Systems Theory for Complex System Governance

Kaitlynn Castelle, Joseph M. Bradley, and Charles W. Chesterman Jr.

Abstract This chapter introduces a refinement on the conceptual framework for the placement of systems theory propositions relevant to complex systems and provides a perspective for understanding their linkages through systems theory axioms. An overview of the evolution of the framework to its current state is provided. The expanded framework offers a taxonomy of axioms and related concepts to support complex systems analysis from a governance perspective. A view of a complex system through this framework supports an enriched view of the total system. The logical interrelations between the identified axioms may be beneficial in understanding of different aspects of a complex system and provide a referential foundation from which to evolve our systems thinking capacity. Use of the framework supports complex systems analysis through articulation of complementary perspectives and relation to systems theory propositions of the complex system to enhance decision-making and governance.

Keywords Systems theory · Complex system governance

1 Introduction

The historical background and academic literature associated with the definition of "system" and its associated properties is a rich reading of philosophical writings as well as the evolution of science, engineering, and social studies. Systems literature

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explains the properties and behaviors of physical, chemical, biological, social, and economic systems, as well as others. Jackson states "a system is a complex whole the functioning of which depends on its parts and the interactions between those parts" [1] (p. 3). There have been two perspectives when observing or studying systems.

> The traditional, scientific method for studying such systems is known as reductionism. Reductionism sees the parts as paramount and seeks to identify the parts, understand the parts, and work up from an understanding of the parts to an understanding of the whole [1] (p. 3).

An alternative to reductionism is,

> Holism considers systems to be more than the sum of their parts. It is of course interested in the parts and particularly the networks of relationships between the parts, but primarily in terms of how they give rise to and sustain in existence the new entity that is the whole [1] (p. 4).

While the understanding of a system may follow the description provided by Jackson or as attributed to Stafford Beer, a system is what it does, and an underlying intent of the provided conceptual framework is that a system is: "Thus, a system may be identified as such if it exhibits and can be understood within this set of axioms. Conversely, any entity that exhibits these seven axioms is, by definition, a system." [2] (p. 120). Accordingly, a universally agreed-upon definition for systems theory does not exist at present, though the term is ubiquitous in systems literature.

Adams et al. [2] proposed a systems theory construct, resting upon an axiomatic set supported by a set of cited propositions from systems theory literature. Whitney et al. [3] revised the construct based on additional research and constructive feedback from the community. This construct was developed by use of the axiomatic method that will be described. This resulting construct affords both practitioners and theoreticians a prescriptive set of axioms by which a system must operate; conversely, any entity defined as a system will be characterized by a set of seven (7) axioms: contextual axiom, purpose axiom, design axiom, operational axiom, centrality axiom, information axiom, and viability axiom. These axioms are presently organized to conform to the discoverers' induction as proposed by William Whewell, where knowledge can be constructed through the union of sensations and ideas [4]. The use of this inductive inference methodology provided insight of the common themes integrated among systems theory propositions in order to produce a set of axioms that describe systems.

2 Systems History

Between WWI and WWII, a multidisciplinary problem-solving research effort began that incorporated a decomposition of the problem system into individual problems that were related to the respective fields in which they applied. These disparate problems were then to be solved independently of each other, and the independent solutions were later aggregated. As can be anticipated, this approach was later realized as ineffective. Ackoff [5] notes that "different terms are used to refer to the same thing, and the same term is used to refer to different things. This state is aggravated by the fact that the literature of systems research is widely dispersed and is, therefore, difficult to track. Researchers in a wide variety of disciplines and interdisciplinary are contributing to the conceptual development of the systems sciences, but these contributions are not as interactive and additive as they might be" [5] (p. 661).

Thus interdisciplinary research began, in which representatives from different disciplines confronted problem complexes together to solve them collaboratively. The growth of systems theories commenced from immense pressure to develop theories capable of interdisciplinary application. In 1954, biologist von Bertalanffy, economist Kenneth Boulding, physiologist Ralph Gerard, and mathematician Anatol Rapoport collaborated at the Palo Alto Center for advanced study in behavioral sciences, where they discovered the wide applicability of their convergent thoughts stemming from their different fields of study [6]. They soon formed the original bylaws for the foundation of the Society for General Systems Research (SGSR) to: (i) investigate the isomorphy of concepts, laws, and models from various fields and to help in useful transfers from one field to another, (ii) to encourage development of adequate theoretical models in fields which lack them to minimize the duplication of theoretical effort in different fields, and (iii) to promote the unity of science through improving communications among specialists [7] (pp. 435–436).

Then, von Bertalanffy [6] continued writing on the subject throughout his career, recognizing the gravitation toward integrated natural and social sciences, centered in systems theory. He noted that by unifying principles expressed in dissonant fields, the effort could eventually lead to a "much-needed integration in scientific education" [6] (p. 37). Biologist Paul A. Weiss declared that this conceptual integration would "render the map of knowledge more complete and more consistently coherent" [8] (p. 159).

