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SICK SYSTEMS: TOWARDS A GENERIC CONCEPTUAL REPRESENTATION OF HEALTHCARE SYSTEMS

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ABSTRACT
In this paper, we argue that the healthcare systems within which patients are treated are like patients themselves. The systems display symptoms which may give indication of problems in an "organ" of the system. The human system that forms the core of healthcare activities is a complex system and so are healthcare systems. The success of medical diagnosis has been facilitated by a generic concept of the human anatomy and its systems, organs, and corresponding physiology. The lower levels are the building blocks on which the upper levels depend. Disease processes cause failure at the chemical levels and this failure affects organs, systems, and even the whole body. We observe an interesting similarity between the medical diagnosis process and the systems design approach, yet there is no corresponding generic representation of healthcare systems akin to the anatomy and physiology of the human system. Our goal in this paper is not to match the healthcare system to the human system part by part and organ to organ but to discuss how the structured medical diagnosis process can be applicable to healthcare systems if an appropriate conceptual representation of the system can be developed.

Keywords: Conceptual representation, Healthcare, systems, simulation modelling

1. INTRODUCTION
It could be considered impossible to design, model, simulate or analyse a system without a conceptual representation of it. Even when we avoid the use of a formal conceptual representation of the system, in the process, our mental models are always involved (Sterman, 1991; Forrester, 1991). It is therefore surprising to find how little research has gone into the development of a formal and consistent approach to conceptual modelling particularly in healthcare systems. In the field of Operations Research (OR) and simulation modelling for instance, this appears to be a newly discovered area of research (Robinson et al., 2011).
Healthcare systems are undeniably very complex but the human body as a system may be even more complex (Thibodeau & Patton, 2010, p3). If a generic conceptualization of the healthcare system exists as it does for the human system (the human anatomy), it may facilitate the achievement of two goals namely; a diagnostics approach to understanding healthcare system problems and the effective communication of healthcare system issues to practitioners. This paper discusses the conceptual representation approaches in a number of research communities, presents the human system anatomy and physiology analogy and proposes an embryonic generic conceptual representation of healthcare systems for the above stated goals.
For centuries, anatomists, physiologists and pathologists have endeavoured to develop a proper understanding of the structure, functions and mechanisms of disease of the human system. These efforts have led to a well established, fundamental and generic, conceptual representation of the human system that has become the key to the medical diagnosis process (Singer, 1957; Gonzales-Crucci, 2007). For several decades, the bulk of healthcare research has focused on the clinical aspects of care, however, it is now understood that the quality of healthcare must be measured by the quality of the structure within which care is provided, the process by which care is provided and the outcome of care (Donabedian, 1966). All of these together, form the system for providing quality care.

The growing interest in healthcare system research has led to the emergence of several challenges for both researchers and practitioners. Amongst these challenges are the effective application of industrial tools in healthcare (Young et al., 2004; Kopach-Konroad et al. 2007; Young and Mclean, 2009), the understanding of the complex nature of the healthcare system (Palley and Gail, 2010) and the conceptualization of the healthcare system for various purposes including system design, modelling and simulation (Brailsford, 2007). This paper will focus on the challenge of conceptualization.

Healthcare systems research has become a multi-disciplinary endeavour with disciplines ranging from operations research, modelling and simulation, information technology, organisational theory, to name a few. As a result, several conceptual models have been developed that seem to address certain aspects of healthcare that is of particular interest to a discipline. In some disciplines a unified approach does not exist. In the field of operations research (OR) modelling and simulation, conceptual modelling is just emerging as an active field of research (Robinson et al., 2006; Robinson et al., 2011). Some of the commonly used conceptual models are discussed in more detail in section 3.

The generic representation proposed in this paper is novel in a number of ways: first of all it adopts the “Sick Systems” approach which means considering a system with problems as “sick” and requiring diagnosis and treatment as a physician would consider a human being with health problems. Secondly, it is argued that this approach to conceptualising the system would facilitate communication of systems design and modelling concepts and issues to healthcare practitioners and help improve uptake and implementation. This metaphor is intuitive and sometime used informally in some aspects of healthcare management but has not yet become a subject for research. For instance, the renal service managers of an NHS Trust in England have developed an “analogous list of metrics that indicate the health of the local kidney care system”, and refer to various elements of the system as organs or body parts. There is also the TRICORDANT consultancy in England that has used the “unwell” systems metaphor for years with clients in healthcare. To underpin these concepts with research should help reap the maximum benefits in application.

