CLINICAL SYSTEMICS: TOWARDS AN INTEGRATED FRAMEWORK AND METHODOLOGY FOR ALLEVIATING PATHOLOGIES IN COMPLEX SYSTEMS

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ABSTRACT

Clinical systemics is a framework and methodology induced from Western medicine for the purpose of identifying and treating pathologies in complex living systems. Motivated by climate change and other significant trends in the 21st century, clinical systemics is envisioned as a means of science-based, multidisciplinary collaboration and practice not only in social-ecological systems, but in other natural and artificial living systems as well. This paper will outline the philosophical underpinnings of such a framework and methodology, provide a contextual overview of the systems and complexity science project, and will describe the features of complex living systems, health, pathology, and healing. Building on these ideas, a vision for a clinical systemic framework and methodology will be articulated by drawing on examples from the history of Western medicine. And lastly, benefits and challenges of such a framework and methodology will be identified, followed by a suggested sequence of development and implementation.

Keywords: Climate Change, Clinical Systemics, Interdisciplinary Collaboration, Medicine, Policy Methods, Resilience, Sustainability, Systems Engineering, Systems Isopathology, Systems Literacy, Systems Pathology, Systems Practice, Systems Science

INTRODUCTION

The 21st century is a time of great change and accelerating complexity in social, political, economic, technological, ecological, and climatic systems. These systems are coupled in such a way that pathological imbalances could lead to catastrophic destabilization, resulting in the possible collapse of human civilization and/or severe impacts to the planetary biosphere. Clinical systemics is envisioned as a generalized framework and methodology for approaching such challenges, and draws on the Western medical model, particularly the specialities of emergency and critical care medicine.

Motivation

"Necessity is the mother of invention." – Unknown

"…the basis of invention is science, and science is almost wholly the outgrowth of pleasurable intellectual curiosity." – Alfred Whitehead

There are two motivating factors behind the prospect of an integrated clinical systemics: an immediate existential need, and a vision of a long-term and potentially valuable scientific foundation for human progress.

Climate change is arguably the most studied and accepted catastrophic threat amongst the scientific community (IPCC 2018; USGCRP 2018), and will require local and regional adaptation in preparation and response to adverse effects (Frame and Allen 2008). Further complicating matters is global net energy decline as the ratio of energy input to net energy extracted, otherwise known as Energy Return on Investment (EROI), is conservatively forecasted to reach unsustainable levels before mid-century (Ahmed 2017). Alternative energy technologies such as wind or solar power have much lower EROI's than fossil fuels when the costs of infrastructure and energy storage are taken into account (Hall, Lambert, & Balogh 2014), and so even if they are able to meet the current energy needs of global civilization they will not possess the capacity to power climate adaptation and disaster response activities to the same degree as fossil fuels. Supply chains and transportation will be heavily impacted by diminished energy availability (Friedemann 2016), further reinforcing the focus on local and regional efforts. Existing pathologies such as severe wealth inequality contribute to social unrest and trends towards authoritarianism, and advanced technologies such as social media, artificial intelligence, and the internet of things (IoT) alter the topologies and kinds of interactions between individuals or groups of humans and the world at large. Collectively, these trends will interact in ways that may not be predictable, adding a significant degree of uncertainty to how humans will respond to the changing environment.

Apart from the contemporary crisis of global civilization there is a more forward-looking and hopeful motivation behind clinical systemics. By creating and evolving a general framework for assessing and treating complex living system pathologies a number of applications may become possible. For example, in social-ecological system (SES) management (aka coupled human and natural systems (CHANS)) clinical systemics may be employed for the creation and maintenance of integrated community resilience and circular economy initiatives, or bioregional infrastructure planning and development. Clinical systemics may inform systems engineering (SE) both in how some technological artifact may affect the SES/CHANS system in which it is introduced as well as how some complex technological artifact may pathologically malfunction in and of itself. Accumulated knowledge from both of these broad areas of application may one day inform complex life support systems for space exploration (Polk 2007).

Overview

Clinical systemics can be defined as an isomorphic framework and methodology induced from the Western medical tradition that can be applied to pathological systems in other fields of inquiry and practice. "Clinical" is defined as "1) relating to the bedside treatment of a patient or to the course of the disease, or 2) relating to the observed symptoms and course of a disease" (Berube et al. 2008). "Systemics" refer to systems in general, defined as "…a set of *elements* having *attributes* linked by *relations*" (Zwick 2018). Thus clinical systemics can be viewed as a method of directly interacting with a system for the purpose of identifying pathological relations between elements by interpreting observable attributes, coupled with the application of practical treatments to remedy such pathologies. In this way, clinical systemics is an integration of scientific inquiry and the art of practice.

Conceptually speaking, clinical systemics can be located within the framework of an "exact and scientific metaphysics" which, drawing from Bunge, Zwick describes as a system of mathematically describable concepts and principles that are drawn from and contribute to empirical sciences (Zwick 2018). Exact and scientific metaphysics is a broad way of describing the modern systems project that began after World War II, and it includes cybernetics, general systems theory, systems science, complexity science, and many other theories, frameworks, concepts, and methods developed in a number of diverse fields. In addition to using systems language to describe clinical ideas, clinical systemics draws from and is designed to contribute back to the study of complex adaptive systems (specifically living systems), systems practice (specifically resilience and sustainability), and systems pathology. This generality, in addition to potentially providing new insights and perspectives to solitary fields of study, has the advantage of being an accessible framework for multidisciplinary teams. See Figure I.

