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Chiang H. Ren

How Systems Form and How Systems Break

A Beginner's Guide for Studying the World

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Chiang H. Ren
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To Kelly

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About the Author

Dr. Chiang H. Ren is an entrepreneur, C-Level executive, and systems analysis expert who is currently the Chief Solutions Architect for Planned Systems International Inc. Prior to this appointment, he had been the chief technology officer for two other companies. In these positions and as a senior analyst for multiple United States government agencies, he has further published numerous peer-reviewed journal articles in operations research, disaster preparedness, information technology management, systems engineering, theoretical biology, and particle physics. Dr. Ren holds a B.S.E. degree Magna Cum Laude in Mechanical Engineering and Applied Mechanics from the University of Pennsylvania, an S.M. degree in Aeronautics and Astronautics from the Massachusetts Institute of Technology, and a Ph.D. degree in Systems Analysis from the University of Bolton. Further he is a certified Six Sigma Black Belt, a member of the Tau Beta Pi engineering honor society, and an Associate Fellow of the American Institute of Aeronautics and Astronautics.

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Chapter 1
The Mysterious Discipline

Abstract The introduction reviews the history of systems research and explains how the discipline has matured and divided into branches such as systems engineering, systems thinking, systems operations research, analysis of economic systems, theories for social and anthropological systems, modeling of biological systems, and management of organizational systems. This fragmentation of the discipline makes it difficult for a young student today or an interested novice without years of experience in a field that connects to systems studies to learn about systems analysis. There are many books written within each branch of systems research, but this book is unique and very much needed because it establishes a framework for studying systems that connects with all research branches but does not require the reader to have any prior backgrounds.

Friends, when I was a young engineer studying aerospace systems in graduate school, I greatly admired how the book *Six Easy Pieces*, by Nobel Laureate Richard Feynman [1], brought the wonders of physics to a more general audience. It is good to sometimes step back from the equations and look at the bigger picture. Then, as I entered the world of business, I greatly admired how the book *The 7 Habits of Highly Effective People*, by Stephen Covey [2], helped people focus on the real factors of success in life. It is good to sometimes stop working and think about what one is doing. Thus, after 25 years of studying systems and publishing systems research papers in fields such as disaster response, public administration, program management, national security, astrophysics, and theoretical biology, I find myself wondering why no one has published a book on the basic discipline of studying systems. The skill of being able to self-identify and explore behaviors and problems in our world from a systems perspective is so useful that it should be taught at the high school level.

Do not get me wrong. There are many fine books on systems engineering, systems thinking, systems operations research, analysis of economic systems, theories for social and anthropological systems, modeling of biological systems, management of organizational systems, and so forth. Further, there are books on specific processes and techniques derived from the study of systems, such as Lean

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Six Sigma, Total Quality Management, Balanced Scorecard, Fifth Discipline, and Agile Development. If I were a young student today or an interested novice without years of experience in a field that connects to systems studies, this great diversity of books that approaches the study of systems from different angles can be overwhelming. How do I begin to acquire systems analysis skills? And how do I move beyond the dictionary definition of a system being a group of parts that work together to yield total effects? Even so-called primers and introductory volumes are often oriented toward specific methodologies and philosophical perspectives.

The dictionary definition of a system indicates that we will find systems everywhere in our world and that all of nature can be considered a giant system. Some systems are made by man. Some systems are observable by man as clear constructs of nature. And some systems are more flexibly defined by man to help us better understand nature, society, and organizations. As a result, the study of systems is across many fields (transdisciplinary) and integrates methodologies from many fields (interdisciplinary). This strength of endeavor is perhaps also why systems studies is so fragmented and lacking a well-defined rudimentary core. I will further elaborate on this statement. But first, let me propose that, even for academic researchers and practitioners, it might be useful at times to step back from competing theories, contending schools of thoughts, set processes, and established tools to think about the basics. So, the search for the basics for those familiar and not so familiar with systems studies is the objective of this book.

The fragmentation of systems studies is tied to the fact that so many of us came to it from our own fields of study and bring to it our own biases in methodologies and research philosophies. I, for example, started with the design and engineering of well-bounded systems and later began to investigate the techniques for rapidly analyzing large military system of systems architectures in the course of providing technology and acquisition planning recommendations within the Pentagon during the latter years of the Cold War. Then, as I became involved in studying Information Warfare and exploring ranges of potential futures, yet another dimension of systems analysis opened up to me. This experience in the mid-1990s promoted a life-long research interest in complex system behaviors that can be projected through system models but cannot yet be validated because of a lack in supporting data. Sometimes, mechanisms for collecting the appropriate data have yet to be formulated, and, other times, the need to collect the appropriate data must be presented. I am sure that many others, such as biologists learning to build node and link diagrams as a part of the emerging field of systems biology and managers learning to build process flow diagrams as a part of business system reengineering, all have wonderful stories of how systems studies entered their lives. Further, I am sure that those who have majored in systems engineering and operations research will have a thousand stories of challenges, accomplishments, and collaborative experiences.

There is, however, a much bigger story of systems studies that extends back to the establishment of the scientific methodology by Johannes Kepler in 1602, [3] and it is worthwhile to summarize this story to help place all our experiences and the objective of this book in context. Kepler's Laws of Planetary Motion is an observationally and analytically established model for planetary systems. Since the days of Kepler, scientists have been deductively breaking apart all aspects of natural systems into measureable and relatable pieces to support hypotheses, theories, and validated facts. For complex natural systems such as living organisms, the efforts to identify their component parts intensified with the discovery of the cell in 1676 and cell structures in the 1800s [4]. The philosophy that a system is no more than its identifiable component parts, scientific reductionism, in turn, became very popular in natural science communities [5]. As scientific instrumentation advanced in the twentieth and twenty-first centuries to identify all component parts, the philosophy of positivism, which states that knowledge should only be based on what can be measured and mathematically/logically explained, also became popular in natural science communities [6]. These philosophies continue to influence those with prior scientific training in their study of systems.

