Application of Complexity Science Concepts and Tools in Business: SUCCESSFUL CASE STUDIES

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Background

This paper describes successful applications of Complexity Science concepts and tools to a number of practical business and social problems by a team of scientists and software developers under the leadership of Professor George Rzevski.

George's interest in managing complexity developed in early 1980s when it became obvious that, with the transition from Industrial to Information Society, the social and economic environments within which we live and work will experience a rapid increase in complexity and that the new levels of uncertainty and dynamics of these environments will require new management and problem solving methods.

Acknowledgement

In 1990, when George was Professor, Design and Innovation Department, the Open University, UK, and Director of the Centre for the Design of Intelligent Systems, he was invited by the Soviet Academy of Sciences to give a series of lectures on multi-agent technology in Samara, Russia. This visit marks the beginning of a long-term collaboration with Petr Skobelev, a young, talented researcher whom George met in Russia. George Rzevski and Petr Skobelev have jointly founded and provided technological leadership for commercial organizations that have developed software for all projects described in this article, namely, Magenta Corporation Ltd and Knowledge Genesis Ltd, both based in London and Samara.

Fundamental Features of Complexity

The following paragraphs from Wikipedia are a good introduction to the concept of complexity.

"Complexity has always been a part of our environment, and therefore many scientific fields have dealt with complex systems and phenomena. Indeed, some would say that only what is somehow complex – what displays variation without being random – is worthy of interest.

The use of the term complex is often confused with the term complicated. To understand the differences, it is best to examine the roots of the two words. "Complicated" uses the Latin ending "plic" that means, "to fold" while "complex" uses the "plex" that means, "to weave." Thus, a complicated structure is one that is folded with hidden facets and stuffed into a smaller space. On the other hand, a complex structure uses interwoven components that introduce mutual dependencies and produce more than a sum of the parts… This means that complex is the opposite of independent, while complicated is the opposite of simple.

For the purposes of solving complex problems described in this paper, complexity was defined in a manner compatible with that of Prigogine [1], as follows.

A situation, problem or system is said to be complex if it exhibits the following characteristics:

1. It consists of a large variety of *autonomous components,* which may have *conflicting goals*, and are engaged in rich *interaction*; there is no centralised control; a good

example of a complex system is the global market, in which massive numbers of different suppliers, customers, middlemen, investors and administrators, each with individual declared or undeclared objectives, produce, sell, purchase, borrow, invest and regulate, often exchanging information using high-speed communication networks such as the Internet.

2. Its behaviour *emerges* from a myriad of interconnected local behaviours of constituent components; it is therefore unpredictable; for example, the matching of supplies to demands in the global market emerges from billions of transactions between individual agents.
3. It behaves "*far from equilibrium*", the expression used by Prigogine [1], [2], or "*at the edge of chaos*", as described by Santa Fee Institute researchers [3], because it is frequently disturbed and has no time to settle down in intervals between two events that cause disruptions. For example, at present the occurrence of events that affect distribution of supplies to demands is so frequent that, contrary to conventional economic theory, free market has never sufficient time to reach equilibrium [4].
4. Its behaviour is *nonlinear*; a small disturbance may cause large changes in their global behaviour (*butterfly effect*) whilst large disturbances may go unnoticed [5]. A butterfly effect (or snowball-like behaviour) causes unpredictable serious consequences in many complex systems such as global financial networks (consider current subprime credit fiasco), self-combustion and epidemics (e.g., aids). Large unpredictable changes in global behaviour of complex systems are sometimes called *Black Swans* [6].
5. It is capable of autonomously *self-organizing,* that is, changing its behaviour or even structure in response to unpredictable events, and is therefore *adaptive* to changes and *resilient* to attacks.

A Method for Managing Complexity

Contrary to expectations of many protagonists of old-style physical sciences, complexity cannot be simplified and the behaviour of complex systems cannot be predicted. Mathematical models that leave out diversity of constituent components of a complex situation or ignore conflicting goals of constituent actors lead to misleading results. Deriving clever formulae to fit experimentally observed trajectories have no practical value because history of a complex system is no a guide for its future behaviour. Conventional mathematical optimisers and schedulers that are effective when markets are reasonably stable, and which required 8 to 10 hours to plan a big business process such as a car production plant, become useless when the complexity of markets grows and the frequency of changes in demand increases to once in every two hours.

