Considering Complexity Theory in Understanding Information Management in Health Systems

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ABSTRACT: *In 2008, as part of a national agenda of Healthcare reform, the Australian Federal Government commissioned a report into the state of the Australian public health system. The resultant 2009 report by the National Health & Hospitals Reform Commission (NHHRC) described the Australian Health Sector (AHS), and its information and management processes, as "fragmented". Observed in the NHHRCs depiction of the AHS was that the various levels and services offered within healthcare operate largely arbitrarily, and at multiple local system nodes of a whole larger – albeit fragmented – system. Recommended were numerous strategies designed to 'fix' this fragmented complex system. Implied in this depiction and resulting recommendations is the NHHRC's pre-supposition that systems need to be (traditionally) 'ordered' and managed to be considered as functioning in their optimal state. This paper argues that an alternative paradigm, informed by the science of complexity – which conceptualises complex organisations and their processes in terms of being Complex Adaptive Systems (CAS) – is able to provide a more appropriate theoretical foundation for both understanding and facilitating information management within highly complex organisational structures. Chaos and Complexity theories offer – for the organisational theorist – an investigative framework better suited to the dynamic and unpredictable characteristics of information and process management within a complex organisation. In this context, traditional information and management science approaches to understanding organisational characteristics such as fragmentation, process and information duplication, redundancy, and system regulation may require a rethink.*

Keywords: Complex Adaptive System, Australian Health Sector, Organic Information Management, Complexity Theory, Living Systems, Post-reductionism

Keywords: Social communication, Aging society, Communication Activation, Topic recommendation

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1. Introduction

This paper discusses how the science of Complexity might inform the information and management sciences in regards to understanding how complex organisations – conceptualised as complex adaptive systems (CAS) – engage information, and how to better facilitate information management (IM) using a complexity paradigmac view.

The contextual/practical example used as part of the discussion comes from the highly complex Australian Healthcare Sector, recently described by its own *National Health and Hospitals Reform Commission's* parliamentary report to the Australian federal government as fragmented [1, p3; p50; p56; p68; p108; p148; p157] and overly complex [1, p3; p40; p45; p51; p53; p56; p121].

2. Traditional Systems and Information Management Approaches

The 2009 Report by the *National Health and Hospitals Reform Commission* (NHHRC) [1] to the Federal government described the Australian Health Sector (AHS) as "fragmented".

The NHHRC went on to contextualise this fragmentation, describing the AHS as being fragmented in relation to:

(1) funding models and performance accountability [1, p3; p146];

(2) hierarchical and management structure [1, p56];

(3) approaches to aged care [1, p108];

(4) approaches to e-health and Health-ICT implementation [1, p130];

(5) integration between State and Federal healthcare information and responsibilities [1, p50; p148]; *and*

(6) systems management and support [1, p157].

In addition, the perceived fragmentation is often portrayed in the strongest of terms:

"*In every dimension and at every level, the Australian health system is not just fragmented, but atomised. Like iron filings scattered randomly on a piece of paper, its many players are influenced by different motivations, which in turn draw them in different, often opposing directions…*" [1, sub 328, p157]

Observed in this depiction of the Australian Health System is that the various levels and services offered within healthcare operate largely arbitrarily, and at multiple local system nodes of a whole, larger – albeit fragmented – system. Recommended in the depiction is that the fragmented system(s) need to be standardised until they are somehow 'fixed'. Implied in this depiction, is the NHHRC's pre-supposition that systems need to be (traditionally) 'ordered' and 'managed' to be considered as functioning in their optimal state.

2.1 The link between paradigm, research approaches and system solutions

When presented with the observation that an organisation and its information or management processes are fragmented, it seems natural to assume such a state to be deficient. More often than not, the organisation in question sets out to fix, reform, or standardise their systems in some way. New systems designed to somehow un-fragment the information or various processes are implemented, usually with imposed common vocabularies (information system) or processes (management system) designed to address the fragmented nature of a system perceived to be ailing or broken.