Systems studies followed another path with the industrial age, as man created ever more sophisticated systems to serve society. Inventions, such as those by Thomas Edison starting in 1869, were achieved through inspiration, creativity, and inductive thinking [7]. The figuring out of how parts fit together and the designing of parts for fitting together into systems have been the focal points for the engineering fields. This endeavor has intensified with the miniaturization of electronic devices, the start of the computer age, and the growth of the World Wide Web. To study systems that must work together to form greater systems, the US Department of Defense and others have invested substantial resources since WWII in operations research (how systems perform in real environments), logistics (how systems are supported during operations), lifecycle management (how systems are built, deployed, and retired), and war gaming (how systems specifically compete with other systems in symmetric and asymmetric ways). Recognizing that modern man-made systems must often integrate mechanical, electronic, computer, and communication subsystems as well as take into account the capabilities and limitations of the users, many universities and institutions have established systems engineering departments and divisions. The term "systems engineering" traces back to Bell Telephone Laboratories in the 1940s, [8] and engineering endeavors have since focused on design, modeling and simulation, optimization, control, and reliability. With the advancement of computer tools over the past decades, all these endeavors have matured into specialized fields, and some of the modeling techniques have been adapted to study biological systems.

As the industrial age shifted the structure and tempo of societies, the study of systems followed a third path into the social sciences. Herbert Spencer popularized the philosophy of functionalism, which argued that society should be viewed as a complex system with mutually supporting parts [9]. He also introduced the biological theory of natural selection into social dynamics. As society has economic, political, military, and cultural components, each of the connected academic fields has incorporated systems thinking and systems modeling into their studies. For example, Karl Marx, in 1867, presented one of the earliest theories on social system failure by arguing that economic inequalities will cause internal tensions that lead to social collapse [10]. Von Neumann, in 1944 [11], mathematically modeled the interactions across political systems and systems driven by individual actors based on rational decision-making by all sides. The interactions gave rise to Game Theory, which was advanced by many scholars and later applied also to biology. Yet Karl Ludwig Von Bertalanffy and others in the 1930s made perhaps the most important advancement in systems thinking for the social sciences through the argument that social systems are too complex to be studied by pure scientific reductionism or engineering-based mechanistic models. Instead, the resulting General Systems Theory argued for the study of social systems to be more focused on holism and organic behaviors [12].

General Systems Theory launched the realization that systems involving interacting human actors cannot be tightly bounded or easily quantified despite the endeavors of man to create structured organizations. Like other organic systems, the complexity is often reflected in self-organizing, self-adapting, and even self-proliferating characteristics. However, modeling such characteristics can be more challenging than systems in nature because we do not always have an objective system state or reference frame for how the human system should perform. After advancing operations research in the 1950s, Churchman [13] would declare such systems are "wicked problems," and Ackoff [14] would call such problems "messes". To study these systems, Checkland in the 1980s [15] formulated the Soft Systems Methodology (SSM), which recognizes that our actions to measure a system affects the system and that there are no perfect models of systems. Instead, SSM advocates a recursive learning approach for systems understanding starting with an initially imperfect conceptual model. This methodology is aligned with the philosophy of action research and challenges the idea that man can engineer rigid systems and organizations that have complete mastery of interactions within their environment [16]. Contrary to the objectives of design research, there may always be some hidden consequences, latent patterns, and/or unforeseen forces because the true nature of all real-world systems is unbounded.

I have mentioned deductive and inductive methodologies in systems studies; thus, SSM should be considered a more explorative methodology. However, there are other ways to explore complex adaptive systems as first defined by the Santa Fe Institute [17]. If we are not certain about whether a bunch of parts even constitutes a system or whether many interacting systems will lead to unrealized effects, modern computers now enable us to simulate such behaviors through agent-based models. The philosophy of agent-based modeling is the belief that even simple interactions between agents (computer models representing people, organizations, things, and the environment) lead to highly complex outcomes over time. If we want to study macro behaviors in an extremely large and complex system, modern computers now enable us to simulate dynamics at an abstract level using models built based upon the principles of system dynamics as established by Forrester in the 1960s [18]. One type of abstraction is a way to model the whole world based on inter-regional and transnational division of labor through the World Systems Theory of the 1970s, to be discussed later. However, there are many other theories on how to abstractly model geopolitical and transnational behaviors.

In the United States, system dynamics has greatly influenced the social sciences, economic theories are being extended to biological systems, and researchers are still trying to validate the results of agent-based models. However, Soft Systems Methodology has historically remained unpopular and is left largely to the endeavors of European researchers. We can speculate that the United States has invested tremendously in the design of physical and organizational systems over the years, and control or illusions of control, depending on your perspective, has taken priority over systems understanding in some cases. Certainly this appears true at the organizational management level where many books have been written to help practitioners control organizations for optimization and transformation. Simplistically, some models are more system metrics focused, such as Total Quality Management and Balanced Scorecard [19, 20], some models are more systems process focused, such as Lean Six Sigma [21] and some models are more systems integration focused, such as The Fifth Discipline as established by Senge in 1990s [22]. There are overlaps between these models, and all the models seek to transform organizations. However, the consideration of organic behaviors in the organization varies, and the control points, as a result, vary.

At this point, I will apologize for not doing justice to any of the system study paths and methodologies presented. However, these paths and methodologies will reappear again as we explore the basics in studying systems. All I wish to show for now is the reality that systems studies lack a single coherent core, and that, despite efforts to apply methodologies and techniques across disciplines, the dichotomy between the paths has caused contention and mutual misunderstanding. Practitioners and researchers along different paths of systems studies are indoctrinated into communities, and problems in communities are still falling through the cracks because of philosophical limitations. To the rest of world not familiar with systems studies, it must truly appear like a mysterious discipline. There is so much promise for problem resolution and so much ambition in the scope of problems being tackled. Yet, I will argue that seldom has system study approaches and outcomes been explained clearly and concisely to young students and senior decision-makers. One of the most familiar system diagrams in the news years back is that of a messy chart trying to show the interrelationships between factors affecting stability in Afghanistan. Instead, the chart convinced the general public that the Pentagon had missed the big picture [23].

I am not sure that everyone conducting and applying systems research can ever agree on philosophies, methodologies, and theories. But I do know that I am not the one who can bring about agreement. Sometimes a little disagreement is healthy for the advancement of knowledge, as long as each side is willing to consider the arguments of the other. Other times much potential is lost. My interest is to introduce the wonders of this mysterious discipline to the outside world at a basic level where there are no major disagreements. As hopeful novices, let us now explore how systems form and how systems break. Then, you the reader can decide to what degree you want see the world through the perspective of systems analysis and to what depth you wish to learn about systems analysis techniques.

