process as a whole (Sally finding a flower), the top-down approaches suggests that we study each of the simpler processes(wanting, thinking, etc.). It is unclear whether the combined difficulty of these sub-problems of wanting, imagining, and comparison really is less than the difficulty of the original problem of finding a flower.
A similar problem may be arising in the previously mentioned problem of cooperation. For decades, researchers have used computational tools and methods to study the general evolution of cooperation.\textsuperscript{[2]} Thousands of papers have been published on the matter\textsuperscript{[4]}, but there have as yet been few real world applications.

Suboptimal problem decomposition is one reason that researchers can find themselves in this position. Different sets of sub-tasks for the same problem can have wide variations in difficulty.

Although the alternative, bottom-up design avoids some of the problems of the top-down approach, it, too, has significant risks and weaknesses. The bottom-up process works similarly to top-down design, but in the opposite direction. Researchers using a bottom-up approach first study the smaller, less complex problems, in the hope that they will give insight into the larger problem.\textsuperscript{[11]} The fundamental assumption is that the smaller problems are closely related enough to the larger problem that solutions to the smaller problems will help solve the larger, more general problem. A quintessential example of bottom-up design comes from the work of Pylyshyn\textsuperscript{[8]} in developing computational models of human vision processing. He began by investigating the workings of sensory neurons. Pylyshyn then used those models to model how (he believed) humans perceive object boundaries, etc. on upward.

Although Pylyshyn (among others) made progress on computer vision problems in 1989, it has taken years to advance further on the problem. This type of situation occurs when the basic assumption does not hold particularly well. That is, the simpler, more basic problem is not sufficiently related to the larger problem to have a significant impact on progress towards the goal.

**Methods**

A parallelization of top-down and bottom-up research processes can consistently yield more robust and efficient solutions when compared to either individual approach. These two approaches can be combined by using top-down processes to ensure that the proposed lower-level solutions are relevant to the more general problem and by using bottom-up processes to assess the complexity and difficulty of the proposed subtasks before attempting to solve them.

Intuitively, this seems likely given the relative strengths and weaknesses of the two approaches. Top-down approaches fail when the sub-tasks are chosen inappropriately and turn out to be as difficult to solve as the overall problem. Bottom-up approaches fail when the chosen lower-level phenomenon is not closely related to the higher-level problem.

By taking advantage of the relative strengths of the two approaches, researchers can reduce the risks associated with either of the two individual processes.

**Results**

By using the proposed framework, significant gains can be made in network science by reducing the risk of failure inherent in both of the existing top-down and bottom-up approaches. As described earlier, the majority of network science research uses a top-down approach to study human social systems. At the 2007 Network Science Workshop, Dr. Parmentola\textsuperscript{[6]} advocated a reprioritization of Network Science to emphasize a more complete understanding of simpler systems. In particular, he proposed using social insects as a platform with which to explore some of the basic components of emergent network science phenomena. In essence, Parmentola was proposing a transition from existing top-down approaches to a bottom-up research process. By applying the proposed framework, one can see how a compromise might be achieved. Research should continue on both the top-down and bottom-up fronts, but more effort must be focused on reconciling the two approaches.
Results from human social systems can be compared with results from simpler systems (e.g., social insects). If there is insufficient agreement, this should be interpreted as evidence that the simpler system is not a good approximation of the more complex system and that new approximations must be attempted. Likewise if researchers studying human social systems propose a certain task decomposition, preliminary research into the simpler system can provide evidence whether or not the proposed task decomposition is a reasonable one.

In particular, consider the example of cooperation. It may be that a general model is not the optimal framework for studying cooperation. We may be more successful in studying cooperation in a very specific real-world context. We may, for example, study the mechanisms that lead to coordination in social insects. This would immediately lead to a better understanding of a real world problem, namely, cooperation in social insects, and could provide insight on the real problem of interest, cooperation among people.

Discussion

The proposed framework attempts to combine the relative strengths of top-down and bottom-up processes in a way that eliminates the potential pitfalls inherent in the two processes. Although this framework cannot guarantee success, there is reason to believe that the risk of failure of the proposed framework is smaller than the risk in the original research processes. However, the proposed framework does add a considerable overhead, as both top-down and bottom-up processes must be used simultaneously. Because of this, the combined approach is likely to be most useful in situations with a high risk of failure. Future work is needed to identify situations in which this framework would be preferred over either top-down or bottom-up research processes.

References


Appendices

Research Problem: How can existing research/design processes be modified in order to create more robust solutions and guaranteed results?

Research Statement: Given a top-down research process and a bottom-up research process, construct a new research process that is less likely to fail.

Failure: The inability to make demonstrable progress towards the ultimate research problem in a period of 5 years.