Topics in Safety, Risk, Reliability and Quality

Charles B. Keating
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James C. Pyne *Editors*

Complex System Governance

Theory and Practice

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To my parents Bernie and Charlene and my wife Jean

—Charles B. Keating

To my nephews, Raoul and Reuben, and niece, Raïssa Tchomba

—Polinpapilinho F. Katina

To others in the pursuit of knowledge and understanding

—Charles W. (CW) Chesterman Jr.,

To my many colleagues who continue to contribute this domain

—James C. Pyne

Series Foreword

We are very fortunate, and unfortunate, to be witnessing the possibilities and challenges that our complex systems continue to present. Fortunate in that technology and integration of complex systems are creating opportunities to advance society in substantial ways. New advances such as artificial intelligence, augmented and virtual reality, big data, blockchain technology, cloud computing, Industry 4.0, and Internet of things are creating conditions that promise to enhance the quality of life for people across the world. Despite these advances, we are also unfortunate, in that problems stemming from increasingly complex systems seem to be outpacing our ability to 'keep up.' Despite our best efforts, we continue to be confounded by complex systems, unable to 'tame' them. Our complex systems seem to be producing as many problems as they solve. We would be naïve to think that we have mastered our complex systems.

As we attempt to become more effective with complex systems, we need to answer three questions. First, how did we get here? There is not a particularly satisfying answer to this question. What we do know is that complexity is accelerating and what has worked in the past no longer seems capable of addressing the new reality of complex systems. The second question is, why have we not been able to 'get out' of our predicament, despite being the most advanced society ever experienced in human history? Despite being advanced in technology and knowledge, we continue to be confounded by complex systems. We certainly have not managed to keep up with the demands to deal with increasing complexity effectively. The third question is, how can we escape the stranglehold that complex systems appear to be placing on every aspect of society? Irrespective of advances across all sectors serving society, we are left without a reasonable diagnosis and prognosis for escaping the complexity conundrum. While Complex System Governance is not suggested as a universal answer to address this question, it is poised to make considerable contributions toward an answer.

Complex System Governance (CSG) has been introduced as an emerging field, probably not currently known to a wide audience. However, in the spirit of the scientific revolution, perhaps it should be known. CSG is not known for the quantity of scholars and practitioners who have a working knowledge of the field. Instead, CSG has been quietly unfolding from the first efforts dating to 2014. What has emerged is a new and novel field that has been deliberately and cautiously maturing. The focus of development has been grounded in the underlying conceptual and theoretical foundations as the first point of emphasis. This has set the stage to move beyond conceptual foundations to begin developing tools, methods, and techniques for the application of CSG in operational settings.

It has been interesting to observe CSG maturing over the last several years. What started as a modest undertaking has emerged as a significant body of knowledge with contributions ranging from the theoretical underpinnings to applications. However, the seeds for CSG significantly predate the current state or even the formal instantiation in 2014. In fact, early work in System of Systems Engineering (SoSE) formed an important foundation for CSG. The evolution of CSG was in part in response to the limited acknowledgment of SoSE to consider both the ‘hard’ and ‘soft’ components of complex systems. Systems Theory provided a strong and proven set of language that explains the behavior and performance of systems. Additionally, CSG is geared to address the entire spectrum of dimensions of a complex system, spanning the entire range of socio-technical-economic-political dimensions. The inclusion of Management Cybernetics allows CSG to draw upon a proven approach to deal with the structural configuration of functions and communications channels. Finally, the incorporation of governance provides a significant emphasis on direction, oversight, and accountability for complex systems. The unique integration of Systems Theory, Management Cybernetics, and System Governance has resulted in a new and novel approach to better deal with complex systems.

This book represents a necessary push forward in the amalgamation of theory and practice for CSG. The field is still very young and the CSG story continues to evolve. However, this is an important consolidation of the state of knowledge and the field’s directions. There is much left to be accomplished as CSG continues to develop. However, although significant challenges remain, this work represents a necessary and critical step forward in the development of the new field.

Zürich, Switzerland
November 2021

Adrian V. Gheorghe
Professor and Batten Endowed Chair
on System of Systems Engineering

Preface

Our present-day systems move faster, are more interconnected, and enable possibilities that have only been visionary desires in the recent past. Yet, here we are. We are frustrated with systems that inevitably fail to meet our expectations and seem to generate as many problems as they address. Out of this frustration, the field of Complex System Governance (CSG) is being pursued as an attempt to enhance our capacity to engage complex situations better. The emphasis of this work is such that the desired potential and promises of complex systems can be better realized. The emerging CSG field is about finding a new and novel path forward in dealing with increasingly complex systems and their problems. It is almost cliché to suggest that we are experiencing difficulties in addressing complex systems as we seem incapable of matching the acceleration of information, interconnectedness, and technology driving our current state of affairs. For all the 'goodness' that complex systems have brought, they have also left a wake of problems that appear to be intractable given our current paradigms and methods of attack (Rainey and Jamshidi, 2018; Warfield, 1976). We have all had experiences of being continually disappointed with our inability to keep pace with rapidly changing systems and with all of our prowess and sophistication, there is still something missing. How could we be so advanced in technology, knowledge, and societal advances yet be continually held hostage to underperforming systems? How can systems and their artifacts be built with such noble intentions but degrade to a state where they seem to do more harm than the 'good' for which they were intended? And what can we possibly do to help alleviate the negative consequences of underperforming systems and thus reduce the suffering they inevitably produce? These are rather lofty questions, nevertheless, they are important questions if we are to build, operate, and maintain complex systems that better serve to advance societal prospects.