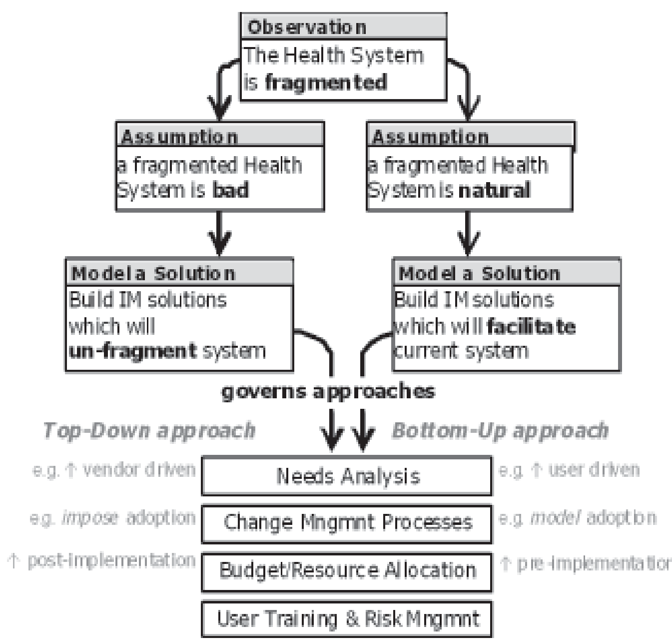

Figure 1. Relationship between Philosophical Assumptions & Systems Solutions

It is less natural to consider that perhaps fragmentation, and in particular information fragmentation, is normal and part of the way the entities – or 'agents' [2] – within a complex organisation interact with each other. It is even harder to consider that the fragmented state is not only a natural reflection of the specific organisation's complexity, but is a candid picture of how the organisation has, over time, evolved and learned how to do its business [3].

Figure 1 illustrates how philosophical assumptions drive the approaches designed for an investigation into, or implemented solution for, a specific information management system problem. In the case of the Australian Health System, the observed phenomenon is 'system fragmentation' – which, by virtue, also includes the fragmentation of the system's information and processes, and the over-riding assumption of this reality – at least according to the NHHRC – is that ***fragmented is bad***. The pre-supposition that 'fragmented is bad' is reflected in the report's vocabulary and descriptions of the general impact of the fragmentation; for example fragmentation is described as resulting in the system being: "*at the mercy of powerful interest groups*" [p50]; "*difficult to access and navigate*" [p108]; prone to "*duplication of administrative processes*" [p146]; leading to poor integration [p148], access [p157], and accountability [p148].

Greater still, the pre-supposed assumption that *fragmentation is bad* not only reflects an assumed *causal* link between fragmentation and various 'negative' characteristics in the system, but strongly drives the report's recommended solutions, since the observed characteristics are attributed to having been caused by the fragmentation. For example, instead of developing solutions which might prove useful to loosen the grip of special interest groups [p50], recommendations by and large revolve around ways to 'integrate' or 'un-fragment' the system through such processes as:

(1) Commonwealth Government imposed technical standards [p8, p35], compliance standards [p35] and security protocols;

(2) Standardised information regarding services available [p22, p23];

(3) Health professional accreditation standards [p32, p127] including, nationally imposed curriculum standards [p33] and reporting standards [p127]; and

(4) standardised clinical engagement protocols, including assessment tools and patient care-pathways [p102].

The problem is that the link between the observed fragmentation and the described negative system characteristics is, in fact, largely assumed. As a result, the imposing of standardisation, integration, and rationalisation in the system is also assumed to have the capacity to fix the individual issues identified at local-levels of the system.

2.2 Conventional Wisdom in Information & Management Science

When explained in the above terms, the conventional wisdom of implementing *integrated* [4-6]; *centralised* [7] or *standardised* [8] solutions; may seem somewhat askew. It is worth understanding however, how this widely accepted current information and management thinking evolved from the original systems theories of half a century ago.

