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

C.H. Ren, *How Systems Form and How Systems Break*, Studies in Systems, Decision and Control 72, DOI 10.1007/978-3-319-44030-9_2

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

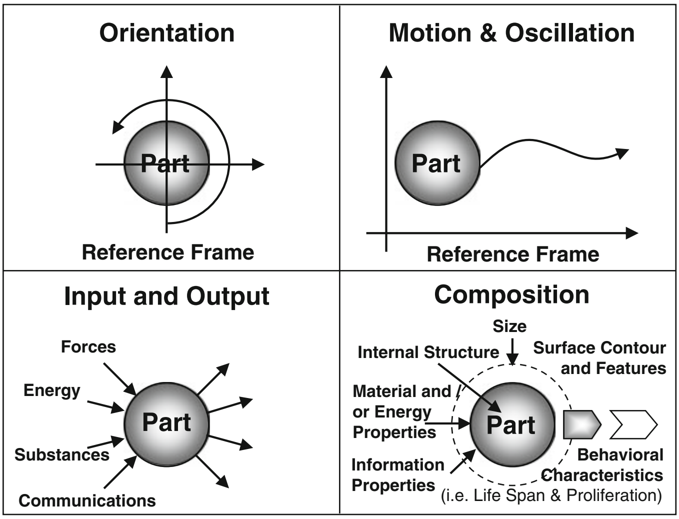

Fig. 2.1 Four types of dynamic characteristics

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

RECORD ID	DESCRIPTOR	PARAMETER A	PARAMETER B	PARAMETER C
1	Part A	Data 1	Data 2	Data 3
2	Part B	Data 4	Data 5	Data 6
3	Part C	Data 7	Data 8	Data 9

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.