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Chapter 2
The Characteristics of Systems Formation

Abstract This chapter establishes the basic concept of what constitute systems and defines characteristics associated with the concept. The characteristics are broad enough to apply to all types of systems and have associated metrics that can define specific system components, structures, and behaviors. Many examples based on natural systems, human organizational systems, and man-made systems are provided in each section to explain how system metrics are to be applied. Methodologies for studying systems are further introduced in the context of applying metrics to specific types of systems. Through the established conceptual framework, we further explain how hidden systems can be discovered, logical divisions between systems can be determined, systems can be designed based on total dimensionality, and the behaviors of systems can be explored.

Our world is filled with systems and activities that can be defined as systems. Therefore, a student studying systems formation might be tempted to just jump into case studies upon case studies. The challenge with this approach of going from the specific to the general is that one might never get the case studies to converge upon a common understanding and one may never be certain that the right scope of case studies have been used to achieve common understanding. Studying real world systems, even at a fundamental level, further requires subject matter skills. The division between subject matter experts then enforces the fragmentation of the discipline.

Our study of systems formation will, therefore, start with the basic concept of what constitute systems and the definition of characteristics associated with the concept. These characteristics will perhaps be obvious to some by first introduction. Yet, if all systems are bound by these characteristics, then we can study systems formation by going from the general to the specific. I believe that these general characteristics will help us discover hidden systems, determine logical divisions between systems, design systems based on total dimensionality, and explore the behaviors of systems. And, we need to first understand how systems form before we can study how systems break. People who are studying specific failure modes might

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argue with me about the last statement, but the statement might make more sense after I explain my definition for formation.

I fully understand that many systems in nature are so complex and so old in origin that their paths of formation will continue to elude us. However, nature and even our own physical bodies teach us that whatever is not forming or growing is often in the process of failing and dying. As soon as our bodies reach adulthood, the process of aging begins. As soon we build a machine, the process of wear and breakdown begins. Breakdown can be controlled and delayed through maintenance, but absolute steady-state is a rare thing. So the study of system formation is the study of the system across its life of changes and transformations to the point where breakdown is unavoidable. Sometimes, failures occur in the process of formation, and other times failures occur after formation has stopped. Either way, to fully understand failures, we need to know not necessarily the beginning of formation but most definitely the end state of formation and formation activities. That end state, even when cut short, is the reference frame to which system breakdown can be measured.

If a system is a group of parts working together as a whole according to definition, then an understanding of system formation must involve the study of:

- The dynamics of the parts and the whole
- The associations between the parts to make the whole
- The structure of the whole based on the parts and associations
- The boundaries of the whole or the boundlessness of the whole
- The interactions between the system and the environment with other systems
- The qualities of the system as a whole
- The integration of systems to form greater systems.

These can be considered the top-level characteristics of systems formation, and the many paths and methodologies of systems studies can be placed in the decomposition of characteristics. These characteristics also affirm that systems studies is a discipline that cuts across other disciplines and integrates disciplines. As researchers have long realized, systems with common characteristics in nature and society often exhibit similar behaviors that enable comparative analysis. Systems with unique capabilities in nature and society might further inspire the design of man-made systems. And man-made systems often integrate with social and nature systems in complex ways that have potentially unforeseen secondary effects.

As a result, our journey into the basics of systems formation will be an examination of system characteristics and interrelationships between characteristics. If you approach all the problems, opportunities, and behaviors of this world through the lens of these characteristics, I guarantee you that the world will never appear the same again. If you partake of other fields of study through the lens of these characteristics, then each field will not appear so distant and so alien to your understanding. The patterns of system behaviors repeat themselves over and over again, and the causes of system failures, which we will explore in Chap. 3, are seen everywhere that we find systems.

2.1 Dynamics: Moving System Parts

Any discussion of systems should probably start with the term “dynamics” because there cannot be a system without change. A bunch of parts connected together in an unchanging way is merely an object. The object can be incredibly complex. However, if there is no work being done and no changes occurring, then the object is a display piece. On the other hand, a combination of very simple moving parts, such as a wheel that grinds wheat being turned by water flowing down stream, forms a system, and the activities of the system are termed system dynamics. Systems dynamics is the dynamics of the parts and the dynamics of the whole system. In very simple systems, the dynamics of the parts is easily translated into the dynamics of the whole systems. In very complex systems with many parts, complex parts, unknown parts, and/or unknown parts relations, the study of the system becomes a dedicated discipline. Before we go too far down the road of complex systems, first let us start with an understanding of the basic dynamics for system parts.

A part that belongs to or could belong to a system is generally described through four types of dynamic characteristics as shown in Fig. 2.1. As the part can be a material component, software module, human actor, biological entity, information element, or a subsystem composed of any combination of the other part types, we must start with a very broad understanding of dynamic characteristics and then advance our understanding toward specifics.

In the first type of dynamic characteristics, the part will have an orientation relative to a reference frame that is based on the system or the system’s operating environment. For machines, one orientation would be how a part fits with other

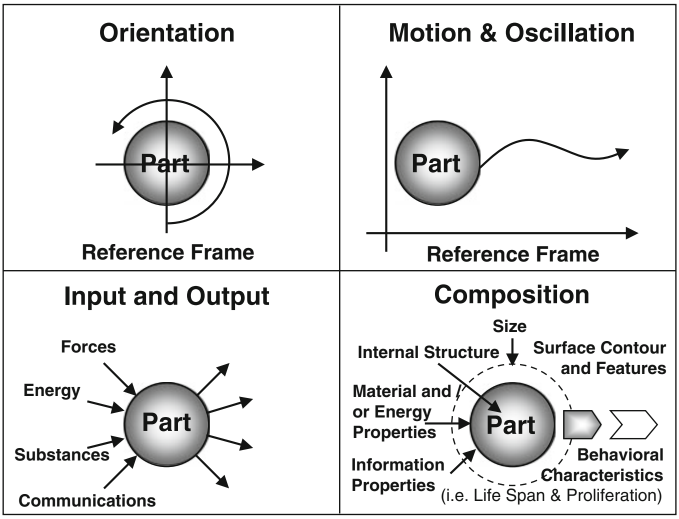

Fig. 2.1 Four types of dynamic characteristics

parts, and the orientation could be relatively fixed in the design reference frame. However, as the machine moves in an environmental reference, the orientation of the part will change relative to the environment as well as the forces and material interactions within the environment. For software, the orientation could be the position of a group of codes relative to other codes and code interfaces. Software parts must reside in physical computer parts, but the management of software through hardware and platform technologies in modern network-based cloud computing systems does not have to follow a one-to-one relationship. For human organizations, the orientation could be the political leaning of a special interest group, the procedural guidance for a team, the needs of different users, etc. For systems of pure information, the orientation could be how a bundle of information is positioned against an agenda such as a marketing campaign with many bundles of information working together. The key point about orientation is that it might be a governing factor to how parts will work together and how the working relationships can change.

