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Networkcentric Healthcare: Strategies, Structures and Technologies for Managing Knowledge

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ABSTRACT
The proliferation of IC^{2}T (information computer and communication technologies) throughout the business environment has lead to exponentially increasing amounts of data and information generation. Although these technologies were implemented to enhance and facilitate superior decision making what we see is information chaos and information overload; the productivity paradox [1-4]. Knowledge management is a recent management technique designed to make sense of this information chaos by applying strategies, structures and techniques to apparently unrelated and seemingly, what appears at times irrelevant data elements and pieces of information so that germane knowledge can be extracted[5-6]. The latter then serve in support of decision making, effective and efficient operations as well as enable an organisation to reach a state of information superiority. Critical to knowledge management is the application of IC^{2}T [ibid]. However it is the configuration of these technologies that is important to support the techniques of knowledge management. This paper discusses how effective and efficient healthcare operations can ensue through the adoption of a networkcentric healthcare perspective that is grounded in the process oriented knowledge generation framework of Boyd and enabled through WHIG (world healthcare information grid) a totally integrated set of sophisticated IC^{2}T[7-9].

INTRODUCTION
Healthcare is an information rich, knowledge intensive environment. In order to treat and diagnose even a simple condition a physician must combine many varied data elements and information. Such multispectral data must be carefully integrated and synthesized to allow medically appropriate management of the disease. Given the need to combine data and information into a coherent whole and then disseminate these findings to decision makers in a timely fashion, the benefits of IC^{2}T to support decision making of the physician and other actors throughout the healthcare system are clear [10]. In fact, we see the proliferation of many technologies such as HER (health electronic records), PACS (picture archive computerized systems) systems, CDSS (clinical decision support systems) etc. However and paradoxically, the more investment in IC^{2}T by healthcare the more global healthcare appears to be hampered by information chaos which in turn leads to inferior decision making, ineffective and inefficient operations, exponentially increasing costs and even loss of life [10-11]. We believe the reason for this lies in the essentially platform centric application of IC^{2}T to date within healthcare, which at the micro level do indeed bring some benefits but at the macro level only add to the problem by creating islands of automation and information silos that hinder rather than enable and facilitate the smooth and seamless flow of relevant information to any decision maker when and where such information is required.

To remedy this problem and maximize the potential afforded by IC^{2}T and consequently alleviate the current problems faced by healthcare, we suggest the adoption of a networkcentric approach to healthcare operations. Such a networkcentric approach is grounded in a process oriented view of knowledge generation and the pioneering work of Boyd [7-9,12].

PROCESS ORIENTED KNOWLEDGE GENERATION
Within knowledge management, the two predominant approaches to knowledge generation are people centric and technology centric [5,13]. A people oriented perspective draws from the work of Nonaka as well as Blacker and Spender [13-16]. Essential to this perspective of knowledge creation is that knowledge is created by people and that new knowledge or the increasing of the extant knowledge base occurs as a result of human cognitive activities and the effecting of specific knowledge transformations [ibid, fig 1a]. A technology driven perspective to knowledge creation is centred around the computerized technique of data mining and the many mathematical and statistical methods available to transform data into information and then meaningful knowledge [13, 17-27, fig 1b].

In contrast to both of these approaches, a process centric approach to knowledge creation not only combines the essentials of both the people centric and technology centric perspectives but also emphasises the dynamic and on going nature of the process. Process centred knowledge generation is grounded in the pioneering work of Boyd and his OODA Loop, a conceptual framework that maps out the critical process required to support rapid decision making and extraction of critical and germane knowledge [12-13].

The Loop is based on a cycle of four interrelated stages essential to support critical analysis and rapid decision making that revolve in both time and space: Observation followed by Orientation, then by Decision, and finally Action (OODA). At the Observation and Orientation stages, implicit and explicit inputs are gathered or extracted from the environment (Observation) and converted into coherent information (Orientation). The latter determines the sequential Determination (knowledge generation) and Action (practical implementation of knowledge) steps [ibid, fig1c]. The outcome of the Action stage then affects, in turn, the character of the starting point (Observation) of the next revolution in the forward progression of the rolling loop.

