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The Emergency Department as a Complex System

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Perspectives on Complex Systems

The following is a useful framework for applying complexity theory to understanding and improving the functioning of a healthcare organization. That organization could be a clinical department like an Emergency Department (ED) or Intensive Care Unit (ICU), a comprehensive full service hospital, a managed care organization, or a vertically integrated system of primary care providers, hospitals, and outpatient services. The framework is tripartite::
1) Description of the healthcare organization as a complex system, using the vocabulary and concepts of complexity theory
2) Application of complexity theory to facilitate change in the organization
3) Use of the concepts and principles of complex systems to construct new organizational processes
In this paper, we will apply this framework, with some embellishments, to the organization known as the Emergency Room (ER) or Emergency Department.

The Emergency Department….. A Paradigmatic Complex System

What we propose is that the Emergency Department is a wonderful example of a complex system, a relatively self-contained health care delivery system that is extensive in the scope and richness of both its mission and its processes.. We will discuss what it is about an ED that makes it such a particularly apt example of a complex system. We will then present instances of how basic concepts and insights of complexity theory can be used to solve specific operational problems in an ED, and in so doing we will develop some operational design principles that have broad applicability not only to ED's but to organizations as a whole. Next we will do a figure-ground shift. If the ED is indeed a particularly rich example of a complex system, then it may suggest some general insights as to how complex systems work. Finally, we will have some specific things to say about information, information displays, and information systems in the healthcare environment--- and how complexity theory can help us understand why most Emergency Department information systems solutions, and indeed why most healthcare information systems solutions simply do not work well.

The Emergency Department as a Simple System

Given the appropriate scale, every complex system can look simple. (Just as given the appropriate time scale, every seemingly stable system can look unstable ["nothing is forever"]).

In its simplest form, the Emergency Department (or "ED") is a self-contained clinical unit into which patients enter and from which patients leave. At a slight increase in the granularity of that description, the ED can be seen as is a clinical unit into which patients enter with an acute medical problem and from which they leave with that problem assessed and addressed. Each patient, when they leave the ED, is either admitted to the hospital or discharged to home. (And as in most attempts at providing a simple description of a system, reality is always messier. Almost all ED patients are indeed either admitted to the hospital or discharged to home. But there are some patients who are transferred to another healthcare facility [eg. another hospital], some patients who die in the ED, and some patients who do not complete their cycle through the ED and either leave without being seen or choose to leave against medical advice, and some patients who enter a prolonged observation mode).

Emergency Department Process for a Single Patient

An Emergency Department is really a scaled down version of a complete hospital, in effect a "mini-hospital" offering the same full breadth of patient care and administrative processes, albeit in a time-abbreviated manner. Just as would occur to a patient being admitted as an inpatient at a full-service hospital, every ED patient goes through a registration and administrative intake process, a series of diagnostic testing encounters, one or more therapeutic interventions, and finally a disposition/discharge process, all of which take place, for the most part, within the four walls of the Emergency Department. ED patients must be registered into the hospital's information system and have their demographic and insurance information properly obtained. The patient's managed care organization may need to be notified. Typically, the patient is initially assessed by a nurse (typically the "triage" nurse), who makes an initial judgment of how rapidly emergency care needs to be rendered. Then the patient is evaluated by a physician, who often orders a series of patient and problem-specific diagnostic tests such as x-rays, electrocardiogram, and blood tests. That physician may need to make multiple contacts to obtain information about the patient – from the patient's personal physician, from prior medical records, from the family, from information available at other hospitals. Depending on the emergency physician's assessment, a series of therapeutic interventions are then initiated, some definitive, others merely the first of many. The patient may be moved into other areas of the hospital in order to have certain tests done, particularly radiologic and other imaging tests. While this is all happening, the patient is continuously being monitored and reevaluated by machines, nurses, and physicians. Depending on information obtained by this continuous monitoring, a previously chosen course of diagnostic testing or therapeutic intervention may need to be modified. Many patients have complicated social and psychological dimensions in addition to their medical problem, all of which must be sorted out if the ED encounter is to be fully successful. At some point, a decision is made as to whether the patient needs to be admitted to the hospital or can be safely discharged home. An administrative disposition process then occurs in which the patient's ED encounter is administratively "closed out". No two paths through this "system" are the same for any two patients. Decisions by emergency physicians and emergency nurses as to what specifically to do next for the patient are continuously being made and modified based on information about the patient that reveals itself and unfolds in real time.