The second type of dynamic characteristics is motion and oscillation as a specific type of motion. Once again, motion needs to be measured against a reference frame, and a part can have different kinds of motion relative to the system and to the operational environment. In the physical world, motion could be linear or rotational. Linear motion merely means that a line vector describes the motion, but the path or pattern of motion could follow a complex trajectory. If a motion continuously reverses and repeats itself, then the part is in oscillation. A part can move linearly alone one directional axis and oscillate along another. Also, a part can oscillate in place back and forth or oscillate about a rotational axis. And, rapid back and forth motion can be described as vibrations. For nonphysical parts, motion is essentially a statement of change for the whole part relative to a nonphysical reference frame. For example, an encapsulated malware is in motion across the World Wide Web until it lashes onto a host software application and causes harm. Humans in society or an organization are said to be in motion if they change locations or if they change their group alignments. As I will discuss later in studying system structures, some systems and structural configurations can tolerate the relative motion of their internal parts more than others. Both internal motion and motion tied to the whole system might affect the input and output characteristics of a part and the composition of a part.

Accordingly, the third type of dynamic characteristics is input and output for different parts. If a part has the structure of a subsystem, then how that subsystem receives inputs and transmits outputs to other parts, systems, and the environment is fairly complex. Regardless, all manner of simple and complex inputs and outputs can be further categorized as forces, energy, substances, and communications. This breakdown is in favor of physical parts, as they can receive and transmit all four kinds of input and output. For information technology systems, the inputs and outputs are limited to energy and communications. However, the communications can be further subdivided into data transmission, software uploads and downloads, protocol exchanges, and status updates. For human systems, inputs and outputs could represent ownership. Products can be given to a human recipient. The human recipient can pass the products to others. And the human recipient can create or modify his/her own products to pass on as output. In fact, a part taking inputs and using them to create outputs is one of the most common component functions in a system.

The fourth type of dynamic characteristic is the composition of a part. At the most fundamental level, a part should have a size and surface contour with features that are relative to the reference frame for that part. If the part is a physical component, then the size can be from the atomic level to the planetary level because the atom is a system, and the stars and galaxies are all systems. The physical features could be receptors that promote integration with other parts or systems, textures that affect contact interactions, and gates that control the inputs and outputs. For software parts, the size could be number of lines of code, and the surface could simply be the code boundaries and interfaces. For parts in human systems, the size could be the number of people in a component group and the surface could be the positions of the people. Finally, an information part could be sized by the quantity of information and the accessibility of the information. Inside each kind of part, there should be an internal structure that could be very complex. Physical structures can have material and energy properties, information properties, and behavioral characteristics. Other structures might only have information properties and behavioral characteristics. The information properties of software parts might be very complex, and the behavioral characteristics of organic and human parts in systems might be even more complex. This complexity sometimes includes how parts can self-proliferate and how parts will age and break down overtime. The sources of complexity lead us to the next step of exploring how to study the dynamics of parts and systems.

As all systems have dynamic characteristics, measuring and studying the macro-dynamics of the total system is a way to identify and understand the system parts. Then, measuring and studying the dynamics of system parts is a step toward understanding the formation process of the system. The measurement of the whole and the pieces can be an interactive process that steadily incorporates the other characteristics of formation as the understanding of the system begins to manifest. However, the endeavors of measurement bring us into the positivism versus soft systems thinking debate.

I will at this point declare that I do not strongly embrace the positivism philosophy like so many of today's scientists. This is because I do not accept that today's instruments and methods can always measure all the parts and part characteristics in real-world systems. Further, I believe that, despite the lack of data, systems studies might still help us press forward with discovering new methods of measurement, new system needs, and even new parameters that have been ignored by other researchers. Instead of building systems thinking around the data, I, like many others, prefer to build systems thinking around the actual problems and dynamics observed in the real world. In this manner, I agree with soft systems thinking in that real-world systems can never be perfectly measured because a perfect set of measurements means that we will have built another model of the real world. To elaborate, every measurement of change that we take with modern instruments is still at intervals across specific parameters. Movies are at a frames-per-second rate that is much faster than the eye and brain can perceive. Digital images breakdown data intervals into pixels per square inch. And computer databases must record data in distinct increments.

The two big shifts in the measurement of systems in modern time are: (1) a dramatic increase in measurement capabilities across many scientific fields, and (2) a dramatic increase in data storage plus processing capability with high capacity blade servers, fiber optic networks, and cloud computing distribution platforms. The most dramatic advances in measurement are perhaps in the biological sciences with the conduct of the Human Genome Project from 1990 to 2003, the identification of countless proteins/enzymes that regulate cell activities, and the discovery of many drug combinations that affect biological processes. However, the details of our universe gathered by the Hubble Space Telescope and other space probes are also impressive advances. The most dramatic advances in database usage are perhaps in the social media business area where the buying patterns, viewing habits, demographics, and preferences of millions of online users can all be recorded as terabytes (1000 GB) of data. However, these databases will soon be rivaled by databases with the electronic health records of billions of people. To place a terabyte in perspective, an IBM PC in 1982 has a 5-MB hard drive. This means that one of today's 4 or 6 TB drives, which only cost a few hundred dollars, will have the data storage capacity of 1 million 1982 IBM PCs.

The net result of this explosion in data collection and storage is that the world now has and may continue to have more data than system models to understand the data. If we believe that the world is composed of systems within systems, then all data in theory has a systems connection. Achieving that connection is perhaps the biggest challenge for systems studies in the future. However, data can be deceptive because immense quantities of data do not mean that the data sets are complete. Hidden patterns in the dynamic characteristics of parts can exist between measurement intervals. Some dynamic characteristics may still not be measured. Some parts may still not be detected in measurements. And some system formations may not be identifiable even with tons of existing data. For example, with all the research attention devoted to capturing the DNA as the map for organic growth, operations, and senescence, I have instead wondered who is doing research on the reference frame for the DNA map [1]. How do cells in the body grow and specialize into shapes and functions using the DNA map? No matter how well we measure the map, the system understanding is incomplete without the mechanism for the reference frame. The search for missing information, undetected parts, and unidentified systems will require an integrated understanding of all the characteristics in systems formation. Therefore, at this point, let us first explore what to do with all the data at hand.