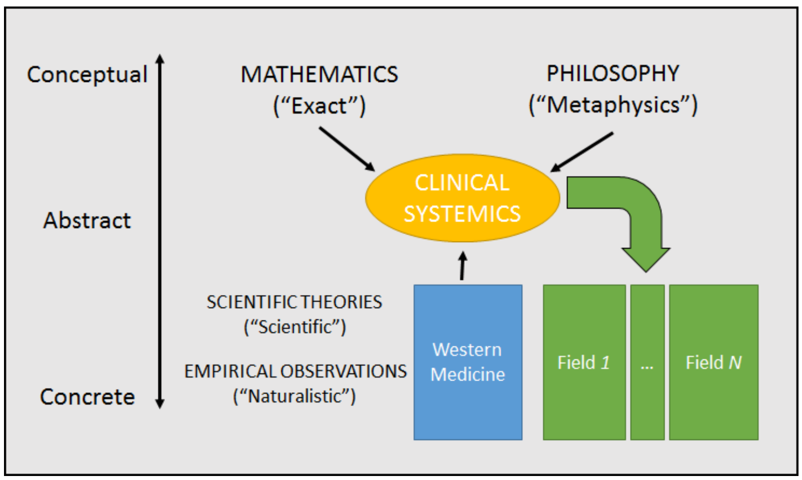

Figure I. The relation of clinical systemics to the "exact and scientific metaphysics" of the systems project.

The focus of medicine is on a human patient, or in the case of veterinary medicine some individual organism belonging to a particular species of animal. Botany has an equivalent subspecialty which focuses on plants, respectively. These living systems are philosophically straightforward to approach, as they are physically discrete from their environment, exist on spatial and temporal scales that are intuitive for humans to understand, have life cycles that are known and predictable from collective experience and empirical study, and are not actively evolving via significant structural change. In contrast, a general clinical approach may be utilized or adapted for systems that do not share these same constraints. For example, a social-ecological system consisting of humans, their activities and artifacts, and the environment in which all of these elements are embedded may not appear to be physically discrete, but rather physically coupled through their various relations and interactions. Spatial scales that are larger than ordinary human perceptual experience or temporal scales that are multigenerational may be difficult for humans to comprehend, and significant structural changes via technological artifacts and resource utilization essentially constitute an evolutionary experiment that may or may not prove beneficial to humans and that may have significant unintended consequences for regional and planetary system processes and life cycles.

The philosophical orientation that is adopted will undoubtedly influence how an individual or group of individuals approaches systemic problems. For instance, the Voluntary Human Extinction Movement ("Voluntary Human Extinction Movement - Wikipedia" 2019), religious fatalists, or Singularitarians who believe in a "Techno-rapture" (Hughes 2008) will have markedly different opinions as to the definition and root cause of a pathology and what treatment options exist or should be utilized. Clinical systemics, on the other hand, is fundamentally rooted in the broad humanist principles that humans have value, that their interests are of central importance, and that improving the human condition is a primary goal. Simultaneously, clinical systemics acknowledges that *Homo sapiens* are not the end of the evolutionary tree and that a post-human or trans-human future is a very real possibility (Bostrom 2005). This is not to say that clinical systemics places humans in some category apart from nature, but rather that without human interest there would be no need for a clinical systemics since natural systems will continue to exist and evolve according to the laws of nature. Insofar as the centrality of humans, clinical systemics acknowledges the ontological parity between systems that exist at differing emergent hierarchical levels of reality (Zwick 2018), as well as finds the notion of "deep ecology" particularly useful (Capra & Luisi 2014). Per Capra and Luisi, "shallow ecology" is an orientation that places humans apart from nature and views the latter as only possessing instrumental value to humans. "Deep ecology," on the other hand, views humans as a part of nature and "…recognizes the intrinsic value of all living beings and views humans as just one particular strand in the web of life." And so, although clinical systemics does not mandate that humans are always of central importance, it does suggest that assessment and treatment of a given pathological system should take into account what the impacts will be on humans from either the successful or unsuccessful treatment of underlying pathologies.

Other philosophical influences include naturalism, rationalism, and pragmatism. Hippocrates (460 BCE to 370 BCE), the Greek founder of Western medicine, had a holistic approach to medicine that was based on naturalistic causes, as opposed to supernatural causes that were common in other medical traditions (Bynum 2008). Rationalism builds on naturalism, by using logical reasoning to assess empirical evidence and draw useful conclusions. And lastly, pragmatism focuses on practical outcomes as opposed to idealistic ends. Perhaps best summed up by the utilitarian goal of triage ("do the most good for the most people"), pragmatism is fundamentally an attitude of optimized problem solving under non-trivial constraints.

Given the background motivations for, and the conceptual and philosophical overview of clinical systemics, the remainder of this paper will explore the proposed framework and methodology of clinical systemics. First, the discussion of foundational systems ideas will aid in establishing normative criteria. Then, the example of Western medicine will be used as a template for developing the clinical systemic framework and methodology. And lastly, benefits and challenges for further development and implementation of the clinical systemic framework and methodology will be identified, including proposed next steps.

THE SYSTEMS PROJECT AND WESTERN MEDICINE: AN INTERSECTION OF IDEAS

In order to create an isomorphic framework and methodology that can be applied to pathological systems in general it is first necessary to identify what kinds of systems can exist in a pathological state, which in turn requires a foundational understanding of systems. Next, there must exist some criteria for what constitutes healthy versus pathological systems. And lastly, to create a structural template for the framework and provide the context for methods, it is useful to examine the evolution of Western medicine over the last 2500 years. These three categories of ideas will be discussed below.

Elements and Relations: An Orientation to Complex Living Systems

"Essentially, all models are wrong, but some are useful." – George Box

The purpose of this paper is not to describe in detail or argue for a particular conceptual view of systems or complexity, as by definition every system has flaws, contradictions, and incompleteness (Zwick 1984). Rather, to be practical and useful clinical systemics requires some means of organizing systems ideas into a conceptual working directory. Otherwise, in an attempt to "see the forest, not the trees" one can become easily disoriented, confused, and possibly lost. Furthermore, having some common understanding of the metaphorical forest, however flawed, can aid multidisciplinary teams in moving past the inevitable discussions and conflicts in terminology and semantics so that they can promptly devote their attention and efforts to the problem at hand. A common theme in medicine is to assess the larger, coarse situation first before narrowing focus to finer grained details; Zwick's forthcoming *Elements and Relations* (Zwick 2018) provides a thorough view of this "coarse whole."