Goal-Directed Measures of Success

The processes of ED care can be tracked and measured and the quality of their outcomes can be judged. Many different quantitative metrics are used to assess how well the Emergency Department is performing as a system that should be optimized tor provide patient care. . For some of the measures, the goal is to score high: patient satisfaction, clinical outcomes, medical staff satisfaction, managed care organization satisfaction, ED patient volume, revenue, hospital admissions (assuming the hospital is still being paid on a modified fee for service basis), payor mix, and community reputation. For other measures, the goal is to score low: patient throughput or turnaround time, complaints, ambulance reroute/diversion time, costs, malpractice cases and losses, and regulatory agency violations. These measures are relatively precise, most of the data are easily obtained, and the majority of these measures are considered standard metrics that lend themselves to cross-ED comparison on a national scale

The existence of these measures means that the outcomes and consequences – both intended and unintended-- of a given intervention that is designed to change and improve a specific ED process can be assessed with reasonable precision..

Three Tiers of ED Management

From an organizational perspective, the ED operates at three different levels. At any given time, the attending physician in the ED functions simultaneously at two of those levels. When that attending physician happens to be the ED director, he/she is probably also functioning, at least in an observational mode, at the third level.

The first level: the emergency physician takes care of patients one at a time. He/she has a physician-patient relationship with every patient whom he/she is treating. This is the emergency physician in the role of clinical doctor. In this role, his/her task is to manage the care of an individual patient. If the physician is

operating effectively in that role, then each individual patient should feel as if he or she is the sole object of that physician's attention, at least during the time when the physician is at the patient's bedside. .

The second level: the emergency physician must care for many patients simultaneously and effectively and provide on-line management of the whole emergency department. Here, the emergency physician's role is akin to an orchestra conductor or executive chef, to provide of on-line leadership and direction to the whole team and prioritize what needs to be done next and by whom. In this role, the physician's task is to manage the team of nurses, techs, and other support staff in order to provide outstanding care to the whole population of ED patients.

The third level: the physician director of the emergency department must provide off-line leadership and management. The task here is to manage the organization—design of the patient care processes, scheduling of staff, deployment of physical space, allocation of resources-- all so as to deliver the very best care for the patient.

Emergency Department as a Complex System
Many features that are unique to an Emergency Department help to make it a very rich example of a complex system. Complexity exists in no fewer than four different domains: the individual patient, the physician provider, the clinical decision-making, and the totality of the environment.

Every patient who comes through the door is an unknown, with a condition that unfolds over time in a functionally nondeterministic way, which is nonetheless substantially determined by patient conditions, if those conditions could be totally specified, which as a rule they cannot. Every emerging patient event that occurs while the patient is in the ED –such as the patient's experiencing an episode of severe pain or the patient's suddenly developing worsening respiratory distress-- forces the ED system to respond and reprioritize, adding more complexity to the system as a whole. ED patients are "monitored", because what will happen and when it happens cannot be predicted in advance. Each patient has a unique and continuously modifiable trajectory of care events through the emergency care system.

ED caregivers exhibit self-organization, one of the hallmarks of complex systems. They gather around each patient to render individual care, with nurse, physician, respiratory therapist, tech all doing those things that are necessary to take care of that patient. At the same time, caregivers have multiple simultaneous demands being made on themselves and experience competing priorities (eg. spend time with the patient versus move on and see the next patient). Their next "move" is inherently unpredictable. Because of new patients entering the system or changes occurring in the condition of existing patients, caregivers experience frequent interrupts that force a continuing reprioritization of tasks. In addition, ED nurses and physicians experience various types of time pressures to act, which adds to the felt complexity of the system. Patients may have conditions that require time-sensitive interventions. For example, if a patient presents in anaphylactic shock, the ED nurse/physician team had better be able to recognize that condition and deliver epinephrine to that patient within seconds of his or her entering the ED arena. There is the time pressure brought about by the need to prioritize and juggle the multiple demands of more than one patient. And there is also the time pressure to effect a disposition decision (admit or discharge) on every patient. Patients who are in the "waiting to be seen" queue who themselves may have medical conditions requiring time-sensitive interventions, and who at the very least will be dissatisfied if their care takes too long to render.

