Applied Interdisciplinary Theory in Health Informatics
P. Scott et al. (Eds.)

doi:10.3233/SHTI190107

General System Theory and the Use of Process Mining to Improve Care Pathways

Owen JOHNSON [a,1]
[a] *School of Computing, University of Leeds, Leeds, UK*

Abstract. General System Theory was proposed in the post-war period as a unifying framework for interdisciplinary science based on the idea that *systems* have a set of similar properties and characteristics regardless of discipline. General System Theory laid the foundations for talking about things in terms of systems, many of its terms are now embedded in everyday language and it underpins a broad range of *systems approaches* and *systems thinking*. This chapter will describe the key elements of the original General System Theory (GST) including *control*, *feedback*, *emergence*, *holism* and the notion of a *hierarchy* of systems within systems. It will review the origin, content and foundational role of systems theory in biology, medicine, computer science, organizational theory and its central contribution to health informatics. In recent years, healthcare organizations have been encouraged to see themselves within the context of learning health systems (LHS) and to use emerging big data analytics techniques such as process mining to develop better, integrated and personalized pathways of care for patients. We use GST to reflect on these emerging approaches through a discussion and case study on recent work in urgent and emergency care. Our aim is to trace the influence of GST through emerging LHS ideas and use the framework of GST to reflect on the opportunities and limitations of our process mining approach. In particular, we will reflect on how GST can explain successes and failure in the application of process mining to care pathways and the challenges and opportunities ahead.

Keywords. General System Theory, Learning Health Systems, Process Mining

Learning objectives

After reading this chapter, the reader will be able to:

1. Review general system theory and the rich set of perspectives it brings to the understanding of health informatics in modern organizations.
2. Illustrate the application of general system theory to current challenges in healthcare.
3. Use general system theory as a framework to review data driven approaches to care pathway improvement with a specific focus on process mining.
4. Use general system theory as a perspective to reflect on the opportunities for learning health systems that focus on care pathway improvement.

[1] Corresponding Author: Owen Johnson, E-mail: o.a.johnson@leeds.ac.uk

1. Introduction to General System Theory

1.1. The origins of General System Theory

Systems approaches to thinking about the world run through much of Western philosophical thought. Eastern traditions have similarly emphasized systems concepts such as holism and the balance between change and homeostasis [1]. Our modern understanding of systems can be traced to General System Theory, proposed by Karl Ludwig von Bertalanffy [2] as a unifying framework for systems that is equally applicable to organisms and organizations. Branches of systems theory underpin software engineering, soft systems methods, cybernetics and Artificial Intelligence (AI). Health informaticians should see *systems theory* as a fundamental and powerful tool in their professional role and no textbook reviewing interdisciplinary theories for health informatics would be complete without a discussion on General System Theory and the impact that modern systems approaches have had on both healthcare and informatics.

The *language of systems* permeates all aspects of computing, information technology and the computer systems that we health informatics practitioners design, implement and study. Our computer systems are a special case of more general systems. They are different from, but also similar to many other types of systems, and of course, they are a key component in what are increasingly being called *healthcare systems* – that complex set of organizations and relationships that provide healthcare to large populations. A systems approach should be particularly appealing to health informaticians because systems perspectives and principles are applicable in medicine, biomedical sciences, systemic approaches to therapy, informatics systems and the organization of healthcare services [3]. New health informaticians may be surprised at the extent to which *systems* are found in medicine and biology and the importance of *systems thinking* in the understanding of the human body, its healthy maintenance and its responses to diseases and therapies.

Both computers and people are complex systems. In the middle ground between computer systems and a medic's understanding of biologic systems lies the myriad web of healthcare organizations, processes, care pathways and health delivery systems which health informatics seeks to improve. In the complex space of healthcare the words "systems" and "systems approaches" are often used rather carelessly and with little understanding or awareness of the *science of systems*. In this chapter, we aim to acquaint the health informatics practitioner with the theoretical base in *systems* that underpin both medicine and computer science and make the case for leveraging General Systems Theory as a toolset for addressing applied healthcare challenges.