Services and manufacturers that sell to the global market are facing levels of complexity never experienced before, and, as Thomas Kuhn predicted [7], new problems are driving the emergence of a new paradigm.

The key assumption of the new paradigm is that although the behaviour of complex systems is emergent and therefore cannot be predicted, it can be *managed*. The well-managed complex systems exhibit *controlled emergence*, in other words, their behaviour although unpredictable, is always within prescribed boundaries.

Tools for the management of complexity contain two main components:

1. Ontology, which contains the problem domain knowledge represented as a network, where nodes are *classes of objects*, characterised by *attributes* and *rules* of behaviour, and links are *relations* between object classes.
2. A Virtual World, which is a model of the domain of the real world that is being managed. Using classes of objects from ontology we build a *Scene*, which is a network, in which nodes are *virtual instances of objects* and links are their *relations*. As real events occur the network of instances, the scene, changes. A set of autonomous Agents, each assigned to an object instance, exchange messages; the messaging among agents models the interaction among components of the domain of the real world that is being managed.

Complexity Management tools were constructed using multi-agent software technology [8], [9].

Case Studies

During the ten-year period, 1999 – 2009, Magenta Corporation and Knowledge Genesis have developed, based on principles and methods discovered and articulated by Professor Rzevski, a very large number of complexity management systems based on Complexity Science concepts and principles, which are in commercial use. All these systems have one feature in common – they have succeeded in solving problems, which were considered too complex for generally available conventional methods and tools.

Examples of selected successfully developed and implemented complexity management systems, include:

1. Managing in real time a fleet of 2,000 taxis, for a transportation company in London
2. Managing in real time a large fleet of car rentals, for one of the largest car rental operators in Europe
3. Managing in real time 10% of the world capacity of crude oil sea-going tankers, for a tanker management company in London
4. Resolving clashes in aircraft wing design for the largest commercial airliner in Europe
5. Real-time scheduling of a large fleet of trucks transporting parcels across the UK
6. Agent-based simulator for modelling the airport and in-flight, RFID-based, catering supply chain, luggage handling processes, and passenger processing, for a research consortium in Germany
7. Selecting relevant abstracts for a research team using agent-based semantic search, for a genome mapping laboratory in the USA
8. Discovering rules and patterns in data using agent-based dynamic data mining technology, for a logistics company in the UK
9. Managing social benefits for citizens supplied with electronic id cards, for a large region in Russia

Two of these case studies are described in some detail below.

Case 1: Real-Time Management of a Large Fleet of Taxis

Introduction

The largest corporate taxi operator in London has a modern ERP system and a call centre with about 130 operators receiving orders concurrently. Some orders are received through the company website. Magenta Corporation has successfully developed and implemented an intelligent taxi management system, which is in commercial use.

Problem Description

The characteristics of this taxi service are as follows:

- A very large fleet of more than 2,000 vehicles (each with a GPS navigation system)
- A very large number of orders: more than 13,000 orders per day; the order flow occasionally exceeds the rate of 1,500 orders per hour; order arrival times and locations are unpredictable
- A large variety of clients – personal, corporate (VIPs, with a variety of discounted tariffs, with special requirements concerning drivers), disabled, requiring child seats, requiring transportation of pets, etc.
- A large variety of vehicles, including minivans and cabs, some with special equipment to match special requirements of clients
- A large number of freelance drivers who lease cars from the company and are allowed to start and finish their shifts at times that suite them, which may differ from one day to another
- At any time around 700 drivers are working concurrently, competing with each other for clients
- Guaranteed pick up of clients in the centre of London within 15 minutes from the time of placing an order
- Unpredictability of traffic congestions in various parts of London causing delays and consequently the interruption of schedules
- Unpredictability of times spent in queues at airports and railway stations
- No-show of clients and failure of vehicles
- A number of exceptions to the general requirement to find the best economic match between a vehicle and a client, such as: (a) matching drivers that drive home after finishing their shifts with passengers travelling in the same direction (to reduce drivers' idle runs) and (b) giving priority to drivers that during a particular day had less work than others (to increase drivers' satisfaction with working conditions); exceptions of this kind may be changed at any time