Clinical decision-making is a complex process. What is the correct diagnostic pathway? What is the likely diagnosis? What medication should be administered. The number of decision nodes in the domain of clinical decision making is vast. The web of decision points is quite complex. Furthermore such decision-making must occur with incomplete evidence. The emergency physician doe not have the luxury of time to wait until "all the evidence is in." The clinician must accept incomplete solutions when full solutions are potentially achievable absent time pressures. Thirdly, the process of clinical decision-making is characterized by fuzzy thinking and emergent pattern recognition. Algorithmic clinical decision trees are simply neither rich enough nor subtle enough to handle all situations. The are usually good enough for the easy 80% of decisions. However, it is the other 20% that distinguish the excellent clinician from the journeyman.

Large amounts of information are needed to describe what is happening inside of an ED, another hallmark of complex systems.. Many agents interact in a small space-- patients, RNs, MDs. It is difficult to predict what the next 30,60,or 90 minutes will bring. The number of repetitive cycles in the system is few before the system appears completely unpredictable. An ED can go from being very busy to very quiet and then back to busy again all within a short period of time. Patient arrival patterns are unpredictable. The standard deviation of the number of patients arriving per hour is high. And no matter how chaotic the situation may feel in the clinical arena of the ED, and no matter how much the staff would like to shut the ED's doors until they feel that they have caught up, patients keep coming into the system— the proverbial faucet cannot be turned off.

Emergency Department: A Unique Operation, Optimized to Exist at the Edge of Chaos
The Emergency Department is optimized to live at the edge of chaos, to handle a multitude of different problems simultaneously, none of which can be predicted in advance. It is a system designed to be resilient to whatever the external environment has to offer. It is a system, perhaps the only system extant, designed to cope with any and every eventuality that can befall a person. Its door is always open, 24 hours a day, 365 days a year. Situations that would totally disrupt another type of organization are routinely handled in the Emergency Department. Imagine if someone collapsed to the ground at a fast food restaurant or walked into a library after having been shot in the chest. The operational fabric of the restaurant and library would be totally disrupted, and it is likely that a panicked chaos would ensue These would be routine cases for an Emergency Department. The ED is a place uniquely designed to accommodate and to respond in a meaningful way to multiple complex stressors of great magnitude, arriving singly or grouped, in any order. In a very literal sense, complexity and chaos is a way of life in the ED, and emergency physicians have developed a variety of approaches and strategies for managing that complexity. And needless to say, if someone walked into an Emergency Department asking for a hamburger to eat or a book to read, they would be accommodated, assessed as to whether or not they had an emergency medical condition, with barely a ripple caused in the care of other patients that was ongoing at the time.

The ED environment can move from order to complexity to chaos and then back again all within a very short period of time. All experienced ED physicians and nurses have experienced an ED in chaos. They often refer to it as a "zoo."   It seems out of control, with too many patients, too much to do, multiple and simultaneous demands being made on everybody, lack of clarity as to what should be done next, a level of tension and noise and activity that is counterproductive to accomplishing anything. . Alternatively, the ED may exhibit a humming complexity, a room resonance, in which large numbers of patients, each with a complicated medical problem and each at a different stage of their Emergency Department work-up, are being managed and handled with grace and deftness by the ED caregivers.

What is even more interesting is that with the same "objective" situation in terms of numbers of patients and types of medical problems, the ED can be in a state of humming complexity or be in out of control chaos. What factor makes one situation tilt in one direction and a similar situation tilt in another? Is it the particulars of a specific nursing team? Is it a function of which ED physicians are working, or is it due to some other factor, seemingly insignificant, that pushes the system in one direction or another? Even more important from the perspective of someone working in an ED that is out of control is what it is that needs to be done to get it back in control. All ED physicians have experienced the situation in which everyone in the ED either seems paralyzed to inaction or is running around the ED creating lots of activity but accomplishing nothing. In those situations, the "obvious" interventions may not be the ones that calm the turbulence, and seemingly insignificant manipulations to the system can have a dramatic effect at restoring relative order.