For data sets that are well structured in that the primary information has clear fields of associated information, computers have been quite successful at storing and using such data through relational databases. Relational databases use table structures to capture data and correlate data fields through a relational index. A spreadsheet is an example of a relational database. As shown in Fig. 2.2, the first

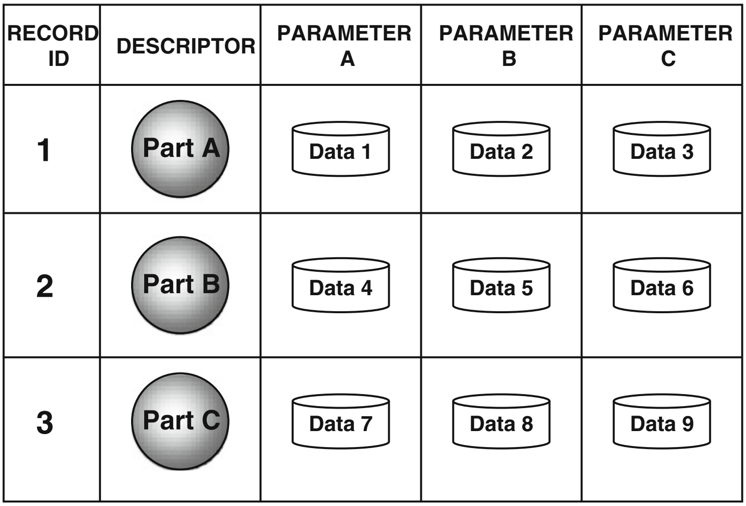

Fig. 2.2 Notional representation of a simple relational database

column of record IDs connects the elements/parts being described with the fields of descriptors and associated information. These databases can be quite large, as long as the relationship structures can be maintained, but there will eventually be scaling problems (perhaps at the terabyte level), as the size of the database cannot be easily handled by current server technology.

In response to large data sets without well-defined relational structures and with the need to leverage distributed cloud computing capabilities, technologies for nonrelational databases have advanced, led by Google and other leaders such as Apache. Essentially, nonrelational databases, as shown in Fig. 2.3, try to encapsulate data and parse data across a terrain. The data can be managed and controlled at the cell level with even security and access to the data controlled at the cell level. With this parsing, packets of data can be dynamically associated with one another in a complex manner based on incremental and iterative advances in understanding the data. The first step in advancing our understanding of the data is data mining. So in this first section on part dynamics, we will review data mining techniques and leave the many analytical techniques that are applicable to mined data for later sections.

Almost everyone today who has been on the Internet has conducted data mining activities. The most popular mining endeavor is the Google search based on key words and phrases. What the user gets in data mining are hopefully pieces of information from vast quantities of data that shed light on the user's problem and research interests. It is easy to understand the concept of a key word search, but there are other more advanced searches into the vast networks of data. I will review some of these advanced techniques below, and many of these techniques will require specialized search tools and inference engines that connect search activities with rule sets.

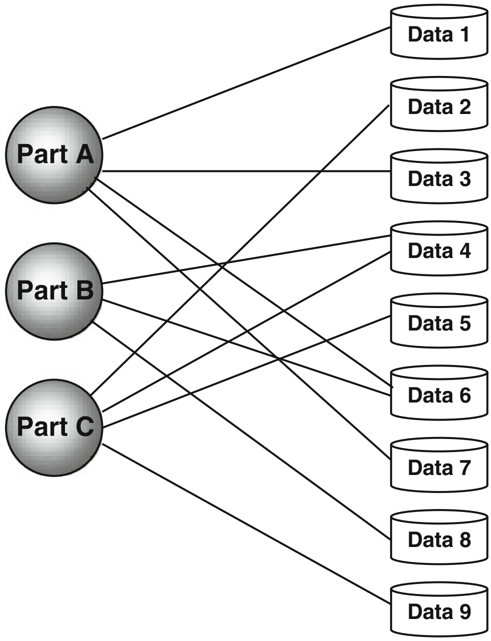

Fig. 2.3 Notional representation of a nonrelational database

2.1.1 Data Mining by Deductive Decision Tree

In this technique, as shown in Fig. 2.4, a search engine is given a hierarchical set of rules, which is automatically applied to search results. With each level of the search, the results are automatically assessed, and the rules tell the search engine which branches to follow in the next level of search. This multistep search capability produces incremental results that are presentable in a tree structure to promote data relationship understanding.

This technique is quite useful in rapidly searching for parts and part characteristics that are associated with an evolving distributed system in a complex environment [2]. For example, this search can automatically map out how a disease system is spreading across a society. Also, this technique is quite useful in tracking down sources of errors in complex multistage organization processes.

2.1.2 Data Mining by Agile Characterization

In this technique, as shown in Fig. 2.5, a search engine collects data broadly and dynamically organizes the data into summary groups, such as groups based on data ranges, for presentation [3]. The purpose of the grouping is to enable rapid comparisons of contrasting data between groups and to adjust group boundaries to