Given that healthcare is such a knowledge rich environment that requires rapid decision making to take place that has far reaching consequences, a process centred approach to knowledge generation is most relevant and forms the conceptual framework for networkcentric healthcare operations.

Figure 1a.

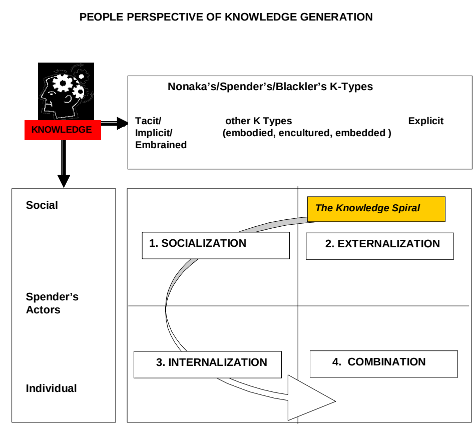


Figure 1b.

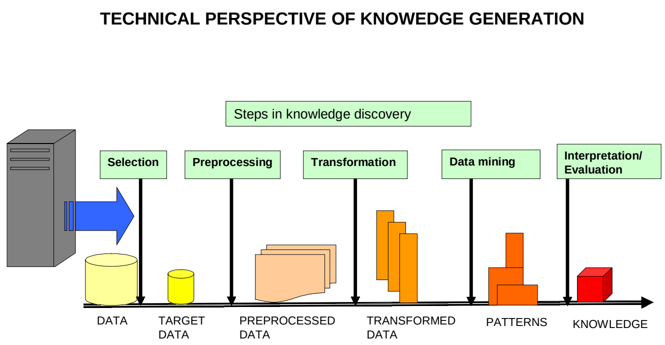
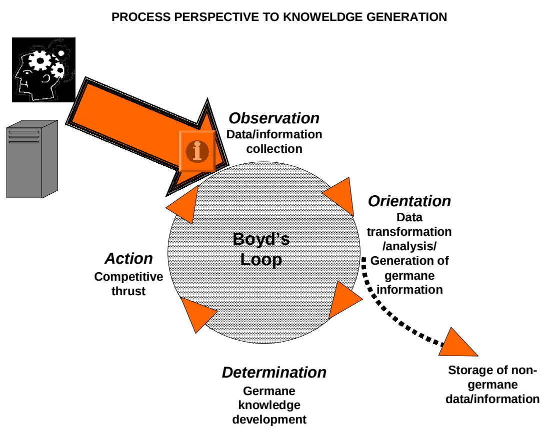


Figure 1c.



NETWORKCENTRIC HEALTHCARE OPERATIONS

Healthcare, like all activities conducted in complex operational space, both affects and requires the functioning of three distinct entities, i.e. people process and technology. To capture this dynamic triad that continually impacts all healthcare operations, the doctrine of healthcare network-centric operations is built around three entities that form mutually interconnected and functionally related domains. Specifically these domains include[7-9]:

1) a physical domain that:
a. represents the current state of healthcare reality
b. encompasses the structure of the entire environment healthcare operations intend to influence directly or indirectly, e.g., elimination of disease, fiscal operations, political environment, patient and personnel education, etc.
c. has data within it that are the easiest to collect and analyze, especially that they relate to the *present* rather than future state.
d. is also the territory where all physical assets (platforms) such as hospitals, clinics, administrative entities, data management facilities, and all other physical subcomponents (including people) reside.

2) an information domain that:
a. contains all elements required for generation, storage, manipulation, dissemination/sharing of information, and its transformation and dissemination/sharing as knowledge in all its forms.
b. within the information domain, all aspects of command and control are communicated and all sensory inputs gathered.
c. while the information existing within this domain may or may not adequately represent the current state of reality, all our knowledge about that state emerges, nonetheless, from and through the interaction with the information domain.
d. all communications about the state of healthcare take place through interactions within this domain.
e. the information domain is particularly sensitive and must be protected against intrusions that may affect the quality of information contained within domain.