As a result, the main motivation for this paper is to make a modest contribution towards a new method of thinking about healthcare systems problems in diagnostics terms akin to healthcare. It is also intended to stimulate debate on the subject within a community that has an interest in the design of healthcare systems.

The next section of the paper presents the study framework, highlighting the ideas that are used to evaluate existing representations and also as the basis for the proposed generic representation. Section 3 discuses the conceptual modelling approaches from a number of fields and theories. Section 4 then presents a summarised evaluation of more forms of conceptual representations. In section 5, we further discuss in detail the proposed generic concept and in section 6, we provide a brief discussion and some direction for future research on the subject.

2. STUDY FRAMEWORK

This paper distinguishes between structure and function; anatomy and physiology. We are not at this stage concerned with the functions of various elements of the system though vitally important. This approach is similar to Henry Mintzberg’s proposed generic structure of an organisation which considered the organisation as comprising essentially of the Strategic apex, operating core, middle line, technostructure and support staff (Mintzberg, 1983). However, Mintzberg’s representation of the system has a functional connotation. The basic questions in this paper are; “what is a healthcare system essentially made up of and can these be generically represented?” and “is the medical diagnostics process analogy of healthcare systems a feasible one”? In the next section we discuss the five basic elements of a system which we propose as sufficient for representing the essential elements of most healthcare systems.

2.1 Elements of a Healthcare System

We consider that there are five major elements that are common to most systems namely; Resources, Processes, Data/Information, Entities and Environment (Wyllys, 2011). These are essentially what these systems are made up of and should be sufficient for describing the system in a very generic sense. These elements are briefly explained below:

Resources: in the general sense, resources are the elements of the system that use or support processes in transforming entities or delivering results for entities. This would include financial resources, human resources and materials.

Processes: these are the elements of the system that involve designed steps necessary to facilitate the achievement of specific goals for entities.
Data/Information: these are the elements of the system that represent the source of the knowledge necessary to ensure effective interaction between various system elements vertically and horizontally.
Entities: these are the elements of the system that go through the processes using data and information and consuming and often competing for resources.
Environment: this defines the boundary of the system and involves elements outside of the system and/or its elements but with which the system may interact.

Using the examples of a GP practice, an emergency department and a hospital setting, Table 1 shows examples of how these elements may be defined.

Table 1. Examples of system elements in healthcare systems

System elements	GP practices	Emergency care	Hospital care
Resources	**People**: GPs, nurses, practice managers and receptionists **Equipment**: blood pressure gauge and stethoscope **Facilities**: reception and consultation rooms	**People**: A&E doctors, nurses, receptionists and consultants **Equipment**: Blood pressure gauge, Stethoscope and ECG **Facilities**: beds	**People**: managers, doctors and nurses **Equipment**: various medical devices **Facilities**: wards, beds
Data/Information	Appointment schedule, referral letters, patient records and test results	Referral letters, patient records, test results and discharge letters	Referral letters, patient records, test results and discharge letters
Processes	Appointment booking, diagnosis, treatment, immunisation and referral	Triage, minor treatment, major treatment, resuscitation and referral	Scheduling, diagnosis, treatment and referral
Entities	general patients and patients in special needs	walk-in patient, GP-referred patient and ambulance patient	in-patient and out-patient
Environment	Homes, referral agencies	GP, Ambulance, support services	GP, A&E, Homes,

Whereas these elements are not based on empirical research, we suggest that the role they play in healthcare systems is self-evident and could be reasonably employed at this early stage of this research. These elements may also be identified at various levels of the healthcare system and form systems themselves. The advantage of these elements is that, they are generic and therefore useful for the human body system analogy that is presented in this paper.