Scheduling of vehicles and drivers under such conditions represents an exceedingly complex process, which is not feasible to achieve with any known mathematical method. The company used manual scheduling by a large number of very skilled dispatchers.

The Solution

An ontology-based, event-driven, multi-agent scheduler was designed, implemented and successfully commissioned [10]. The scheduler improved the profitability of the service by 7% within the first month of operation.

Ontology objects are exemplified by (a) *orders*, with attributes: place of pick-up and drop; urgent or booked in advance; type of service (minivan, VIP, etc.); importance (a number from 0 to 100 depending on the client); special requirements (transport of pets, need for child chair, etc.); and (b) *vehicles with drivers*, with attributes: type of vehicle; capability to fulfil the jobs under special instructions; driver experience (novice or experienced); location of drivers homes; current vehicle location (GPS coordinates); driver state ("unavailable", "break", "working", "free", "will be free in 5/10 minutes", "ready to travel home").

Experienced dispatchers have facilities to overrule the system and to deal with exceptions.

Case 2: Managing a Large Fleet of Rental Cars

Introduction

The customer is one of the largest car rental companies in the world with a very large operation in Europe. European territory of the rent-a-car business is divided into a number of small regions, each consisting of several rental stations; regional offices are the locations where orders are received, cars are serviced and waiting to be delivered and where drivers begin their working day; cars are picked up by customers and returned at rental stations. Magenta Corporation has developed and successfully tested an intelligent car rental management system for three such regions and is commissioned to extend the system to the whole service.

Problem Description

The characteristics of this rent-a-car business are as follows:

- Business processes contain activities that have to be performed in certain logical sequences and at, or between, different locations at different times (e.g., washing cars, delivering them to rental stations and returning them to home regions; transportation of drivers from their home bases to their cars, which may involve additional cars and drivers)
- Unpredictable events that affect the service include arrivals of new orders, changes of orders, order cancellations, breakdowns of cars, no-shows of clients or drivers, misplaced keys, non-conformation of work instructions or of completed work by drivers, seek leaves, delays due to traffic congestions or weather conditions, etc.
- Scheduling decisions must take into account preferences of clients, costs and durations of activities, such as delivering cars to rental stations and returning them to regional offices (which, for example, depend on availability of required cars and drivers, geographical factors and conditions of roads) as well as penalties for delays and for delivering wrong vehicles; drivers are a major constraint because of strictly regulated working hours, overtime payments, human errors (e.g., misplacing mobile phones and therefore not responding to text messages) and the need to return them home every evening
- Scheduling is primarily concerned with discovering and resolving conflicts among orders and therefore the key activity is a search for trade-offs between different criteria rather than optimization (e.g., in the presence of serious delays it is better to use a more expensive resource if it enables delivery of a car on time; it may be advisable to return a car to its home base even if there is no current assignment for that car because if an order for such a car unpredictably arrives, it is faster to deliver it from its home base than from the field)

The Solution

An ontology-based, event-driven, multi-agent scheduler for one region has been designed, implemented and successfully commissioned [11]. At the time of writing the work on schedulers for other regions was in progress.

Conclusions

Current mathematical methods are inadequate for modelling complex problems that are characterised by a high diversity of constituent components, very high frequency of unpredictable, disruptive events and occasional occurrence of unpredictable extreme events. As it happens, a large number of practical business and social problems fall into this category of complex systems.

For such problems it is necessary to employ agent-based modelling using enhanced ontology and rather advanced virtual worlds, including multi-swarm negotiations, constructive distraction, autonomous formation of agent coalitions and agent pro-activity [8], … [16].

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