3) A cognitive domain that:
a. constitutes all human factors that affect operations.
b. is within the cognitive domain that deep situational awareness is created, judgments made, and decisions and their alternatives are formulated.
c. also contains elements of social attributes (e.g., behaviours, peer interactions, etc.) that further affect and complicate interaction with and among other actors within the operational sphere.

In essence, these domains cumulatively serve to capture and then process all data and information from the environment and given the dynamic nature of the environment new information and data must always be uploaded. Thus, the process is continuous in time and space captured by the 'rolling nature' of Boyd's OODA Loop; ie is grounded in the process oriented perspective of knowledge generation.

IC^{2}T Use in Healthcare Network Centric Operations

The critical technologies for supporting healthcare networkcentric operations are not new, rather they are reconfigurations of existing technologies including web and Internet technologies. The backbone of the network is provided by WHIG (world healthcare information grid) [7-9]. WHIG consists of three distinct domains that are each made up of multiple grids all interconnecting to enable complete and seamless information and data exchange throughout the system. Figure 2 depicts the WHIG with its distinct yet interconnected domains each made up of interconnecting grids.

The three essential elements of the grid architecture are the smart portal which provides the entry point to the network, the analytic node and the intelligent sensors [7-9]. Taken together these elements make up the knowledge enabling technologies to support and effect critical data,

Figure 2.

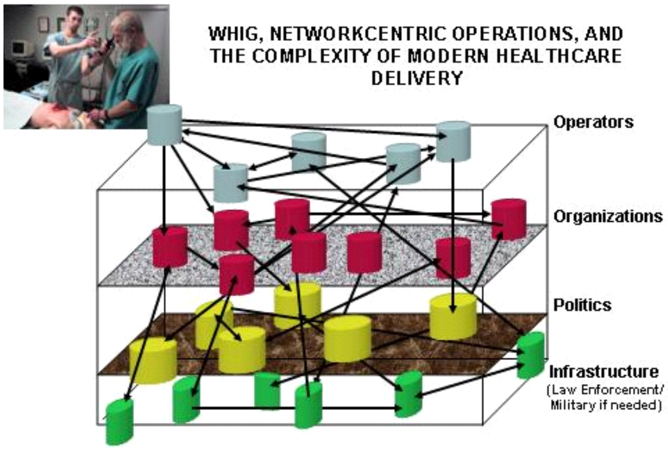
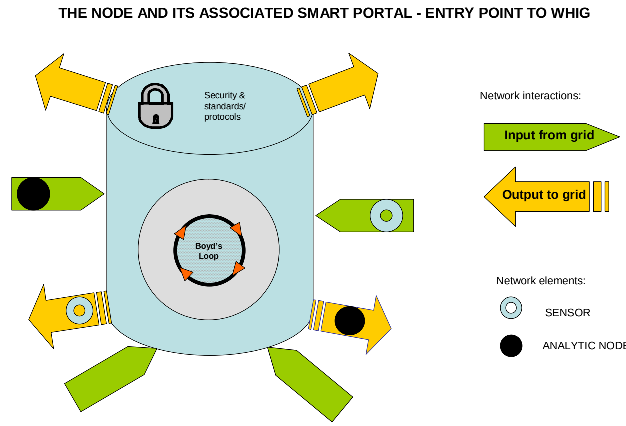


Figure 3.



information and knowledge exchanges that in turn serve to ensure effective and efficient healthcare operations.

In networkcentric healthcare operations the entry point or smart portal must provide the decision maker with pertinent information and germane knowledge constructed through the synthesis and integration of a multiplicity of data points; i.e. support and enable OODA thinking. Unlike current web pages in general and especially current medical web-portals and on-line databases such as MedLine, that provide the decision maker with large amounts of information that he/she must then synthesise and determine relative and general relevance; i.e. they are passive in nature, the smart portal enables the possibility to access the critical information required to formulate the Action (practical implementation) stage of Boyd's Loop. In addition, the smart portal includes the ability to navigate well through the grid system; i.e. the smart portal must have a well structured grid map to identify what information is coming from where (or what information is being uploaded to where). In order to support the ability of the smart portal to bring all relevant information and knowledge located throughout the grid system to the decision maker there must be universal standards and protocols that ensure the free flowing and seamless transfer of information and data throughout WHIG; the ultimate in shared services. Finally, given the total access to WHIG provided by the smart portal to the decision maker it is vital that the highest level of security protocols are maintained at all times; thereby ensuring the integrity of WHIG. Figure 3 captures all these key elements of the smart portal.