2.2 The Human Body System Analogy

In this section, we present a brief discussion on anatomy, physiology and pathology. We focus on the distinction between anatomy and physiology and how the study of these two logically facilitates the study of pathology. The human body system that forms the core of all healthcare activities is a complex system but the structure is fairly well understood. The success of medical diagnosis has been facilitated by a generic concept of the human anatomy and its systems, organs, cellular structure and corresponding physiology. The lower levels are the building blocks on which the upper levels depend. Disease processes cause failure at the chemical or cellular levels and this failure affects organs, systems, and even the body as a whole (Thibodeau & Patton, 2010).
We believe that applying this analogy to the healthcare system itself has considerable benefits. This does not mean matching the healthcare system to the human system part by part and organ to organ but to learn from how the structured medical diagnosis process can be applicable to healthcare systems if an appropriate conceptual representation of the system can be developed.

Anatomy, physiology and Pathology

In medicine, anatomy is fundamentally concerned with the structure of the human body system and the interaction between its grouped systems, split systems and principal organs (see figure 1). Figure 1 (adapted from Thibodeau & Patton, 2010) is a generic conceptual representation of the human body structure (anatomy) as a system of systems. The figure shows the interaction between the various systems and between the entire system and its external environment.

Physiology in medicine is thus concerned with the functions of the body parts or organs. This is therefore closely related to the study of anatomy. Pathology, which is the study of disease, uses the principles of anatomy and physiology to determine the nature of particular diseases (Thibodeau & Patton, 2010). Thibodeau & Patton stress that by knowing the structure and function of a healthy body, physicians are better prepared to understand what can go wrong to cause disease. That is, the formal progression from anatomy to physiology and pathology is a logical one.

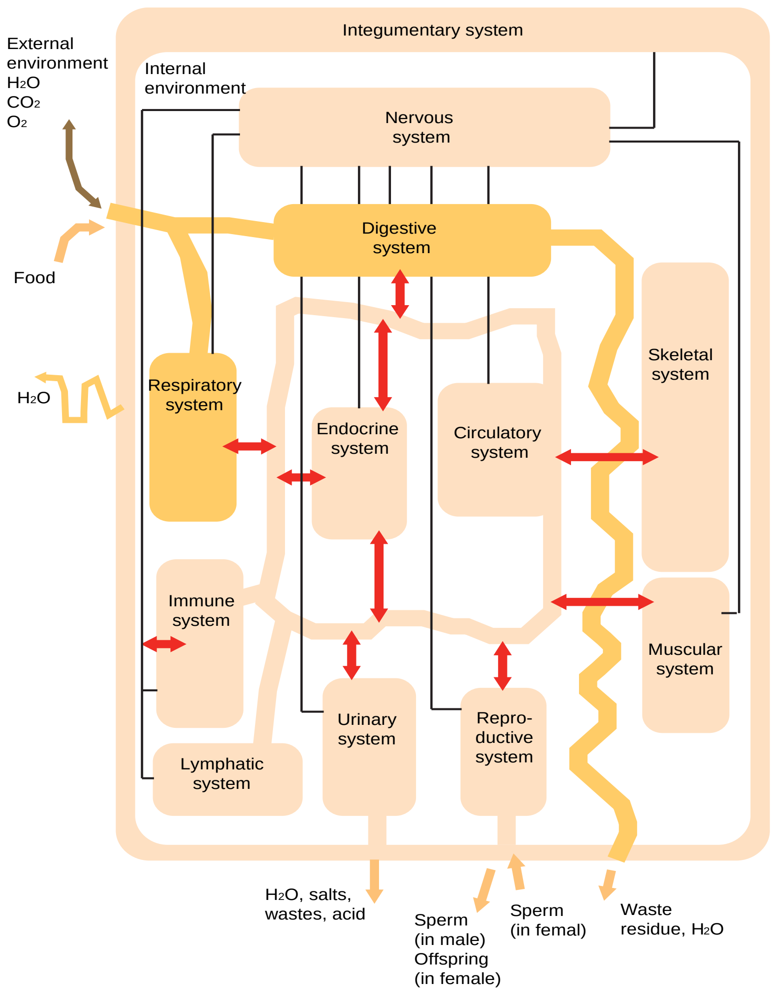

Figure 1. Integration of human body organ systems (adapted from Tibodeau & Patton, 2010)

The medical diagnosis process

Figure 2 shows the typical steps involved in the medical diagnosis process. This was formulated by an experienced vascular surgeon in the NHS. The diagnosis process often starts with the patient recognising that he or she has a problem and needs help resolving it. In medical terms this is known as "adopting the sick role".