Systems theory [9] emerged in the middle of the 20th Century, and found divergent application across multiple scientific disciplines. The core concept of a systems approach was the value placed on the contextual relationships between the entities/agents in any given system [10], seen as important to the system as the system-objects themselves. The concept of the interconnectedness of system agents was quickly embraced by emerging fields such as software engineering, business, information and management sciences; and became the driving paradigm underpinning the design of most modern software and information management systems [11].

Significantly, the thinking behind the types of cause/effect models developed by von Bertalanffy [9] [12] and Boulding [13] was that of the *predictable system*, including the perspective that "*systems (individual organisations/whole populations) are driven by negative feedback processes toward predictable states of adaptation to the environment*" [14, p477]. Put another way, this predictable system world-view must adhere to the assumption that systems, made up of individual interacting 'agents', are inexorably bound to behave in an intentional and rational manner, and that specific attitudes or perceptions result in specific and predictable outcomes. Human behaviour, however, as outlined by Knight and Burn [15], is far more complex than a linear, causal relationship between users' salient beliefs, behavioural intention and resultant behaviour outcomes. The possible limitations of the positivist-driven linear systems paradigm has become increasingly apparent when it is applied to those systems which demonstrate the capacity to evolve and change themselves [16], as can be seen in a modern health system.

The assumptions of linearity between system agents and predictability of agent behavioural outcomes (illustrated in Figure 2) form the basis of the majority of social science behavioural models. For example, models such as: Theory of Reasoned Action (TRA) [17, 18]; the Technology Acceptance Model (TAM) [19]; and the Theory of Planned Behaviour (TPB) [20] are all built on the assumption that there are direct/causal relationships between users' salient beliefs and attitudes and their intention to execute certain behaviours, which in turn has an impact on actual behaviour. The relationship between behavioural intention and actual behaviour is particularly linear in these models, a postulate which remains one of the most "*uncritically accepted assumptions in social science research*" [21, p.245], and does not account for non-linear, quantum [22-23] influences on human thinking and behaviour.

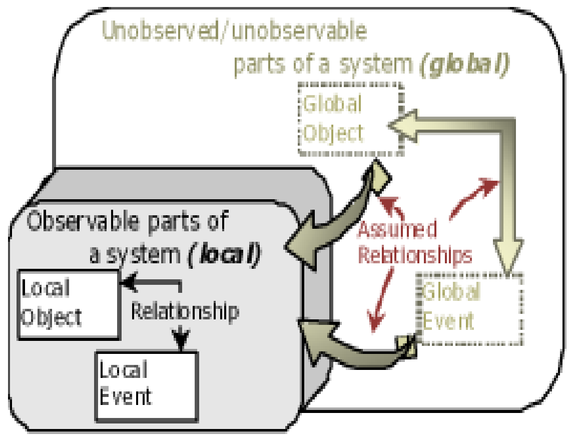

Figure 2. Illustration of the principle assumption of (deductive) linearity and predictability of behaviour and interaction outcomes between system objects in previous Systems research

A postulate is a proposition which, accepted as true, provides the foundation for logical reasoning around specific phenomena. And so, behavioural models such as those cited, based on the reasoned postulates of predictability and linearity, provide much the scientific reasoning around the design and building of new information, business and management systems, as well as any subsequent reviews, evaluations and repairs of those systems. Collectively, in their 25 year history, the TRA, TAM and TPB have over 32,000 scientific citations [24].

2.3 A Complexity Science Paradigm: Developing a Different Understanding of the Information System

An alternative paradigm to this predictable, Newtonian, world-view is that which drives the science of complexity. Complexity Science, which is concerned with understanding the dynamic behaviour of non-linear, Complex Adaptive Systems (CAS) [25-26], offers - for the organisational theorist - an investigative framework better suited to the dynamic and unpredictable human characteristics of information management within a complex organisation. The system and its relational objects are conceptualised as being part of a non-linear, dynamical, and adaptive *Living System* [27-29]; where notions of *chaos theory* [30-31]; system *self-organisation* [32-33]; *redundancy* [34]; *entropy* [35]; *emergence* [36]; *autopoietic* and evolving networks [37]; and *nonlinear dynamics* [38-39]; provide valuable tools for understanding.