There has not been a full adoption of a generally accepted canon of systems theory within the discipline, albeit the potential for systems theory has been realized in theory or practice, as noted by Checkland [9]. Still, practitioners can greatly benefit from the body of knowledge that does exist, which certainly provides necessary propositions that are relevant for common practice.

3 Discoverers' Induction Methodology and Criteria for Inclusion

This section will discuss the use of discoverers' induction as proposed by William Whewell where knowledge can be constructed, in particular the use of this inductive inference methodology provided insight of the common themes integrated among systems theory propositions in order to produce a set of axioms that describes systems. The axioms as they are currently organized conform to the discoverers' induction as proposed by William Whewell where knowledge can be constructed through the union of sensations and ideas [4]. The use of this inductive inference methodology provided insight of the common themes integrated among systems theory propositions enabling the formulation of a set of axioms that describes systems. There are two steps to discoverer's induction, as follows [4]: First, colligate known members of a class by the use of an idea or conception and second, generalize this concept over the complete class, including its unknown members.

Colligation, as defined by Snyder, is "the mental operation of bringing together a number of empirical facts by "super inducing" upon them some idea or conception that unites the facts and renders them capable of being expressed by a general law" [4] (p. 585). This new knowledge adds to the current body of facts, causing them to be seen in a new light. With respect to systems theory, there is an elucidation of the generalized properties of systems.

Generalizable knowledge projected onto unknown members of a class (i.e., unidentified propositions that would support the development of axioms) suggests that the listing of proposed axioms may be incomplete or omitting some aspect of absolute truth.

3.1 Axioms

The purpose of a systems theory construct is to unify the large set of systems theory concepts related to systems studied in academic literature and broad field of systems research, to develop an organizing construct for understanding and studying systems. Axioms capture irrevocable truths that can be universally accepted for the sake of studying systems, in that they have been regarded as established, legitimate, and accepted without further demands for justification:

- Publication as organizing construct in multiple venues for systems literature
- Acceptable to experts/scholars in the field.

Axioms are at the core of the systems theory construct formulated for complex system governance (CSG) and convey themes about systems as supported by the systems theory propositions.

3.2 Proposition

A proposition is a principle, law, or concept presented for consideration as it pertains to the inherent nature of a system by providing insight about the qualities or tendencies of systems, as articulated in empirical research in a variety of disciplines that discuss systems. Propositions reflect the current state of knowledge, without assuming fundamental, universal *truth* about a system. They reflect a widely accepted set of concepts proposed about systems, through empirical research, and discussed in the body of systems theory literature. The following captures the criteria for inclusion as a proposition:

- Multiple citation in the systems literature or capture in seminal work
- Acceptable to experts/scholars in the field
- Provides explanatory or predictive power for system behavior, structure, or performance
- Assignable to an existing axiom or foster creation of a new axiom.

Ontology is the study of what is and Epistemology is the study of knowledge and justified belief. This chapter does not limit the system theory concepts to an objective ontological and epistemological perspective basis. Table 1 below, drawn from [10], lays out a topology of thinking and the developed views from the subjective to the objective approaches to social science.

4 Framework

This section introduces the systems theory framework that provides a basis for complex systems governance. The inductive analysis resulted in the following set of supporting propositions mapped to axioms. The systems theory axioms are provided below. Section 5 will expand on each of the axioms for systems theory with descriptions and their primary proponents in systems literature.

Table 1 Network of basic assumptions characterizing the subjective–objective debate within social science. Adapted from [10] (p. 492)

Subjectivist approaches to social science

Objectivist approaches to social science

Research methods	Exploration of pure subjectivity	Hermeneutics	Symbolic analysis	Contextual analysis of Gestalten	Historical analysis	Lab experiments, surveys
Core ontological assumptions	Reality as a projection of human imagination	Reality as a social construction	Reality as a realm of symbolic discourse	Reality as a contextual field of information	Reality as a concrete process	Reality as a concrete structure
Basic epistemological stance	To obtain phenomenological insight, revelation	To understand how social reality is created	To understand patterns of symbolic discourse	To map contexts	To study systems, process, change	To construct a positivist science
Assumptions about human nature	Man as a spirit, consciousness, being	Man as a social constructor, the symbol creator	Man as an actor, the symbol user	Man as an information processor	Man as an adapter	Man aa a responder
Research methods	Exploration of pure subjectivity	Hermeneutics	Symbolic analysis	Contextual analysis of Gestalten	Historic analysis	Lab experiments, surveys

(continued)

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Core ontological assumptions	Reality as a projection of human imagination	Reality as a social construction	Reality as a realm of symbolic discourse	Reality as a contextual field of information	Reality as a concrete process	Reality as a concrete structure
Basic epistemological	To obtain phenomenological insight	To understand how social reality is constructed	To understand patterns of symbolic discourse	To map context	To study systems, processes change	To construct a positivist science
Assumptions about human nature	Man as pure spirit, consciousness, being	Man as a social constructor, the symbol center	Man a an actor, the symbol user	Man as information processor	Man as an adaptor	Man as a responder
Research methods	Exploration of pure subjectivity	Hermeneutics	Symbolic analysis	Contextual analysis of Gestalten	Historic analysis	Life experiments, surveys

