2012

Information Fusion and Quantum Logic in Family Medicine

F. Matthew Mihelic
University of Tennessee Health Science Center

Information Fusion and Quantum Logic in Family Medicine

F. Matthew Mihelic, M.D.

Abstract

A time-tested model for information fusion and analysis is provided by Family Medicine. Family Medicine is a discipline that operates in the realms of both technical and social sciences to analyze massive amounts of information from multiple sources in order to make decisions that bring about the integration and coordination of interdisciplinary interventions involving scientific, psychological, and social aspects of medical care. This generalist function serves to lower the organizational entropy of complex systems and thereby improve efficiency while reducing the risk of catastrophic failure. Simply bringing a group of specialists together in one place does not bring about the integration and coordination that can only be accomplished by a single interdisciplinary individual functioning as a generalist rather than as a specialist. The type of thought process and decision-making involved in the generalist function of Family Medicine differs from that of medical specialties because it is a quantum logic function, and understanding such generalist function can provide insight to improve complex system design and information fusion function.

Introduction

Contemporary organizations encounter difficulty in integrating and coordinating rapidly accelerating increases in information and complexity, but Family Medicine is a scientific discipline that naturally developed through the Twentieth Century to integrate and coordinate the rapidly advancing preponderance of medical information and capabilities to treat uniquely individual patients. Physicians have agreed for many years that the thought processes of Family Medicine decision-making are qualitatively different from those used in medical specialties, but Family Medicine physicians heretofore have had difficulty in explaining just what that difference is. This paper will explain that difference and show how the concepts involved can be utilized to provide information fusion in areas outside of Family Medicine, and how those concepts are applicable to any multi-agent complex adaptive system such as a biological system, a corporate structure, or an intelligent agent computer system.

The scope of the practice of Family Medicine is eclectic and global. A Family Medicine physician must know and function in all specialty areas of medicine, and must deal with all of the dimensions of patient existence. Family Medicine training is a rigorous three or four year program after medical school, in which residents develop expertise by rotating through multiple specialty clerkships that range across all areas of medicine from Internal Medicine and General Surgery through Obstetrics and Pediatrics to Psychiatry and Critical Care Medicine. Orthopedic Surgery, Ophthalmology, Gynecology, and Neonatal Intensive Care are some of the many and varied specialty rotations that a Family Medicine resident studies and is expected to become proficient in. There is a difference between an expert and a specialist. The Family Medicine physician must become an expert in many areas of medicine, but does not specialize in any one specific area. A Family Medicine physician is expected to maintain up-to-date standards of medical knowledge and practice, and this involves routine decisions regarding the relevance and validity of massive amounts of scientific literature to determine that information's applicability to individual patients.

Family Medicine physicians not only must operate across a broad scope of medical competencies, but they must also consider the many dimensions of a patient's existence. These dimensions include the level of the biochemistry within and between cells, the cellular levels of organization of the tissues of the organism, and the how the various systems of the body function individually and together. Then, in Family Medicine there are further dimensions of human existence to be considered, such as psychological factors, an individual's family situation and support system, broader psychosocial issues, and psychospiritual concerns. Family Medicine physicians must move seamlessly across all of these dimensions of human existence in patient encounters, while also moving seamlessly across a broad scope of medical disciplines to integrate and coordinate bio-psychosocial wellness. This is because, to one extent or another, patient physiological problems are interconnected with each other and with the psychosocial milieu of the patient.

Ideally, a Family Medicine physician's career should be found to have a constantly increasing scope of practice, while a specialty physician's career usually is marked by a constantly narrowing scope of practice. The generalist Family Medicine physician can be considered to be analogous to a stem cell which has a relatively open and unblocked source code, as compared to a specialty cell with a partially blocked source code.[1] While all of the cells in a biological eukaryotic organism contain the same DNA source code, cellular specialization comes about by the blocking of certain parts of the genetic source code so that a liver cell, for example, would have different portions of its DNA blocked and thus non-functional when compared to a kidney cell. So too the differentiation of a medical specialist can be considered to be marked by the blockage of portions of source code related to practice capabilities.