Zwick claims that there are at least two broad approaches to integrating the multitude of systems-theoretic ideas within the systems project as a whole: an internal "structural approach" and an external "functional approach" (2018). The structural approach organizes systems ideas around categories of complexity, while the functional approach categorizes ideas based on how they contribute to other fields. The functional approach will be discussed later, as clinical systemics and several other related projects are defined explicitly by their utilitarian relation to other fields, and thus will be covered in more depth. As for structural approaches, one can either organize ideas into a conceptual network, group them according to emergent differences, or group them according to isomorphic similarities. Boulding (1956) organized a framework around both emergence and isomorphisms, and Zwick (2018) later developed a set of categories along a spectrum of simple to complex that roughly corresponds to the earlier work of Boulding (see Table I).

Table I: Summary of emergent and isomorphic organization of the systems project. Rows correspond to levels of emergence. Zwick's Isomorphic "Synchronic" categories are indicated at the first level at which they appear, and higher levels are assumed to possess traits of lower levels. Living Systems Theory and the "Santiago School" view of life are salient to clinical systemics.

Boulding Hierarchy (Boulding 1956)	Modified Boulding Hierarchy (Zwick 2018)	Autonomy (Zwick 2018)	Zwick's Synchronic Categories (Zwick 2018)		Living Systems Theory (Miller 1978)	"Santiago School" (Capra & Luisi 2014)
Transcendental Systems	N/A	N/A	N/A		Generalized Living Systems consist of 19 subsystem processes that are carried out by various combinations of concrete components at each level of emergence beginning at the cell. This repeating pattern Miller refers to as "shred-out."	Living systems possess the triad of: 1) Autopoietic Unit 2) Cognition 3) Environment Note: Cognition ≠ Consciousness Cognition: A process of knowing that governs interaction with the environment See also: Yudkowsky's spectrum of intelligence (2008)
Social Organizations	N/A	N/A	N/A			
Humans	*Humans*	Self-defining	Complexity; Agency	Cognition		
Animals	*Animals*	Self-directing				
	Plants	Self-adapting				
Genetic-Societal Level	Cells	Self-reproducing		N/A		
Self-Maintaining Open Systems	Autopoietic Systems	Self-producing	Persistence	Identity	N/A	
				N/A		
Control Mechanisms, Cybernetic Systems	Control Mechanisms	Self-regulating	Wholeness (*Fundamentals*); Constraint (*Internal Aspects*); Distinction (*External Aspects*);		N/A	N/A
Clockworks	Dynamic Systems	Self-organizing			N/A	N/A
Frameworks	Static Systems	Self-stabilizing			N/A	N/A

It is important to note that the categories illustrated in Table I all pertain to structure or function, and do not address the system's history. Zwick uses the term "synchronics" as a label for the structure and function of a system during an "extended present" moment (Zwick 2018); one may interpret this as the system existing in some steady state or limit cycle with no significant historical change taking place. "Diachronics," on the other hand, explicitly deals with historical change via processes such as system formation, development, dissolution, and evolution. In short, structure is "being," function is "behaving," and history is "becoming." The goals of clinical intervention will differ depending on whether the system is in a synchronic or diachronic state. For convenience this paper will focus on synchronic ideas.

Fundamental categories of ideas that pertain to any kind of system are wholeness, constraint and distinction (Zwick 2018). Wholeness captures the ideas of elements and their network of relations that are arranged according to some organizing principle. Constraint is another way of referring to a relationship (in that two or more elements are constrained, or bound by one another), and examples of ideas in this category include order, entropy, and chaotic dynamics. Distinction entails concepts such as a system possessing a boundary which separates it from its environment and the notion of qualitative emergence between different levels of reality. These broad categories apply to conceptual, abstract, and concrete systems (J. G. Miller 1978), and are sufficient to describe static, dynamic, and simple feedback control systems (see Table I).

Although "pathology" has not yet been formally defined, it is necessary to narrow the kinds of systems that can be pathological. Conceptual systems such as mathematics, logic, and philosophy may contain paradoxes or problems, but it is arguable if such systems can be pathological, and ergo these kinds of systems will not be considered at this time. Within the realm of abstract and concrete systems it is useful to consider two categories of problems: ontological and focal. Ontological problems are essentially gaps between ideal and actual states that are fundamental to existence, not just for humans but for all living beings (Zwick 1995). Although these kinds of problems manifest in concrete and abstract systems they might be considered “absolute constraints:” they are essential to a clinical systemician’s knowledge base, but they are do not constitute a set of pathologies that can be resolved. Focal problems, on the other hand, pertain to individual systems that can in theory be meaningfully influenced. These systems may range in size from molecular to planetary, but can broadly be divided into simple non-living systems and complex living systems. Non-living systems may include artifacts generated by living systems. Such artifacts may be functional, dysfunctional, or non-functional depending on their purpose, but they would not be considered pathological. Such systems entail no time dependency for repair or prognosis, and even a complicated machine with many interacting parts may be diagnosed and repaired with conventional engineering approaches. On the contrary, complex living systems manifest pathologies that possess emergent properties and that have time dependencies for repair and prognosis.

Complex living systems, or simply put “living systems,” were described by Miller as “…open systems which process a throughput of matter, energy, and information via 19 critical subsystems” (1978). Gradients drive this flux of matter, energy, and information (J. G. Miller 1978; Zwick 2018) which in turn is essential for self-repair and effective functioning (Capra and Luisi 2014). According to Prigogine, open systems in a steady state minimize entropy production (J. G. Miller 1978), which is related to the “maximum power principle” as described by Lotka, Odum, and others (“Maximum Power Principle” 2018; Holmgren 2017). Information contained within the system governs energy utilization, which in turn affects entropy production (J. G. Miller 1978). Stresses or disruptions to matter, energy, or information flux can cause the system to regress to less complex but more energy efficient structures and processes (Schneider and Sagan 2005; Gunderson and Holling 2002; Walker and Salt 2012), and in the case of individual organisms can lead to a cascading collapse of essential systems processes, and ultimately death (Capra and Luisi 2014).

