A Computational Approach to Patient Flow Logistics in Hospitals

by Anke Hutzschenreuter, Peter Bosman and Han La Poutré

With the aging of the population and the demand for cost-efficiency, logistics and planning in hospitals are becoming increasingly important. In many countries, hospitals are organized in a decentralized fashion, with (medical) departments and units having a high degree of autonomy in management and planning. The Agi-Care project (Agent-based intelligent health care planning) develops computational approaches to the optimization of patient flow logistics in hospitals, i.e., concerning the various pathways of inpatients moving through various units in a hospital. The Agi-Care project has been carried out at Eindhoven University of Technology, in cooperation with the Catharina Ziekenhuis Eindhoven and Centrum Wiskunde & Informatica (CWI - the Dutch national research centre for mathematics and computer science), in the Netherlands.

Scheduling decisions in hospitals are often taken in a decentralized way. This means that different specialized hospital units make autonomous decisions relating to such issues as patient admissions and schedules of shared resources. Decision support in such a setting requires different methods and techniques to those described in the majority of existing literature, which tends to assume a centralized model. The design and analysis of such methods and techniques is the focus of the project, which is now in its final stages. Specifically, we developed computational models to provide dynamic decision support for hospital resource management and the prediction of future resource occupancy, and we studied the application thereof.

Hospital resource management targets the efficient deployment of resources like operating rooms and beds in various care units (intensive care, medium care, nursing room etc). Allocating resources to hospital units is a major managerial issue as the relationships between resources, their utilization, and the combined pathways of different patient groups through the hospital is complex (see Figure 1). These issues are further complicated by the fact that patient arrivals are dynamic, and treatment processes are stochastic.

Our approach to providing decision support combines techniques from multi-agent systems and computational intelligence (CI). This combination of techniques allows us to properly consider the dynamics of the problem while reflecting the existing distributed decision-making practice in hospitals. Multi-agent techniques are used to realistically model multiple hospital care units and their decision policies, multiple patient groups with stochastic treatment processes, and uncertain resource availability due to overlapping patient treatment processes (see Figure 1). Optimization and learning techniques from CI allow for designing and evaluating improved (adaptive) decision policies for the agent-based model, which can then be implemented easily in hospital practice.

In order to gain insight into the functioning of this complex and dynamic problem setting, we developed an agent-based model for the hospital care units (partly) used by the cardiothoracic surgery (CTS) department, with their different (sub)types of patients. To assess the applicability of this agent-based model, we developed an extensive simulation. Several experiments demonstrated the functionality of the simulation and showed that it is an accurate representation of the real world. The simulation is used to study decision support in resource management and patient admission control.

To further improve the quality of decision support, we studied the prediction of future hospital resource usage. Using these predictions, the future impact of taking a certain decision at a given moment can be taken into account. In the problem setting at hand, for instance, predicting the resource utilization resulting from an admission decision is important to prevent future bottlenecks that may cause the blocking of patient flow and increase patient waiting times. The methods we investigate for the task of prediction are forward simulation and supervised learning using neural networks. In an extensive analysis, we used stochastic techniques to study how accurate and precise prediction outcomes can be obtained.

Figure 1: Example of various types of patients with their possible pathways through different care units (CU) in a hospital. Every pathway type has its own color, where branchings in a pathway of a certain patient type occur with some probability, reflecting the uncertainty in patient treatment within the patient types, and where lengths of stay at a certain care unit are stochastic within a patient type.
To optimize resource allocation decisions, we considered multiple criteria that are important in the hospital problem setting. Specifically, we focused on three conflicting objectives to be optimized: maximal patient throughput, minimal resource costs, and minimal usage of back-up capacity (of beds). All criteria can be taken into account by finding decision policies that have the best trade-off between the criteria (“Pareto optimality”). We derived various decision policies that partly allow for adaptive resource allocations. The form of the policies allows them to be easily understandable by hospital personnel. Moreover, we incorporated a ‘bed exchange mechanism’ that enables a realistic implementation of these adaptive policies in practice.

In our optimization approach, the parameters of the different decision policies were determined using a multi-objective evolutionary algorithm (MOEA). The MOEA uses the agent-based simulation in order to evaluate the quality of potential solutions, and it thus optimizes the output of the simulation (ie the three optimization criteria) as a function of the policy parameters. Optimization using the MOEA with its embedded simulations was performed on a high-performance cluster. Our results on resource management showed that the benchmark allocations obtained from a case study are considerably improved by the optimized decision policies. Furthermore, our results showed that the use of adaptive policies can lead to better results and that further improvements may be obtained by integrating prediction into a decision policy.

Anke Hutzschenreuter will defend her Ph.D. thesis that has resulted from this project in the upcoming months.

Links:
http://is.tm.tue.nl/
http://www.cwi.nl/en/research-groups/Computational-Intelligence-and-Multi-agent-Games

Please contact:
Anke Hutzschenreuter
E-mail: a.hutzschenreuter@gmail.com
Han La Poutré, CWI, The Netherlands
E-mail: han.la.poutre@cwi.nl

Computational Modelling and Simulation for an Interconnected World

by Jim Duggan

Our modern world is complex, and comprises a multitude of natural, engineered and social systems. The goal of this project is to design computational simulation approaches that can help us understand the way in which these systems interact, so that we can design better futures.

This research project, entitled Computational Methods for Modelling Complex Dynamic Systems, is a four-year research programme located in the College of Engineering and Informatics, at the National University of Ireland, Galway. Funded by Science Foundation Ireland, seven researchers are pursuing an interdisciplinary work programme to explore novel approaches to modelling complex social, economic and industrial systems. The core motivation for this research programme is to develop mathematical techniques that can help decision makers to: (i) understand the inter-connected nature of our modern world; (ii) evaluate possible policy design alternatives in silico; and (iii) generate qualitative and quantitative insight into the possible future behaviours of these systems.

The project draws on three related methodological approaches for generating insight into economic and social systems:

• System Dynamics is a modelling approach based on the idea that systems can be understood by analysing their embedded feedback loops. These interlocking loop structures can be formulated as equations, and simulated using numerical algorithms. Feedback loops then can be formally analysed to demonstrate the impact of loop structures (for example, virtuous and vicious cycles prevalent in economics) on overall system behaviour.
  • Agent-Based Computational Modelling is a complimentary approach to feedback modelling, where the unit of representation is an individual (or agent), and individuals have states (physical and psychological) and a range of behaviours. Individual decisions are based on an agent’s state space, and information from their immediate network is also considered. The key idea of the agent approach is to generate macroscopic explanations from local behaviours. For example, in the property market, an agent-based model could represent individual consumer behaviours, and from that, generate an explanation of the recent boom and bust cycle.
  • Multi-Agent Systems and Game Theory put the focus on how to combine the efforts of many autonomous agents, where each has different information and separate goals. Game theory is an essential technique for this analysis, as it provides the basis for the mathematical investigation of interactions between independent, self-interested agents. Within game theory, games can be classified as being non-cooperative or cooperative, and the application areas include economics, political science and computer science.

In the research project, three valuable perspectives are integrated through a multi-method simulationworkbench. At its core is a numerical integration algorithm, which acts on a very large set of equations, where each equation represents a state of behaviour of an individual in the population. Different agent types can be designed, and any number of these agents (within the resource limit of the machine) can be instantiated. For each simulation, an appropriate network structure is selected. The options include the classic network types such as small world, lattice, grid, random and scale free, and the user also has the opportunity to create a hybrid network structure based on any combi-