The analytic nodes of the WHIG perform all the major intelligence and analysis functions and must incorporate the many tools and technologies of artificial intelligence and business analytics including OLAP (on-line analytic processing), genetic algorithms, neural networks and intelligent agents in order to continually assimilate and analyze critical data and information throughout the grid system and/or within a particular domain. The primary role of these analytic nodes is to enable the systematic and objective process of integrating and sorting information or support the Orientation stage of Boyd's Loop. Although we discuss the functional elements of the analytic node separately, it is important to stress that the analytic node is in fact part of the smart portal. In fact, the presence of the analytic node is one of the primary reasons that the smart portal is indeed "smart" or active rather than its more passive distant cousin the integrated e-portal that dominates many intranet and extranet sites of e-businesses today.

The final important technology element of WHIG is the intelligent sensor. These sensors are essentially expert systems or other intelligent detectors programmed to identify changes to WHIG and data and/or information within a narrow and well defined spectrum, such as for example, an unusually high outbreak of anthrax in a localized geographic region, which would send a message of a possible bio-terrorism attack warning to the analytic node, or perhaps the possibility of spurious or corrupt data entering the WHIG system. The sensors are not necessarily part of the smart portal and can be located throughout WHIG independent of the analytic nodes and smart portals Figure 3 depicts the three essential technical components of WHIG.

Knowledge Development, Support, and Dissemination

In our earlier paper [8] we have pointed out that healthcare information quality depends inversely on its range, i.e., the shorter the distance between the source and recipient, and the lesser degree of information content manipulation, the higher the quality. Similar observations have been made by other authors in the context of military activities whose complexity closely matches that of healthcare [28]. At the moment, and even more so in the future, the highest quality of healthcare information reposes within medical libraries associated with major medical centers around the globe. However, despite over a twenty year long history of IAIMS (Integrated Advanced Information Management System) initiative [29] and increasing need for a drastic change of operational philosophy [30-31], the majority of medical libraries continue to function as the repositories for print-based knowledge (or its electronically disseminated substitute) whose participation in healthcare operations is driven by customer demand (essentially passive) rather than operate as dynamic, knowledge developing and disseminating entities capable of *actively shaping* the healthcare world. As pointed out by several authors [31-33] future medical libraries must "filter, focus, and interpret information" [34] and "distribution of information, not control, is key to establishing, and maintaining power" [35]. In the context of networkcentric healthcare operations the role of medical libraries transforms even further – the library becomes a node.

Presently, major strides are made toward practical incorporation of the IAIMS concept in reality [36-37]. However, global scale networkcentricity demands capabilities extending beyond "reliable, secure access to information that is filtered, organized, and highly relevant to specific tasks and needs…" [36]. In addition to these essential requirements, networkcentric operations demand merging of multispectral information streams into coherent, operation-centered knowledge bases, development of real-time or near real time operational space awareness, and predictive capabilities that are beyond the current scope of medical library operational profiles. Thus, contrary to the technologically advanced library of today, the library-node of tomorrow must adopt Boyd's Loop principles of interaction with the environment as the principal philosophy of its interaction with the information world within which it functions [8]. Adaptation of such philosophy is also the critical step in transforming operational profile of the existing medical libraries from essentially passive repositories which, with varying degree of efficiency and reliability, transform the reposited information into coherent knowledge-base blocks, into active information seeking entities (nodes) that conduct their exploratory work not only within their pre-determined domain of healthcare, but also within all other domains whose content may be potentially relevant to healthcare itself. There is no doubt that the proposed change is fundamental. On the other hand, it is the change that moves the medical library beyond its current notion of the institutional "networked biomedical enterprise" [34] into a global-level knowledge development, -management and -dissemination center. Most significantly, aligning such centers within the WHIG structure will lead to a massive enhancement of their overall operational power which [7], accordingly to Metcalf's law, increases in proportion to the square of the nodes connected to the network.