Miller’s living systems theory describes seven layers of concrete systems ranging from cells to the supranational system, and thus has a focus on humans and human social organization. Within this framework Miller claims that the 19 critical subsystems carry out fundamental processes which are “shredded out” in more complex ways at each level of emergence. Although these processes are ubiquitous, depending on the level of emergence these critical processes are carried out by different arrangements of structural components. One essential set of processes are “adjustment processes” which seek to alleviate stress created as the strain (or difference) between a given variable’s set point and actual value nears its edge of stability. Miller asserts that there exists a hierarchy of values which order the urgency of reducing strains amongst a set of variables; such a prioritized list of variables would be essential to identify for each class of living systems so as to guide clinical assessment and treatment (J. G. Miller 1978).

Insofar as critical subsystems, Miller states that living systems that lack all 19 subsystems can persist via parasitism or symbiotic relationships with other systems, however the “decider subsystem” is mandatory for a system to be considered an independent entity (J. G. Miller 1978). This is related to Capra and Luisi’s criteria of cognition, or process of knowing, for living systems (2014). Another overlap between Miller's living systems theory and Capra and Luisi's view of life is that of the "reproducer subsystem" (J. G. Miller 1978; Capra and Luisi 2014). Per Capra and Luisi the primary characteristic of life is the process of autopoiesis (Greek "self" + "making"), sometimes described as the continuous self-organization and regeneration of system components (2014). Miller describes a "template" (1978) which serves as a blueprint for system regeneration and reproduction. Such "algorithmic information" (Zwick 2018) specifies the structure of components as well as sets goals for system variables, and thus affects the occurrence of strains, growth rates, adjustment processes, et cetera (J. G. Miller 1978). An important aside is the claim that social systems are autopoietic and that social symbolism exists in the abstract domain (Capra and Luisi 2014), which suggests the need to assess both concrete and abstract aspects of pathological systems.

Augmenting Miller's focus on critical subsystem processes, Capra and Luisi put forth four phenomenological observations of life not limited to humans or human social systems (Capra and Luisi 2014). The first observation, that of homeostatic self-maintenance, has been discussed in terms of matter, energy, and information flux, adjustment processes, and autopoiesis. The second observation, that life is non-localized and can only be understood as an emergent phenomenon, is related to the third observation: that emergent properties cannot be reduced to the properties of the components, although the component structures can be studied with reductionist methods (Capra and Luisi 2014; J. G. Miller 1978). And lastly, the fourth observation describes the interaction of an organism with its environment via three processes: structural coupling, structural determinism, and cognition.

Structural coupling in essence describes the recurring set of interactions between the living system and its environment. As such, the system and its environment are non-decomposably linked (H. A. Simon 1996), and therefore cannot be understood in isolation of one another. Structural determinism entails three basic ideas. First, the idea of self-organized criticality describes how causation is shared by the state of a system's structure as well as some outside disturbance, as is the case when grains of sand falling on a sand pile trigger periodic avalanches; structural determinism can be thought of as an iterated and ongoing example of self-organized criticality. This leads to the second idea, that non-living systems react predictably to stimuli, whereas living systems respond unpredictably to stimuli. Both of these ideas relate to the observation that living systems co-evolve with their environment as system and environment respond to one another by altering their respective structures. And lastly, cognition mediates the interaction of the living system with its environment. This concept was illustrated in a centralized sense with Miller's "decider" subsystem as described above, but it can also be expressed in a decentralized way in the form of collective intelligence. One example of decentralized cognition might be in the heterogeneous temperature set points of a colony of honey bees which enable the bees to precisely control hive temperature while preventing destabilizing oscillations (J. H. Miller 2015). For additional discussion of cognition, specifically the spectrum of intelligence, see Yudkowsky (2008).

Health and Pathology

"It's either too high, too low, too fast, too slow, I don't know, gotta go, and be sure to get the bear before the bear gets you." – Anonymous Paramedic

Clinical systemics is concerned with alleviating pathologies in complex living systems so as to restore system health. This section defines health, pathology, and the general process of healing, and concludes with a brief overview of generalized approaches to pathology within the systems community.

The American Heritage Medical Dictionary defines "health" as "1) The overall condition of an organism at a given time. 2) Soundness, especially of body or mind; freedom from disease or abnormality" (Berube et al. 2008). Thus health can be seen both as an emergent attribute of a living system, as well as the state of this attribute commonly characterized by the lack of disease (Capra and Luisi 2014). Beyond this common understanding of health, Capra and Luisi claim that a precise definition is impossible and that "health is a state of well-being that arises when an organism functions in a certain way" (2014). They state that health is "…largely a subjective experience whose quality can be known intuitively…" and that a systemic understanding of health "…implies continual activity and change, reflecting the organism's creative response to environmental changes." Given the previously described understanding of living systems as autopoietic systems that cognitively interact with their environment, it follows that dimensions of health mirror the biological, cognitive, social, and ecological dimensions of life (Capra and Luisi 2014). Furthermore, a systems view of health can be applied to the three mutually interdependent levels of life: the individual, social, and ecological (Capra and Luisi 2014).

Pathology is "the medical science concerned with all aspects of disease" (Berube et al. 2008) and, like disease, spans two levels of emergence: underlying structures and their emergent attributes and functions. Disease, as commonly understood, is the malfunctioning of biological structure and mechanisms (Capra and Luisi 2014) which in turn leads to the manifestation of emergent signs and symptoms (Berube et al. 2008). Signs are objective observations that can be made of the pathological system by another system, and include qualitative descriptors, abnormal behaviour, and alterations in normal functioning. Symptoms, on the other hand, are subjective perceptions by the pathological system that indicate some abnormal state. In fact, the meaning of the term "pathology" is the "study of suffering" (from the Greek words "logos" and "pathos") (Kumar, Abbas, and Fausto 2005), and thus implies that pathological systems possess some degree of cognition and/or consciousness. This is echoed by the claim that "…every illness has mental aspects" (Capra and Luisi 2014). Collectively, these emergent signs, symptoms, and dysfunctions belong to the aspect of pathology called "clinical significance" that addresses the consequences of structural problems.