In many cases, we talk about poorly performing systems as if they have human qualities and 'are out to get us.' However, with a deeper introspection, one recognizes that the 'systems' are a human construct of convenience, developed to make the infinite more finite. This perspective permits us to better grapple with something we can 'get our hands around,' with a stark realization that our systems have all been designed by us, built by us, executed by us, and maintained by us—humans. Our systems are not guided by a conscionable sense of justice and value. This leads to a powerful realization that, on the contrary, our systems simply do what they do when well-intentioned designs meet the operational setting. If there is disappointment and blame, it should not be directed at the system, as the system is entirely innocent of what it generates. Instead, we should direct criticism and judgment toward our role in designing, executing, and evolving the system to achieve results that we deem desirable. CSG was conceived in part as a remedy to the aforementioned misconception.

The focus on 'governance' for CSG is taken as the active steering of a system through the artful and integrated design, execution, and evolution of the system [6]. Thus, the primary motivation for this book is to share the current state of CSG, and the new approach to governing systems that appear to be ungovernable given our current circumstances. This is the reason for this book—to recognize the human role to provide improved system performance by advancing CSG as an alternative for the design, execution, and evolution of complex systems.

The CSG field, although still in the earliest stages of development, has not been haphazardly developed. Instead, as will be presented in the various chapters, there has been a slow continuous progression of the field to the described current state. This slow progression has permitted CSG to first focus on establishing the theoretical/conceptual grounding. These underpinnings have brought together three previously disparate fields: General Systems Theory [1, 10], Management Cybernetics [2, 12], and Governance [3, 4]. While each of the fields has achieved some notable stature, their intersection has never been exploited. In fact, much of the seminal work, particularly in (general) Systems Theory and Management Cybernetics, has been relegated to an existence off the main stage of developing complex systems. The intersection of these fields was primarily the inspiration for the emergence of the CSG field. Additionally, the time was ripe for this book to capture and share the current stage of CSG development and to project the field into the future. For this book, and the topic of CSG, there was a trade-off that had to be made. Although the field has made significant strides, there is much left to be achieved. The trade-off of waiting for additional field development versus getting the 'message' out to a wider audience across multiple sectors was deliberated. Ultimately, we elected to err on the side of getting the message out rather than waiting for further development. We were sufficiently confident that that time was right to capture the present state of the field, its contributions, and directions for ongoing development. We hope to open new dialogs and applications of CSG to accelerate the advancement of the field and its body of knowledge.

The genesis of CSG can be traced to three pivotal elements that profoundly impacted the development. First, work at Old Dominion University's National Centers for System of Systems Engineering started in 2003. Early work at the center identified several issues that the mainstream development of System of Systems Engineering (SoSE) was not addressing. Among these was the absence of taking a holistic view of SoS that included the entire spectrum of socio-technical-economic-political considerations. Furthermore, the domination of approaches based on 'technology first, technology only' generation of solutions (e.g., technical interoperability) was viewed by the center as limiting. Also, SoSE lacked any grounding in a theoretical/conceptual body of knowledge. Absent this grounding, long-term sustainability of the field would be doubtful. As a result, CSG was born as an evolution of SoSE to remedy the shortcomings identified in the trajectory of SoSE.

The second pivotal element stemmed from the foundational work of the Complex System Governance Learning Community at Old Dominion University. This learning community was composed of faculty, doctoral students, and post-doctoral researchers with interests in CSG. Through the work of this community, the CSG field was significantly enhanced. Several significant accomplishments of the learning community include the production of two special issues of the International Journal of System of Systems Engineering [2015, vol. 6, no.1/2; 2016, vol. 7, no. 1/2/3] [7, 8] dedicated exclusively to CSG; discussions that challenged the foundations of CSG and added rigor to the formulation; and providing a sounding board for doctoral dissertations and an emerging research agenda based on explorations of CSG. The early gains in CSG are largely attributable to the learning community and the CSG field owes much gratitude to this group of scholars who continue to push the boundaries of knowledge for CSG.

The third pivotal element in CSG development was the applications of aspects of CSG in operational settings. This was essential to the tempering of theoretical formulations through the lenses of deployment and application. These deployments in operational settings proved invaluable to working out inconsistencies and accelerating knowledge from applications. In sum, given the state of the CSG field, we had an intuitive sense that the time was right to develop this book. The book stands as a culmination of research, scholarly development, and application experiences. CSG is incomplete and continues to evolve. However, propagation of the field to a wider audience and range of applications/practitioners is an important step in that evolution.