1. **Contextual Axiom**: The contextual axiom states that *system meaning is informed by the circumstances and factors that surround the system*. The contextual axiom's propositions are those which bound the system by providing guidance that enable an investigator to understand the set of external circumstances or factors that enable or constrain a particular system.
2. **Purpose Axiom**: The purpose axiom states that *systems achieve specific goals through purposeful behavior using pathways and means*. The goal axiom's propositions address the pathways and means for implementing systems that are capable of achieving a specific purpose.
3. **Design Axiom**: The design axiom states that *system design is a purposeful imbalance of resources and relationships*. Resources and relationships are never in balance because there are never sufficient resources to satisfy all of the relationships in a system's design. The design axiom provides guidance on how a system is planned, instantiated, and evolved in a purposive manner.
4. **Operational Axiom**: The operational axiom states that *systems must be addressed in situ, where the system is exhibiting purposeful behavior*. The operational axiom's propositions provide guidance to those that must address the system in situ, where the system is functioning to produce behavior and performance.
5. **Centrality Axiom**: The centrality axiom states that *central to all systems are two pairs of propositions; emergence and hierarchy and communication and control*. The centrality axiom's propositions describe the system by focusing on (1) a system's hierarchy and its demarcation of levels based on emergence arising from sub-levels and (2) systems control which requires feedback of operational properties through communication of information.
6. **Information Axiom**: The information axiom states that *systems create, possess, transfer, and modify information*. The information axiom provides understanding of how information affects systems.

7. **Viability Axiom**: The viability axiom states that *key parameters in a system must be controlled to ensure continued existence*. The viability axiom addresses how to design a system so that changes in the operational environment may be detected and affected to ensure continued existence.

5 Framework Use and Identification of Anticipated Outcomes

This section will describe how the framework can be used and provides to the user what can be anticipated outcomes with the use of the framework.

5.1 Contextual Axiom

Contextual axiom states that *system meaning is informed by the circumstances and factors that surround the system*. The contextual axiom's propositions are those which bound the system by providing guidance that enable an investigator to understand the set of external circumstances or factors that enable or constrain a particular system.

Proposition and primary proponent	Description of proposition
• Complementarity [11]	Two different perspectives or models about a system will reveal truths regarding the system that are neither entirely independent nor entirely compatible
• Boundary [6, 12]	The abstract, semi-permeable perimeter of the system defines the components that make up the system, segregating them from environmental factors, and may prevent or permit entry of matter, energy, and information
• Incompressibility [13, 14]	Each element in the system is ignorant of the behavior of the system as a whole and only responds to information that is available to it locally. As such, the best representation of a complex system is the system itself and that any representation other than the system itself will necessarily misrepresent certain aspects of the original system
• Holism [15]	A system must be considered as a whole, rather than a sum of its parts

The way we interpret systems is dependent upon the perspective of the observer and the boundary drawn around the open system, which determines what is included and excluded to inform the interpretation of system throughput and system environment. No two vantage points are identical.

Imagine you are in a restaurant with two of your friends. The menu has recently changed. What caused the menu to change? Your friends are disappointed and begin a debate, speculating reasons for the new menu. One decides that the restaurant is trying to increase profits by changing the portion sizes and limiting the amount of ingredients in inventory. The other says the changes must be as a result of a change in management.

You are not disappointed because the menu changed, because you understand that the needs the restaurant fulfills extend beyond the preferences of your friends. You reason that the menu change could be due to one or many factors, including that the menu selections may be governed by, for example, time of year for seasonal items, tourism fluctuations, internal change of staff, locals' preferences, market trends, and others. As the conversation drifts towards your ongoing software modernization project, you realize the debate between use of one automation tasking tool versus another also largely depends on the context surrounding the system's use case and desired outcomes.

System actors and observers are limited by their perspectives, and the more complex the system, the more challenging it is for the represented system to be "compressed" as perception is limited to the only available information. The best representation of the system is the system itself, with explicit and shared understanding of the intended system purposes, as the set of contextual elements is rarely fully exhaustive and objectively interpreted. Understanding the nature of the intended outcomes of the system stakeholders and use cases becomes a basis to inform the development of a solution to address a system need. Through any transformation, the solution system with selection of changes based on contextual considerations (with or without appropriate appreciation of context) can have intended or unintended outcomes as new component interactions take place that change the system definition.

When we think about systems, we must think of them as integrated wholes, as they are more than a collection of interacting parts decoupled from other systems and their environment. Their combined interaction transcends our ability to model the total system's behavior; thus, we acknowledge incompressibility. Holism is a metaphysical ideal, defined by Smuts [16] as "the ultimate synthetic, ordering, organizing, regulative activity in the universe which accounts for all the structural groupings and syntheses in it, from the atom and the physic-chemical structures, through the cell and organisms, through mind in animals, to personality in man" (p. 314).

As our view of the complex system is limited, similarly, our interpretation of system purpose is also limited. As such, Stafford Beer conceded that the observer of the system is the one that recognizes the purpose of the system; i.e., what the system does [17]. What the system does, and whether it meets the intended needs, is largely influenced by the system design choices and their fit for the application context.