Emergency Departments have long recognized that, no matter how well-staffed and no matter how slick the operation, there will always be situations that overwhelm even its impressive elastic capability to respond appropriately. Of course. the more robust and elastic the Ed systems, the better able it is to handle a wider range of situations in "complexity" mode without deteriorating to chaos. But for any system, there is some set of initial conditions that will tax it to the maximum, and there is some set of initial conditions that will break it. In ED parlance, those situations are called "disasters." In fact, every ED is required to have a disaster plan. These plans are invoked when the capacity of the system to respond is temporarily overwhelmed— usually by too many patients in too short a time. In those cases, the ED shifts into

"disaster mode," brings in additional resources, changes some of its usual operational patterns, and trades off many of the positive aspects of the everyday system for an enhanced ability to accommodate more emergency patients at a faster pace.

So far we have used the vocabulary and concepts of complexity theory to describe the Emergency Department as a complex system. For the remainder of this paper, we will utilize complex systems theory to help manage change, redesign current processes, and construct new processes.
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The principles of complexity theory can be used to bring about organizational change, redesign current processes, and construct totally new systems and subsystems. Some of the principles that will be discussed are: allow complexity to emerge as a result of the interactions of small modules, construct short feedback loops, and close all loops the 85%/15% rule, the 80/20 rule, small things count, and sunshine information

Effecting Change in Complex Systems: Changing Behavior
How do you guide an organization that is "here" and help get it to "there?" How does one effect change in a complex system for which you have management and leadership responsibility? This is the central question of management.

Complex systems are like ocean liners; they are hard to turn. Like cats, they are hard to herd. Complex systems are too big and too complicated for anyone to be able to get one's hands around them completely. Over-control and over-design will not work. Just when you think that you have total control of the system, something will happen to prove that you do not. An alternative strategy is required.

The brutane" head-on approach to changing a complex system is likely to fail. One simply cannot apply enough external energy to effect change that way. The complex system, by the nature of its complexity, is an energy sink. Rather, the way to effect change in a complex system is to use akido moves, small maneuvers that leverage off of the energy that already exists within the complex system and propels change in the desired direction. The paradoxic intervention of family therapists is a good example. A typical family therapy intervention designed to help a family that is having a problem communicating with each other is not to tell them that they must be more open and honest with each other. Rather, their assignment over the next week is to try hard <u>not</u> to communicate with each other, and even not to speak to each other. This little seed crystal acts as an irritant that propels the behavior to self-organize in the desired direction.

One of the industry standard methods of reengineering a given process in an organization is CQI (continuous quality improvement). It is an approach that often fails to solve the problem for which it was employed. This approach usually starts with every stakeholder in the process explicitly and laboriously plotting out all the steps and decision points in the process, in excruciating detail and completeness during repeated group meetings. The underlying idea is that once the process is completely mapped in all its complexity, then opportunities for redesign will suggest themselves. However what usually happens in an organization is that three months into the CQI reengineering program, the process is not yet 70% mapped out, and 60% of the participants have lost interest and dropped out. This approach to change is really akin to is trying to get one's hands around the whole complex system at one time, a nearly impossible task.

Consider a contrasting approach to effecting change within complex systems: the 85%/15% rule. This rule recognizes that you cannot get your hands around 100% of a system, and suggests that the most of a system you can directly influence at any one time is about 15%. The key to success is to find the right 15% and to effect the right change in that 15% so that the rest of the system "flips" or self-organizes into the desired direction. Consider a battleship. If you want it to change direction, you have to find the one key part of the ship—the rudder. One mantra of changing complex systems is: "find the rudder."

Human behavior and interactions among people are among the most complex systems that exist. Not surprisingly, one of the hardest things to change is human behavior. In general, it is very difficult to "get" people to do things differently when they have been doing them one way for long periods of time. Direct approaches, such as telling people to behave differently, usually fail. Staff education efforts may only be marginally more successful. Although these educational efforts may produce immediate changes in behavior, too often the changes are transient. Those new behaviors often slip back to baseline after several

weeks or months. If a particular aspect of a complex system has resisted change in the past, despite multiple attempts at "fixing" it, then a continued frontal assault direct approach is likely to fail.

An example is instructive. In our Emergency Department, the prevailing culture had been that when the patient load got particularly intense, the staff slowed down, focused negatively on how busy things were, and asked that the ED be placed on "ambulance diversion." Each new patient was met with less than the Patient First enthusiasm that is our organization's watchword.

