Project title: Mining Processes to Understand Real Time Decision Deltas in a UK Healthcare Department

Project reference: DT4H_19_2024

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Aim of the Project

Digital twins of healthcare systems have huge potential to transform operations and outcomes, however, this is limited by challenges in implementation. Digital twins of healthcare systems require a good integration of real-world data with structured models – for example, of processes undertaken on a hospital ward. However, real-world process data is messy, does not necessarily match the structured process models expected to be implemented, and changes over time as staff adapt to changing demand pressures, policies, and temporary system faults. It is paramount that decision makers are able to engage with this real-world data, have efficient ways of identifying and predicting significant changes and variations in processes – for example as a result of proposed policy change – and can understand the impact of behaviour changes on overall system properties. This project will explore the combination of domain-specific modelling, healthcare process mining, agent-based simulation, and data visualisation to address these challenges.

Project Description

The PhD project will address the following research question: "How can a near-real-time decision analysis tool integrated in a digital twin of a healthcare system utilise process mining to support decision makers in real-world interpretation of data?" The following sub-questions will be addressed to help explore the overarching research question:

- How can "deltas" between simulation and reality be visualised over time?
- How can the significance of variations be identified to decision makers – when is a variation important, and how can this be communicated?

Healthcare systems all over the world are facing huge demand pressures and are increasingly struggling to meet policy targets. For example, in the UK the "4-hour wait" target requiring patients in emergency departments (EDs) to receive a decision whether to admit to hospital has not been met across a large proportion of UK EDs since it was first put in place. At the same time, the policy significantly impacts clinical staff behaviours depending on whether a particular patient is just about to breach the target or has already breached the target [1]. Similarly, the policy limiting ambulance wait outside of an ED to 45 minutes [2] impacts the behaviour of ED Rapid Triage teams in ways that are not well understood.

How can data about these effects be made accessible to decision makers as part of a healthcare digital twin? We have previously used Domain Specific Modelling Languages (DSMLs) and Agent Based

Modelling (ABM) to simulate EDs in ways easily accessible to ED staff [3][4]. This research has identified several limitations:

- *Incorporation of real-world data:* how can models explicitly created to capture ED staff mental models of the process be linked with real-world data about actual behaviour, disease prevalence, etc? How can decision makers be enabled to handle the disconnect between processes as modelled and processes as actually executed and how can they handle changes of processes over time?
- *Efficient generation of complex-system representations:* How do we quickly create new high-level representations of a complex system like an ED as it changes over time? How do we efficiently understand the impact of these changes on overall system behaviour without the need for full system re-simulation?

The project will explore a combination of solution approaches to tackle these challenges:

- *Process mining* is a set of techniques to retrieve insights from an event log [5]. Whilst there are significant challenges to applying this in healthcare settings (not least the complexity and richness of the clinical processes that are being mined [5][6][7]), it is proposed that process mining can be used to generate behaviour to be used within ABM simulations modelled, as well as to handle near-real-time processing of data.
- *Delta visualisation:* using an appropriate DSML for modelling healthcare processes, how can techniques from model versioning be used to visualise changes in behaviour in ways easily accessible to decision makers?
- *Incremental simulation:* can more detailed logs generated during a simulation run be used to predict changes in overall system behaviour without the need for full re-simulation?

Suggested reading:

[1] NHS England, 'Delivery plan for recovering urgent and emergency care services', NHS England. Accessed: Sep. 16, 2024. [Online]. Available: https://www.england.nhs.uk/publication/delivery-plan-for-recovering-urgent-and-emergency-care-services/

[2] P. Brand, 'London ambulances will only wait 45 minutes before leaving patients in corridors', ITV News. Accessed: Sep. 16, 2024. [Online]. Available: https://www.itv.com/news/2023-01-03/london-ambulances-will-only-wait-45-minutes-before-leaving-patients-in-corridors

[3] T. Godfrey, 'Domain-Specific Modelling Languages for Participatory Agent-Based Modelling in Healthcare', in 2021 ACM/IEEE International Conference on Model Driven Engineering Languages and Systems Companion (MODELS-C), Oct. 2021, pp. 654–659. doi: 10.1109/MODELS-C53483.2021.00105.

[4] T. Godfrey et al., 'Supporting Emergency Department Risk Mitigation with a Modular and Reusable Agent-Based Simulation Infrastructure', Online World Conf. Soft Comput. Ind. Appl., 2023, doi: 10.1109/WSC60868.2023.10407894.

[5] J. Munoz-Gama et al., 'Process mining for healthcare: Characteristics and challenges', J. Biomed. Inform., vol. 127, p. 103994, Mar. 2022, doi: 10.1016/j.jbi.2022.103994.

[6] E. Rojas, J. Munoz-Gama, M. Sepúlveda, and D. Capurro, 'Process mining in healthcare: A literature review', J. Biomed. Inform., vol. 61, pp. 224–236, Jun. 2016, doi: 10.1016/j.jbi.2016.04.007.

[7] M. S. Sundari and R. Nayak, 'Process Mining in Healthcare Systems: A Critical Review and its Future', Int. J. Emerg. Trends Eng. Res., vol. 8, pp. 5197–5208, Sep. 2020, doi: 10.30534/ijeter/2020/50892020.