General System Theory (GST from here onwards) was developed by a biologist, Karl Ludwig von Bertalanffy (1901-1972), was given support and a framework [4] by an economist, Kenneth Boulding (1910-1993) and has been subsequently refined and developed by many other scientists from a diverse range of disciplines. Bertalanffy developed his ideas for GST before and during the Second World War but did not publish them until afterwards and at a time where there was an explosion of post-war systems ideas and approaches. This interest in systems coalesced into a wider systems movement and included developing the principles and theories for the first computer-based systems. The foundational role of GST was that it provided this new systems movement with the belief that there was unifying framework underpinning their efforts. GST made the case for a single language for systems and for systems approaches as science [2].

GST was a development of Bertalanffy's work on *open systems* in biology. In physics, the laws of thermodynamics are based on conservation of energy and a tendency towards entropy (disorder) in a theoretical "isolated system". Bertalanffy noted that such isolated (or closed) systems rarely, if ever, exist in nature and, in biology, organismic systems (his phrase) tend towards order rather than disorder and, most obviously, organismic systems can grow and replicate as they interact with their environment, exchanging energy, matter and information. Many organismic systems are able to dynamically respond to their environment in order to maintain a steady state (homeostasis) in, for example, body temperature. More generally, the tendency towards order can be found in atoms, molecules, cells, organs, organisms such as people and organizations such as social groups and even health care providers. Structures emerge based on finding effective relationships between components whether these are protons and neutrons in an atom or a surgical team trying to save the life of a critically ill patient. Bertalanffy's development of GST was motivated by his desire to provide a fundamental language of systems that would improve scientific understanding across all disciplines [5].

1.2. What is General System Theory?

General System Theory in the narrowest sense was defined by Bertalanffy as the attempt to derive a general definition of "system" as a **complex of interacting components that together have the characteristics of an organized whole** [5, pg 91]. The emphasis of a system as an "organized whole" incorporates the concept of *holism* developed by Aristotle and commonly expressed as "the whole is more than the sum of its parts". GST makes the connection that holism is an *emergent* characteristic of systems as a product of the relationships between its components as they work together to collectively interact with their environment.

There are three key principles that follow from this general definition and the emphasis on holism. Firstly, GST asserts that this definition of a system should be generally applicable across all disciplines and that the systems perspective can generate new, and hopefully useful, insights.

Secondly, GST states that components of systems are often systems in their own right. Each member of a surgical team is also a person with similar but also unique emergent characteristics that might included their degree of experience in the specific role, their skills but also their affinity with other members of the team and degree of tiredness, hunger etc. which could be traced to their digestive systems and maintenance of blood sugar levels. From the perspective of GST, systems can be seen as being both composed of, and existing within, a *hierarchy* of systems. Our surgical team may be part of a busy Accident and Emergency department within a large hospital that is part of a larger healthcare provider and a regional or national health system. The team's performance will be affected by their immediate environment, which will include other systems (teams, departments, etc) within the hospital that it interacts with (in collaboration with or even in competition against) and also external environment factors such as the arrival of more patients.

Thirdly, GST places the emphasis on the *relationship* between components rather than simply the components themselves. The fact that surgical teams generally cope so well with all the complexity thrown at them is a testament to the relationship between team members - roles are clear but also sufficiently flexible and dynamic to adapt quickly to each other's needs as well as the patient's. An emergent property of a surgical team is that it is good at doing the appropriate medical or surgical interventions. The same people given the right training and tasked with organizing the introduction of a new computer system might struggle to work as an effective team simply because the relationships required are likely to be very different.

Two major criticisms of General Systems Theory are worth reflecting on at this point – one is that it is too general, and the other is that it is not really a theory. Bertalanffy was keen to insist that the aim of GST was not to provide a general theory of everything that would be so general as to have no practical application [2]. In his view, GST should provide a perspective *where it is useful* in providing a language or a framework for thinking about and discussing systems, particularly between disciplines that could benefit from sharing fresh ideas. While there are a dizzying range of potential hierarchies of interacting systems and sub systems in our surgical team example, a sensible use of GST is to focus on just those systems where a systems perspective generates fresh and useful insight. The second criticism of GST as "not really a theory" has some foundation. Bertalanffy himself argued that GST was conceived as a working hypothesis, a goal rather than a clear axiom [5]. Tom Mandel in "Yes, there is a general system principle, No it is not a theory" [6] makes a fair case for GST being regarded as a principle although the counter argument might be that the theory is that the principle applies. Semantics aside, it is perhaps best to regard GST, as Bertalanffy intended, as a "theoretical model" whose value lies in the practical "explanation, prediction and control of hitherto unexplored phenomenon" [5, pg 99].