How to go about changing this prevailing attitude and culture? By all the usual methods-- hiring new people, setting clear standards, opening lines of communication, leading from the top. Those take time, and had been only partially successful in the past.. An additional solution: leverage off of everyone's desire to be part of a record-setting endeavor and their knowledge of video arcade games and top ten score lists. On our Emergency Department's clinical information system, the staff member can look at a list of the top 10 days of the year in terms of patient volume. The list also provides a real time comparison of how the current day's patient volume is faring in comparison to each of those top ten days, as well as in comparison to an "average" day. The staff's response to this new information display was interesting: On very busy days, there was immediate pride in knowing that they were part of a team that was handling a "top ten" patient volume day with aplomb. On a particularly busy day, when at 9:00 PM it appeared that the current day was likely to be a "top 10", the staff geared up in an attempt to be part of a record day. In one case, when they were within 3 patients of seeing the most patients ever, the staff actually went out into the registration/triage area at 11:50 PM to ensure that all people who were seeking care were properly registered prior to midnight.

The top 10 days chart illustrated another core concept from complexity theory—the law of unintended consequences. All the ramifications and consequences of an intervention or change can not be known in advance. It is futile to think that everything can be predicted, because there will always be something that will turn out to be of surprise. In this case, the top 10 days chart showed us something that we had not known before: Monday was unequivocally our busiest day of the week, something that most of us would not have predicted. Which in turn illustrated another observation about complex systems-- nothing beats looking at real data if you really want to understand what is going on.

Building a Complex System: Simplify Processes with Fewer Steps and Fewer People
One of the principles of complex systems theory is that a few very simple elements can give rise to very complex, elegant and harmonious systems. When a system arises as a result of the multiplicative interaction of simple subprocesses, its complexity is rich and harmonious. Consider the game of Go, specificable in four or five simple rules, or consider beautifully intricate fractal designs that are generated by simple equations. Contrast this with an equally sized system, but one that results from the additive interaction of many fewer building blocks, each of which is extremely complicated and convoluted in its design. Such a system is much less efficient, much less productive, and much less elegant. We should strive to create systems whose complexity arises and emerges from interactions among simple parts instead of systems in which "complicatedness" results from the convoluted design of piling one part on top of another.

The practical application of this principle is that complex systems such as organizations work better when the processes that comprise them are designed with fewer steps and fewer people. If processes are kept short and simple, fewer opportunities exist for something to go wrong. Less degradation of information occurs, because there are fewer "handoffs" of information from one person to another. Fewer steps mean that fewer feedback loops need to be constructed in order to ensure that errors or faults in the process are detected and corrected.

An example of process redesign in which eight steps are replaced by three is the replacement of central laboratory processing of emergency department blood test samples with point-of-service laboratory testing in the emergency department. In a centralized laboratory system, obtaining a blood test a patient is an eight step process: the order for the test is written on the chart, where it is then noted by the nurse, and entered as an order into the "order entry" computer system by either the nurse or the clerk. A lab request slip is then generated on a nearby printer. The patient's blood specimen is then attached to this slip and the pair sent, via pneumatic tube or transporter, to the "accessioning" position of the laboratory. The sample is

then distributed to the section of the laboratory that is appropriate for that particular test. Once completed, the test results are transmitted back to the ED, via telephone call or fax to the unit secretary, who then must relay the results back to the physician who ordered the test. This process involves at least 7 people, 8 steps, and takes 60 minutes. Contrast this with a point of service laboratory, a "mini-laboratory" situated in the middle of the ED and staffed with a laboratory technologist. To order a blood test, the physician marks the desired test on a sheet of paper, and hands that paper directly to the point-of-service laboratory technologist. The technologist locates the blood sample and runs the test. Three minutes later, the technologist returns the sheet of paper complete with results to the physician; two people, three steps.

The institution of point of service laboratory testing in our emergency department illustrated yet another example of the law of unintended consequences: the turnaround time for critical tests sent to the main laboratory decreased considerably after point of service testing was started. The reason was that the emergency department now had a laboratory technologist in its midst who became an advocate for its interests. Whenever a test whose result was urgently needed had to be sent to the main laboratory for processing, the point of service laboratory technologist would convey the urgency of obtaining the result to her colleague in the main laboratory. That colleague responded to a call from a fellow technologist in a manner different from a call from someone unknown.

