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Measuring complex patterns in space–time

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ABSTRACT

Complex systems generate complex information structures. Understanding and managing the behavior of systems, including business systems, requires the study of these complex structures to gain greater understanding of the processes and mechanisms at play in their generation, self-replication and evolution. However, the study of the information generated by such complex structures requires going beyond traditional analytical approaches, i.e. many/most of the existing statistical methods. This paper considers the nature of complex systems in information terms and discusses the issues associated with traditional measurement and summary of their information. The paper then introduces new approaches to conceptualizing and measuring data generated by complex social systems that address these issues by mapping the interaction(s) of the systems' agents through space–time.

摘 要

复杂系统生成复杂的信息结构。了解并掌握系统的行为，包括经商系统，要求对这些复杂结构进行研究，获得对在生成、自我复制和演变中发挥作用的过程和机制的更大理解。但是，这些复杂结构生成的信息研究要求超越传统的分析方法，即：现有的许多/大多数统计方法。本论文关注信息中的复杂系统特性，探讨与传统的信息测量和汇总有关的问题。本论文随后介绍关于复杂的社会制度生成观念建构和测量数据的新方法，而且关注这些新方法如何将系统主体的互相作用映射在时空而解决上述的问题。

1. Introduction

In line with the aims of this Special Issue of the Australasian Marketing Journal on Complex Systems and Agent-Based Modelling, this paper addresses measuring the behavior of participants in complex systems and the analysis of this information.

Complex systems are comprised of numerous entities or agents interacting with each other over time (Gell-Mann, 1994a). Social systems, by their very nature, are also comprised of numerous interacting entities and so social systems are inherently complex systems (Clippinger, 1999). The measurement and analysis of complex behavior in social systems, including those in business and marketing, therefore requires the study of the patterns of complex behavior created through the interaction of social agents.

1.1. Background: complex patterns through interactions

The concept of *interaction* between agents is of fundamental importance to the behavior of complex systems because, as the agents interact, they create patterns of behavior emerging over space and time which qualitatively change the behavior of the group (Gell-Mann, 1994a; Wolfram, 2002; Laughlin, 2005; Schelling, 2006; Crutchfield, et al. 2009).

One of the main ways in which agents in business systems interact is through *transactions* (Alderson, 1957; Kleinaltenkamp and Ehret, 2006) which are of such fundamental importance to business and marketing that Shelby Hunt described marketing as "the *science of transactions*" Hunt (1976 p. 25), and Kotler stated "Marketing is specifically concerned with how transactions are created, stimulated, facilitated and valued" Kotler (1972 p. 49). Transactions in business can include the "exchange of information, money, goods or services" Wilkinson (2008 p. 13). Therefore, at a fundamental level business and marketing systems comprise the flow of signals in the form of information as well as signals embedded in physical movements of goods and services.

As agents in social systems interact they influence each other's behavior, that is, "individuals are doing something—searching for information, spreading a rumor, or making decisions—the outcome of which is influenced by what their neighbors are doing" Watts (2003 p. 55). For instance in marketing, "The consumer possesses some innate preferences over the available products, but can be influenced by the opinion of others" Goldbaum (2008 p. 2). And

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so instead of people acting independently, they at least in part do what others are doing.

These interactions can cause signals to be magnified or changed by *feedback* as they flow through the system (Kelly, 1994). Feedback effects are fundamental in science (Peitgen et al., 2004) and are found in many natural and technological systems (Kelly, 1994), as well as throughout business (Arthur, 1990).

Feedback can have different forms such as acting to increase or to decrease a change. This can have an effect on the behavior of the entire system as Buttriss and Wilkinson (2006) explain:

> "Events can trigger feedback mechanisms that reinforce or undermine the recurrence of particular outcomes and patterns in the future. Feedback is positive when change in one direction sets in motion reinforcing processes that produce change in that same direction; it is negative when change triggers processes that counteract the initial change and return the system to something like its original position. Positive feedback therefore generates change and growth while negative feedback produces patterns of stability"
>
> Buttriss and Wilkinson (2006 p.171)

For instance, an important example of this interaction and feedback behavior occurs when imitation takes over in a group, as Leigh Tesfatsion explains:

> "An *information cascade* is said to occur when agents ignore their own private information and simply imitate the selections of the agents who selected before them. Two well-known examples of information cascades within economics are bank panics and stock market crashes."
>
> Tesfatsion (2002 p. 67)

The exact form feedback takes can be more than just positive or negative and might be expressed by some complicated mathematical formulation (Gleick, 1987; Peitgen et al., 2004).