5.2 Purpose Axiom

Purpose axiom states that *systems achieve specific goals through purposeful behavior using pathways and means*. The goal axiom's propositions address the pathways and means for implementing systems that are capable of achieving a specific purpose.

Proposition and primary proponent	Description of proposition
• Equifinality [18]	If a steady state is reached in an open system, it is independent of the initial conditions and determined by the system parameters, e.g., rates of reaction and transport
• Multifinality [19]	Radically different end states are possible from the same initial conditions
• Purposive behavior [20]	Purposeful behavior is meant to denote that the act or behavior may be interpreted as directed to the attainment of a goal, i.e., to a final condition in which the behaving object reaches a definite correlation in time or in space with respect to another object or event
• Satisficing [21, 22]	The decision-making process whereby one chooses an option that is, while perhaps not the best, good enough

Now, consider the perspective of a franchise restaurant owner. Equifinality holds that a given outcome (Y), for example, increased year-over-year net profit of 15%, can be reached from a number of different strategies or development paths (X_1, X_2, …, X_n), including a range of possible menu changes. Although it may be that the paths are not equal, rather, other interacting factors in the environment may contribute to the achievement of the goal.

Conversely, the vast contextual factors enhancing or restricting system performance increase the difficulty in proving a causal relationship from a chosen path. Multifinality reduces our confidence that a restaurant franchise's market strategy X will lead to predicted success Y, as even franchises with similar initial conditions will have dissimilar outcomes (Y_1, Y_2,… Y_n). To establish a casual relationships between strategy X and outcome Y, it is required that: (i) the two variables covary, such that changes in the change in the strategy correlate with change in the profit; (ii) the change in the variable assumed to be the cause, in this case, the strategy precedes in time the observed change in the resulting profit; and (iii) alternative explanations for the rise in profits have been ruled out (e.g., overall food costs, improved efficiency).

Consider another case study: The LCS class Littoral Combat Ship was allowed two different design philosophies for which the Navy would later down select to a single design. Simultaneously, the Freedom (displacement hull) class and the Independence (trimaran) class were developed. Both ships designs met the operational requirements established by the US Navy and achieved them through different approaches, demonstrating equifinality. To demonstrate multifinality, consider the program's significant cost and schedule overruns due to changing requirements (among other reasons), eventually leading to contract cancelations for the first two contractors. A range of cost and schedule variances in either direction are possible when deviating from an initial set of requirements. Still, entirely different outcomes could have occurred, and tracing the specific contextual factors leading to outcomes and the point in time in which their individual and combined contribution to the inevitable outcome is difficult to draw absolute conclusions. The Virginia Class submarine provides another example, as it fulfilled its purpose of meeting delivery cost and schedule demands, but carries lessons forward for improving other program outcomes in future classes, such as supply chain growth and sustainment costs.

Achieving a specific purpose is not accomplished without a vision, philosophical assumptions, stategic plan, and feedback process to inform the governance scheme. The execution of the design will be discussed in the next section as well as the effort involved with the evolution of the design.

5.3 *Design Axiom*

Design axiom states that *system design is a purposeful imbalance of resources and relationships*. Resources and relationships are never in balance because there are never sufficient resources to satisfy all of the relationships in a systems design. The design axiom implies that the system viability is influenced by the governing framework by which a system is planned, instantiated, and evolved in a purposive manner.

Proposition and primary proponent	Description of proposition
• Minimal critical specification [23, 24]	This proposition has two aspects: negative and positive. The negative simply states that no more should be specified than is absolutely essential; the positive requires that we identify what is essential
• Power law [25]	The probability of measuring a particular value of some quantity varies inversely as a power of that value
• Requisite parsimony [26, 27]	The capacity of human short-term recall is no greater than seven plus or minus two items
• Requisite saliency [28]	The factors that will be considered in a system design are seldom of equal importance. Instead, there is an underlying logic awaiting discovery in each system design that will reveal the significance of these factors
• Requisite hierarchy [29]	The weaker in average are the regulatory abilities and the larger the uncertainties of available regulators, the more hierarchy is needed in the organization of regulation and control to attain the same result, if possible at all

A system under observation by the observer can be considered as in existence, undergoing change, or the observer is part of a team/group that has been tasked with creating something new. Any of these observations of where a system is in its evolution does not detract from the contribution of system design and the various propositions. Associated with system design, most are familiar with the organization or structure of formal elements in the terms: requirements, intentions, synopsis of intent, and specification. Each of these terms helps bring forward to the system design an understanding of what the system is to be doing. The practicality of these terms is to reduce the instruction so that the end is fully achieved. So as part of observing a system, matching system construct and mechanisms to specifications lends itself to determining how well the system has been organized.