Structural problems, on the other hand, belong to three additional aspects of pathology: aetiology, pathogenesis, and morphologic changes (Kumar, Abbas, and Fausto 2005). Aetiology concerns the causes of disease. Miller identified 8 broad categories of living systems pathologies based on the flow and utilization of matter, energy, and information (see Table II) (J. G. Miller 1978). Capra and Luisi stated that pathology was the "…consequence of imbalance and disharmony…" (Capra and Luisi 2014), whereas modern medical pathology textbooks such as the one cited here claim that no lone aetiologic agent is sufficient to explain the cause of disease (Kumar, Abbas, and Fausto 2005). The development of the social-ecological model (SEM) of public health in the late 1980's (McLeroy et al. 1988) reflects this acknowledgment of complex multilevel causation, and aligns with the aforementioned concepts of structural coupling and structural determinism (Capra and Luisi 2014).

Table II: Aetiology of Living Systems Pathologies

Eight Categories of Pathological Causes (Miller 1978)			
Lack of Matter-Energy Inputs	Excess of Matter-Energy Inputs	Inappropriate Forms of Matter-Energy Input	Abnormalities in Internal Matter-Energy Processes
Lack of Information Inputs	Excess of Information Inputs	Maladaptive Template Information	Abnormalities in Internal Information Processes

Pathogenesis refers to the development and progression of a disease, and morphologic changes refer to structural alterations as a result of said disease. Both Miller (1978) and Capra and Luisi (2014) refer to variables exceeding tolerance limits as defining features of disease, and the resultant adjustment processes can be observed in both pathogenesis and morphological changes. When the costs of adjustment processes become significant they begin to negatively impact routine system maintenance and function (J. G. Miller 1978). When this occurs the system loses flexibility due to lack of resources, and results in a loss of health (Capra and Luisi 2014). The concepts of flexibility and adjustment processes are closely related to resilience theory, wherein resilience is defined as "…the capacity of a system to absorb disturbance and reorganize so as to retain essentially the same function, structure, and feedbacks – to have the same identity" (Walker and Salt 2012); this adaptive capacity can be partially understood within the medical community as a patient's "metabolic reserves" or "residual capacity."

There are essentially two categories of pathologies that place the concept of healing in perspective: self-limiting and non-self-limiting diseases. Systems self-repair by balancing feedback processes (Capra and Luisi 2014), and when critical variables are below thresholds for irreversible adjustment processes, then the "vix medicatrix naturae," or "healing power of nature" is adequate for the system to heal itself (Bynum 2008). This is the definition of a self-limiting disease, and most often supportive care is all that is required. Non-self-limiting diseases, on the other hand, occur when critical variables exceed threshold values, resulting in a cascade of reinforcing feedback loops of adjustment processes, which, if left untreated, will consume all of the resources available to the system resulting in collapse and death. These kinds of diseases require the intervention of practitioners in order to prevent disability or death (Capra and Luisi 2014). Interventions can entail the provision of external resources as well as structural adjustments via medicines, surgery, or other treatments, all with the aim of transforming the non-self-limiting disease into a self-limiting one. Ultimately, addressing the root cause or causes, whether internal or external, is necessary to prevent the continuation or recurrence of disease. Hippocrates originated several aphorisms which are relevant to the healing approach to pathological systems (Bynum 2008):

- "Natural forces are the healers of disease."
- "As to diseases, make a habit of two things – to help, or at least do no harm."
- "Dangerous diseases require dangerous remedies."

Three independent concepts of systems pathology exist in the literature. The first conception originated in the medical specialty of pathology and, drawing from systems biology, general systems theory, and contemporary complexity science research, focuses on human subjects via the subspecialties of "systems pathology" and "clinical systems pathology" (Costa 2012). Systems pathology "seeks to integrate all levels of functional and morphological information into a coherent model that enables the understanding of perturbed physiological systems and complex pathologies in their entirety" (Saidi, Cordon-Cardo, and Costa 2007; Costa 2012), whereas clinical systems pathology "deals with specific problems of a particular patient using the tools of complex science to come up with the solution(s) to the clinical problem" (Saidi, Cordon-Cardo, and Costa 2007; Donovan, Costa, and Cordon-Cardo 2009; Faratian et al. 2009; Costa 2012). It is implied that both of these fields utilize systems ideas for the study and treatment of human disease, and that both fields, drawing from genomics research, have a particular focus on molecular oncology (Costa 2012). This conception of systems pathology makes no attempt to be generalizable outside of the field of medicine, however insights from this established area of study may be useful to such broader applications.

The other two conceptions of systems pathology originated in the systems science academic community as functional approaches to integrating systems ideas, as was discussed in the previous section (Zwick 2018). "Systems pathology," as described by Troncale (and what might alternatively be called "systems isopathology" to prevent confusion with the previously discussed project in medicine), is the study of how systems dysfunction (2013). The normative aspect of functioning is based on the integrated systems framework called "systems processes theory," which draws from numerous fields of rigorous scientific study to identify and describe isomorphic processes. By focusing on isomorphic processes and categorizing pathologies according to these universal processes it is hoped that this knowledge base can contribute to prevention and/or amelioration of dysfunctions in complex systems, especially in the field of systems engineering (Troncale 2013).

The third conception of systems pathology also originated in the systems community, and, owing to its philosophic nature, can be used both as a way of understanding ontological problems as well as approaching focal problems (as was previously discussed). Zwick's "ontology of problems" was envisioned as "…an abstract and coherent account of the origin and essence of problems" (1995). Some problems, such as the seemingly paradoxical nature of good and evil, are fundamental to reality and as such can't be "solved," although by better understanding their nature one may gain valuable insights. "It is imperfection which generates the need for insight," Zwick states, and "…metaphysics can be a rich source of insights needed to improve the human condition and a component of a new scientific worldview" (Zwick 2001). In the dyadic relation of system function and structure, Zwick's functional "ontology of problems" compliments his structural "elements and relations" in much the same way as Troncale's "systems pathology" compliments his "systems processes theory," albeit Zwick adopts a broad metaphysical approach whereas Troncale utilizes a more focused empirical approach. A combination of these two approaches may provide a powerful foundation of knowledge to be utilized for thoughtfully and effectively addressing pathologies in complex living systems.