The process is not always straight forward as can be seen in figure 2. It involves considerable uncertainty. The computerisation of this process has been the subject of significant research in artificial intelligence and expert systems for decades (Szolovits & Pauker, 1978). Szolovits & Pauker viewed medical decision making as a spectrum with categorical reasoning at one extreme and probabilistic reasoning at the other. They found that experience of the clinician has a considerable impact on the process. In a more recent work, Baerheim, 2001 identify two phases of the diagnostics process as abductive (in which a doctor infers one or more diagnosis from a patient's story) and deductive (where the doctor begins to check his diagnosis with specific tests). Of most relevance here is the emphasis that the deduction from a hypothesis is the process of using logic to check the patient's particulars against a given medical theory. This further highlights the fact of the importance of the underlying knowledge of anatomy, physiology and pathology in the diagnostics process. This is why we believe that the generic concepts of system "anatomy" and "physiology" are important to the development of the subject of "sick systems".

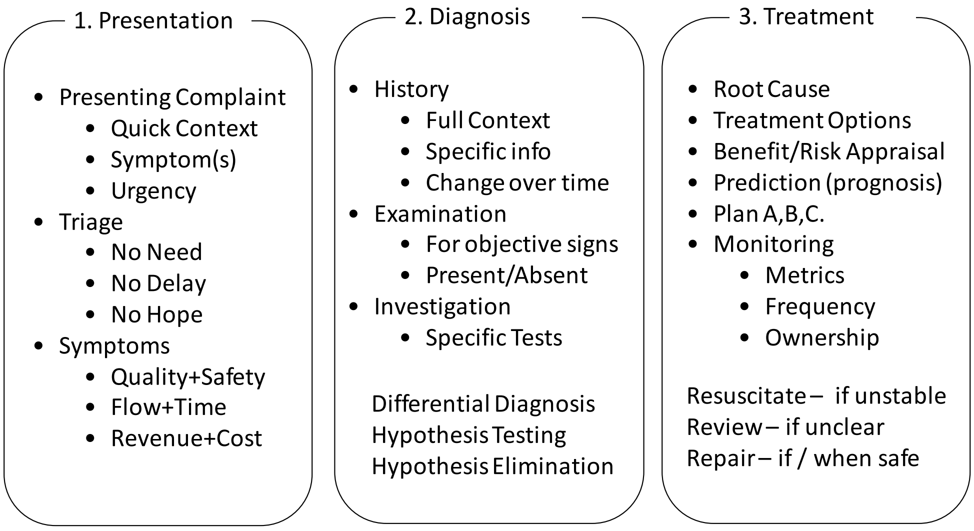

Figure 2. Medical diagnostics process produced by an experienced vascular surgeon

Most healthcare managers know when there is a problem in their system but often may not understand the problem or how to deal with it. For a patient, this is often easier when sickness is dramatic, that is "acute" as it is known in medicine. It is more difficult to adopt the sick role when sickness is degenerative or in medical terms, chronic. A patient, however, may become aware of the creeping disease in a dramatic way as may be the case in a heart attack. Again, an application of this concept to a "degenerative" system problem is not far-fetched.

The above arguments therefore form the framework for the discussions and proposals that follow.

3.0 CONCEPTUAL REPRESENTATION OF SYSTEMS: STATE-OF-THE-ART

Conceptual representations are a part of every field that involves some abstraction of reality to facilitate problem solving. We have reviewed several conceptual models including IDEF0 (Feldmann, 1998), contingency theory, socio-technical system theory (Jackson, 2000), work system design (Carayon et al., 2009) and the Tricord model (Thanes, 2007). All of these models are either, problem or project specific, languages and methods or focused on some aspect of the organisation. Following our review and to the best of our knowledge, no conceptual representation exists that attempts to represent the intrinsic elements of the system in a generic sense as desired in this study. Whereas we have considered the major areas of study that deal with systems and conceptual representations, we acknowledge that this is not a comprehensive review of all the pertinent literature. Brief discussions on five of these models are presented in the following sections due to space restriction. In some areas such as the Operations Research (OR) field, the discussion represents the present state-of-the-art in conceptual representation.