The ability to fully observe and understand a system under observation may not be fully achievable, especially due to the size of the system under observation and the capacity of the observer. Hence, the parsing of the observation to a team centered on solving a specific problem and a minimum viable product can be effective, remembering that the team likewise will need a design, and in many respects, the propositions associated with system design are most applicable to the creation and tasking of a team. For example, software development team's shift from "waterfall"- to "agile" development will find their team members focused more distinctly on the features and properties most salient to the end users, based on their use case and needs. This recognition goes beyond small teams that are collocated, but rather is thought to be adaptable to any size and dispersion of groups of people.

There are three interrelated concepts that can help with the creation and tasking of a team for system design or observation of a system under observation. Where the system under observation appears to be large and complex, the needs of the hierarchy will be large as well, but with a degree of purposeful design for how a team of teams will work together to achieve outcomes, and how they will account for learning. Observations of what to build or how to build it are not all equal in importance, and with continual observation, the actual system design will materialize, and with this emergence, the significant factors more easily identifiable. Lastly, as the human has limited capacity, a team of teams must be organized in such a way that they may focus their energy on a minimum viable products with a common understanding of goals. This supports the team's ability to maintain momentum in a sustainable manner, and reduces the frequency of context switching and the need to re-orient within the system. At scale, teams must be brought back together to observe what has been captured, adjust for learning and prioritization, and then sent with new tasking The selected items to accomplish within a prescribed timebox are meant to be parsimonious in nature, and allow for natural evolution of a robust and viable system that may be flexibly integrated.

The observation of the system in situ, the understanding of its capabilities as it performs operational functions while maintaining viability will be discussed in the next section.

5.4 Operational Axiom

Operational axiom states that *systems must be addressed in situ, where the system is exhibiting purposeful behavior*. The operational axiom's propositions provide guidance to those that must address the system in situ, where the system is functioning to produce behavior and performance.

Proposition and primary proponent	Description of proposition
• Dynamic equilibrium [6, 30]	An entity exists as expressions of a pattern of processes of an ordered system of forces, undergoing fluxes and continuing flows of matter, energy, and information in an equilibrium that is not static
• Homeorhesis [31, 32]	The concept encompassing dynamical systems that return to an acceptable trajectory through adjustments in dynamic equilibrium controlled by interrelated regulation mechanisms
• Homeostasis [33]	The property of an open system to regulate its internal environment so as to maintain a stable condition, by means of multiple dynamic equilibrium adjustments controlled by interrelated regulation mechanisms
• Redundancy [34]	Means of increasing both the safety and reliability of systems by providing superfluous or excess resources
• Relaxation time [35, 36]	Systems need adequate time to recover from disorder that disturbs its equilibrium, at which point characteristic behavior resumes
• Self-organization [37]	The spontaneous emergence of order out of the local interactions between initially independent components
• Sub-optimization [38]	If each subsystem, regarded separately, is made to operate with maximum efficiency, the system as a whole will not operate with utmost efficiency

Where the system design provides guidance on how a system is planned created, established, and that with time it has modified itself in a fashion that is reflective of a purposive manner that is directly related to the system design, the propositions associated with this section deal with the guidance on the system functioning to produce behavior and performance. Whether one is involved with a small system or only associated with a small portion of a large system, one with little time can recognize that even small systems are composed of small entities that form a whole.

The abstraction of this can be that government is made up of various hierarchies from local up to the federal level and beyond. Each type of government has the tendency to operate within their level in this hierarchy. There are several observations with respect to government that can be made:

- If each level of government is allowed to operate with maximum efficiency, the whole system as a whole will not operate with utmost efficiency (sub-optimization).
- Means of increasing both the safety and reliability of government is by providing superfluous or excess resources (redundancy).
- Government needs adequate time to recover from disorder that disturbs its equilibrium (earthquakes, extensive fire, hurricanes) at which point characteristic behavior resumes (relaxation time).

These observations while not always universal nor necessarily globally applicable, hopefully, they will convey some of the characteristics of where human guidance does produce a behavior and performance of a system. For the observer of a system that is a commercial enterprise, human characteristics will be recognizable.

Taking the observations and overlaying them on the system design, it is possible for there to be a one-for-one match between the observations and the design. In fact, one would expect that there may be a one-to-many match between design and observations where the differences found between the many observed identify where there is more than one process requiring more observation and evaluation. Where the observation leads one to conclude that the system does not appear to be static but is not undergoing a wide range of radical changes, this reflects the system design exercising regulation of its internal environment so as to maintain a stable condition, by means of multiple dynamic equilibrium adjustments controlled by interrelated regulation mechanisms.

A Systems Theory—Operational Axiom in CSG Vignette—Sub-optimization
Behaviors expected from systems should be described by the axioms proposed in this chapter. As an example, one should expect that any system should exhibit sub-optimization. For a system as complex as the Boeing 747, this means that there had to be trade-offs made, so for increased cargo-carrying capacity, there was an associated maximum airspeed. For a system such as a laptop computer that there may need to be a minimum temperature for optimum operation of the faster processing chip, hence, the use of the laptop in the artic may not be advisable. These examples hopefully illustrate that the use of one of the propositions described in the book, the axioms, and associated propositions provides to the reader insight and hopefully understanding of the internal system behavior. Gaining this insight affords all how system theory affords a more significant overall system understanding.