Forging a new field is difficult and CSG is no exception. As described in this book, the current state of CSG is our attempt to create a waypoint. This waypoint stands at the intersection of current development and establishing the future trajectory of the CSG field. Although the journey to this point has been difficult, it has certainly been worth the toil. The opportunity to consolidate the state of our CSG knowledge and define future developmental challenges for the field is an important stepping stone for the field. Thus, this book offers a temporary respite between what has been achieved to advance the field and what is on the horizon for CSG. The book is a challenge to continue the development and propagation of CSG to take its place as an important systems-based methodology for generations to come [5]. This book, born of a passion for improving complex systems, is a significant step in the continuing evolution of the field.

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Norfolk, Virginia, USA — Charles W. (CW) Chesterman Jr.
Norfolk, Virginia, USA — James C. Pyne

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One aspect of academic citation apparatus is acknowledgment of the relevance of the works of others to the topic of discussion. This we have done. However, this apparatus fails to capture the influences of many that were involved in current efforts. With this in mind, the editors wish to acknowledge different people and organizations involved in discussions of this research.

Over the years, several faculty members helped by reviewing changes and providing feedback. Also instrumental in development and propagation of the foundations for CSG was the Complex System Governance Learning Community at Old Dominion University. Several of the chapters in this work are authored by members of that community. Many industrial practitioners also assisted us by commenting on draft chapters. We also wish to acknowledge several students in classes in which we tested teaching/research materials. Finally, we want to recognize stimulating comments and criticisms of Prof. Adrian V. Gheorghe—National Centers for System of Systems Engineering, Old Dominion University, USA and Emeritus Prof. Vernon Ireland—The University of Adelaide, South Australia, Australia.

Indeed, the editors offer apologies for those whom we have forgotten.

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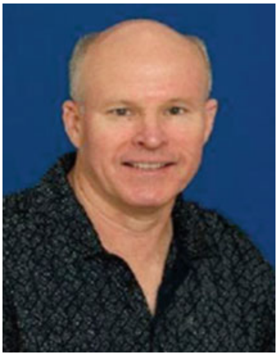

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Introduction

Charles B. Keating, Polinpapilinho F. Katina, Charles W. Chesterman Jr., and James C. Pyne

Abstract Complex System Governance (CSG) is an emerging field that remains in its infancy. Significant progress has been made to advance the field in both theory and practice. Although there is much left to accomplish in maturing this promising field, the time is right to provide the current state of theory and practice to accelerate advancement and share knowledge. Society continues to be dependent on increasingly complex and interconnected systems. This evokes an urgent need to improve the theory and practice to 'tame' modern complex systems and their problems more effectively. This chapter introduces the genesis, present state, and future prospects for the CSG field. Four primary themes are developed. First, the complex system problem domain is examined. The emphasis is on the conditions of this domain that precipitated the development of CSG as a viable response. Second, a brief introduction to CSG as a focused response to the domain challenges is discussed. This discussion establishes the foundations of CSG and its response to address pitfalls in addressing complexity. Third, the current state of the CSG field is examined. The existing literature and works of CSG are explored for the emerging set of themes that delineate the field. Fourth, acknowledging work that has been completed, challenges that must be addressed if the field is to remain viable are explored. The chapter closes with the prospects and promises that CSG theory and practice holds for effectively dealing with increasingly complex and interrelated systems.

Keywords Problem domain · Complexity · Complex System Governance

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1 Introduction

Complex System Governance (CSG) is an emerging field that has been described as the *design, execution, and evolution of the metasystem functions necessary to provide control, communication, coordination, and integration of a complex system* [82]. However, prior to delving into this field, it is important to understand the nature of the CSG genesis. CSG was derived from two primary concerns. First, the overreliance on technology as a default response to increasingly complex systems and problems was starting to diminish in returns. Technology has been, and always will be, important to addressing complex systems and their problems. However, *'technology first, technology only'* solutions to complex system problems are overly narrow. Second, complex system problems require an entire range of considerations. The entire spectrum of human/social, organizational/managerial, and political/policy influences must be considered for holistic solution development. Anything less is a miscalculation of the nature of complex systems and their problem domain.

Five enduring themes can characterize the problem domain within which a complex system must operate. While this set is not presented as 'complete' or 'absolute,' nevertheless, it captures the state of the problem domain facing present and future practitioners charged with the design, execution, and development of modern complex systems. The five themes include complexity, ambiguity, uncertainty, context, and holism. The confluence of these themes has been presented in other works [44, 65, 70, 74, 79, 80, 83, 87– 91]. However, they are presented here as an important grounding for the emergence of CSG.