1.3. Extensions to General System Theory

In Advances in General System Theory [5], Bertalanffy explored how the explosion of post-war systems approaches might fit with GST to provide a broader general theory of systems developing the principles of *communication* and *control* that describe how systems work. *Shannon's Information Theory* introduced the concept of information as quantity and "negative entropy" (information reduces uncertainty) and developed the principles for describing information transmission used in computer science[2]. Systems use information from their environment to reduce uncertainty about the range of appropriate responses, for example, when a medic uses diagnostic results to rule out possible diseases, narrowing down the options to identify the most likely disease and decide on the best treatment. *Cybernetics*, based on the role of information feedback in circular causal chains, helps explain how systems can be self-controlling. As early as 1948, William Ross Ashby applied cybernetic principles to build a synthetic brain, called the Homeostat, from four interlinked air force bomb control units that worked together as a system to maintain *homeostasis* through reinforcement and learning. Ross Ashby's *Law of Requisite Variety* is useful here; the *survival* of a system over time depends on it retaining sufficient (requisite) variety in its internal structure to respond to the variety in its environment; systems fail when they are unable to adapt to their environment. *Game Theory* describes logical decision making in humans, animals, and computers and provides insights into how some systems are maintained through *competition* between components where each component competes to maximize gain and minimize loss. In organizational systems, market forces often dominate - students compete for higher marks, professionals compete for salary, roles and kudos, and both private and public organizations compete for work and resources. GST includes the idea that relationships

[2] Discussed further in Chapter 3, "Information theory and medical decision making".

between system components can be competitive; in many systems, it is the dynamic tension of relationships between components that creates structures that stand the test of time. Similarly, Bertalanffy argues that GST also embraces *decision theory*, which analyses rational choices within human organizations, and *network* and *graph theory*, which can help GST develop models of the complex relations between system components in, for example, social networks. GST expanded from a theory into an ambitious project to join together disparate systems related ideas.

Perhaps the best attempt to provide a useful synthesis of all the multiple systems theory perspectives comes from Ken Boulding's (1956) paper titled "General systems theory: The skeleton of science"[4]. Boulding's framework categorizes various types of system in terms of eight levels of increasing sophistication that could be seen as systems archetypes. Level 1 (Simple Structure) are borderline candidates for systems in that they have physical structure but are essentially static, for example a rock. In healthcare we might think of objects such as a scalpel, a bed or a room, such objects still have an emergent property of wholeness and, for human created artifacts, often some discernible purpose. Level 2 (Clockwork) are more sophisticated than Level 1 in that they have movement and may maintain an equilibrium but such movement is predetermined, most obviously a clock-work clock and other simple machines but also the solar system. In healthcare, such concepts underpin stochastic dynamic modeling of, for example, the seasonal rise and fall of demand. Level 3 (Control Mechanisms) are Level 2 systems that also have some element of *information* closed-loop control, the classic example being a thermostat which turns heating on or off based on comparing the feedback of the current temperature to the control setting[3]. These are the principles of *cybernetics* in computing and *homeostasis* in biology and in management underlie principles of stock control and resource planning now often encoded within enterprise resource management systems. Level 4 (Open Systems) are Level 3 systems that have a self-maintaining structure in constant interaction with its environment, such a definition might include a flame or a river but more generally is the essence of simple life, a cell or a virus where we can add in the property of being able to self-reproduce. Level 5 (Plant) are Level 4 systems which have an organized whole based on a structure of differentiated and mutually dependent parts, for example plants where roots, leaves, seeds etc are functional parts themselves composed of specialist cells (i.e. Level 4 systems). Level 6 (Animal) are Level 5 systems which display *intelligence*, typically with sophisticated information intake, processing and control including the construction of a *knowledge* structure that enables them to compete (*Game Theory*) and make informed decisions (*Decision Theory*). Level 7 (Human) is distinguished by adding *self-consciousness* and, one would hope, more intelligence, greater reasoning based on knowledge and a capacity for more complex processing of symbols such as in the use of language. Level 8 (Social Organization) are the complex collections of people in various *roles* that manifest as discernible systems. An individual may simultaneously be a mother (and a daughter) in a family, a surgeon in a surgical team, an employee within a healthcare organization and a researcher doing a part time PhD at a university. The family, surgical team, healthcare provider and university all fit the definition of Level 8 systems and are *social networks* of people. Experience tells us that all of these can be hugely complicated, constantly changing and yet somehow their structures persist and evolve through changing relationships and the arrival and departure of new people. In Boulding's words, Level 8 includes "human life and society in all its complexity and richness" [4, pg 200].