5.5 Centrality Axiom

Centrality axiom states that *central to all systems are two pairs of propositions: emergence and hierarchy and communication and control*. The centrality axiom's propositions describe the system by focusing on (1) a system's hierarchy and its demarcation of levels based on emergence arising from sub-levels and (2) systems control which requires feedback of operational properties through communication of information.

Proposition and primary proponent	Description of proposition
• Communication [12, 39, 40]	Communication is a transaction between the information source terminal and the destination terminal, with the sole aim of generation and reproduction of symbols. Information is transmitted as a selection along possible alternative states
• Control [9]	The process by means of which a whole entity retains its identity and/or performance under changing circumstances

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Proposition and primary proponent	Description of proposition
• Emergence [9, 41, 42]	Whole entities exhibit properties and patterns that are meaningful only when they are attributed to the whole, not its parts
• Hierarchy [9, 43]	Entities meaningfully treated as wholes are built up of smaller entities, which are themselves, wholes. In a hierarchy, emergent properties denote the levels

The axioms and propositions up to this point have described the various areas to consider with respect to a system with the exception of the boundary that demarks the system and the environment. The centrality axiom is a focus on the vital, critical, and important aspect of the condition of being central to a system. It is this pairing of two sets of propositions that describes that of being central.

It has previously been described that systems exhibit properties and patterns that only when they are considered as whole entity, they exhibit meaning. The first pairing of propositions deals with structure of the entities or parts of a system. While there may be character to some of the parts, it is not recognized as complete till it is all assembled. An excellent example is a train, where it is more than just an engine, it has one or more cars, and one of any of the cars being in the furthest position away from the engine is considered the caboose or end of the train. This combination of engine and car/s exhibits properties that when considering just an engine and/or a car/s, none of these individual units can emulate a complete train. Additionally, as there is a hierarchy or combination of the smaller entities, which all would agree are whole themselves, then one can understand that as the train exists in a hierarchy, that each of the entities can have emergent properties that are different from the whole train.

The second pairing of communication and control brings forth identity order. The train example will be used to continue the discussion. The movement of a train is limited by various forms of communication to its operators as well as the design and material condition of the track as well as weather. The overall effect of communication and control is to have a train pass from one geographic place to another safely and on schedule. In the design of the communication for the train, safety is a paramount factor even with ever-changing weather conditions. Communications provide a foundation for control of the train as well as informing entities external to the system. The execution of control ensures that the identity and performance of the train are within the design.

The centrality of a system has been discussed, and the next section will develop how information is involved in a systems operation.

5.6 Information Axiom

Information axiom states that *systems create, possess, transfer, and modify information*. The information axiom provides understanding of how information affects systems.

Proposition and primary proponent	Description of proposition
• Information redundancy [44]	The number of bits used to transmit a message minus the number of bits of actual information in the message
• Redundancy of potential command [45]	Effective action is achieved by an adequate concatenation of information
• Conway's law [46]	The basic thesis … is that organizations which design systems … are constrained to produce designs which are copies of the communication structures of these organizations

The use of this axiom leads to an understanding of how information (data/information) affects a system of interest. Specifically, the information is created, it is retained/stored, it is moved from one location/individual to another, and the information is not static, but changes. Chapter "Perspectives on Complex System Governance Performance" will go in much greater detail on the mechanisms of communication, but the reader when looking at a system of interest can start to question, observe, and articulate answers to the following questions; how information is created, where is it possessed, how can it be changed (it will be), and how it has moved from its initial starting point.

The secondary level of questions/observations with respect to information is to determine the "who" whether internal to the system under observation or the external environment—coupled with the "who" is the rate of information or volume of information created. Additionally, when the information is received, does it result in the accomplishment of the intended action? Does the set of observations begin to develop answers, relative to the information, a result of normal system actions, or is it the observation the instigator of actions in the system under observation? Also, where the results are anticipated? And, was there an increase or decrease of variety?

This set of efforts develops a mapping of information (from-to), the reason for the instigation of information movement, and the effect of the information on the recipient. It starts to layout part of the foundation of the system under observation identity as well as defining the roles of the participants, either internal or external. This set of efforts must also take Conway's law into account when designing the organization, as it will also affect the products of that organization.

A Systems Theory—Information Axiom in CSG Vignette—Conway's Law

Mel Conway proposed the following idea in a paper from 1968, now famously known as Conway's Law:"Any organization that designs a system (defined broadly) will produce a design whose structure is a copy of the organization's communication structure." The hypothesis orginated from Conway's observations that software with components that function well together were developed by teams that worked closely and communicated often. What this tells us is that when segregated teams are building parts of a system, the design of the subsystem or components may be based on uncommunicated and differing assumptions, leading to locally optimized design choices, potential inconsistencies and dependencies, integration risk, and requiring additional communication. Frequent iteration is also less likely, and reliant on formal mechanisms that constrain the team's ability to self-organize.

5.7 *Viability Axiom*

Viability axiom states that *key parameters in a system must be controlled to ensure continued existence*. The viability axiom addresses systems that remain in continued existence do so by adequately adapting to changes in their environment.