1. *Complexity as a defining characteristic.* It is somewhat naïve to believe that there can be an agreed upon definition of the term 'complexity.' This pursuit was given up as futile after 71 different definitions were discovered and the effort stopped without an end in sight [89]. However, for our purposes, we can provide a perspective of complexity that informs the CSG field perspective taken for complexity related phenomena. This perspective rests on four primary themes. First, a large set of interconnected elements for which the set is not 'finite,' 'definite,' or 'static.' This entails that a complex system can never be completely known. Second, complex systems are dynamic and change over time. Knowledge of complex systems can be fallible, incomplete, and evolves as new knowledge and understanding dynamically develop over time. This does not suggest poor or sloppy engineering. On the contrary, this simply attests to the nature of complex systems, irrespective of efforts to define and understand them. Third, complex systems are richly interconnected, with the structure elaborating as the system operates. Thus, elaboration of rich structural relationships suggests that repeatability, reliability, and confidence in stable cause-effect relationships becomes increasingly doubtful. Fourth, complex systems are subject to emergence. Emergence suggests that behavior, performance, and consequences for a complex system come about through the operation of the system, cannot be known in advance, and are not predictable.

2. *Ambiguity in definition and understanding.* Ambiguity, or a lack of clarity, exists in understanding the structure, behavior, and performance dimensions of a complex system as well as the context within which it is embedded. The formulation of a complex system is subject to multiple perspectives that provide a variety of interpretations. Each of the interpretations is both correct and incorrect depending upon the vantage point and worldview that informs the perspective. Irrespective of the noble objective of 'consensus and agreement' in the definition and perspective of the system, it will always be subject to varying degrees of ambiguity. This ambiguity will also shift over time, as new knowledge of the system and its context continue to evolve. The variability in the understanding of a complex system also extends to the definition of such critical aspects as system identity, boundary conditions, definition of system elements, and the definition of the context within which the system is embedded. For complex systems, ambiguity can never be fully resolved.
3. *Uncertainty as a dominant attribute.* At a fundamental level, uncertainty suggests that the cause-effect relationships cannot be known for truly complex systems. There is doubt in being able to fully understand the variables, relationships, and consequences that exist for a complex system. The precise behavior/performance relationships are difficult, if not impossible to fully understand, analyze, or predict. Additionally, the system will evolve over time, in unpredictable ways, that will further render cause-effect relationships to be indeterminate. In fact, not only are deterministic (e.g., algebra, calculus) methods ineffective, so too are probabilistic (e.g., risk, statistical inference)-based approaches. Thus, traditional reductionist-based approaches become inadequate for complex systems. Instead, more holistic approaches, coupled with a corresponding mindset, are necessary to deal with uncertainty.
4. *Context as an enabling/disabling factor*. Context is taken as the set of circumstances, factors, conditions, trends, or patterns that impact, and likewise are impacted by, a complex system. It is important that context can both constrain and enable structure, behavior, and performance of complex systems. Context impacts thinking, decision, actions, and interpretations taken in response to system challenges. Context also includes the multiple stakeholders and their worldviews related to the system of interest. These worldviews can be convergent or divergent in nature. However, what is certain is that they will have an impact on the design, execution, and development of a system. Ultimately, context cannot be disregarded with respect to the direct and indirect impact on system performance.
5. *Holism considerations across a spectrum of dimensions.* Holism suggests that complex systems are subject to considerations that span multiple dimensions. While technology is important and tends to dominate conversations of complex systems, it is limited in providing the robust range necessary to address complex systems and their problems. Instead, looking beyond technology, complex systems are subject to the holistic influences of human, social, organizational, managerial, political, policy, and information dimensions. To view a complex system narrowly from a 'technology first, technology only' perspective is

shortsighted. The robust range of holistic considerations is necessary to more appropriately understand structure, behavior, and performance generated from complex systems. The interplay between the different holistic dimensions of a system is in keeping with a systems worldview, suggesting that their interaction produces what the individual components cannot.

These five themes capture the landscape within which CSG must provide for design, execution, and development of systems capable of thriving rather than simply surviving. This is especially the case since some of our systems 'have become hopelessly interconnected and overcomplicated, such that in many cases even those who build and maintain them on a daily basis can't fully understand them any longer' (Arbesman [7], p. 2). Table 1 presents a more definitive set of challenges which CSG must meet if a successful response to the problem domain is to be achieved and sustained.

Given the current problem domain and what it is producing for complex systems, we must admit that our responses are falling short. Instead of continuing to indulge responses that fall short of the mark, CSG is suggested as a new and novel approach. This approach offers the potential to minimally 'shift the dominant dialog' and at best generate the foundations for a 'sea change' in dealing with complex systems and their problems.

To capture the current state of affairs and position CSG in response, we suggest an 'issue triad' and a CSG 'response triad' (Fig. 1). The issue triad consists of *Complexity, Entropy, and Control*. The issue with *complexity* is that we seem incapable of addressing the increasing interconnectedness and interdependence of myriad entities. Additionally, complexity suggests that there is a dynamic (temporal) nature to shifts in a system and its context. Complexity also entails the dominance of emergence, suggesting that unpredictable events, behavior, or performance is characteristic of complex systems. *Entropy* captures the concept that a system, absent input of resources, will continue to maximum disorder to achieve the lowest energy state. Complex systems require the continuous import of resources to negate the natural proclivity to move to disorder. As systems become more interconnected and boundaries expand, more energy, matter, and information must be allocated to address the inherent disorder. *Control* involves the introduction of constraints that provide a regulatory capacity to govern a system. This ensures that the system maintains sufficient equilibrium to produce satisficing behavior, structure, and performance to remain viable. Our ineffective appreciation and mastery of system control leaves systems overregulated (stealing autonomy and wasting resources) or underregulated (failing to constrain systems adequately) which permits ineffectiveness in properly constraining a system to produce desired results.