Complexity theory offers a unique and novel way to adequately conceptualise the complexity of the Australian Health System, and investigate how information might be managed within and between its multiple clinical-contexts, or system-nodes.

3. Discussion: The Application and Implications of Complexity to Health Information Management

3.1 Complexity: Phenomena, Interconnectivity and Emergence

A complex system is defined as one with a large number of parts which have many interactions [40-42]. A complex *adaptive* system has all the qualities of a complex system but demonstrates the added capacity to evolve and change in unpredictable ways [16] [43], described as '*emergent*' [44-45] [41] systems behaviour.

Johnson [46] describes complexity science as being "*the study of the phenomena which emerge from a collection of interacting objects*" [46, p3]. It is this notion of *emergence* which puts complexity somewhat at odds with traditional reductionist approaches to understanding scientific phenomena. Traditionally, scientists – in an attempt to limit investigative variables [47]; decrease ambiguity [48]; and increase validity and generalisability [49] – typically study small, isolated aspects of phenomena. The decontextualisation of system objects – in a positivist/reductionist sense – has demonstrated to be of little value however, when trying to understand emergent behaviours within a complex system, since it is the collective interaction of the system components, as much as their physical properties, which determine this behaviour [25]. The human brain, for example, is made up of about ten thousand million nerve cells, called neurons, with around one hundred billion connections between them. The emergent behaviours of this complex system of neurons and connections includes such complex phenomena as cognition, emotion, sensation and motion. Significantly, no single neuron possesses these properties in isolation.

3.2 Pictures from Nature: Rethinking Systems Phenomena

Similar emergent properties can be found in many complex systems in natural and urban settings, from termite colonies to traffic jams [50]. The application of complexity science principles to the investigative frameworks used to examine these complex systems has given researchers unique insights into how natural, biological, and even man-made complex and complex adaptive systems work. These studies have challenged conventional assumptions about how systems principles apply to business, information and management systems.

3.2.1 Redundancy and Resilience

Redundancy in the Information and Management Sciences has had a history of being associated with inefficiency and waste [51]. Non-use of information or information pathways and any duplication of processes are often earmarked for removal – usually in an attempt to rationalise organisational systems or to save organisational resources. This mode of thinking is demonstrated clearly in the NHHRCs [1] report of both the problems and the recommended solutions within the Australian Health System.

Significantly, in complexity thinking, redundancy has come to be theorised as an essential ingredient in a living, adaptive system's capacity to cope with stochastic events. In neurology: the plasticity of the brain is becoming increasingly apparent, as previously in-active (or redundant) neurological pathways are activated through intensive rehabilitation, after predominant neurological pathways are damaged in a brain injury [52]. In genetics: research paints redundancy as an integral part of the ready-to-be-used arsenal of genetic material [53-55] As Science continues to deconstruct various species genome, it has become clear that large amounts of genetic material sits dormant – as if dormant were the 'default' position for much living material. DNA waits for specific chemical reactions to switch it 'on' so it can evolve into a tail, or a pair of legs.

The reasons why natural systems keep so many of their redundancies represent an exciting area of biological and natural science research. There seems to be clear evidence, even at this early stage in the research, that narrowing gene-pools puts species at risk. Conversely, redundancy appears to provide an organic 'back-up' plan for when natural systems encounter unexpected events. The application of these concepts to information management systems potentially facilitates new and innovative approaches to information management systems design and rationalisation, since it sees the removal of system redundancy and duplication as likely resulting in less resilient information management systems.