Proposition and primary proponent	Description of proposition
• Circular causality [47]	An effect becomes a causative factor for the future "effects," influencing them in a manner particularly subtle, variable, flexible, and of an endless number of possibilities
• Feedback [48]	All purposeful behavior may be considered to require negative feedback. If a goal is to be attained, some signals from the goal are necessary at some time to direct the behavior
• Recursion [17]	The fundamental laws governing the processes at one level are also present at the next higher level. Recursive Systems: The fundamental laws governing the processes, functions, and structure at one level are also present at the next higher level. In a recursive organizational structure, any viable system contains and is contained in a viable system
• Requisite variety	Control can be obtained only if the variety of the controller is at least as great as the variety of the situation to be controlled

Ashby's work on the Law of Requisite Variety postulated that for a system to remain viable, the variety of the environment must be matched by the variety of the system Variety represents complexity or the number of potential states of a system or environment: The more possible states, the more complexity is present [49]. Attenuation describes a system's feedback mechanism which allows regulation of key parameters by transduction or filtering of variety from the environment, a necessary ability for a viable system [17] to independently detect, respond, or adapt to challenges in the environment [50].

Viability is the ability of a system to continually maintain function and structure within a certain environment [51] at a system's level of recursion: "In a recursive organizational structure, any viable system contains, and is contained in, a viable system" [17] (p. 118). Stafford Beer's work on the Viable System Model (VSM) is built on the work of Ashby and defined necessary and sufficient conditions for a system to remain viable at any level of recursion [52]. "Recursion" refers to a concept of viable systems existing within each other and is applicable to any organization, regardless of size, sector, scope, or purpose.

The basis of viability is founded on adequate system governance: adequate regulation, control, communication, and coordination [53]. Systems attenuate variety from the environment through generation of requisite variety resulting from:

- Events within the system environment that become a causative factor for the future environmental effects
- Interaction with other systems
- Interaction of inter-system components.

Consider the As We Flourish You Lose theorem (AWFUL) [54]: We live in a zero-sum resource world, without biophysical limits on growth and expansion, yet competition prevents everyone from winning, and the success of any species necessarily requires comparative disadvantage of others in the exploitation of finite resources. Laszlo [55] states that one of the main challenges to humanity at this point in our collective history is to,

> find systemic alternatives to either adapting the world to us to the point of overload or adapting ourselves to the world to the point of evanescence. The options in this third direction must promote systemic sustainability, that is, integral approaches to human relationships between ourselves and co-adaptation—strategies for adapting with the world, rather than either adapting ourselves to it or forcibly adapting it to us (p. 165).