In reply to the issues, CSG provides for a response triad rooted in *design, execution, and development*.

- *Design* involves the purposeful instantiation of the structural configuration of mechanisms for a system. This design configuration determines the degree to which a system can address ongoing and emergent issues being generated both internally and externally to a system. In essence, system design determines

Table 1 Complex system difficulties CSG must address

Difficulty	Description
Conflicting Perspectives	Differing perspectives are to be expected. However, sources of differences may lie well beneath the surface manifestations of differences. These may extend to differences in the basic worldviews held by individuals and entities in conflict. Understanding and potential resolution of conflicting perspectives will not be borne out by superficial surface treatment. Instead, conflicts must be addressed at the 'deep rooted' sources producing the conflicts. This does not suggest selecting a 'right' perspective for resolution of the conflict. Instead, the objective is to understand differences in supporting logic and assumptions as the sources of conflict
Insufficient Information	Given the continuing explosion of information, this difficulty seems unremarkable. However, care must be taken not to confuse availability of large quantities of information with the sufficiency of that information. In fact, extensive quantities confound the information sufficiency dilemma. If there is not accessibility to the right information to facilitate appropriate decision/action, then sheer quantity of information has little to offer
Unstable Resources	Dealing with complex systems and their problems is difficult enough under the best resource conditions. Stable resources support planning for an appropriate response based on scarce resource allocation. However, when resources are unstable and can shift radically, any pretense of detailed planning is rendered innocuous. On the contrary, such planning may be detrimental and a waste of resources given unstable resources
Extreme Uncertainty	Truly complex systems have a high level of uncertainty, where the understanding of cause-effect relationships is questionable. This renders more traditional approaches to decision and analysis to be of limited utility. Non-ergodicity (no clearly defined states or discernible transitions between system states) and non-monotonicity (inherent difficulties in understanding and provoking continuous transition to identified goals) are characteristic [99] of complex systems. Thus, application of traditional approaches, that assume the ability to reduce systems to well understood causal relationships, is a miscalculation. Complex systems represent a type of system where uncertainty is a rule rather than an exception. Assumptions to the contrary should be questioned

(continued)

robustness (the range and degree of perturbations which the design is capable of managing) and resilience (the degree and timing for which a system can return to a satisficing configuration following a perturbation).

- *Execution* involves the 'performance' of the system design. Execution is never optimal, has inherent variability as humans are involved, and is subject to shifts over time. Design inadequacies can be compensated for by shifts in execution

Table 1 (continued)

Difficulty	Description
Unclear Entry Point	Complex system problems are poorly structured and generally difficult to define with specificity. In fact, what 'appears' as a complex system problem may simply be a surface manifestation of a deeper underlying problem or set of intertangled problems. Therefore, even if the decision 'to begin' is made, 'where to' begin becomes problematic. The lack of clear entry point calls into question perspectives rooted in 'defining' the problem as the first and independent step in analysis
Solution Urgency	Modern complex system problems demand urgency in developing a response. While there are certainly circumstances that permit a 'leisurely' pace to completion, it is more likely the case that the solution to the situation is demanding a resolution as soon as possible. This is problematic for complex systems in the case where the depth of the problem requires a tradeoff in time allocated for exploration, understanding, and resolution
Misinformation–Defensiveness	It is a misnomer to think that all information serves noble intentions. On the contrary, information can have a veracity that in the worst case can be misinformation and in the best case might be disingenuous. Additionally, there can be a defensiveness in dealing with information where there is a perceived threat to 'status quo' positions. This defensiveness may rely on interpretations or selective construction/dissemination of information
Ambiguous Boundaries	Boundaries are a basic attribute of systems. They serve to separate a system from all that is external. Matter, information, or energy can cross the boundary as inputs and, once transformed, become outputs of value to be consumed by the environment. A lack of clarity in definition of boundary conditions, and the criteria for inclusion/exclusion for what lies outside the system, is problematic for complex systems
Unintended Consequences	Complex systems are designed with desired outputs and outcomes in mind. However, the realities of complex systems in operation result in behaviors, structure and performance that emerge. This emergence cannot be known or predicted in advance and can often result in unexpected and undesirable behavior. It is systemically naïve to think that systems will not produce consequences that may be far from those desired, intended, or anticipated

(continued)

(e.g., working additional hours to compensate for scheduling issues that the system design was incapable of managing).