The proposed transformation of the medical library into a fully capable healthcare knowledge management and dissemination node will require major changes in the profile of the employed personnel. Today's librarian, exquisitely skilled in client-mandated database searches and information retrieval will become a powerful knowledge worker intimately familiar with the processes of active seeking new information, converting often unrelated information into coherent knowledge streams, and, ultimately, unifying individual streams and fusing them into the body of general healthcare knowledge base. The new breed of healthcare knowledge workers will be essential in development of CDSS, identification of new disease patterns, creation of new administrative tools, and positioning of global healthcare systems toward "just-in-time" responses to crises. Thus, the currently subordinate role of a librarian presently operating as a support element in healthcare delivery will shift to that of an equal partner of a physician and administrator. In some situations, particularly those involving large area events, healthcare knowledge workers may even assume the subordinate role of countermeasure effort coordinators and leaders. The widened scope of their importance in global healthcare operations imposes the need for rapid change in education of the new generation of "librarians" who, particularly in the context of networkcentric healthcare operations, will need to function as integral members of large, multidisciplinary management teams and be intimately familiar with several disciplines stretching beyond the classical realm of medicine and its affiliates. The rapidly approaching need for new skills is evidenced by increasing number of papers devoted to this subject and the introduction of new training programs aimed at the creation of "new generation" specialists [38-42]. There is thus no doubt that, in similarity to military activities (from which the concept of networkcentricity also evolves), healthcare operations will need to adopt the philosophy of "jointness' where many currently independent disciplines will need to combine and interact in order to attain the stated overall goal – maintenance of global health.

DISCUSSION AND CONCLUSION

At its most fundamental (and maybe also the most naïve) healthcare is about assuring and maintaining individual's adequate level of health necessary to function as a fully capable member of the society. In reality, healthcare, particularly in its global context, became a business growing at an unprecedented rate, where global disparities in healthcare delivery become increasingly more apparent, where technology emphasizes them rather than assists in their obliteration, and where the current expenditure of trillions of dollars yearly appears to have no impact at all. Part of the problem rests with the fact that the majority (if not all) solutions to the healthcare crisis are, essentially, platformcentric, i.e., concentrate on the highly specific needs of a specialty (e.g., molecukar biology), an organization (e.g., hospital) or a politically defined region (e.g., US or EU). Hence, most of the technology-based solutions, while highly functional and of unquestionable benefit to their users, fail to act as collaborative tools assisting in the unification rather than subdivision of effort. Highly useful information generated within individual systems is, for all practical purposes, lost since it is inaccessible to others either because of its incompatibility with different operational platforms or simply because others are not even aware of its existence! The latter issue becomes particularly significant when relevant information exists within healthcare-unrelated domains. Particularly apt and very recent example of such failure were the recovery efforts after the tsunami disaster of 2004, where the world dispatched badly needed medical supplies to the affected regions but failed to relate the transport to on site distribution. The supplies piled up at major airports while healthcare workers in the field were short of the most basic commodities. The currently practiced approach to healthcare informatics supports reoccurrence of similar events: for all practical purposes healthcare informatics limits its sphere of activity only to subjects *strictly related to medicine, its practice, and administration at the healthcare organization level*. Yet, healthcare relates to a number of other elements of life – political structure of the region, its stability, its economy, even its weather. Failure to incorporate these seemingly irrelevant domains of information results in the emergence of medical "earthquakes" such as the discovery that, contrary to the assumptions of the West, cardiovascular disease is the predominant killer in among the populations of the underdeveloped World [43].