Specialist Function vs. Generalist Function

Generalist physicians are best understood by four functional characteristics that enable them to integrate and coordinate information and activities within the system of their function. The four functional characteristics of a successful generalist are a broad scope of competency, complex decision-making ability, the ability to function well in an environment of uncertainty, and an orientation toward action.[2] These functional characteristics enable the successful generalist to develop and maintain synergisms within a system through increasing the exchange of information between the various agents of that system. There are no "information silos" when a Family Medicine physician is appropriately involved in the care of a patient, but without such generalist function there is frequently a lack of communication between specialists. A significant limitation of the contemporary analysis of complex adaptive systems is a specialty bias that deemphasizes analysis of information flow while emphasizing analysis of resource flow in such systems. In contrast to specialty physicians, generalist physicians are more information-oriented than they are resource-oriented, and therefore tend to be non-hierarchical.

Specialist function develops in order to perform a limited number of specific tasks in a very efficient manner, while generalist function entails the performance of multiple tasks but less efficiently. In nature it would be rare for an agent to be purely a specialist agent or purely a generalist agent because most biological agents have at least some function in both realms; however, it is useful for illustrative purposes to consider specialist function and generalist function as performed by separate agents. For reasons of efficiency in the narrow and specific task(s) performed by a specialty agent, the unused portions of the specialty agent's source code are blocked. This is in contrast to the relatively unblocked source code of the generalist agent. The specialty agent's blocked source code enables a more direct and efficient decision tree-type of logic that allows for concentration on the specific task(s) of the specialist. In contrast, the generalist agent's more broadly open and available source code enables a decision loop-type of logic that allows for consideration of the entire holistic concept of the system that is defined by that source code. So specialist logic should be considered as a serial logic best characterized by flow charts, protocols and decision trees, while generalist logic should be considered as a quantum logic that is best characterized by decision loops.

The serial logic and function of the specialist agent fits nicely into a pyramidal organizational structure, while the generalist agent function is more decentralized and available throughout an organizational structure. The hierarchical affinity of specialist function can provide systemic stability, but that stability can also become a source of rigidity, while the decentralized nature of generalist function provides the system with its source of flexibility and adaptability.

Decision Loops and Quantum Logic

Repeating decision loops have been associated with conceptual "breakthroughs" and performance "jumps", and there are many that have been proposed. The "Scientific Method" (Research, Hypothesis, Experiment, Conclusion) is based upon Sir Frances Bacon's work of 1620 A.D., and this earliest published example of a decision loop has had undeniably great impact on scientific advancement.[3] Other examples of decision loops include the Shewhart/Deming Cycle (Plan, Do, Check, Act) of quality control management, the DMAIC (Define, Measure, Analyze, Improve, Control) Six Sigma management loop, and the ADPIE (Assessment, Diagnosis, Planning, Implementation, Evaluation) loop of Nursing Process.[4]

Perhaps the most quintessential decision loop is the "OODA Loop" (Observe, Orient, Decide, Act) described by Col. John Boyd, USAF.[5] This decision loop was conceived by Boyd through the unique circumstances presented by jet dogfighting in the Korean War, in which the actual duration of the time involved in the thought process of fighter pilot decision-making became vitally important to winning in the high-speed air-to-air combat confrontations between the relatively evenly matched North American F-86 Sabrejets and Mikoyan-Guervich MiG-15s. Boyd felt that the most important part of the OODA Loop was the orientation phase, and that he consistently prevailed in high-speed jet dogfighting because he was able to run his mental decision loop faster than his opponent.

The orientation phase of the OODA Loop involves the analysis and synthesis of data, and this type of thought process is present in every such decision loop in one form or another. Decision loops are basically a loop of hypothesis generation and testing, and the orientation phase of any decision loop is key to the generation of a conceptual leap because it is intimately involved with hypothesis generation in uncertain or low data circumstances. Remember that it is characteristic that a successful generalist must function well in a complex and uncertain environment. The logic involved in the orientation and/or hypothesis generation of a decision loop is different from the sequential logic of a decision tree because it is quantum logic, and it is quantum logic that is the hallmark of generalist function.