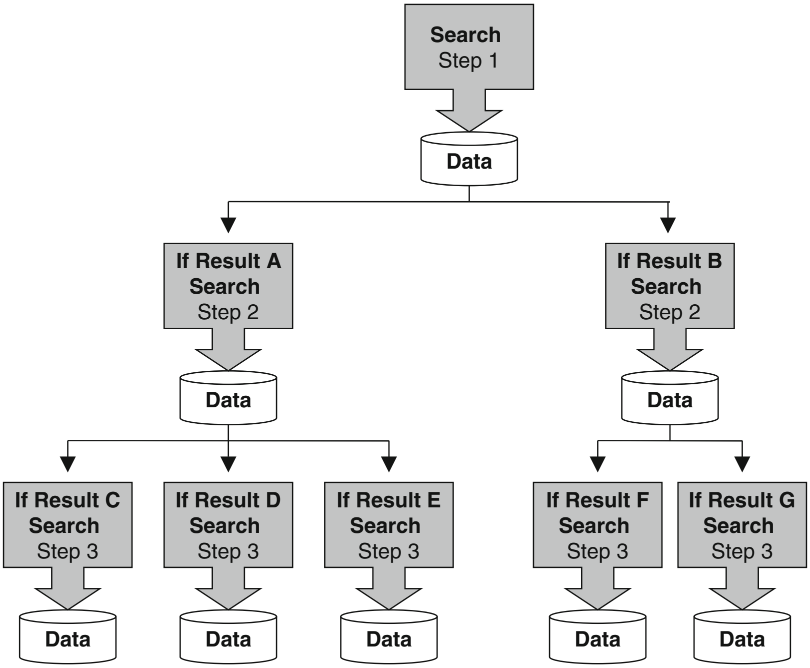

Fig. 2.4 Notional representation of mining tree

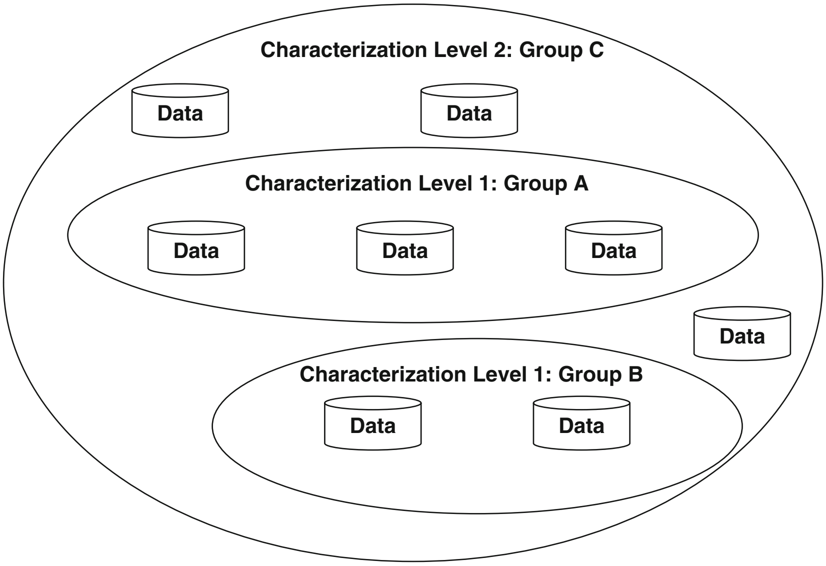

Fig. 2.5 Notional representation of characterized groups

better characterize data for follow-on searches. This process of characterization and recharacterization might require sufficiently generalized definitions of groups in the beginning, but the iterative searches that increasingly place data in more accurate groups can yield precise descriptive results.

This technique is quite useful in figuring out which distributed system, such as military forces, owns which parts as systems interact/conflict with one another. Also, this technique is useful in isolating system parts, such as biological agents, from an environment of similar parts. The refined definitions of groups can be further used to describe the associated system at a macro-dynamic level, and the process of grouping can be used to design or form systems from raw material.

2.1.3 Data Mining by Complex Classifications

In this technique, as shown in Fig. 2.6, a search engine identifies properties that are common across all or portions of the data and interrelationships between data elements based on these properties [4]. The initial identification process can use a correlation matrix. Once there are properties to link data elements, these links can be used to determine parts that belong to a system and the associations between the parts.

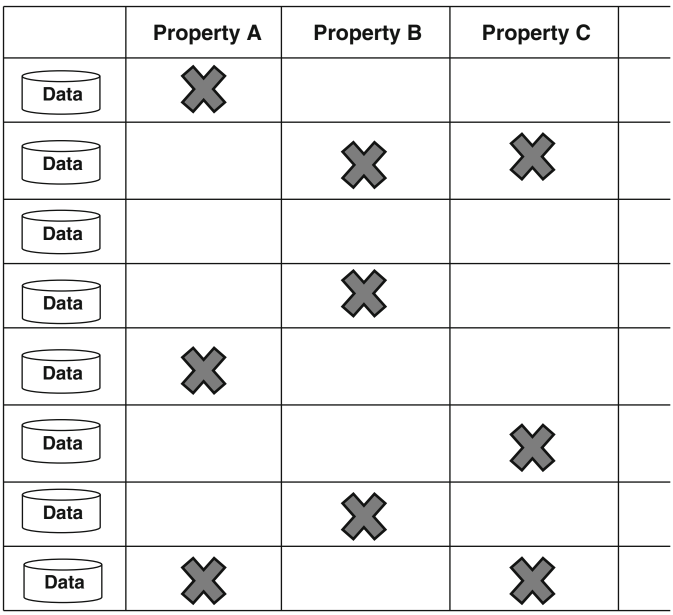

Fig. 2.6 Notional representation of complex classifications

This technique is quite useful in filtering data elements, such as properties of people in society, for behavioral patterns that link select elements to systems, such as secret organizations. Also, this technique is useful in separating properties/effects that belong to parts in a system from other related properties/effects from the environment.

2.1.4 Data Mining by Regression Analysis

In this technique, as shown in Fig. 2.7, a mathematical best fit line or curve fitting tool is used to discover how to extend the known patterns in data into regions of

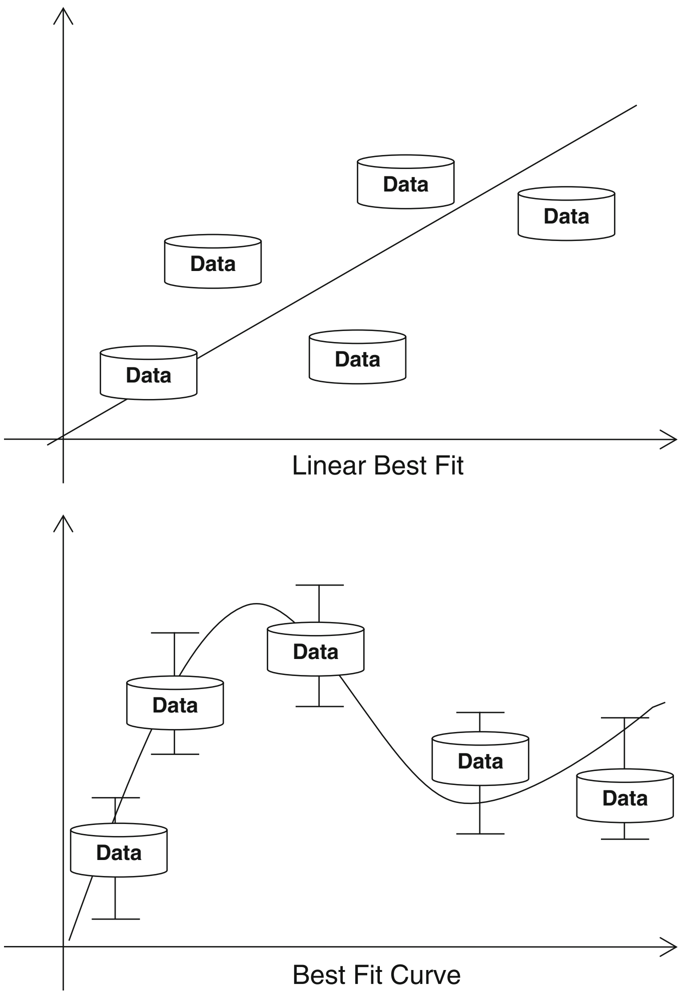

Fig. 2.7 Notional representation of regression analysis

unknown data [5]. Linear regression can project the nature of data in regions beyond current measurement capability. Alternatively, curves can show us ranges of potential data.