We believe that adoption of the networkcentric approach that is integrally connected to the process perspective of knowledge management may provide at least part of the solution, especially at the worldwide level of healthcare. The concept is not new. In 1994, DA Lindberg described a vision of global information infrastructure based on extensive implementation and exploitation of US-leadership in high performance computing, networking, and communications in developing a large-scale, technology-based approach to healthcare. During the same decade, the US Department of Defense followed by military establishments around the world adopted the notion of networkcentric operations as the most viable solution to the ever increasing complexity of military operations [28]. Similar concepts are brought to life in multilayered, dynamic business activities [44]. Healthcare operations are equally complex, if not more so, than either business or military ones. Their information/knowledge needs are equally multispectral and intense. And while healthcare is, indeed, about providing an individual with easy access to healthcare provider, and providing the provider with tools to provide adequate healthcare, it all takes place in a vastly more complicated environment of economies, policies and politics, and, far too frequently – conflicts. We believe, therefore, that in similarity to the two other fields of human activity to which healthcare is (maybe unfortunately) also related – business and war – healthcare needs to expands its incursion into the world of IC^{2}T to the concept of networkcentricity and pursue it with utmost vigour. As already demonstrated in practice [44], networkcentric operations increase efficiency, reduce cost, and increase chance of success. All of these are of critical importance in the conduct of a single, most expensive and yet significantly inefficient activity known to humankind – the conduct of global healthcare operations.

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LEGENDS TO FIGURES

FIG. 1

The processes of creating and capturing knowledge, irrespective of the specific philosophical orientation (i.e. Lockean/Leibnitzian versus Hegelian/Kantian), is the central focus of both the psycho-social (people) and algorithmic (technology) theories of knowledge creation. However, to date knowledge creation has tended to be approached from one or the other perspective, rather than an holistic, combined perspective [5]. Fig. 1a highlights the essential aspects of the three well known psycho-social knowledge creation theories; namely, Nonaka's Knowledge Spiral, Spender's and Blackler's respective frameworks into one integrative framework by showing that it is possible to change the form of knowledge; i.e., transform existing tacit knowledge into new explicit knowledge and existing explicit knowledge into new tacit knowledge or to transform the subjective form of knowledge into the objective form of knowledge [5-6,13-16, 27]. In effecting such transformations the extant knowledge base as well as the amount and utilization of the knowledge within the organization increases. According to Nonaka [14]: 1) Tacit to tacit (socialization) knowledge transformation usually occurs through apprenticeship type relations where the teacher or master passes on the skill to the apprentice. 2) Explicit to explicit (transformation) knowledge transformation usually occurs via formal learning of facts. 3) Tacit to explicit (externalization) knowledge transformation usually occurs when there is an articulation of nuances; for example, as in healthcare if a renowned surgeon is questioned as to why he does a particular procedure in a certain manner, by his articulation of the steps the tacit knowledge becomes explicit and 4) Explicit to tacit (internalization) knowledge transformation usually occurs as new explicit knowledge is internalized it can then be used to broaden, reframe and extend one's tacit knowledge.

The two other primarily people driven theories that focus on knowledge creation as a central theme are Spender's and Blackler's respective frameworks [5, 13, 16, 27]. Spender draws a distinction between individual knowledge and social knowledge, each of which he claims can be implicit or explicit [ibid]. Spender's definition of implicit knowledge corresponds to Nonaka's tacit knowledge. However, unlike Spender, Nonaka doesn't differentiate between individual and social dimensions of knowledge; rather he just focuses on the nature and types of the knowledge itself. In contrast, Blackler [ibid] views knowledge creation from an organizational perspective, noting that knowledge can exist as encoded, embedded, embodied, encultured and/or embrained. In addition, Blackler emphasized that for different organizational types, different types of knowledge predominate and highlighted the connection between knowledge and organizational processes [ibid].

In contrast to the above primarily people oriented frameworks pertaining to knowledge creation, knowledge discovery in databases (KDD), and more specifically data mining, approaches knowledge creation from a primarily technology driven perspective. In particular, the KDD process focuses on how data is transformed into knowledge by identifying valid, novel, potentially useful, and ultimately understandable patterns in data [17-27]. KDD is primarily used on data sets for creating knowledge through model building, or by finding patterns and relationships in data using various techniques drawn from computer science, statistics and mathematics. From an application perspective, data mining and KDD are often used interchangeably. Fig 1b presents a generic representation of a typical knowledge discovery process. Knowledge creation in a KDD project usually starts with data collection or data selection, covering almost all steps in the KDD process; the first three steps of the KDD process (i.e., selection, preprocessing and transformation) are considered exploratory data mining, whereas the last two steps (i.e., data mining and interpretation/evaluation) in the KDD process are considered predictive data mining.