Evolving a Clinical Framework and Methodology

Now that health, pathology, and the types of systems that possess these attributes have been identified it becomes possible to outline the broad framework and methodology of clinical systemics. It is convenient to utilize the historical template of Western medicine to accomplish this task, and Bynum's brief introduction to the topic serves as a useful guide (2008). In this work Bynum partitions medicine into five categories that in general correspond to the historical period in which they were developed. These categories are "bedside medicine," "library medicine," "hospital medicine," "laboratory medicine," and "community medicine" and shall be elaborated upon below (Bynum 2008).

Bedside medicine, or "clinical medicine" as it is commonly called, is the art and practice of directly interacting with a patient for the purpose of diagnosing and treating pathology. In the Western tradition bedside medicine originated with Hippocrates, whose work included writings concerning botanical medicines, surgery, diagnostics, therapeutics, prevention, and the role of the environment (Bynum 2008). Hippocrates' practice of medicine was guided by a philosophy of holistic individualism which sought to tailor mixed therapies for each unique patient and set of environmental conditions. This approach was based on a humoral understanding of disease, and the humoral model led to the persistent themes of balance and moderation in Western medicine. Galen (129 CE to ca. 210 CE) later formalized the humoral framework, which remained the dominant paradigm until the 19th century, as well as consolidated experimental medicine (Bynum 2008). This coarse view of medicine leads to the recognition of four fundamental elements for clinical systemics: 1) a focal (target) system that is afflicted by some pathology, 2) an environment with which the embedded focal system interacts, 3) an independent intervening system within the environment which seeks to remedy the focal system's pathology, and 4) a body of knowledge from which the intervening system draws insight (see Figure II). This tetrad can be considered the fundamental isomorphic structure to clinical systemics, as it can be used to describe various Western medical schools of thought (e.g. allopathy, osteopathy, etc.) as well as Eastern, indigenous, and other healing traditions. The key differences between these various approaches has to do with the body of knowledge, which in turn defines the essential elements and relations, how tightly or loosely coupled the focal system and environment are, what the aetiologies of disease are, and what treatments are effective and/or desirable.

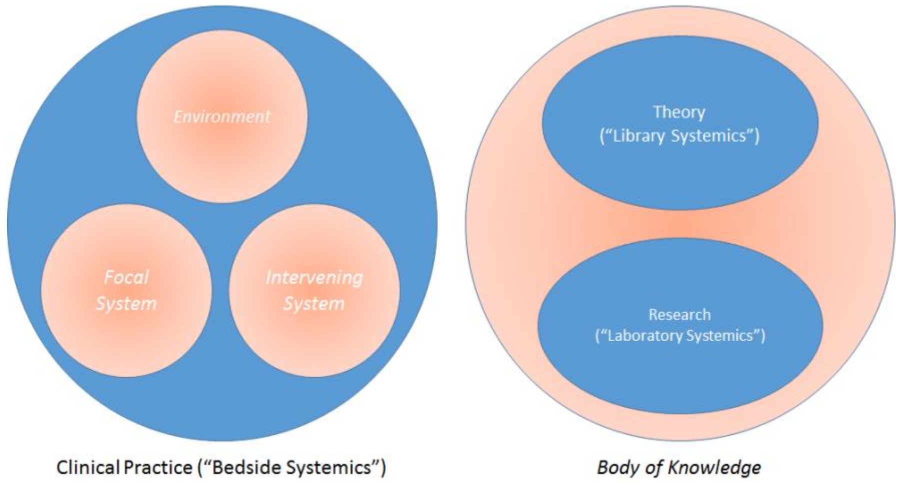

Figure II: The "clinical systemic tetrad" (in red) as it relates to select categories of medicine (in blue).

In order to maintain the health of focal systems, alleviate focal system pathologies, and document case studies for the purpose of improving the body of knowledge it is essential to have a structured methodology. For the intervening system three categories of methods necessitate consideration: intervening system configuration, functional protocols, and documentation. According to the Law of Requisite Variety, the complexity of a regulator needs to meet or exceed the complexity of the environment in order for a regulator to effectively respond to disturbances to some set of essential variables (Ashby 2015). One might consider the intervening system to be a sort of regulator that is making adaptive decisions on behalf of the focal system, and as such could consist of a single individual for simple problems (or thoroughly understood pathologies like those encountered in primary care medicine) or a team of individuals for more complex problems. Multidisciplinary teams would be required to approach multidisciplinary problems since by definition complex systems are non-decomposable (Simon 1996), and thus interventions in any given part would affect the remainder of the system. Such teamwork is advocated by Bar-Yam (2016) in response to problems of social complexity, and can be illustrated in the medical context by trauma teams utilizing various specialists for the care of critically ill patients.

Functional protocols can be grouped into two categories: operations and clinical care. Operations essentially consists of the cycle of activation, activity, and deactivation which is unique to the particular focal and intervening systems (e.g. emergency medical service (EMS) systems have a six phase cycle: early detection, early reporting, early response, on scene care, care in transit, and transfer to definitive care ("Star of Life" 2019); hospital systems cycle a patient through a stationary facility via initial presentation, admission, treatment, and disposition/discharge; disaster management systems have a cycle of mitigation, preparedness, response, and recovery (Bledsoe, Porter, and Cherry 2009)).

In addition to having some protocol (aka algorithm) for initiating, managing, and ending the clinical process it is necessary to have clinical protocols to govern interactions between the focal system and intervening system. The "clinical cycle," which is isomorphic to methodologies in various other fields such as permaculture (Holmgren 2017), consists of an iterative loop of assessment, treatment, and reassessment. The process of assessment can be coarsely described by the "SOAP" mnemonic: Subjective, Objective, Assessment, and Plan. "Subjective" refers to symptoms perceived by the focal system, "objective" refers to any number of diagnostic tests that can be performed on the focal system, "assessment" refers to observable signs that the intervening system perceives during physical interaction with the focal system, and "plan" refers to the process of forming a tentative "differential diagnosis" or, ideally, a definitive diagnosis of pathological causes and processes, coupled with a prescribed plan for therapeutics. Treatments may include supportive care for self-limiting pathologies (as described above in the section on healing), therapeutic introduction of various kinds of matter, energy, or information (e.g. medicine, nutrients, psychological counselling, etc.), or surgical repair/alteration of structures. Lastly, once a treatment is administered it must be given time to take effect, after which the focal system must be reassessed to determine effectiveness and to plan for additional interventions if necessary. The assessment-treatment-reassessment loop is iterated until the system recovers, reaches a new stable steady state, or collapses.