Humans utilize quantum logic frequently, although it is somewhat transparent unless one understands what to look for in order to perceive its use. Pre-medical students are frequently told that the most important class that they must do well in is organic chemistry, because the logical process involved in working organic chemistry problems is very important to medical decision-making. Such organic chemistry problems involve changing one organic molecular substance into another molecular product by subjecting the initial substance to an ordered series of various chemical reagents to eventually produce the desired chemical product. The ordered series of reagents might include ten or more steps, and at each step there are many possible choices of reagents that can be selected. The key to properly solving organic chemistry problems lies in choosing the right reagents at the right times in the chemical process. In order to solve such an organic chemistry problem it often seems as though one is working both ends of the problem toward the middle while working the middle toward both ends at one time, and consequently what is really going on is that one must see the entire problem completely at one time in order to solve it, and this is quantum logic.

Students also encounter such a quantum logic problem solving process when working mathematical proofs in trigonometry or plane geometry, but the very first time that students directly encounter a quantum logic problem solving process is when they are first learning how to do long division. In general it is not difficult to teach grammar school students the basics of addition, subtraction, or multiplication because it basically involves the memorization of a few matrices and the application of a few sequential logic steps. Likewise learning simple division is done by simply reversing the process of memorized multiplication tables. But something different happens when long division is being taught, because there is no easy process to enable what essentially amounts to the factoring of larger numbers, and so the teacher will often recommend some strategies of "educated guessing" that are in reality the hypothesis generation and testing of a decision loop. What is going on cognitively in such "educated guessing" is a quantum logic process of simultaneous random search that is the essence of the orientation phase of Boyd's OODA Loop. Interestingly enough, a driving reason for governmentally-sponsored research into quantum computing is to be able to rapidly factor large seemingly-random numbers, because that is important in the breaking of encoded messages. In fact the algorithms by which quantum computers could perform such factoring and related searches have already been developed. Shor's factoring algorithm allows for the prime factoring of large random numbers almost instantaneously, and Grover's search algorithm allows for the directed search of large random data bases almost instantaneously, so what remains now is to build the actual quantum computer itself to run such algorithms.

Information Fusion, Information Entropy, and Quantum Logic

Information fusion involves the bringing together of multiple pieces of seemingly disparate information to a single point, and quantum logic deals with the superposition of information within a single quantum bit or "qubit".

When multiple pieces of information are brought together for analysis there is a potential amount of uncertainty that is associated with each piece of information. That uncertainty can be thought of as entropy (often referred to as information entropy or Shannon entropy), which is a measure of the potential disorder between those pieces of information. Current methods of dealing with such uncertainty or entropy are stochastic in nature, and are exemplified by techniques involving statistical analysis, Bayesian analysis, heuristics, or "fuzzy logic". The problem with such stochastic methods is that, while they may reduce or quantify the uncertainty, they cannot remove it, and that uncertainty increases logarithmically with the number of pieces of information considered. In the end a final analysis product might be presented to a decision maker, but such a "metadata" product (eg an executive summary) contains such entropy or disorder that is directly related to the number of data points that it links or considers.

An example of how the build-up of entropy affects decision-making can be drawn from contemporary meteorological science. In computerized weather predictions multiple pieces of meteorological information are input into a computer program and a statistical prediction for the next day's weather can be generated, along with some calculation of the uncertainty of the forecast. The same computer program can then generate forecasts for successive days, each with the calculation of increasing uncertainty. The generation of forecasts can continue until after some number of days, even though a forecast can be generated by the computer, that forecast would be no better than a random guess. This occurs because of the logarithmical increase of entropy at each decision node, which in this example includes each day of the forecast and each piece of meteorological information upon which the forecast was based.

Biological organisms are complex adaptive systems that contain billions of cells, each of which can be considered as an agent. Each agent can be considered as a piece of information, or a decision node, or a qubit. A qubit is any situation of superimposed information, and so each agent or decision node can be considered to be an information-bearing qubit that possesses its own entropy in relation to the other data points or nodes in the system. Biological organisms theoretically deal with such entropy via quantum logic mechanisms.[6] In such a quantum logic mechanism information is not "fused" at an entropic "metadata" point, rather, such information is held in superposition across the coherent quantum biological system without entropy. So an important difference between current stochastic systems of information fusion and a quantum system of coherent information superposition is the tremendous entropy gain (ie uncertainty or disorder) of the stochastic system as compared to the quantum system.