A process centric perspective view of knowledge creation is found in Boyd's OODA Loop model (Fig 1c). The Loop (Fig 1c) is based on a cycle of four interrelated stages essential to the extraction of germane knowledge necessary to support critical analysis, rapid decision making: Observation followed by Orientation, then by Decision, and finally Action (OODA). At the Observation and Orientation stages, implicit and explicit inputs are gathered or extracted from the environment (Observation) and converted into coherent information (Orientation). The latter determines the sequential Determination (knowledge generation) and Action (practical implementation of knowledge) steps [13]. The outcome of the Action stage then affects, in turn, the character of the starting point (Observation) of the next revolution in the forward progression of the rolling loop. In Fig 1c, this is represented with the removal of non germane data/information/knowledge from continuing to the next step. It is important to note that at all stages within the OODA loop both people and technology perspectives are supported and required to enable and facilitate germane knowledge extraction.

FIG. 2

Although ultimately directed at the individual patient, delivery of modern healthcare is an exceedingly complex operation involving several layers, many of which are not directly related to healthcare itself. In most extreme cases (e.g., smallpox) treatment of a single patient may trigger a cascade of events affecting several countries that may be separated by very large distances. Rapid containment of the consequences of such events may require highly specialized knowledge, high degree of dynamic and environment-sensitive multispectral information/ knowledge coordination, analysis, and transformation into a multidimensional picture of the "operational space" characterizing the event. Presently, due to the mutual incompatibility of the existing information/knowledge resources (platformcentricity),, inefficiency of knowledge management organizations, and lack of coordination among national and international bodies either directly or indirectly involved in healthcare delivery, efficiency of the "operators," i.e., healthcare delivery personnel and their parent organizations (ambulance units, ambulatory clinics, hospitals, etc.) is significantly reduced, particularly during cataclysmic events when the need reaches its peak.

The concept of networkcentricity in healthcare operations reduces the current deficiencies by assuring continuous, unimpeded and polydirectional flow of information among the nodes (depicted as cylinders) populating the WHIG (World Healthcare Information Grid). At the level of the "Operators" each node constitutes of an efficient knowledge management organization (e.g., medical library attached to a major medical centre – see ref. XX (HICS paper). Operator layer nodes interact with the nodes within other networks such as Organizations' Network (national and international governmental organizations, NGOs, insurers, etc.), Politics Network (such as ministerial level organizations, judicial or parliamentary elements), Infrastructure Network (communication facilities, transportation, power grids, etc.) that, at times may also be linked to law enforcement/military nodes (particularly during humanitarian/disaster relief healthcare operations). Commonality and compatibility of standards determining extraction, analysis, storage, and dissemination of the information/knowledge within WHIG are mandatory in networkcentric operations. The power of WHIG is directly proportional to the square of the number of the populating nodes, while adherence to the ASP (Application Software Provider concept) and the development of intelligent WHIG access portals will assure accessibility even to those entities whose technology-base is less than optimal.

FIG 3.

The entry point to WHIG is a "smart" portal (Fig 3). Unlike a traditional portal the smart portal is active or dynamic. It provides the decision maker or effector access to relevant data, pertinent information and germane knowledge required for a specific query [9]. This is achieved by the interaction of the decision maker via the smart portal in conjunction with the analytic nodes. It is in fact the intelligence capabilities and knowledge management technologies of the analytic nodes throughout WHIG which support process centric knowledge management, that make the smart portal "smart". The analytic nodes obtain and process all multispectral data throughout and process it into pertinent information and germane knowledge that is assimilated and synthesized at the smart portal and then made available to the decision maker. Other design elements unique to the smart portal include the ability to navigate well through the grid system, sophisticated security protocols and the existence of sensors in the network that detect erroneous or critical data.