- *Development* is concerned with modifications of the system design or execution to ensure that a system remains viable. Modifications are necessary to compensate for environmental/context shifts which can render the design no longer capable of effectively responding. Modifications can be targeted to: (1) *system execution*,

Table 1 (continued)

Difficulty	Description
Emergent Situations	As complex systems operate, they will inevitably produce emergent situations. The precise nature of situations cannot be known or predicted in advance. Instead, they come about as a system operates and must be managed 'in the moment' of their appearance. For complex systems emergence will occur. However, the precise timing, nature, and impacts cannot be known in advance. This does not absolve the responsibility for emergence. Instead, it heightens the emphasis on preparation of the system design to be sufficiently robust and resilient to weather emergence
Shifting Demands	Frequently, the demands placed on complex systems will be dynamic in that they will change over time. This is not necessarily indicative of poor management. On the contrary, it may be the result of complexities which cannot be fully comprehended at the time a systems endeavor was initiated. Shifting demands are a fact of life for complex systems and should be anticipated
Instabilities	There are multiple potential sources of instabilities for a complex system. Instabilities may come from within the system itself (e.g., conflicting procedures), the environment (e.g., stakeholder inconsistencies), or the particular context within which the system is embedded (e.g., weak leadership). Irrespective of source, instabilities are disruptive to maintenance of system performance. Care must be taken to design systems such that instabilities are not capable of incapacitating the system before the results can be mitigated
Divergent Stakeholders	Variability of stakeholders is inevitable in complex systems. However, significant divergence between stakeholders should be accounted for. The assumption that divergence can be overcome might be somewhat naïve for complex systems. As long as unresolvable divergence exists, it will be a source of concern for continuing viability of a complex system
Politically Charged Decisions	All complex systems are subject to 'politics' as the pursuit of strategies to gain or maintain power (influence) over the system. To ignore the fact that politics is in play for the decisions concerning complex systems is naïve at best. Politically charged decisions can and will be a source of concern for complex systems. Designs that fail to account for the existence of politics in complex systems are shortsighted at best and debilitating at worst

where 'first-order' modifications are made in response errors based on detection of 'system performance issues' and correction by adjustments to execution while leaving the system design intact, or (2) *system design*, where 'second-order' modifications are made in response to errors based on detection of 'system design performance issues' and corrections by enacting adjustments to system design.

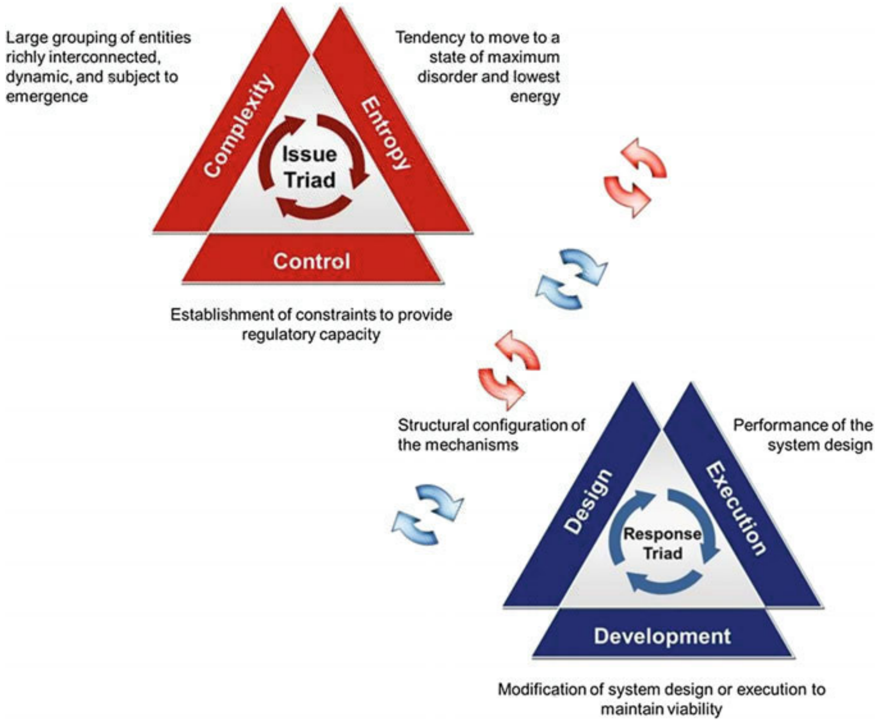

Fig. 1 Issue and response triads for CSG

The interplay of design, execution, and development is the CSG response to the challenges posed by the issues triad.

Thus far, we have set the problem domain targeted by CSG, the need for CSG, and the high-level response of CSG. In the remainder of this chapter, we present an overview of CSG, articulate the present state of the field, and discuss challenges for the future development of CSG.

2 The Emerging CSG Field—A Response to the Future

In this section, four primary themes are developed. First, CSG is put forward as an emerging system-based approach to improve the design, execution, and development of complex systems. This overview briefly introduces CSG as a focused response to the problem domain challenges identified above. This discussion also establishes the foundations of CSG and its response to address pitfalls in addressing complexity. Second, the current state of the CSG field is examined. The existing literature and works of CSG are explored for the emerging set of themes that delineate the field. Third, acknowledging work that has been completed, challenges that must be addressed if the field is to remain viable are explored. The chapter closes with the implications and promise that CSG theory and practice holds for advancing prospects for more effective design, execution, and development of complex systems.