This technique is quite useful in guiding researchers toward areas of missing system dynamics information, such as output qualities when inputs are increasing beyond current measurements. Also, this technique is useful in formulating/projecting the existence of additional parts for systems with the understanding that such parts are pending future verification.

2.1.5 Data Mining by Inductive Data Association

In this technique, as shown in Fig. 2.8, a computer tool creates real-time node and link constructs in data based on discovered associations [6]. As to be explained in the next section, association type and strength can be reflected in the definition and distance of linkages. This representation can further be used to identify spatial gaps in data and future collection requirements. The initial inductive model might not be accurate, but through iterative data mining based on the model, the study of system parts and the whole system can be folded together in the data mining process.

This technique is quite useful at quickly linking the behaviors of the parts to the dynamics of the total system. Also, projected links are useful in finding data as well as hidden system parts. The changes in links and link characteristics will provide insight into the dynamics of parts and the system, and massively complex point-to-point relationships in data, such as those in protein studies (proteomics), might be more easily represented by nodes and links than other capture methods.

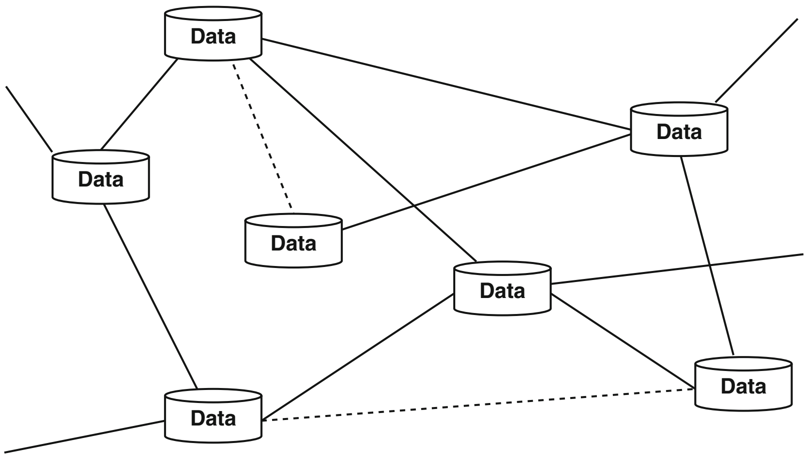

Fig. 2.8 Notional representation of inductive data association

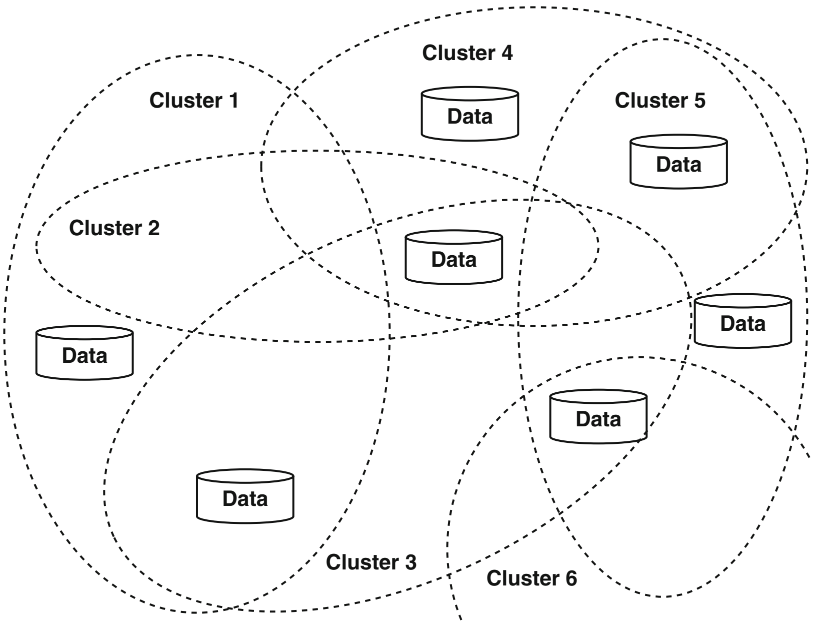

Fig. 2.9 Notional representation of cluster analysis

2.1.6 Data Mining by Clustering Analysis

In this technique, as shown in Fig. 2.9, the search engine conducts artificial grouping and regrouping of data to discover metadata sets where knowledge discovery is better achieved [7]. The meaning of a cluster is often understood after analysis whereas the meaning in data classification is more connected with the classification process.

This technique is quite useful at studying a mass of data, such as in information-driven systems, with no clear interrelations and delineations. At the beginning of the data collection processes, clusters can be flexibly assigned and overlapping. Then as data changes, the clusters can be refined to more accurately reveal system content and system dynamics understanding.

2.1.7 Data Mining by Baseline Pattern Searches

In this technique, as shown in Fig. 2.10, the search engine looks for entire patterns, groups, and states in data based upon traceable paths and/or baseline reference frames [8]. These entities may sometimes be obscured by other data elements