There are many examples of graphic representations of data points linked within some sort of organization. Such examples include institutional organizational charts (so-called "org charts"), link analysis diagrams, decision trees, flow charts, computer system diagrams, and PHYLIP (PHYLogeny Interference Package) tree diagrams, etc. At each point in such a representation there is level of entropy that can compound logarithmically across serially linked points. If one considers the specific example of a typical hospital's organizational chart one might consider that the CEO (Chief Executive Officer) of the hospital sits at the top of the pyramidal structure with an organizational layer or two of upper and middle management between the CEO and the hospital departments. The Family Medicine physician functionally participates at all points in the hospital (and consequently at all points in the organizational chart), from the medical-surgical floors to the pediatrics department, orthopedics, obstetrics, and pathology, etc., while also interacting with all levels of hospital management. Specialists can functionally participate with all vertical levels of hospital management, but are horizontally limited in their functional participation to a few specific areas of medical care within the hospital. While the CEO can move freely about all areas of the hospital and management, the CEO's functional participation is effectively limited to upper levels of management (and perhaps the cafeteria). So the only agents functionally participating horizontally and vertically at all positions and levels of the organizational chart, and consequently gaining the dynamic information that is only functionally available at those positions and levels, are the Family Medicine physicians, and information fusion thereby takes place within such generalist agents functioning in a decentralized non-hierarchical manner. The CEO might receive reports of the status of the various departments of the hospital as they are sent up the chain of command within the organizational structure, but at each point or level (or node) that a report crosses, the entropy or uncertainty within that report increases logarithmically. However, if the report were to be generated directly by the Family Medicine generalist agent then the number of nodes crossed would be reduced, and the report would necessarily contain much less entropy or uncertainty.

In his book *Warning Analysis for the Information Age: Rethinking the Intelligence Process* John W. Bodnar discusses the similarities between the entropy inherent in an organizational chart's degree of organizational assembly and the entropy involved in chemical reactions.[7] He notes the respective analogous correlations between the chemical concepts of enthalpy, entropy, and activation energy, with the organizational concepts of power, degree of assembly, and decision energy. He states that the power within an organization can be represented by the resources of the organization such as money, commodities, or military strength, and that the stored power or "energy" of the organization can only be released when the organizational entropy that is inherent in the degree of assembly of the organization is overcome by a higher "decision-making energy of activation" in a manner analogous to the way in which a chemical energy of activation must be overcome to allow a chemical reaction to take place and release energy in the form of enthalpy or heat.

The key to understanding this analogous correlation lies in understanding that, in both chemical reactions and in organizational structures, the level of the energy of activation for either a chemical reaction to take place or for an organizational decision to be made, is determined by the entropy involved.

In a chemical reaction the energy of activation can be lowered by a catalyst which reduces entropy by supplying information into the chemical system. In a biochemical system, which exists as a milieu of many potential reactions that could potentially take place, only specific necessary reactions are catalyzed by biochemical catalysts that are known as "enzymes". Enzymes function within a biochemical milieu of multiple potential reactions, by lowering the entropy for a specific reaction to take place. In a biologically-based multi-agent complex adaptive system the catalyst that lowers the organizational energy to the point of the activation energy of decision-making is the generalist agent. The generalist agent lowers the organizational entropy to enable appropriate specific decision-making by functioning as a catalyst to lower the decision-making energy of activation. The generalist agent can act as an information-bearing catalyst to carry (superpositioned) information that can reduce the entropy surrounding decision-making.

The information that the generalist agent carries is not entropy-ridden metadata that has been filtered through the organizational structure of the system, rather, it is unfiltered information that the generalist agent carries in quantum superposition. That information is applicable at any node in the system's organization. The generalist agent can thereby act as a "bridge" between nodes that do not otherwise have a direct connection, and in so doing can effectively decrease the "degree of assembly" related to a specific decision, thereby lowering the decision-making energy of activation in order to bring a specific decision into accordance with the overall (unblocked) source code concept of the system. Such generalist function is a quantum logic function and is information fusion.