Importantly, interaction and feedback can lead to the emergence of highly complex and counter intuitive patterns of behavior (Kelly, 1994), such as the highly unpredictable effects experienced in chaos theory (Gleick, 1987). These emergent patterns can be amazingly complex and not easily accessible through common intuition or analytical methods (Langton, 1990; Wolfram, 2002) as recipient of the Nobel Prize for Economic Science, Thomas Schelling describes:

> "These situations... usually don't permit any simple summation or extrapolation to the aggregates...And sometimes the results are surprising. Sometimes they are not easily guessed."
>
> Schelling (2006 p. 14)

2. Measurement of complex dynamics

Any system is hidden from research and must be measured before it can be studied (Borsboom et al., 2003; Laughlin, 2005; Crutchfield et al., 2009). Good quality measurement is particularly important for understanding complex systems. The highly unintuitive and unpredictable nature of complex systems means that complex emergent behavior is not readily derived from first principles as Nobel laureate Robert Laughlin (2005 p. xv) comments: "Physical law cannot generally be anticipated by pure thought, but must be discovered experimentally."

This can be seen in studies of complex systems where even very basic rules have been shown to form highly unintuitive structures (Wolfram, 2002). What is more, complex systems can be in very unstable states where even slightly inadequate measurements can lead to highly misleading results (Laughlin, 2005; Crutchfield et al., 2009).

2.1. Difficulties with traditional measurement

Appropriate measurement of complex behavior is therefore important for understanding social systems. However, in the social sciences, including economics, business and marketing, the complex nature of systems has often not been adequately measured and researched.

For instance, an important gap in the study of complex social systems is that the concept of interaction has not always been adequately considered. This has led many traditional theories and methods to reach highly incorrect conclusions such as underestimating trading volume and price volatility in financial markets (Arthur, 1995). The physicists Michard and Bouchaud (2005) have researched this concept and commented:

> "Traditional economics treat the aggregate behaviour of a whole population through a "representative agent" approach, where the heterogeneous preferences of individual agents are replaced by an average preference curve, which determines, for example, the dependence of the demand on the price of a certain product. This approach considers that agents determine their action in isolation, with no reference whatsoever to the decision of their fellow agents; interactions between agents are totally neglected. The representative agent idea has been fiercely criticized by some authors... The need to account for interactions stems from the fact that imitation and social pressure effects are obviously responsible for the appearance of trends, fashions and bubbles that would be difficult to understand if agents were really insensitive to the behaviour of others... interactions lead to an aggregate behaviour that may be completely different from that implied by a representative agent approach. Catastrophic events (such as crashes, or sudden opinion shifts) can occur at the macro level, induced by imitation, whereas the behaviour of independent agents would be perfectly smooth"
>
> Michard and Bouchaud (2005 p. 151)

Research in the social sciences often makes use of measurement and analytical approaches which are not suited to the study of interaction between agents and the resulting complex system dynamics. In particular, approaches described as variance based methods are widely used and have influenced the interpretation of much research in the social sciences (Van de Ven and Engleman, 2004). Variance methods are concerned with the use of random variables to describe the characteristics of business systems, as explained here by Buttriss and Wilkinson (2006):

> "Typically, variance-based theories are proposed in terms of one or more dependent variables being the result, directly or indirectly, of various independent or predictor variables, such as the performance or some behaviour of a firm being explained in terms of various attributes of the firm and its environment. The theories are tested by developing measures of the relevant dependent and independent variables and accounting for variance in the dependent variables in terms of some linear configuration of the variance of the independent variables"
>
> Buttriss and Wilkinson (2006 p. 158)

However, variance methods impose inappropriate concepts on the understanding of complex systems (Borsboom et al., 2003; McKelvey and Andriani, 2005). And while "The variance approach works perfectly well for examining research questions about comparisons among entities or relationships among variables..., in the study of change and development, its assumptions prove too restrictive." Van de Ven and Engleman (2004 p. 351). For one thing, "The underlying causal process that generates the outcomes is presumed to operate continuously over time." Van de Ven and Engleman (2004 p. 348). And the "feedback effects, in which