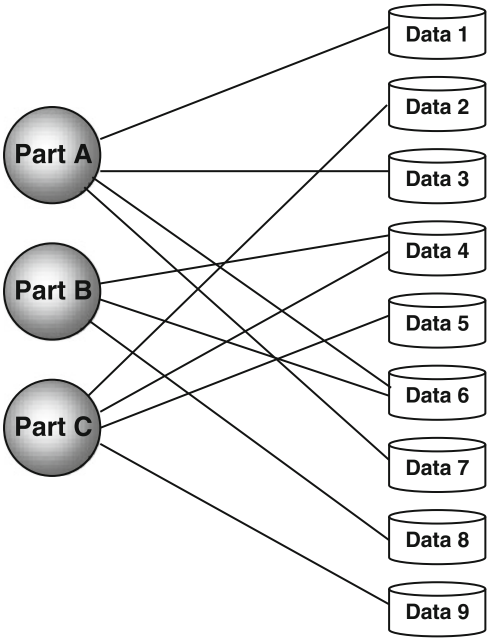

Fig. 2.3 Notional representation of a nonrelational database

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

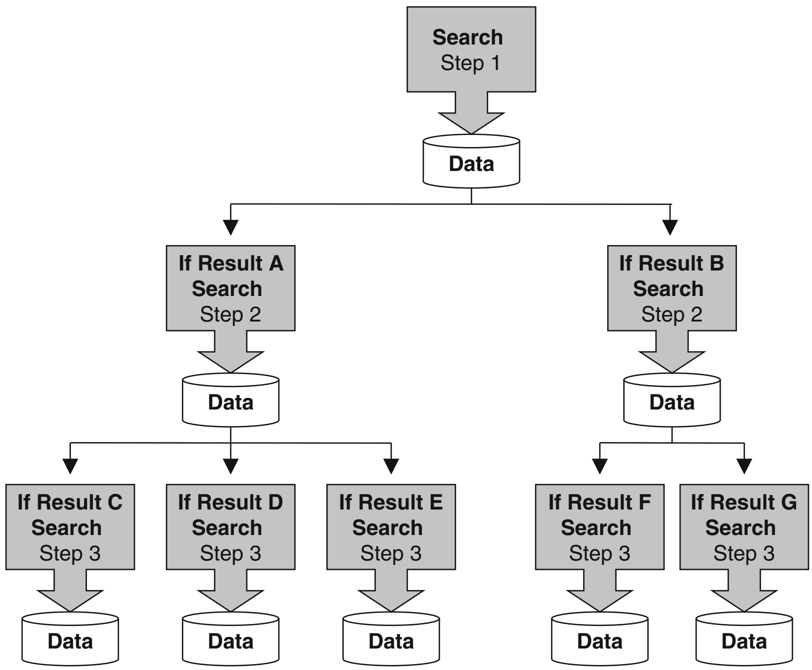

Fig. 2.4 Notional representation of mining tree

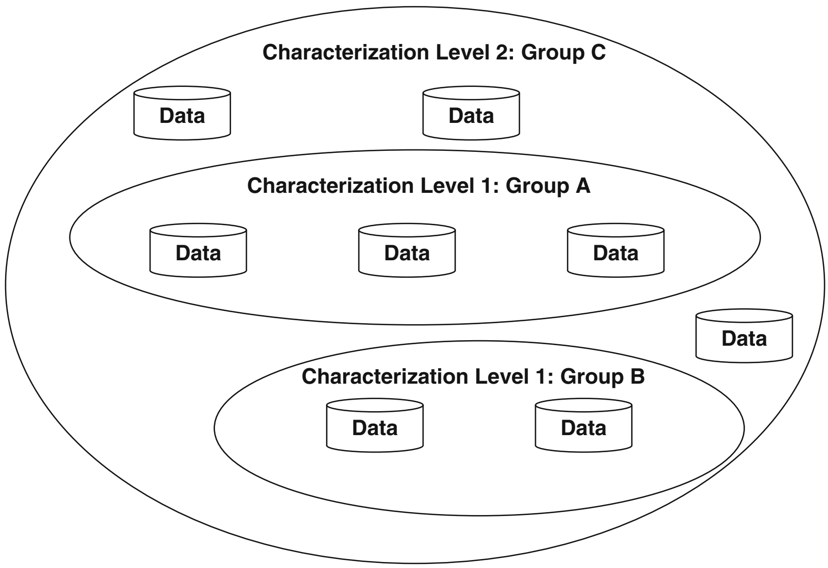

Fig. 2.5 Notional representation of characterized groups

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.