2.1 The Three Fields Upon Which CSG is Based

CSG lies at the intersection of three primary fields, including Systems Theory, Management Cybernetics, and System Governance (Fig. 2). Systems Theory is a primary grounding field for CSG and is focused on effective integration and coordination of disparate elements into a coherent whole. Systems Theory demands that the whole is subject to and must conform to the axioms and corresponding propositions of Systems Theory. The axioms and corresponding propositions define, explain, and govern behavior, both negative and positive, of systems. Management Cybernetics brings an emphasis on communication and control essential to continuing system existence (viability). Viability is necessary for a system as it deals with the inevitable internal flux and environmental turbulence endemic to modern complex systems. Management Cybernetics enables CSG to appreciate and respond to the constant change in the context and environment for a governed system or system of

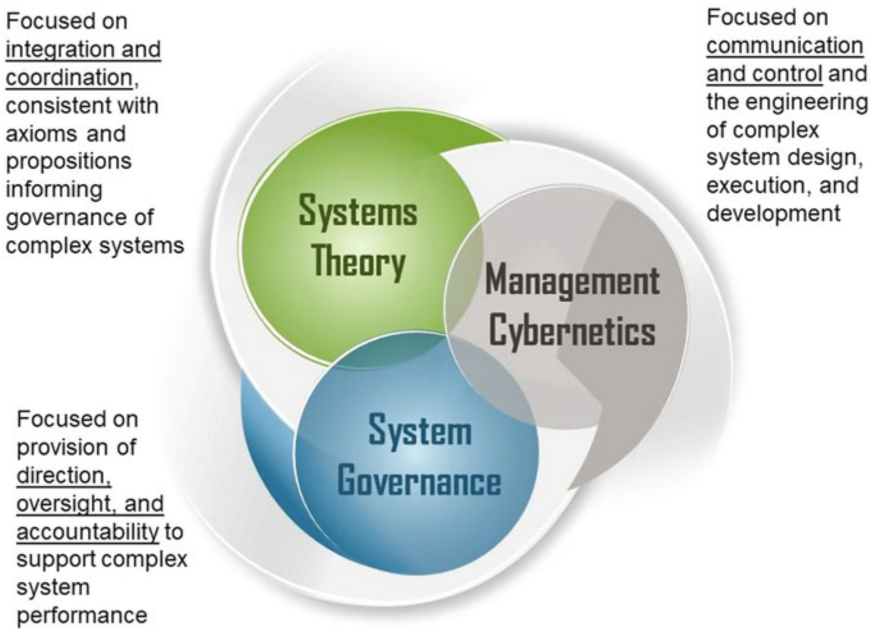

Fig. 2 Three fields contributing to CSG development

systems. Thus, while governance necessarily takes a long view to provide long range stability, it must also monitor and acknowledge the potential impact of near term fluctuations on system viability. Finally, System Governance provides an emphasis on direction, oversight, and accountability for the execution and development of a system. Individually, each of the three fields underpinning CSG has made substantial contributions to the state of human affairs. However, they have not been brought together in meaningful ways that take advantage of their intersection (Fig. 2). CSG evolves from the intersection of these fields to produce a novel alternative for complex system development.

Based on the three underlying theoretical/conceptual foundations, CSG has been constructed as the *design, execution, and evolution of the metasystem functions necessary to provide control, communication, coordination, and integration of a complex system* [82]. Detailed explanations of CSG are covered within this book and in previous works [70, 76, 77, 79, 80, 82]. However, for introductory purposes, in this section, we provide an overview of three essential aspects of CSG, including: (1) the fundamental essence of CSG, (2) the CSG paradigm, and (3) primary contributions of CSG for complex systems.

2.2 The Fundamental Essence of CSG

Descriptions and discussion of the nature and specifics of CSG are elaborated in this book and have been explored in a number of prior works [76, 79, 80, 82]. Rather than provide a rehash of the details of the CSG field, instead we offer several summary points of emphasis and distinction to present the CSG field:

- CSG is *holistic* and considers design, execution, and evolution across the spectrum of technology, human, social, organizational, managerial, policy, information, and political dimensions of modern complex systems. Consistent with this perspective is a concentration on ensuring that the governance of a system is targeted correctly to the purpose, problem, or need that the system is intended to address.
- At a most basic level, CSG is concerned with performance of functions that provide *control* (installation of the minimal specification necessary to achieve desirable system performance while providing the greatest degree of autonomy to system constituents), *communications* (exchange of information such that consistent decision, action, and interpretation are supported), *coordination* (provision of sufficient standardization among system constituents such that unnecessary fluctuations are avoided), and *integration* (function of the system as a 'unity' to produce capabilities, behavior, and performance beyond that of individual constituents).
- CSG is built around performance of the set of nine interrelated metasystem functions common to all complex systems, including: *policy and identity, system context, strategic system monitoring, system development, learning and transformation, environmental scanning, system operations, operational performance, and information and communications*. The metasystem functions are achieved

through implementing mechanisms (artifacts that enable performance of functions) that operate within the parameters of Systems Theory axioms and propositions. Inconsistency in application of Systems Theory or violations of its tenets (axioms/propositions) represent CSG pathologies that act to inhibit or degrade system performance [45–50, 53, 76].