3.1 Operations Research (OR) Community

In the OR community, conceptual modelling is receiving more attention in particular as it applies to the simulation process. Thus conceptual models are vital to the success of a simulation modelling project. Surprisingly, however, very little has been written on the subject. In his review of the subject, Robinson identifies the following issues that require research attention in the OR field (Robinson, 2006):

- Definition of conceptual model(ling)
- Conceptual model requirements
- How to develop a conceptual model
- Conceptual model representation and communication
- Conceptual model validation
- Teaching conceptual modelling
- Other issues in conceptual modelling

This paper seeks to contribute to the conceptual model representation and communication problem. The state-of-the-art in conceptual modelling in the field of OR is such that no unifying definition and unifying approach to conceptual modelling exists (Robinson et al., 2011). The closest to this is described by Onggo, who proposed a unified conceptual model representation by combining a number of different diagramming methods (objective diagram, influence diagram, business process diagram and activity cycle diagram) (Onggo, 2009). The problem with this model is that it is problem focused and does not capture the essential elements of the healthcare system in a generic way.

3.2 Organisation modelling (OM)

According to Morabito et al. OM attempts to unify concepts of organisation structure in Organisation Theory (OT) and information modelling. At the heart of OM is the concept of the organisation molecule. Figure 3 shows a culture molecule of an organisation adapted from (Morabito et al., 1999). OM is a level of modelling that spans all areas of an organisation and it is argued that both biological and organisational systems may be configured as molecules (Morabito et al., 2008).

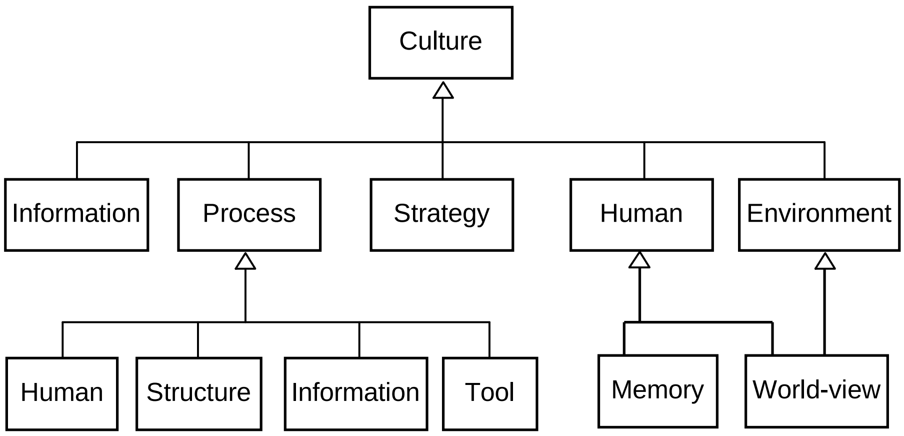

Figure 3. A culture molecule in Organisation Modelling (adapted from Morabito et al, 1999)

The concept of the molecule is used as a generic and useful means of defining aspects of the organisation, for example, process molecules, information molecules or strategy molecules. What is lacking with this approach, however, is that the biological system analogy is limited to the definition of the molecule but that does not fit together as to how the whole organisation works as an organism. As a result this concept is considered a useful complement to the present formulation as discussed in section 5.

3.3 Design Community

In the design community conceptual models or representations are found in two areas. The first area of conceptualisation is a stage in the design process known as “conceptual design” (Pahl et al., 2006). The second area of conceptualisation is that of the capturing and representations of what designers do, also known as the “design process”.

There has been extensive research into conceptualising the design process and there are excellent reviews on this (Wynn and Clarkson, 2005; Dubberly, 2005). Of particular relevance to the method proposed in this paper is the chromosome product model proposed by Andreasen (1992).

Andreasen, 2008 presents a useful background to the development of the chromosome model. The discussion here only highlights the mechanism of the model as it is adapted into the current proposed

model of the sick system. The model provides a very intuitive way of understanding how to deliver functions and operations to specifications by logically linking processes, parts organs and components together.
Though a product model, the chromosome model seems well suited for a service (or healthcare) environment at the operational level when an operation or process requiring a skill (function) that has to be carried out by a specialty (organ) made up of staff or equipment (parts). This model and that of the organisation molecule are further discussed together with the "sick system" model in section 5.