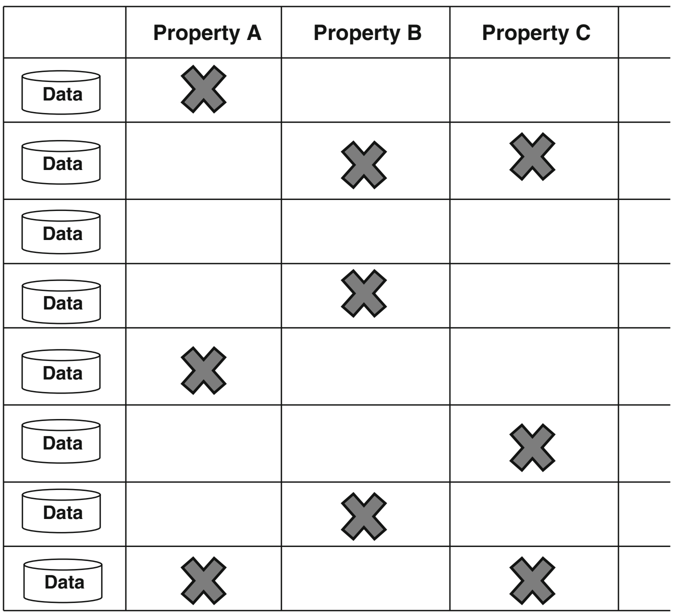

Fig. 2.6 Notional representation of complex classifications

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

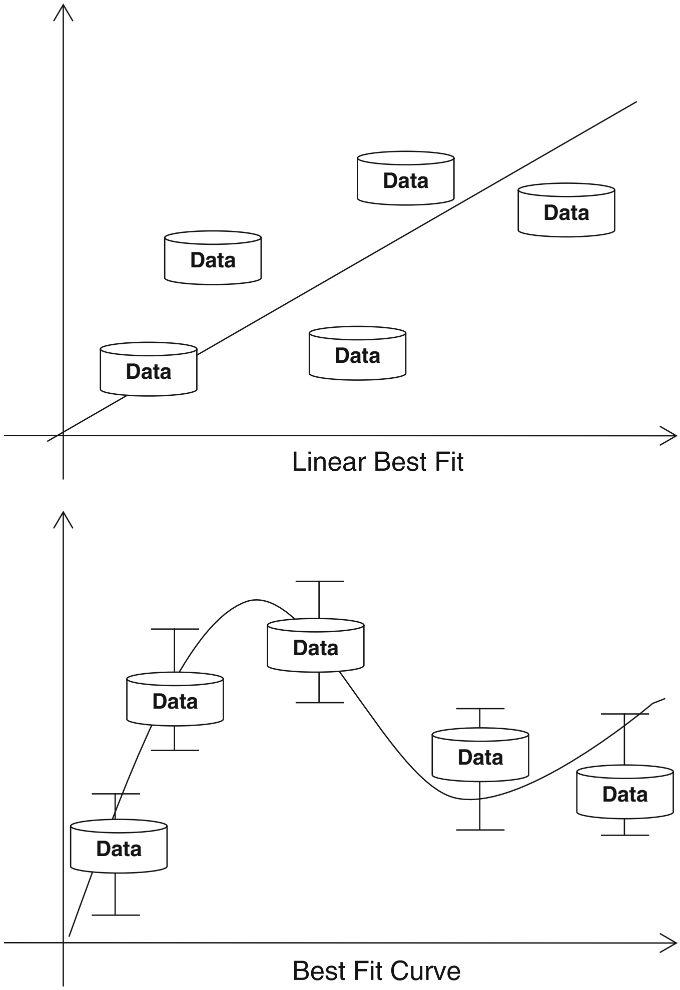

Fig. 2.7 Notional representation of regression analysis

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.