[3] See also Chapter 14, "Control Theory to design and evaluate audit and feedback interventions".

Boulding's levels should not be mistaken for an attempt to provide a definitive taxonomy of GST or of life. It does however provide, and is best used as, a simple framework for discussing system models of increasing complexity. GST also provides a starting point for the rich world of systems thinking and systems approaches that can help health informatics practitioner understanding and improve the use of health informatics in modern organizations. Such approaches include systems engineering, Peter Checkland's Soft Systems Method [1], complexity science, systems dynamics, simulation and Peter Senge's Learning Organizations [7].

2. Using GST in Health Informatics

2.1. How health informatics professionals can use GST

Health informatics professionals can:

1) Use GST in its narrowest sense to identify, model and define a system of interest following the definition of GST in Section 1.2. A careful choice of boundary is essential as the components and relationships within the system should be directly responsible for the system appearing as a coherent whole. GST forces deep reflection on what the system actually is, how it survives over time, its structure and environment. A good understanding of how and why a surgical team works well should be an essential pre-requisite to an implementation project introducing a new informatics solution that is expected to help their performance. Conversely, of course, it can help understand why health informatics projects often fail. We would encourage the former.

2) Use the language of GST for interdisciplinary communication. We have italicized most of the key GST terms in this chapter and the informatics practitioner who is familiar with and can use these terms in discussion with healthcare professionals (and even managers) should find that they are speaking a common language if only because most will have learnt them in biology classes.

3) Develop their understanding of GST into a broader systems approach to problem solving. There are many good books, courses and online material that are linked to and build on GST and systems approaches. Once you have started thinking in systems, it is difficult to stop and there are many practitioners who consider systems thinking has transformed their professional approach.

The following examples of the applications of GST within health informatics will, we hope, illustrate the scope and potential.

2.2. Applications of GST in Healthcare Computing

Our modern computer systems were first developed within the climate of the post-war systems movement and computer science has contributed to, and benefited from, GST. In common with other systems, computer systems have components (software and hardware) and relationships (interfaces, dependencies and networks) and we can describe these in terms of *inputs*, *processes*, *outputs*, feedback and control. Component based and layered architectures are designed to *manage complexity* while delivering functionality and performance at scale. Most people know from experience that some computer systems are better than others and that some can crash or slow down unexpectedly. Computer system performance (and usability, security and other non-functional characteristics) are emergent properties of the system-as-a-whole. The complexity of modern systems is such that solving one performance issue or bug may introduce others and a holistic perspective on the system together with a deep respect for the complexity of its internal structure becomes essential.

As our computer systems have become more complex, they have become, following Boulding's Level 7, more human. Holistically they can display emergent properties of being buggy, annoying, slow stubborn, inflexible – to the extent that we may find ourselves shouting "stupid computer" at them or complaining about them as though they were a troublesome colleague. From a GST perspective, none of this should be a surprise - most health informatics systems fit comfortably into Boulding's definitions of Level 5 and above and may have many of the characteristics of Level 7, and perhaps Level 8 too. Especially as modern advances in computing such as AI, neural networks, distributed systems and edge computing increasingly follow biologic models of systems of competing sub-components. The result is that even their designers cannot know exactly how they work. For healthcare this presents an unusual problem: should clinicians trust a computer system that no-one can adequately explain? Medical devices have been regulated on the basis that their programming is rules-based (GST Level 3 and 4) but complexity in general and medical AI in particular have advanced computing well beyond these levels. GST may be needed to help regulation, legislation, the professions and society adjust to human-level computer-based systems.

One significant difference between all computer systems and all biologic systems is the relationship with data. Biologic systems process and act on information and store useful information and successful responses to it as knowledge for future reference, and they have used this learning system process to evolve successful survival skills over many thousands of years. Our current computing systems are an awkward fit with GST; they are less than 70 years old and they work differently. Specifically, they can and do store huge amounts of raw data and it is their reliance on data, rather than information and knowledge that can make them appear "stupid". Future, bio-inspired computing may evolve similar intelligence but for now the key opportunity for organizations is to mine the wealth of *big data* stored within legacy computer systems. In healthcare, data mining of electronic health records is seen as having the potential to transform our understanding of medicine [8]. Locked away in these records is the history of millions of clinical encounters and their successful or unsuccessful outcomes.