3.4 Systems engineering (SE) community

Several conceptual representations are used in systems engineering but the most generic representation of a system is shown in figure 4 adapted from the systems engineering handbook (Haskins et al., 2007).
This figure provides a generic structure for representing systems which is provided for addressing specific problem situations. Though this may be modified to apply to other systems, it seems to have been designed with a focus on engineering systems involving parts, components, assemblies and subassemblies.

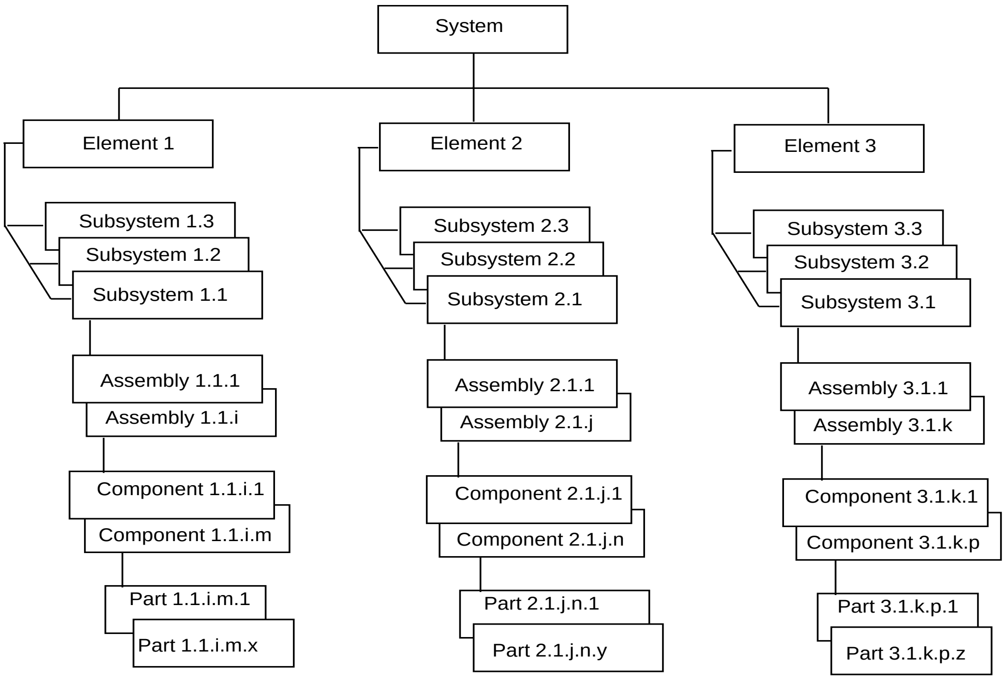

Figure 4. The Systems Engineering Hierarchy within a system model

4.0 EVALUATION OF SELECTED MODELS

In section 3, we discussed four areas where conceptual models are used and their relevance to the present argument. There are several other models which space would not allow for further discussion.
Table 2 therefore presents a brief evaluation of some selected areas of conceptual modelling according to which elements of the system they explicitly capture as discussed in section 2 above.
The purpose of this table is to show primarily that various models do not often address all the five elements of a system as discussed in section 2.1. This in part confirms the lack of research focussed on the development of a generic conceptual representation of systems as proposed in this paper.

Table 2. Evaluation of selected conceptual models

	System Conceptualisation Models								
System elements	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9
Resources		♦				♦	♦		♦
Data/Information	♦	♦	♦	♦	♦		♦	♦	
Processes	♦	♦	♦	♦	♦	♦	♦	♦	♦
Entities	♦				♦	♦	♦		♦
Environment								♦	

SC1= Design (chromosome); SC2= OR; SC3 = BPM; SC4 = OM; SC5 = Systems Engineering; SC6 = Contingency Theory; SC7 = Work System Design; SC8 = Socio-Technical Systems; SC9 = Soft Systems Methodology.