Building a Complex Systems: Construct Local Feedback Loops
Processes in complex systems work best if a feedback loop exists at each step that ensures the correct functioning of that step. What is a feedback loop? It is an error identification and correction mechanism that works by determines whether or not the output at any step is a "proper" function of the input of that step and "feeds" that information back, either on-line during the process or off-line on audit of the process to enable correction of the process..

The worst-functioning system is one that has no feedback loops, a unidirectional process in which it is impossible to identify whether or not the final outcome is correct at all. Only slightly better is a system with only a global feedback loop, one in which only the final output is scrutinized. Global feedback loops can identify only that "problems exist," they cannot identify at which step in the process that the problem is occurring. In a process with only a global feedback loop because there can be no assurance that the process is correct at every step, there may in fact be no way of knowing whether or not the final output is correct or not.

Local feedback loops are the signature of well-designed processes. They occur at the level of a single step of a process. If a process has seven steps and seven local feedback loops, one at each step, then any error that exists in the final output can be traced back to the exact step where it occurs. Conversely, if each step in the process is demonstrated by its local feedback loop to be correct, then the overall process will be correct.

"Telephone" is an example of a childhood game that depends on the absence of local feedback loops for its "success." In this game, information is passed from one person to another in a chain of people. The fun of the game is to see what the last person in the line thinks was said compared to what the first person actually initiated. The comparison of the two at the end of the game is a global feedback loop. The game works because of the absence of feedback loops at each step in the process. If each person who received information confirmed with the person providing the information what it was they thought they heard, then no degradation of information would occur at then end of the line.

Local feedback loops thus permit the easy identification of where in the process the error or breakdown is occurring. Consider the process for a typical hospital's system of emergency department billing. Every patient who enters the emergency department (ED) seeking care is registered into the hospital's ADT (Admissions, Discharge, and Transfer) or registration computer system, where demographic and insurance information is recorded. A clinical chart records a clinical encounter and is generated by nurse and physician. This chart is then passed to coders who extract billable charges that resulted from the patient's visit and enter those charges into the hospital's billing computer system, which is usually the same ADT system in which the patient was registered. Patient identification, insurance, and charge information are then passed on to a billing section (or a separate billing company) which then sends the bill on to the

appropriate third party payor (insurance company). The insurance company responds either by paying that portion of the bill for which they are contractually obligated or by sending an "explanation of benefits" (EOB) back to the hospital explaining why they are refusing payment. These are the steps in a unidirectional process in which information is passed down the line from ED registration clerk to ED nurse and physician to ED coder to billing company to insurance company to hospital. At every step in the process, the potential exists for information to be correctly transmitted, incorrectly transformed, or simply not transmitted at all. Unless local feedback loops exist at every step that reflect whether or not information properly and completely made it to the next step in the process, no way exists for knowing the reason why poor outcomes exist at the end of the stream, ie poor cash collections, or even if those outcomes are poor at all. For systems to perform optimally, they should be constructed with local feedback loops at every step in the process, loops that reflect whether or not that step was successfully completed.

Managing Complex Systems:
Management by Principle, Rule, and Aphorism

Most great ideas can be simply and succinctly expressed. Perhaps it is even the case that for an idea to be considered truly "great," is that it must be able to be formulated in a simple and succinct manner. In the realm of concepts, elegance and parsimony of expression are requisites for greatness.

What are arguably the two greatest ideas of the twentieth century cab each be expressed in a single sentence, Godel's Incompleteness Theorem and Einstein's Special Theory of Relativity. Godel's Incompleteness Theorem states: there exist true but unprovable statements in mathematics
Einstien's Special Theory of Relativity can be expressed in two different ways: the laws of physics are the same in all inertial frames of reference; or alternatively, the speed of light is always "c.".

Complex systems, by virtue of of their complexity, are inherently difficult to describe in detail. A more fruitful approach is to seek organizing formulas that can generate to the system. A beautifully complex fractal design, impossible to describe in words, is the product of a single very simple formula. The game of Go can be completely specified in a few simple rules.

Organizations are complex system. Describing the workings of one in total detail is like trying to describe a fractal design. Instead, one must resort to simplification and abstraction. One way to understand, to construct, or to change a complex system like an organization, is to use a guide. The process of using principles, rules, or aphorisms to navigate change or construction of a complex system mirrors the way the complex system is itself best constructed—out of simple building blocks interacting with each other. A few simple ideas, uniformly applied, can lead to beautifully intricate and well-functioning systems; innovative solutions to process problems can grow.