Since all information is physical, the physicality of information must be taken into account in the consideration of information fusion.[8] True information fusion takes place within a single agent and involves the quantum superposition of the information being "fused" in a single qubit. Information fusion happens within a single source code or qubit, and is then disseminated. In a group setting it becomes a judgment decision by an individual, and not the potentially discordant compromise of a group decision. True information fusion is not consensus or a distilled summary that always carries an uncertainty factor. The global or "holistic" function of generalist agents is in reality a quantum logic function of information superposition, and is the essence of true information fusion. Therefore multi-agent complex adaptive systems are better characterized as quantum adaptive systems because the adaptation of such systems is a function of the decision loop quantum logic of the generalist agents of the system.[9]

Systemic Implications of Generalist Function

The effects of generalist function in a multi-agent complex adaptive system lead to improved communication, improved innovation, and improved resilience, while maintaining system orientation toward the overall goal and concept of the system. Adequate generalist function leads to appropriate subsystem adjustments that result in increased overall system efficiency and global system economy, while a deficiency of generalist function leads to an increase in systemic entropy that becomes evidenced by decreasing innovation and increasing system rigidity. Systems deficient in generalist function that are under significant perturbation will characteristically experience catastrophic failure with unpredictable timing and/or location and/or severity because of the entropic increase in the system, while systems with adequate generalist function characteristically fail more gracefully when faced with overwhelming perturbation because of a capability to predict and respond to the perturbation.[10]

Part of the function of a family physician is to act as the central point of information about the care of a patient, and without that function specialist care is frequently uncoordinated, sometimes without efficacy, and potentially conflicted. This can be considered as analogous to the intelligence community circumstances surrounding the terrorist attacks of September 11, 2001, in which a lack of communication between various law enforcement and intelligence agencies contributed significantly to the inability to predict and prevent the attacks. In fact it was reported by the 9/11 Commission that "The agencies are like a set of specialists in a hospital, each ordering tests, looking for symptoms, and prescribing medications. What is missing is the attending physician who makes sure they work as a team."[11] Even more interesting is the Commission's characterization of the intelligence failures of the 9/11 attacks as in large part being due to a failure in "imagination", implying a lack of innovative ability in the intelligence community with regard to this situation.[12] Such a lack of innovation is indicative of a deficiency of generalist function, and more specifically a failure in the hypothesis generation that is a result of decision loops rather than of serial logic. It is not unusual for long-standing organizations with large stable structures to suffer from a lack of innovation. In such organizations this can be considered to be ultimately related to inhibited generalist function, because in such organizations as specialists become promoted within the organizational structure, the decision-making processes that they institute tend to reflect their specialty bias, which would inhibit generalist decision-making function and thereby decrease system resilience, eventually leading to a catastrophic failure secondary to decreased innovation and increased organizational entropy.[13]

Generalist function is essential for the resilience of complex adaptive systems, and enables them to predict and respond to dynamic perturbations. A broadly available source code is an important factor in system resilience, as evidenced by the correlation of an ecosystem's resilience with its genetic diversity.[14] The relatively unblocked source code of a generalist agent enables a broad scope of hypothesis generation that is essential for risk analysis, and the generalist agent's orientation toward action enables the system's measured response to dynamic perturbations. In the planning for, and response to, the eventuality of what was Hurricane Katrina in New Orleans, voluminous detailed plans were prepared for the response to such a disaster, but those plans were never put into effect. Part of that planning was for school buses to be used to help in the evacuation of the city, but images of those school buses trapped in the flood waters attests to the failure of emergency managers to reach a "decision-making energy of activation". Despite all of the planning, after the disaster the organizations that were responsible for the response were paralyzed with inaction that was ostensibly related to a burden of "process" or "red tape". There was an inability to integrate and coordinate the response capabilities of the various response agencies as the perturbation of the hurricane had effectively overcome relatively rigid response planning. Carl von Clausewitz was a German military theorist of the early Nineteenth Century who intuitively spoke of an organizational "friction" that developed because of uncertainty related to the "fog of war", and this is analogous to the build-up of entropy or uncertainty that occurs in any multi-agent complex adaptive system, and can lead to inaction in any human organization. Tasked with getting the response to Hurricane Katrina back on track, US Army General Russel Honoré referred to the result of such "friction" in the response as being "stuck on stupid", and he exhibited generalist agent function by cutting across organizational boundaries and protocols to lower organizational entropy and bring about more effective disaster response.