- Communications provide for the flow and interpretation of information for the metasystem functions in CSG. CSG communication occurs through support 'channels,' which describe what the communication vehicles must satisfy for continued system viability. Communication support channels for CSG include: *command* (non-negotiable directives), *algedonic* (system threat warning that bypasses all other channels and functions), *dialog* (examination of purpose and essence of the system), *learning* (identification of system adjustments to correct detected variabilities), *environmental scanning* (provides intelligence of external conditions), *resource bargain/accountability* (resource distribution and output expectations), *operations* (providing directions for system operations), *audit* (provides monitoring of routine as well as emergent anomalies in system performance), *coordination* (provides for harmonizing elements within the system to avoid unnecessary fluctuations), and *informing* (providing for routine information in the system).
- CSG functions are performed through mechanisms (artifacts that permit the achievement of metasystem functions and communications). The completeness and performance of the set of mechanisms (e.g., strategic development procedure) determine system performance.
- Effective execution of CSG permits a system to maintain performance amid internal flux and external (environmental) turbulence. CSG assumes inherent instabilities, complexity, and emergence. This requires a sufficiently robust and resilient design to compensate such that performance is maintained and system viability (continued existence) is assured.
- Design for CSG permits the 'active matching' of the infinite variety (a measure of complexity) that is generated by both internal (system flux) and external (environment turbulence) to the system. Left without compensating design (e.g., CSG), this variety has the capacity to destabilize the system and inhibit a system's ability to meet performance expectations.
- All complex systems that continue to exist perform the nine metasystem governance functions mentioned above. The degree of performance of a complex system is determined by the efficacy of the governance functions.
- CSG development is not a 'one time' or 'sporadic' event. CSG development is a continuous process that purposefully advances the maturity of CSG and effectiveness of its execution. CSG development operates at the individual, entity, and system levels.
- CSG development is not an 'all or nothing' proposition. There are benefits that can accrue from different levels of CSG engagement, ranging from the enhancement of individual practitioner effectiveness through structured engagement of organizational system performance.

This concise overview provides a rudimentary backdrop that captures the essence of the CSG field. We now shift to exploring the CSG paradigm.

2.3 The CSG Paradigm

Although the underlying theory, concepts, and execution of CSG are challenging, the essence of CSG is not difficult to grasp. The essence of CSG might be captured in Fig. 3 and described as

> *Subject to fundamental system laws, all systems perform essential governance functions. System performance is determined by effectiveness in the achievement of governance functions consistent with system laws. System performance can be enhanced through purposeful design, execution, and development of governance functions in accordance with system laws.*

The CSG paradigm might be summed up in six essential points:

1. *All systems are subject to the Systems Theory propositions (laws, concepts, principles) of systems*. Just as there are laws governing the nature of matter and energy (e.g., physics law of gravity), so too are our systems subject to laws. These system laws are always there, non-negotiable, unbiased, and explain

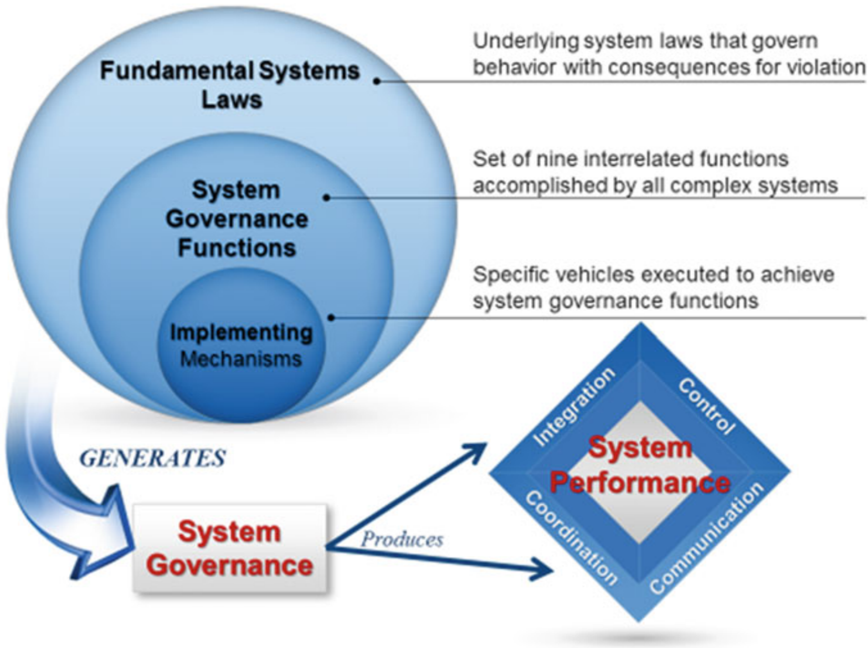

Fig. 3 The CSG paradigm