Memes are simple but infectious ideas, those that take hold and can turn an enterprise. They are rules, principles, aphorisms, guides that simplify, organize, and provide a way into management of the complex system. Management by memes is an especially potent way or working in complex organizations. Their complexity makes them suitable for such an approach; indeed by virtue of their complexity, no other way will work as well. The process by which change occurs or new processes are built using memes as seed crystal to organize processes mirrors the actual construction of the system out of simpler building blocks. The interplayt between the simplicity of the meme and the consequences of its applications is no different from the simplicity of a formula and the complex intricate design it generates. Just as reductionism and emergency are two sides of the same coin, so are the simplicity of memes and the complex systems they generate.

What are some examples of memes that can guide the design, redesign, construction, or reengineering of a complex system:
a) The 80/20 rule: 80% of the return can usually be achieved with the first 20% of effort. The remaining 20% takes four times as much effort. The principle is to design for the usual case, and sometimes even forget about designing for the exception. The process should be streamlined for the 80% of the time it will be applied instead of making it applicable 100% of the time, which comes at a cost of it being

unpleasantly cumbersome for the majority of cases. The 80/20 rule implies the "Good enough, Push on" principle that can prevent becoming trapped in an unachievable perfectionism.

b) The 85%/15% rule: Complex systems are too complex to get your hands around the whole system. The most you can influence or effect at any one time is about 15% of the system. The challenge is to find the right 15% and effect the right change or intervention in it so that the rest of the system "flips" or self-organizes in the desired direction.

c) Avoid overdesign. It is better to effect small changes and then move on again after seeing their consequences than to try to design the whole system comprehensively before testing out any of the parts. Since complex systems are by nature unpredictable, it is difficult to know in advance of actually running the system what will work and what will not. Unforseen consequences usually happen with any intervention. If a major investment of time and resources has been made in the "one right way," and that right way does not work, then one has spent all one's capital in a futile effort. Avoiding overdesign saves time and money, enables you to move forward, and keeps you open to new ideas.

d) Seek minimum specifications ("min soecs"). This is a variant of the previous rule of avoiding overdesign. Sometimes the best way to design a process or system is to establish the three or four key things that the process is meant to accomplish and then let the agents of the process (usually people) self-organize to achieve those minimum specifications. .

e) Permit self-organization and emergence. These are two of the most potent features of truly complex systems. The whole is indeed greater than the sum or even product of the parts. If simple and clear goals or "min specs" are set, then people will often organize themselves to accomplish those goals. Sometimes, totally unforseen consequences will emerge that will be more important than the original purpose of the process,

f) Palpable synechdoche-- small things count. In any process the aspect of the process that is deemed important in the eyes of the designer may not be what is important in the eye of the consumer. It may well be little things, such as the cleanliness of the bathroom or the smile of the person across the counter, which are more important to the process being deemed successful than the throughput time or the actual quality of the product.

g) Unintended consequences. There will always be outcomes that are unanticipated when old processes are changed or new processes constructed.

h) Invest in people. The most important part of any organization are the people who make it work.

Invest in People

The atomic unit of many complex systems is the intelligent agent. Complex organizations require people for them to work. People are the intelligent agents of complex systems. Since what needs to be done in every situation cannot be completely prespecified, the skill and intelligence of the people comprising the organization will determine the outcome.

In the middle of the night, something unanticipated will happen. The leader of the organization will not be around to fix it. The organization needs to have people who will to be able to deal with the problem and solve it. They need to have the tools, the knowledge, the training to deal with the situation. But they also need to have sound judgment, good values, and a sharp mind. The most important factor in effecting improvement in a complex system are the values, goals, and skills of the people, not the detailed process reengineering. That is why organizations which spend 10% or 20% more to get the best people to work for them receive a 100% return on their investment in terms of quality outcomes and productivity

If intelligent agents are given reasonable goals, clear "min specs" of what the desired outcomes are, then they can self-assemble and self-organize to meet those goals. This implies ceding control down to local level in large organizations.

The 85%/15% Rule and Sunshining of Information: A Strategy for Solving Organizational Problems

Organizational process problems that have resisted solution despite repeated attempts, especially those that occur as problems across many different institutions, are probably problems of complex system. These are typically problems that have resisted traditional CQI/TQM process mapping techniques.