3.2.2 The Role of Regulation

Issues around information accessibility, security, quality, and so forth, have lead to models of IM which include high degrees of information regulation. It is not uncommon to see the introduction of Standard Operating Environments (SOE) or software version control, down to keyword standardisation and regulated ontologies for information retrieval. The perceived need for better regulation and standardisation of system information is clearly demonstrated in the recommendations made by the NHHRC [1] report into the Australian Health System, and is in line with established traditional business and management models.

Complexity theory however, constructs regulation in very different terms. Contrary to the traditional management view of regulation being an active controlling mechanism, chaos theory has been able to mathematically demonstrate that for many complex systems, regulation is a passive relational construct. In systems where regulation is imposed, the resultant over-regulation leads to linearity, or *decomplexification* [56], which in many instances within natural systems paints a portrait of the system in a "less healthy" state [57]. The notion of *complexity-loss* has become an important medical research construct in disease pathology, with the observation of what Goldberger [56] summarises as the paradoxical appearance of highly periodic, predictable system dynamics in many medical disease/disorders. "*Many disease states are marked by less complex dynamics than those seen under healthy conditions*" [56, p1313].

An over-regulated heartbeat is a common characteristic of a cardiac arrhythmia [58, 59]; over-regulated breathing is associated with asthma [56]; over-regulated firing of muscle fibres bundles is found in Parkinson's disease [57]; and general loss in complexity in multiple systems is observed in aging [60]. Research into nervous system over-regulation continues to develop as a promising sub-field in the quest to understand cognitive and mental illness disorders such as schizophrenia [61] bio-polar disorder [62-63] and autism [58]. In other scientific disciplines, researchers are finding evidence that over-regulated patterns in complex systems like personal relationships are associated with both loss of adaptability and ill health of relationships [64]; and over-regulation of traffic can lead to more severe traffic jams [50].

A major implication of understanding, and learning to measure, this general loss in complexity in the pathology associated with specific diseases, is the increased potential for early diagnosis [65]. The application to the management and information sciences is more conceptual, as researchers begin to develop a more realistic metaphor for the healthy, robust and adaptive information system.

3.2.3 Individual Self-Preservation and System Self-Organisation

A particularly challenging Complexity construct for the management and information sciences is the notion of agent (individual) self-interest, the role of which seems intrinsically linked to a system's capacity to sustain itself through self-organisation.

The self-sustaining nature of natural, living systems has interested particularly the harder information and computational sciences (*e.g.,* [66-70]), since to imitate such a characteristic in a built information system would be the pathway to developing any true artificial intelligence [71]. Emergent fields such as digital ecosystems [72] represent new ways of conceptualising component parts of an information system [73-74]. Early in the computer science discourse into complexity and information systems design, Flores [75] wrote of future technologies built as "complex, dynamic and heterogeneous infrastructures" describing each part of the system (i.e., people, organisation, software and information) as "*infohabitants*" [75, p17]. A noted characteristic however, was the natural tendency of the interacting infohabitants within a complex system to lean towards their own protocols [76] described by Kephart *et al.*, [77] as their own *individual optimality*, which was then said to have the capacity to threaten the overall stability of the system. Thus, even those authors advocating the need to embrace information systems as complex self-sustaining systems did so while still arguing the need to overtly manage them.