It is important to have standardized treatment algorithms in place to ensure the correct treatments are administered to the particular pathology in question; this is also essential for effective research programs aimed at improving clinical care. To manage both information during the clinical encounter as well as provide case studies and data to research efforts it is necessary to have standardized documentation. Documentation formats on the front (intervening system) end must be simple, easy to use, not require excessive time to complete, and should contain relevant clinical information for review during reassessments. On the back end, documentation is essentially a tabular dataset; to cross-compare different kinds of systems isomorphic variables need to be identified and labelled, optimally during the design of the documentation system (although this may be accomplished post hoc).

The second category of medicine as identified by Bynum is that of library medicine. Prior to the Renaissance the salient feature of medicine was the appreciation, preservation, and commentary of ancient medical texts (Bynum 2008). During this time three lasting features of medicine were created: 1) the Roman invention of hospitals to house and heal wounded soldiers, 2) the hierarchical division of practitioners into physicians (holist practitioners), surgeons (specialist practitioners), and apothecaries (remedy producers), and 3) the university system with medical training that focused on "…disputation rather than practical training or experiments…" (Bynum 2008). These components continue to persist, and some of them have equivalent structures in other fields. As the Renaissance built momentum, investigations into anatomy began with public dissections (ca. 14th century), and later the anatomy text "De humani corporis fabrica" (1543) by Andreas Vesalius (1514-1564) became the first work in medicine where the illustrations were more important than the text (Bynum 2008). Thomas Sydenham (1624-1689), nicknamed the "English Hippocrates," believed that diseases could be classified, the act of which could allow remedies to be empirically tested (Bynum 2008). Overall, library medicine was concerned with curating and expanding the body of medical knowledge, and this knowledge was then disseminated via printed books, public outreach, and through the university system. Identifying which features of library medicine exist and which might be useful to create for the purposes of clinical systemics will be left as an exercise to the reader.

Hospital medicine emerged out of the French political revolution (1789-1848) and had significant positive impacts on both medical education and research. In contrast to the division of medical practitioners and focus on didactic education which prevailed prior to the Enlightenment, Antoine Fourcroy's (1755-1809) medical pedagogy consisted of intense, hospital-based practical training in both medicine and surgery where students treated large numbers of patients (Bynum 2008). The innovations of daily rounds (bedside discussions) and grand rounds (case study presentations) began during this period and persist to this day, and the integration of medical education and hospitals was so successful that "…a medical school without an attached hospital was second rate" (Bynum 2008). Among research innovations, three pillars of hospital medicine emerged: 1) a systematic approach to patient assessment, 2) patho-clinical correlation consisting of extensive documentation of clinical features prior to the patient's death, followed by autopsies to locate structural lesions, and 3) large N-numbers of patients to establish diagnostic criteria and to evaluate therapies (Bynum 2008). Similar methods could be utilized to educate systemic generalists within the present academic framework given a vehicle for supervised practice, and once standardized assessments were developed (perhaps based in part from Miller's 19 critical subsystems (1978) and the constraints and goals of specific classes of focal systems) they could be used to assess historical case studies prior to being used on "live" focal systems.

Laboratory medicine accelerated during the 19th century in parallel with the sciences of physics and chemistry. Scientific medicine was rational and rooted in experimental evidence, and the reductionist paradigm on which it was based led to the steady refinement of the fundamental unit of study from the body to the organs, and eventually to the cells, thus finishing the transition away from the Greek humoral framework (Bynum 2008). Three categories of experimental medicine were established (physiology, pathology, and therapeutics), which is congruent with the philosophical categories of health, pathology, and healing discussed previously. Like many contemporary fields of research, scientific medicine is currently evolving as information processing power enables the use of systems and complexity models (Costa 2012).

The final category of medicine is that of community medicine, otherwise known as public health. Early examples of public health existed during the European Black Plague, which "…tested the limits of…the inevitable nexus of the state and medicine during times of crisis," but it was the 19th century cholera pandemics coupled with new statistical techniques that led to the beginnings of modern public health (Bynum 2008). Public health could be considered an environmental approach to maintaining the health of a population via preventative measures such as sanitation, inoculations and vaccines, and improved standards of living (Bynum 2008). Public health also concerned itself with disease surveillance via surveys and other reporting methods, which often uncovered additional issues requiring attention, and in the event of a disease outbreak the public health system coupled with the state would work to contain the spread of infection (Bynum 2008). From a systems viewpoint, public health aims to prevent and manage focal system pathologies for an entire population from an environmental level of emergence. This is relevant to clinical systemics because it illustrates the need for the explicit awareness of cross-level interactions and feedbacks. At a theoretical minimum clinical systemics would assess system, subsystem, and suprasystem (environmental) levels, although in practice this could be much more expansive depending on the focal system and context (e.g. in treating whole patients medical physicians routinely assesses the molecular level via potassium or calcium blood concentrations, etc.; EMS response must concern itself with the environment operationally (aka how it affects ability to care for a patient) as well as clinically (aka how did/does the environment affect the patient's condition)).