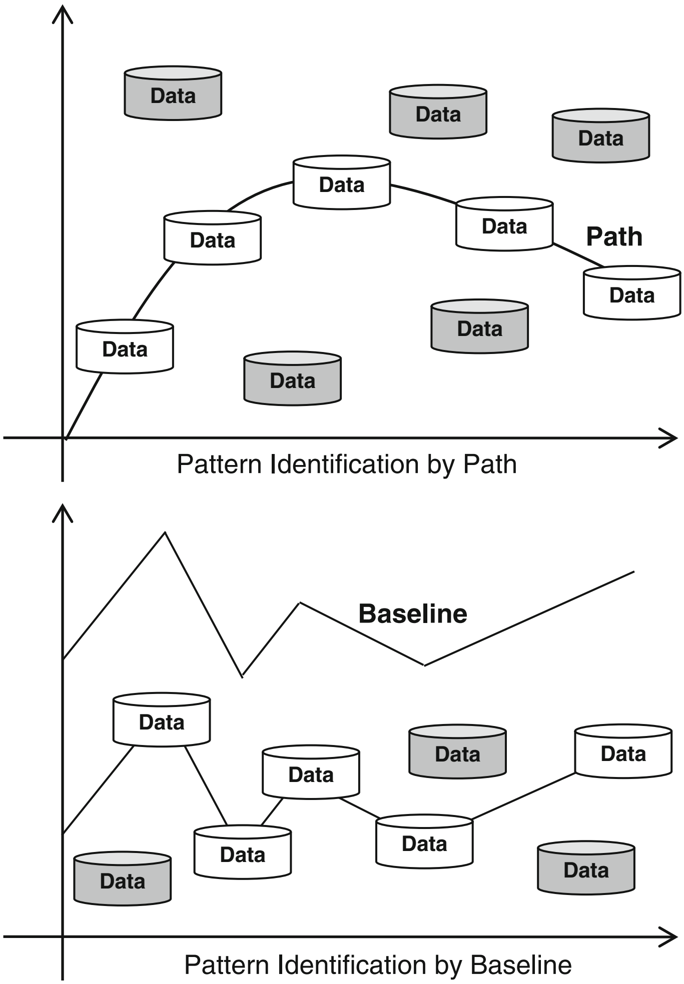

Fig. 2.10 Notional representation of pattern searches

intermixed into the patterns and groups. Therefore, a path or baseline is used very much like a filter to discover behaviors and relationships within apparent chaos.

This technique is quite useful in comparative data analysis, such as finding similar patterns of disease propagation in other cities when there is a baseline pattern from the originating cities. Also, this technique is useful in finding new, perhaps hidden, patterns by trying out a variety of nonrandom paths as filters. For example, admits the individual activities of people in a city, unique patterns of behaviors, such as specific person-to-person interactions or movements from location to location, can be discovered to indicate a coordinated terrorist plot.

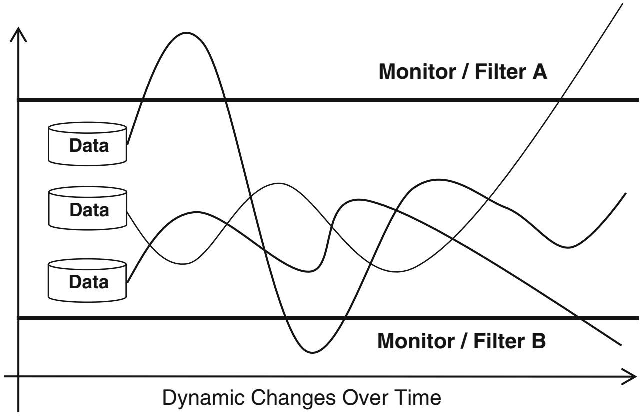

Fig. 2.11 Notional representation of state change and deviation filters

2.1.8 Data Mining by State Change and Deviation Filters

In this technique, as shown in Fig. 2.11, data filters are continuously applied to monitor for when dynamic patterns have exceeded specified ranges [9]. If the data is connected with system parts, then the dynamic characteristics of the parts, as described above, can be used as a basis for determining what states to monitor.

This technique is quite useful in understanding peak behaviors in defined system parts undergoing volatile periods of changes, such as worker dynamics in an organization hit by a business crisis. For example, who needs counseling support and who needs to be released can be assessed by behavioral filters. Also, this technique is useful in finding parts that are acceptable in a system, such as mechanical testing of manufactured components for performance within designed limits.

The above techniques for data mining are naturally mathematically involved during implementation, and many complex algorithms as well as computer codes have been developed in the exploding field of "Big Data" analytics. However, it is important for us to not lose sight of the fact that the human mind, which processes data in a nonlinear manner, is still superior to the computer's linear processing in some ways despite the computer's overwhelming speed, capacity, and accuracy. Therefore, I introduced the above concepts not merely to be a beginner's tutorial but also to be a stimulus for people closest to data to see pass the obvious for insights based on thinking about how to look and what to look for. To elaborate, the computer sees data as discrete elements and must work through data from one piece to the next. If the computer draws a curve through points, it goes from point A to B to C. In contrast, the human mind sees data as a whole as well as in discrete elements. Therefore, when we draw a curve through points, we can, if trained and focused, see how the curve fits simultaneously at all points. At times, we can still present a better fit solution in a faster time frame, particularly if the problem is unbounded. One might argue the man is inherently more able to think and act against uncertainties because the human mind is built to study real-world systems, while the computer is built to study bounded abstract models of systems created by man. I am, thus, a believer in the systems researcher using computers as tools and am quite concerned by systems research activities bounded from the beginning by the limitations of computer models and capabilities.

For those diving into the realm of "Big Data" with terabytes and even petabytes of information, I wish to add a reminder that data is not a mirror to the world, and all large data sets have errors. Errors might occur as a result of the processes in collecting, storing, and transferring data as well as in generating metadata from source data. These errors are typically systematic, occurring in a predictable manner, and can often be corrected through process changes when identified. Errors might also occur through a variety of external factors independent of process, such as random human mistakes in data collection, unforeseen environmental influences, and unanticipated glitches in the mechanistic activities of data management. These errors are typically nonsystematic, occurring in a perceptively random manner. This implies that their detection and correction must often occur in a one-by-one manner. Sometimes, a lack of validating methods might require data mining techniques to be adapted for error identification. Given the size of databases, the challenge is to figure out how to get machines/computers to learn the causes of errors through iterative discovery.

The nature of errors in data includes incorrect information, false information mixed into valid information, missing information, and inconsistent information. Incorrect information can be caused by the data capture person or device (collectors), states and behaviors of the source, and corruption after data capture. False information can be caused by the collector's inability to discriminate/filter data, opposing forces generating false data, and extraneous data that made their way into the database. Missing information can be caused by flawed collection such as not enough range or repeat cycles, flawed transportation such as packet loss across a communications circuit, and flawed storage such as ineffective data architecture design. Finally, inconsistent information can be two or more competing data elements for one parameter, two parameters with a common data element, and data elements in the wrong places.

In this section, I started discussing dynamics within system parts, but dynamics also contribute to the other system formation characteristics that we are about to explore. Therefore, this book is cumulative in its presentation style—each section becoming a foundation stone to understanding following sections. With the dynamics of the parts, the next logical step is to understand how parts associate with one another to form integrated dynamic properties.