2.3. Applications of GST in Learning Health Systems

In health informatics, there has been growing interest in *Learning Health Systems*, a phrase coined by Charles Friedman [9] in the USA which envisaged rapid learning based on a federated, national approach to exploiting EHR data gathered by different US healthcare providers. More generally, Learning Health Systems are seen as organization-wide or pan-organizational regional and national systems that deliver healthcare to a large population. In Friedman's vision there is a symbiotic relationship between the health provider system and the health information systems that it uses. The *Learning Organization* concept was developed from systems theory by management theorists, notably Peter Senge [7]. In learning organizations, systems approaches that reward effective learning are embedded within management culture at all levels of hierarchy. The organization is seen as organic with structures evolving through continuous learning to meet changing environments and ensure survival in a fast paced, ever changing world.

Exactly as described in GST. In Learning Health Systems (LHS), these ideas are extended to include developing new medical learning and there is a strong emphasis on the use of health informatics solutions as both the provider of the data that will be used for *evidence-based medicine* and the vehicle for delivering knowledge to the clinical teams through automated decision support and workflow management.

The Heimdall Framework [10] provides a taxonomy of types of learning health system where new clinical insight and patient process improvements are driven by the analysis of data from the electronic health record (EHR) and other health information systems. In GST terms, clinical and management control is informed by feedback about processes and outcomes and is implemented as interventions to the inputs and process. More data, faster data flows and improved analytical abilities improve control and the organization's long-term ability to continuously learn and adapt to its changing environment. A key insight from GST is that of systems-within-systems, each contributing to overall success. An LHS approach can therefore be applied to a surgical team, a ward, a department or clinical specialty as well as the organizational, regional and national systems in Friedman's vision. Following GST carefully would suggest that LHS should indeed be implemented at all levels of the organizational hierarchy including the individual human as reflective practitioner. Adoption of integrated informatics solutions, interoperability standards and improved methods for mining health data are essential for LHS but the long term vision is of systems that self-learn through embedded AI and a new generation of digital-native clinicians who are part of, but remain firmly in control of, their health system. LHS is seen as a driver for health informatics but to succeed it requires the deeper understanding of the relationships between organizational structure, people, processes and technology that comes from applying GST.

2.4. Applications of GST in Process Mining of Care Pathways

The care pathway is a commonly used concept for considering how the processes of delivering healthcare should best be organized around the needs of the patient [11]. A care pathway is a design template for a healthcare process – it describes the sequence of care that is recommended for patients with similar conditions requiring similar treatment. Comparing the actual care that patients received as recorded in the EHR against the intended care pathway should help healthcare organizations understand the gap between what they think they are doing and what they are actually doing, a key requirement for learning. Coiera [12] suggests that LHS should use process mining to develop automated process-level metrics and identify common multi-variate process patterns to help better understand how healthcare delivery is structured. Process mining is a set of big data analytics tools and techniques that use time-series event data to specifically address process characteristics and there is growing interest in process mining in healthcare [13]. Ronnie Mans and Wil van der Aalst [14] provide a comprehensive guide to process mining in healthcare including health reference models and pathways. Process mining has been combined with process simulation to create a mixed methods approach to support the development of LHS [11]. In the following example we illustrate how process mining of a care pathway fits with GST and an LHS vision.

3. Success factors in process mining of care pathways

3.1. Connected Health Cities

The Connected Health Cities (CHC) project in the North of England aims to implement a region-wide LHS through a range of initiatives linking and using health data and sharing insights and best practice (www.connectedhealthcities.org). The approach has included the development of federated data repositories of EHR data as advocated by Friedman, the development of a learning culture for sharing and disseminating knowledge and a focus on care pathways that can be mined, analyzed and improved. Challenges have included: developing architectures and consent models for ethical access to health data; linkage of health data from different sources, standards and variable data quality; engagement with multi-disciplinary teams across multiple organizations; engagement with busy clinicians and already stressed organizations; and the development of better methods for process mining of care pathways. Solutions have included: national level engagement on legal and ethical frameworks; public engagement through a social media campaign (called #datasaveslives) and citizens juries; Trusted Research Environments (TREs) for the secure curation of data; developing experience in multi-disciplinary collaboration; a focus on specific high-impact problem areas; and ClearPath, a novel method for care pathway process analysis that draws on GST and, more generally from a systems thinking approach.