With this being said, the five categories of medicine relate to an integrated clinical systemics in the following way: "bedside medicine" pertains to direct interaction between a focal system and an intervening system, whereas "community medicine" defines the focal system as an aggregate population of focal systems; this illustrates the need to examine multiple hierarchical levels of emergence, and for convenience these two categories might be compressed into a single entity, "clinical practice" (see Figure III). "Hospital medicine" is defined primarily through its physical location, which may vary in clinical systemic practice; ergo this category is omitted explicitly from the framework, although the utility of having some vehicle that integrates clinical practice, research, and education is implicit. "Library medicine" is the curation and dissemination of knowledge, and might be broadly labelled "theory," whereas "laboratory medicine" has a focus on experimentation and thus might be characterized as "research." These three salient categories (as seen in Figure II) relate to one another as illustrated in Figure III, creating a feedback loop of scientific practice. "General Systemics" might better characterize this framework as a whole, since the theory and research elements are familiar to systems science, and science in general. Clinical systemics might best describe the clinical practice element, combined with its relations to the research and theory elements, respectively.

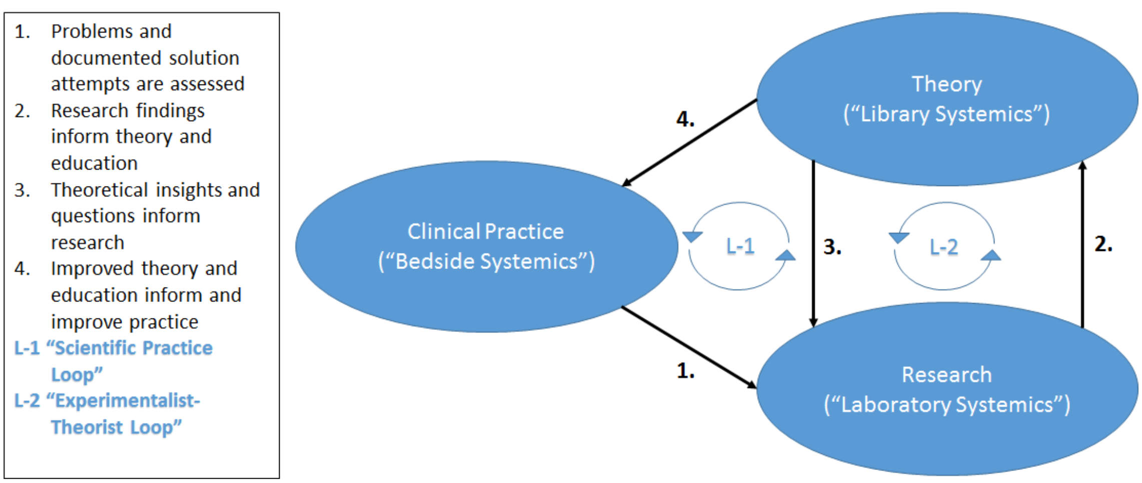

Figure III: Clinical Systemics (or more appropriately "General Systemics") might best be characterized as a framework that integrates clinical practice (e.g. systems practitioners, domain-specific practitioners, multi-disciplinary teams) with research

(e.g. systems pathology, systems engineering, domain-specific research) and theory (e.g. systems philosophy, systems and complexity science, natural and social sciences). The methodology of clinical systemics is most concerned with integrating sets of "soft" and "hard" systems tools, standardizing clinical practice, and closing the "scientific practice loop" via links 1 and 4.

SUMMARY

Clinical systemics is a framework and methodology induced from Western medicine for the purpose of identifying and treating pathologies in complex living systems. It does so by creating standardized protocols and documentation for multidisciplinary teams engaged in clinical practice, and by integrating clinical practice, research, and theoretical elements. The primary benefit to this approach is the ability to address systemic pathologies by integrating disconnected subject matter disciplines. Other benefits include 1) multidisciplinary team practice may prevent, mitigate, or anticipate undesirable consequences from interventions due to the Law of Requisite Variety, 2) standardized operational and clinical protocols enable experimentation with operational processes, clinical processes, tools, and interventions, 3) standardized documentation allows for the empirical study of clinical effectiveness in addition to generating data for the study of isomorphic processes and pathologies, and 4) the "scientific practice loop" created by the integration of practice, research, and theory creates an information pipeline which shortens feedback delays, thus increasing the pace of innovation.

A number of ethical and practical challenges exist in the development and implementation of a general clinical systemics. In terms of value ethics, establishing criteria for what constitutes healthy or "good" systems is of critical importance, as complex adaptive systems will behave in accordance with the goals set by the organizing principle(s). Other ethical considerations are familiar to the field of medicine, and must be addressed in new and differing contexts: clinical studies require the informed consent of the study subjects, breaches of data privacy can create serious problems for the owners of the data, transparency and accountability are necessary to create trust between the clinical systemic institution and those individuals whom are affected by the institution's actions, and decisions made without historical precedent should have ethical considerations documented. And suffice it to say, adopting a clinical approach to natural living systems (e.g. ecosystems) that extend beyond political boundaries will necessitate political and legal considerations. Practical challenges are no less than the ethical ones, and include significant coordination efforts amongst the various disciplines that specialize in a given element of a particular focal system, as well as coordination of the activities of groups focused on practice, research, and theory.

The scientific practice loop informs the next steps in developing and deploying the clinical systemics framework and methodology First, building on this initial assessment and vision, a formal clinical systemic theory needs to be developed, even if it is at first coarse or tentative. Such a theory serves as the "initial conditions" of the iterative scientific practice loop. Next, the clinical systemic framework needs to be communicated to students and practitioners via academic education and continuing professional education. Next, the students and practitioners can deploy methods in actual clinical practice, generating data in the process. This data, in the form of standardized documentation, is then analysed by researchers, which in turn refines theory and the whole loop continues cycling.

In conclusion, the 21st century is a time of many systemic changes, both dangerous and hopeful, in our human systems and in nature. In order to navigate this changing landscape, humans need to creatively adapt to shifts in social structures, economies, and the environment writ large. Clinical systemics offers an integrated, collaborative approach to this systemic adaptation that is grounded in naturalism, rationalism, and science, in contrast with superstition, pseudoscience, and various fundamentalist political, economic, and religious beliefs. As has been the case throughout history, mistakes will be made and societies will rise and fall, but perhaps by actively engaging with scientifically established truths in whole systems the project of clinical systemics can offer insight and hope for the improvement of the human, and planetary, condition.

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