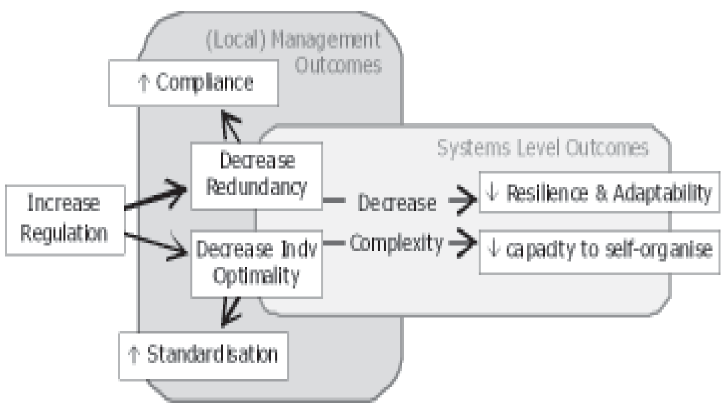

Figure 3. Expected Local/System level Outcomes to imposed Regulation

The view that an individual agent's self-centred behaviour should be considered problematic is not shared when the understanding of system behaviour is driven by a complexity paradigm. Nature is, in fact, full of examples where the self-focusing behaviour of the individual leads to a collective advantage for the whole system. Reynolds [78] demonstrated through computer simulated mathematical algorithms that birds don't flock as a result of traditional models of leadership (i.e., a leader-bird showing the way) but by each bird following three simple, local, and self-preserving behaviours; namely: (1) fly at the same speed as the next bird; (2) fly towards the centre of the flock; and (3) don't collide with other birds. This same type of individual self-preserving behaviour is illustrated in the way that fish school [79-80].

Self-focusing agent behaviour can also take place in the way two agents within a system might interact together to the exclusion of other agents. *In neuroscience*, the '*Hebb rule*' (*cited in* [81]) describes how two neurons' repetitive interactions can develop a sort of *relevant strength*, resulting in an almost co-dependent pathway which can become over time relatively insensitive to other neurological noise (or stimuli). This behaviour (i.e., the Hebb rule), Hopfield [82] argues, forms the basic elements of neurological memory and subsequent whole nervous system learning.

Figure 3 illustrates how increasing system regulation in the management of local system nodes results in the removal of redundancy and individual variance in the global system. So too, regulation has the capacity to decrease individual optimality, imposing a standardisation to group norms. The figure also illustrates the system level outcome of a decrease in complexity, i.e., removing redundancy it seen to remove the system's capacity to adapt to unplanned changes, thereby decreasing system resilience. In addition, removing individual optimality decreases the system's capacity to self-organise since individual decision-making - usually made in response to system changes - is weakened.

4. Conclusion: Implications & Future Research

4.1 New Ways of Seeing old Problems

"*The true value of the (complex system theory) approaches may lie more in a revision of our way of thinking about social science processes and how the study of those processes should be approached*" [83]

The beginning of this paper presented a very specific observation made of the Australian Health Sector by its own National parliamentary inquiry into itself (*see* [1]) that the Australian Health System is currently "*fragmented*". Moreover, the recommended actions to address this observed fragmentation revolve around a whole-system integration of the AHS' information and process systems. It is the conjecture of this paper, that before the Management, Systems and Information sciences take up the challenge presented by the NHHRC to develop a robust systems-driven information management plan, serious consideration should be given to a discourse which goes beyond a traditional mechanistic view of the Health System. Indeed, Health Science literature reveals that the very nature of health systems across the globe is extraordinarily complex [84] – to the point where even the most rudimentary relationship within the Health System, between healthcare professional and their patient – is so naturally fragmented, that it is described by Gunter and Terry [85] as being "*episodic*" in basic form and character. Importantly in the context of this discourse, a living and complex system paradigm provides an investigative framework where "fragmented" is not necessarily perceived as a bad. Conversely, it need not be considered good either. Instead, observed fragmentation within the system is considered to be a natural reflection of the high complexity contained inside and around the system. In addition, other constructs relating to agent and system redundancy, regulation and self-centred behaviours can be framed within an entirely different theoretical paradigm which suggests that many of the assumptions made previously in regards to how systems work are not necessarily correct [71].

4.2 New ways to Frame & Investigate Old Problems

The scientific discourse around complexity and complexity theory is relatively new [46] and spans across multiple disciplines. In this context, the application of complexity to a context such as understanding information management within the AHS requires that researchers consider a broader epistemological framing to their investigation [86-87]; and a more diverse set of methodological approaches than are commonly engaged in Information, Health and Management Science Research [88-89]. Importantly, complexity theory provides a empirical foundation to move away from previously assumed knowledge of how systems in the real world actually work.