3.2. The ClearPath Method

The ClearPath method [11] is an extension of an established process mining method (called PM^2, see [14]) that incorporates a stronger systems method of enquiry and produces care pathway simulations that can be used for experimentation and learning. In our work in this area it became evident that a more holistic systems approach was essential to address what have been called "data quality" issues. From the perspective of GST we see health data not as the product of a machine but as the product of a highly complex sociotechnical healthcare system that is evolving, adapting and responding to its environment. We would argue that the failure of "big data" methods in healthcare is due to a failure to apply GST. A conventional approach to healthcare data mining includes complaining about data quality, cleaning data to suit the analysis and assuming that more data means less unknown systemic bias. The reality of healthcare data is that it is messy and incomplete, it can shed some light on the activity of busy clinicians and the administration of healthcare processes but with different systems used differently by different departments, highly variable pathways and moving systems boundaries the only real certainty is that data will be different between systems and over time. Recent advances in process mining recognize this phenomenon as process evolution or "concept drift" and new techniques such as applying sliding time windows to spot changes in process are being developed with some success [15].

Our approach within the CHC project has been to combine process mining of EHR data with a systems approach to enquiry. Following GST, the starting point is to identify and define a system of study that has a clear boundary and a single clear structure. For example we have worked with a number of urgent care departments and have treated each one as a separate discrete system, resisting the temptation to aggregate urgent care data across the region because such an aggregated view would fail GST's test of what is a system, a common mistake made by those who advocate big data in healthcare. We have however modelled urgent care as a part of the larger system of a hospital and the wider health system, for example across a district and a city region, using a systems-within-systems approach that does fit well with GST. We recognize health systems as GST Level 8 open systems; the relationship between system and environment is complex and evolving. In this context, process mining is useful in looking for those patterns and structures that emerge from a holistic view of the system.

In the UK there have been national targets for at least 95% of patients attending Accident and Emergency departments to be admitted, transferred or discharged within four hours. A pattern that emerges from process mining many such departments is that a median of 3.9 hours is common. Root cause analysis discussions with domain experts suggests this is game theory at work. The national target leads to the perverse behavior that the staff wait until, and then respond to, the impending deadline perhaps also believing that a full waiting room and a long wait will discourage less seriously ill patients. We also found evidence that the patterns and sequences of processes change during the day. Standard process conformance metrics were noticeably at their worst around early evening when routine processes give way to a period of apparent chaos with, for example, beds being requested for patients that had not yet been seen by a clinical specialist. We traced this flurry of activity to the time when the overnight shift starts work and a new allocation of beds become available; our discussions suggest that the new shift prioritize operational concerns such as booking beds over the routine updating of the computer system. In both cases these are very human activity patterns that can be explained through GST and only revealed by systematic enquiry.

The other contribution from GST has been the construction of models to represent systems of study. Simple models such as process maps and mathematical formulae can be seen as GST Level 2 or 3 and therefore inadequate for explaining the behavior of a GST Level 8 organization. In the ClearPath method we use a care pathway simulation tool called NETIMIS (www.netimis.com) to present dynamic, runnable models back to multidisciplinary teams as part of a facilitated discussion about care pathway improvement. Simulation modelling might be seen as GST Level 4 and therefore inadequate in capturing the complexity of real-life healthcare. However, the real learning in LHS is still done by people so the discussion and the interactions and ideas it sparks are the real outputs of process mining of care pathways.

4. Discussion

4.1. Is GST relevant to modern health informatics?

The enduring strength of GST is that it opens a window into a powerful way of viewing the world. At its most general, it sees the world as made of systems many of which are dynamic, complex and ever changing _ a melting pot of complexity where structures still emerge and have permanence while the relationships that hold them together are maintained, a wave crashing on a beach, a flight of birds forming a characteristic “V” shape. In our healthcare contexts, a patient’s body fighting serious infection and a surgical team at the end of a tough shift while also perhaps battling with a stubborn computer system. Or the cash-strapped health provider organization that spent too much procuring that computer system because it lacked the internal competencies to appreciate the importance of health informatics.