5.0 PROPOSED GENERIC CONCEPTUAL REPRESENTATION

This conceptual formulation is based on the view that healthcare systems are Complex Adaptive Systems (CAS) (Begun et al., 2003) but with the assumption that these systems have reducible radical openness and contextuality (Chu et al., 2003). The levels of grouping are arranged according to a modified form of the levels of human body system level after Thibodeau and Patton, 2010. They reduce the entire human body system to three grouped system level namely; Skeletomuscular system, Neuroendochrine system and the Urogenital system. These are further divided into the major body system, split system and then the principal organ level (figure 5a). The organs are also reduced down to the molecular and chemical level.

In figure 5(b) the various levels of system groupings are shown with the system of resources broken further down from the Grouped system level to the operational or “organ” level. The grouped system level is a conceptual level of abstraction and represents the major essential elements of the system. These are made up of systems of resources, processes, information and entities. These concepts have been defined in section 2 above. The emphasis on systems at this level is to indicate that each of these elements is in fact a collection of several interconnected subsystems of the system at the major system level. At the major system level, the elements of the grouped system level become more identifiable but on a bigger scale as indicated in the figure for the system of resources broken down into various types of system groups. The split system level is a further identifiable grouping of the resources of the system. The model also shows the internal and external environments with which the system exchanges dynamic elements generally indicated as in-flows and out-flows. At the operational or “organ” level it should be possible to identify specific resources for specific processes. These processes would be defined as system molecules as explained below.