The reductionist strategy of isolating parts of a system into individual phenomenon has proved highly effective in developing scientific understanding of specific phenomena. It has proved less effective, however, at explaining how complex phenomena interact within a complex system since the capacity to generalise what is learned about individual phenomenon is contingent on an assumption that nature is linear, uniform and predictable [90]. Complex systems have multiple interacting parts, with time, sequence, and level/amount of interaction also subject to multiple variables, making their impact on system outcomes difficult for reductionist science to conceptualise and investigate. Give those interacting parts the capacity to shift subsequent (and ongoing) interactions, the system becomes a complex adaptive system, requiring post-reductionist thinking [91] such as that associated with complexity and chaos theory to help develop ways for science to conceptualise and study them.

4.3 Challenging Previously Held Assumptions

This paper has demonstrated that the AHS' road to information systems integration, including how the sector applies more traditional business analytical strategies around information management concepts, is paved with the philosophical assumptions associated with how the sector perceives the concept of "system". Interestingly, in the almost 300 pages which make up the extensive NHHRC report into the state of the Australian Health System, not once did the commission ask the most basic systems questions: "*What is a system?*" The conceptualisation of the Australian Health System as a living, adapting and evolving system allows the researcher to apply the metaphorical constructs associated with complexity at multiple levels of the health system and its various sub-systems – or *system nodes*. Pragmatically, this enables the researcher to recognise that the system and its information are not static, but behave more like an ecological system. In this system, infohabitants behave like living organisms in a complex "*web, or network, of interactions with other organisms*" [92, p16], not necessarily bound to mechanistic causality. An evolving system perspective also allows for individual IM solutions at local system-nodes, and pushes future designers of information management systems to consider how to integrate the data from multiple local-systems rather than assume a top-down one-solution imposed implementation of information management.

In an attempt to scratch the surface of complexity theory's application to future IM frameworks and project implementations, it is noted that the topics and constructs involved reach far beyond the content of this paper. This paper has therefore set out to specifically address whether the information and management disciplines are ready to consider the design of IM systems which: have (1) more redundancy; and (2) less regulation; are inherently self-serving; have a better capacity to evolve and adapt to their context of implementation, i.e., within a complex adaptive system; than current modes of IM system design.

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â€œComplexity is a movement in time that is both knowable and unknowable. Uncertainty is a basic feature of all complex systems.â€ â€" Esko Kilpi. A framework for complexity. To better understand what this means in practice, Iâ€™ve found the Cynefin framework hugely helpful. The framework outlines contexts, or domains, that describe a â€œsense of placeâ€ from which a system can be perceived. By understanding your context and the nature of the system, you can better make sense of the available information and better understand how to make decisions. The domains are obvious, complicated, complex, and chaotic. Something that is obvious is deterministic and certain. We propose a theoretical lens for understanding and studying complexity in healthcare systems based on degrees of interrelatedness of system components. We also describe, with relevant caveats, how complex healthcare systems are generally decomposable, rendering them more tractable for further study. The ideas of interrelatedness among the components of a system as a measure of complexity and functional decomposition as a mechanism for studying meaningful subcomponents of a complex system can be used as a framework for understanding complex healthcare systems. Using examples drawn from current literature and our own research, we explain the feasibility of this approach for understanding, studying, and managing complex healthcare systems. 3 Complexity theory has been increasingly used within the health sector to explore the ways in which interactions between component parts of an intervention or system give rise to dynamic and emergent behaviours. 4 5 Interventions are often defined as â€˜complexâ€™ in terms of their being (1) multicomponent (ie, the intervention itself may comprise multiple components that may interact in synergistic or dissynergistic ways); (2) non-linear (they may not bring about their effects via simple linear causal pathways); and (3) context-dependent (they are not standardised, but may work best if.Â There are many potential sources of complexity to be considered in both complex interventions and complex systems perspectives.