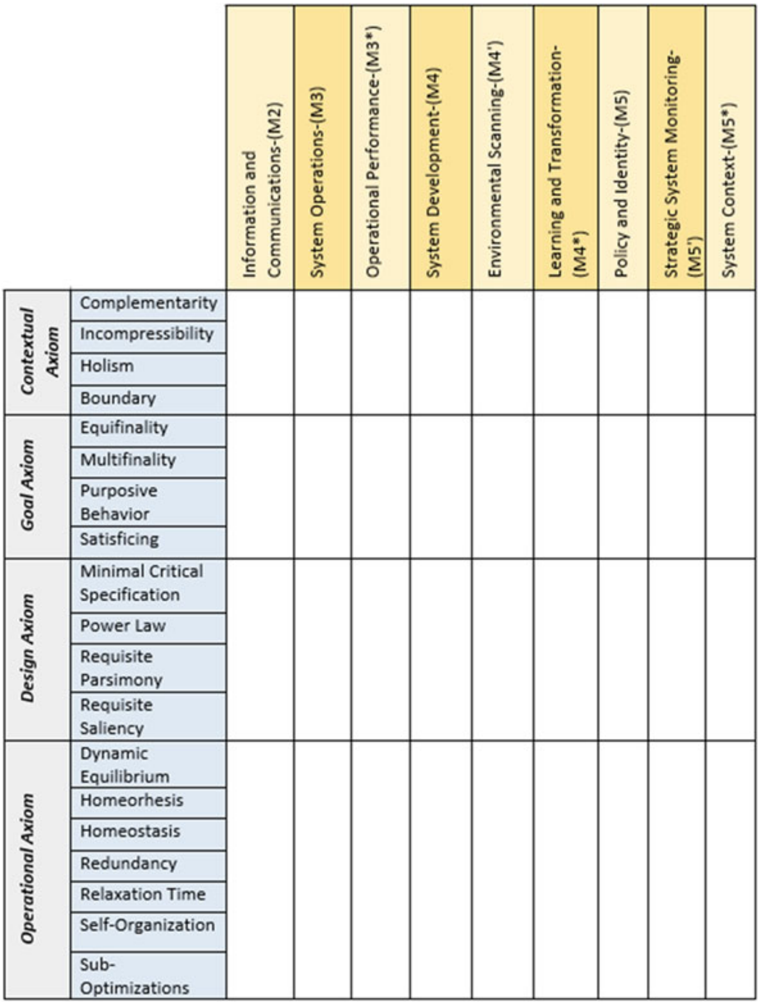
6 Conclusion

This chapter built upon the reader's understanding of the systems theory framework to enable it to be the basis of informed design and decision-making concerning governance functions. The theoretical basis of systems theory increases one's understanding of real-world systems and provides for improved interpretation while supplying the fundamental underpinning for analyzing complex systems. The construct for systems theory presented in this chapter provides a foundation for understanding multidisciplinary systems by improving the ability to explain and predict the behavior derived from the natural order of systems, thereby enabling holistic analysis and problem-solving. An associated language of systems is enabled in the assimilation of systems theory, which becomes a "lens" to facilitate the interpretation of complex systems and related problems by allowing the grounding of observations in a theoretical-based foundation. Systems theory is also multidisciplinary in application, as it is removed from traditional disciplinary problem-solving approaches. As such, it provides an ideal groundwork for the consideration of governance in complex systems.

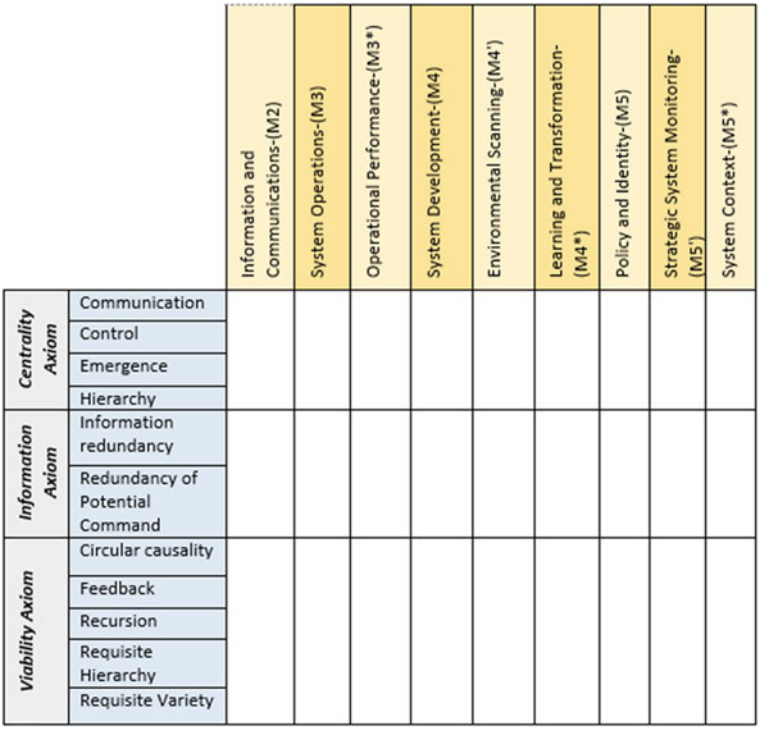
The authors believe that building upon the propositions associated with systems theory as presented here enables the reader to develop an important foundation to navigate through issues related to systems. Practitioners can especially use this chapter and the reading of other chapters to develop the appropriate perspective to use as a lens when viewing multidisciplinary systems and their associated issues and problems. This lends itself to decision-making that is informed by systems theory allowing for informed considerations by the user. Specifically, these sets of seven axioms with supporting propositions cover the vital arena of systems theory and inspire confidence in understanding issues that one encounters. We suggest that the use of the presented well-developed foundation based upon the theory will increase confidence in systems theory-based decision-making.

7 Exercise

1. Provided is a table of axioms and propositions that are relative to the metasystem functions. From the reading, determine which axioms and relative propositions are appropriate for the metasystem functions.



		Information and Communications-(M2)	System Operations-(M3)	Operational Performance-(M3*)	System Development-(M4)	Environmental Scanning-(M4')	Learning and Transformation-(M4*)	Policy and Identity-(M5)	Strategic System Monitoring-(M5')	System Context-(M5*)
Contextual Axiom	Complementarity									
	Incompressibility									
	Holism									
	Boundary									
Goal Axiom	Equifinality									
	Multifinality									
	Purposive Behavior									
	Satisficing									
Design Axiom	Minimal Critical Specification									
	Power Law									
	Requisite Parsimony									
	Requisite Saliency									
Operational Axiom	Dynamic Equilibrium									
	Homeorhesis									
	Homeostasis									
	Redundancy									
	Relaxation Time									
	Self-Organization									
	Sub-Optimizations									



		Information and Communications-(M2)	System Operations-(M3)	Operational Performance-(M3*)	System Development-(M4)	Environmental Scanning-(M4')	Learning and Transformation-(M4*)	Policy and Identity-(M5)	Strategic System Monitoring-(M5')	System Context-(M5*)
Centrality Axiom	Communication									
	Control									
	Emergence									
	Hierarchy									
Information Axiom	Information redundancy									
	Redundancy of Potential Command									
Viability Axiom	Circular causality									
	Feedback									
	Recursion									
	Requisite Hierarchy									
	Requisite Variety									

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