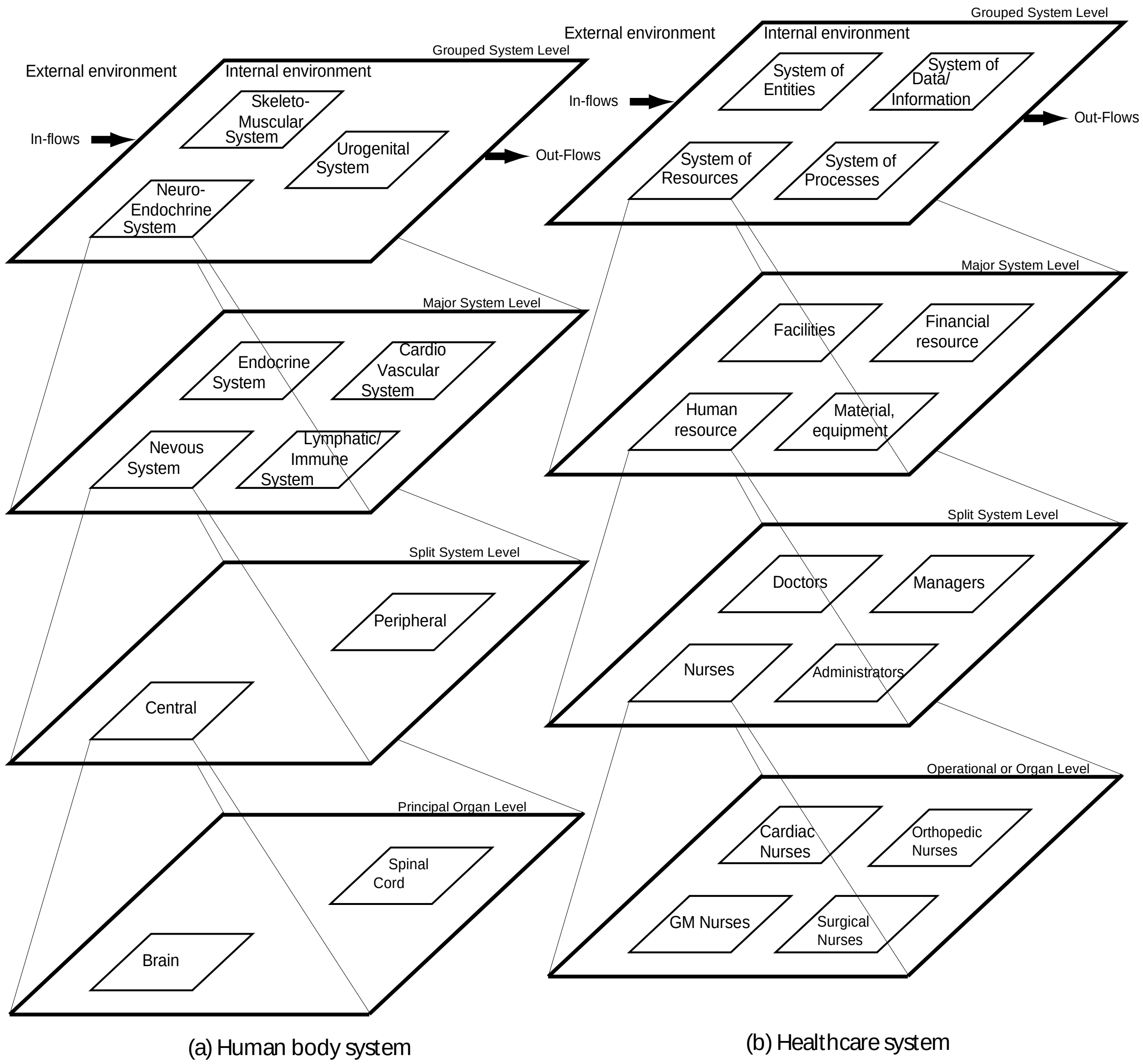

Figure 5. The generic conceptual representation of healthcare systems compared to the human body system

5.1 System molecule

In section 3.2, the concept of the organisation molecule in Organisation Modelling (OM) was presented. At the operational (“organ”) level of the above conceptual representation of the system, there is the need to define specific processes or operations and the various other elements that would be involved. We consider the concept of the molecule an appropriate method for achieving this. This has the advantage of flexibility since any type of molecule can be defined. Once molecules are defined, the task of examining the element of the molecule that provides specific functions as achievable by the chromosome model can begin.

5.2 System chromosome

Throughout this paper we have emphasised on our concern for the structure (anatomy) of the system rather than the function (physiology). We briefly discussed the chromosome model by Andreasen, 1992 in section 3.3 above. At this point we adopt the chromosome concept as an appropriate concept for systematically examining the functions of system elements as defined in the molecules. This would be developed as we continue to do further work on this subject.

6.0 DISCUSSIONS AND FUTURE WORK

The application of the human body system metaphor to healthcare systems seems intuitive, however, it has not yet become a research subject. At the same time, researchers particularly in Operations Research modelling and simulation are beginning to focus on new and better ways of representing conceptual models of healthcare systems and by these communicating systems issues effectively to healthcare practitioners.

We have tried to show through the above arguments that existing conceptual models from various fields vary in their focus and none entirely seeks to represent the system entirely in a generic sense as with the human system analogy. We have also stressed the need for a systematic approach to the "anatomy" and "physiology" of healthcare systems as has been the case in medicine showing that this theoretical knowledge significantly underpins the medical diagnostics process. If healthcare systems may be considered "sick" and needing diagnosis and treatment then there is still a lot of work to be done in systematically explaining the disease process in these systems.

In medicine, it is understood that the lower levels are the building blocks on which the upper levels depend and that disease processes cause failure at the chemical or cellular levels and this failure affects organs, systems, and even the body as a whole. It may be obvious that in a healthcare system, if nursing processes on the ground fail consistently, it might lead to the failure of a department and even a whole hospital. We anticipate that if this way of looking at the healthcare system is embraced, it might lead to a paradigm shift.

At this stage, however, we find that the "sick system" view of the system may also raise questions we cannot yet imagine how to address. For instance if the concept of anatomy and physiology helps to explain the physical health of the system, what would be the equivalent of the emotional health of the system? In spite of the potential challenges, however, we find that this way of thinking raises even more exciting questions which may be worth pursuing as outlined next under plans for future work.

FUTURE WORK

This conceptual work presents several opportunities for further research. The following questions are a few that we hope to further explore: What are the symptoms of a sick system? If we had a healthy system how would we tell? That is, what defines a healthy system? What makes a system unwell and can we understand the rate of decay from a healthy to an "unwell" system? What are the pathological processes that can affect a system and how would they manifest? What diagnostics tests would we need? How would we interpret the results and how would they affect management decisions? What determines the "emotional health" of a system? Following diagnosis, what treatment options could be available? What are the risks and benefits of each? As with every new concept, we also hope that this would lead to interesting and important questions that we have not yet imagined.

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