As discussed above, one way to tackle these problems is to apply the complex systems theory to the problem-solving, in particular the 85% / 15% rule. Find the right 15% of the system to change and let the agents in the system self-organize to change the other 85%.

Very often, the "right" 15% is information describing the system, and the "right" intervention is the sunshining of that information. By making process information public, people tend to act so that the information reflects favorably on them.

One common problem that occurs in many hospitals is getting emergency department patients who have been admitted to the hospital out of the emergency department and up into a "clean ready" inpatient bed. The problem is that four departments are involved in this process of bed turnover-- admitting, environmental services, nursing, and the emergency department. The communication among the four groups is often less than open, with each group having only partial information about the exact availability of hospital bed. No single and clear picture exists as to the current status of each and every bed in the hospital that is shared by all the groups. A patient may have been discharged from a nursing unit and that bed has become empty, but if that information is not known to the environmental services department and the admitting office, that room will stay marked as occupied long after the patient has left. Although the admitting office typically controls the assignment of beds, it often must check with the nursing unit to make sure that the bed it wishes to assign is indeed appropriate for the patient. The emergency department, always under pressure to keep its beds open for patients who are yet to enter its system, is often baffled why it receives eight bed assignments at the same time and why that time is sometimes 11:00 PM. Did eight patients really just get discharged within the previous hour, or is there a lag in information being disseminated to all who need it?

In many hospitals, this problem has typically resisted solution, despite the best efforts of well-intentioned people. Task forces composed of representatives of all the stakeholder departments have met and applied CQI and TQM tools to its solution, only to come up short after months of effort in actually effecting change. One possible reason for lack of success is that the problem is too complex for a comprehensive solution to be designed in. If "information" is the 15% handle in the 85%/15% rule, then maybe an effort to display or "sunshine: the information about the status of all beds in the hospital – empty and clean, empty and dirty, pending discharge, occupied—combined a display of information about all patients

needing bed assignment-- emergency department, elective admissions, unscheduled admissions, transfers—would enable all four of the stakeholder groups to self-organize to optimize the process.

Insights Gained about Complex Systems from the ED

Thus far, we have looked at the Emergency Department can be viewed through the lens or filter of complexity science. The premise of this paper is that complex systems theory can offer useful insight into how to improve an ED's patient care processes and how to approach and solve a particular management problem. We can apply some of the principles of managing complex systems to managing and obtain new solutions to organizational, system, and process problems that would not otherwise have been arrived at.

The converse is equally interesting: use the Emergency Department to learn about complex systems. The Emergency Department is designed to put an orderly wrapper around events that would be deemed chaos-inducing in other environments Why is the ED able to respond to such a wide range of inputs and situations that would perturb or cripple other systems? What are the factors that optimize the ED for managing inherently complex situations? The Emergency Department can serve as a living laboratory for complexity science.

The ED environment can move from order to complexity to chaos and then back again all within a very short period of time. All experienced ER physicians and nurses have experienced an ER in chaos. They often refer to it as a "zoo."   It seems out of control, with too many patients, too much to do, multiple and simultaneous demands being made on everybody, lack of clarity as to what should be done next, a level of tension and noise and activity that is counterproductive to accomplishing anything. . Alternatively, the ER may exhibit what could be called a humming complexity, a room resonance, in which large numbers of patients, each with a complicated medical problem and each at a different stage of their Emergency Department work-up, are being managed and handled with grace, deftness, and smoothness.

What is even more interesting is that with the same "objective" situation in terms of numbers of patients and types of problems, the ED can be in a state of humming complexity or be in out of control chaos. What factor makes one situation tilt in one direction and a similar situation tilt in another? Is it the particulars of a specific nursing team? Is it a function of which ED physicians are working, or is it due to some other factor, seemingly insignificant, that pushes the system in one direction or another? Even more important from the perspective of someone working in an ED that is out of control is what it is that needs to be done to get it back in control. All ED physicians have experienced the situation in which everyone in the ED either seems paralyzed to inaction or is running around the ED creating lots of activity but accomplishing nothing. In those situations, the "obvious" interventions may not be the ones that calm the turbulence, and seemingly insignificant manipulations to the system can have a dramatic effect at restoring relative order. This might be a very fruitful avenue for experimental study. It might be called "a cure for chaos."