"Fiefdoms" of influence and "information silos" are a naturally occurring and expected result of specialty function and are necessary to enable the very efficient performance of specific tasks within a system. As such they are not "good" or "bad" in or of themselves, but they need continuous integration (by generalist function) into the goals of the overall source code concept of the system. If that integration is not provided then those fiefdoms quickly begin to exhibit characteristics of "malignancy" such as loss of coordination with the overall system concept and modification of source code toward self-serving ends. This is as true for human organizations as it is for cellular systems, and is related to generalist function deficiency resulting in a loss of quantum logic coordination (ie a "decoherence") across the system. Symptoms of such a developing systemic pathology include an increase in serial logic protocols and a blocking of portions of the broader systemic source code within agents.

Cures for such systemic pathology should center on returning to the overall source code concept of the system through reestablishment of generalist function.

Conclusion

Conventional means of information fusion in multi-agent complex adaptive systems involve stochastic statistical methods to deal with the uncertainty or entropy that becomes compounded logarithmically across the data points or nodes of the system. Naturally-occurring systems deal with such entropy via quantum logic mechanisms that are mediated by generalist agents of the system that utilize decision loop methods of decision-making as opposed to the sequential logic of specialist agents that utilize decision-tree methods of decision-making. Family Medicine is an example of such generalist function that can serve as an example for enabling generalist agent function in any multi-agent complex adaptive system.

Endnotes

1 Blake, G. and Stockton, M. (2005) "In Response: A 4-year Family Medicine Residency Program", *Family Medicine*. Vol. 37, No. 1, January 2005, pp.6–7.

2 Mihelic, F.M. (2005) "Generalist Function in Intelligence Analysis", Proceedings of the 2005 International Conference on Intelligence Analysis. May 2005. http://cryptome.org/intel-2005.htm

3 Bacon, F. *Novum Organum Scientiarum*. 1620.

4 Deming, W.E. (1986) *Out of the Crisis*. MIT Press, pp. 87-89. Tennant, G., (2001). *Six Sigma: SPC and TQM in Manufacturing and Services*. Gower Publishing Company, pp.86–93. Funnell, R., Koutoukidis, G.& Lawrence, K., (2009). *Tabbner's Nursing Care*. (5th Edition), Elsevier Pub, Australia, p.72.

5 Coram, R. (2002) *Boyd: The Fighter Pilot Who Changed the Art of War*. Hachette Book Group, pp327–339.

6 Mihelic, F.M. (2011) "A theoretical model of multi-agent quantum computing", *SPIE Proceedings*. Vol. 8057, June 3, 2011.

7 Bodnar, J.W. (2003) *Warning Analysis for the Information Age: Rethinking the Intelligence Process*. Joint Military Intelligence College, p.88.

8 Landauer, R. (1961) "Irreversibility and heat generation in the computing process", *IBM Journal of Research and Development*, 5:3, pp.183–191.

9 Mihelic, F.M. (2010) "A theoretical mechanism of Szilard engine function in nucleic acids and the implications for quantum coherence in biological systems", *AIP Conference Proceedings*, Vol. 1316, pp.287–290.

10 Bak, P. (1996) *How Nature Works: The Science of Self-Organized Criticality*, New York: Copernicus, pp.59–61.

11 *National Commission on Terrorist Attacks on the United States*, (2004) 9/11 Commission Report, p.353.

12 Ibid., p339.

13 Wally, S. and Baum, J. (1994) “Personal and Structural Determinants of the Pace of Strategic Decision Making,” *The Academy of Management Journal*, 37(4): pp 932–956.

14 Gunderson, L. and Holling, C. (2002) *Panarchy: Understanding Transformations in Human and Natural Systems*. Island Press, p.9.

F. Matthew Mihelic, MD

F. Matthew Mihelic, MD is an Associate Professor, Department of Family Medicine, Graduate School of Medicine at the University of Tennessee in Knoxville, Tennessee, USA. Email: fmihelic@utmck.edu

ooOoo