One student on a recent Systems Thinking course said they found GST difficult because “anything could be seen as a system depending on the boundaries you set”. The student was in one sense correct, but in GST we also expect systems to have emergent structures and simplicity. We recognize that both a wave and a hospital are actually very complex but are happy to accept they exist as systems that we can observe and reason about. Choosing boundaries wisely is important.

The challenges facing health informatics professionals are getting harder not simpler. Many healthcare organizations have successfully implemented health information systems and are now asking how they can use their computer systems to improve their internal structures, processes and deliver better care. We would recommend GST and a systems approach to help make a hard job somewhat easier and more rewarding.

Teaching questions for reflection

1. Reflect on a health informatics system that you are familiar with; write a definition of the system following the definition of GST in Section 1.2. Describe the system in terms of its most significant components and their relationships. Reflecting on the healthcare environment where this informatics system is used, identify a system of healthcare provision and write a similar definition and description. How should the health informatics system contribute to the “survival” (continued viability and effective working) of the healthcare system it is part of?
2. Discuss your understanding of General Systems Theory with people from a range of disciplines (clinical, informatics, management etc.). Looking through the italicized terms in this chapter ask your colleagues whether they recognize these terms and whether they have the same meaning regardless of discipline.
3. From the perspective of GST, our complex healthcare systems can be seen to be in a state of continuing flux and the data in our health informatics systems reflects this. Can Artificial Intelligence (AI) that has been trained on such highly variable data ever be considered safe for clinical use in these constantly changing environments?
4. Reflect on a care pathway that you are familiar with; how could you help implement a learning health system that used health informatics to capture data that would help health care professionals continually learn about and improve the pathway?

References

[1] P. Checkland, *Systems Thinking, Systems Practice*, Wiley, NY, 1981.
[2] K.L. von Bertalanffy. An outline of general system theory. *British Journal for the Philosophy of Science,* **1**, 1950. 134-165.
[3] E. Coiera, *Guide to Health Informatics,* CRC press, NY, 2015.
[4] K.E. Boulding, General systems theory—the skeleton of science, *Management Science,*1956 Apr;2(3):197-208.
[5] K. L. von Bertalanffy, *General System Theory: Foundations, Development, Applications,* NY, 1968.
[6] T.M. Mandel, Yes, there is a general system principle, No it is not a theory. In Proceedings of the 56th Annual Meeting of the International Society for the Systems Sciences (ISSS) 2012, San Jose, CA, USA 2013 Mar 8.
[7] P. Senge, *The fifth discipline, the art and practice of the learning organization*, Wiley, NY, 1991.

[8] T.B. Murdoch, A.S. Detsky. The inevitable application of big data to health care. *JAMA* 2013;309 (13):1351–2.
[9] C. P. Friedman, A. K. Wong, D. Blumenthal, Achieving a Nationwide Learning Health System. *Science Translational Medicine.* 2, 57cm29 (2010).
[10] S. McLachlan, H.W. Potts, K. Dube, D. Buchanan, S. Lean, T. Gallagher, O.A. Johnson, B. Daley, W. Marsh, N. Fenton. The Heimdall Framework for supporting characterisation of learning health systems. *Journal of Innovation in Health Informatics*, **25:**2 (2018), 77-87.
[11] O.A. Johnson, T. Ba Dhafari, A. Kurniati, F. Fox, E. Rojas. The ClearPath Method for Care Pathway Process Mining and Simulation. In *PODS4H, 16th International Conference on Business Process Management (BPM 2018)*, Sydney, Australia 2018 Sept 10.
[12] E. Coiera. The forgetting health system. *Learning Health Systems*. 2017 Oct;1(4):e10023.
[13] E. Rojas, J. Munoz-Gama, M. Sepúlveda, D. Capurro. Process mining in healthcare: A literature review. *Journal of Biomedical Informatics*. **1:**61 (2016), 224-36.
[14] R.S. Mans, W.M. van der Aalst, R.J. Vanwersch. *Process mining in healthcare: Evaluating and exploiting operational healthcare processes.* Heidelberg: Springer; 2015 Mar 12.
[15] T. Li, T. He, Z. Wang, Y. Zhang, D. Chu. Unraveling Process Evolution by Handling Concept Drifts in Process Mining. In *Services Computing (SCC)*, 2017 IEEE International Conference on 2017 Jun 25 (pp. 442-449).