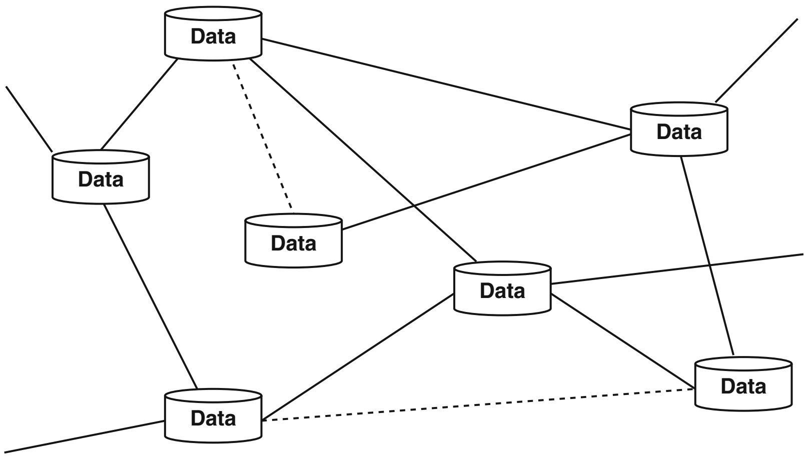

Fig. 2.8 Notional representation of inductive data association

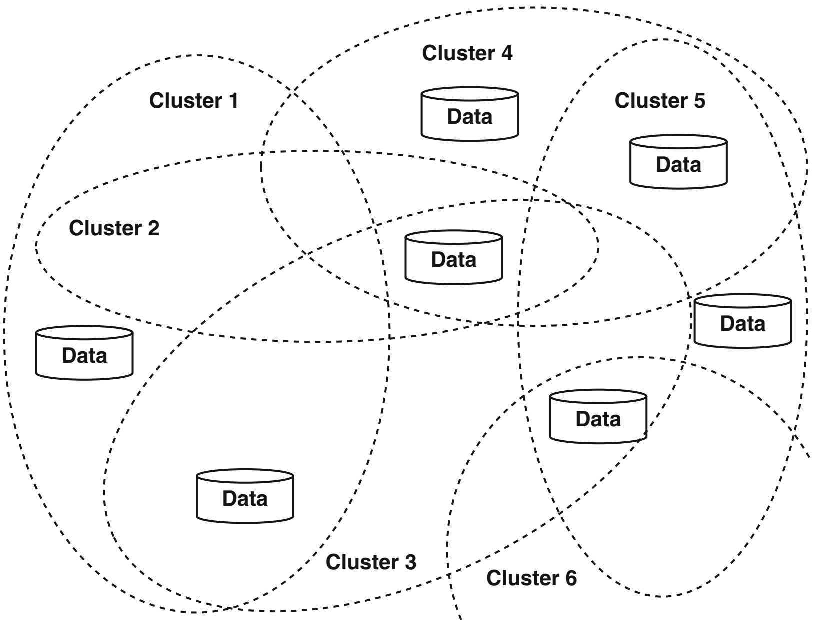

Fig. 2.9 Notional representation of cluster analysis

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

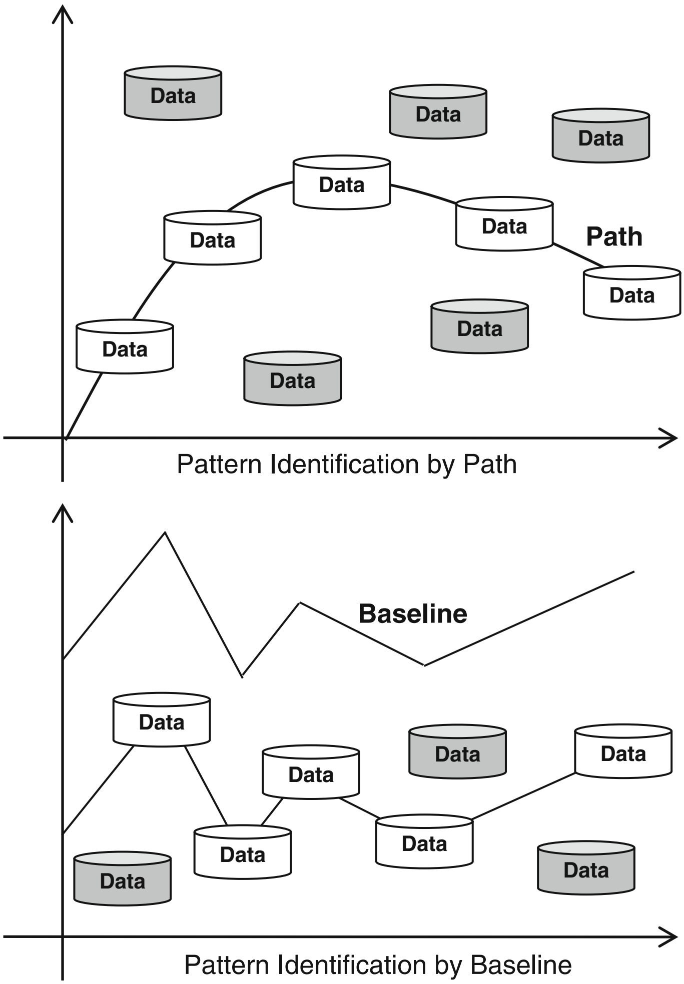

Fig. 2.10 Notional representation of pattern searches

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.

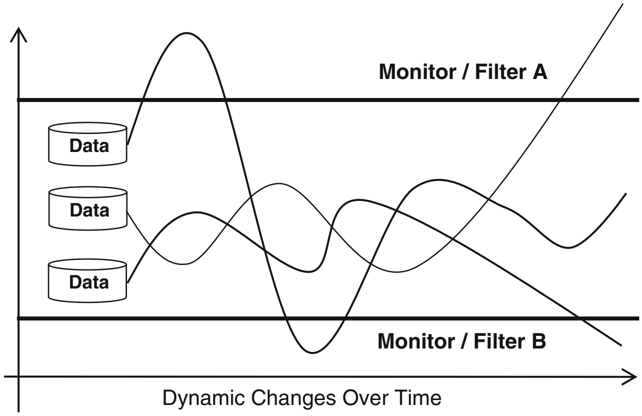

Fig. 2.11 Notional representation of state change and deviation filters

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.

2.2 Associations: Connections Between System Parts

As systems are parts working together, there must be associations between the parts. Every part does not have to be and should not be associated with every other part. However, when two parts have an association, there are characteristics that are identifiable. We can deduce four ways to describe the association, as shown in Fig. 2.12: (1) type or types of association that is between the parts; (2) the orientation of the association that can be connected with the orientation of each part; (3) the quality of the association that can be driven by each part's dynamic characteristics; and (4) the effects upon the association that can support or challenge the quality of the association. Beyond these descriptive characteristics, the parts connected together by associations can be treated as a high-level entity/subsystem with total dynamic characteristics as described earlier. In other words, the parts together have group orientation, motion, inputs and outputs, and composition.

In regards to the types of associations, two parts can be linked together in a way that there is a continuous ability to transfer force, exchange physical material, communicate information, and/or detect one another's role and status in the system. For example, the planets in our solar system are continuously under the gravitational force of the Sun and one another. A pipeline could pass oil or natural gas from a reservoir to a user machine, such as a home furnace. A wireless network

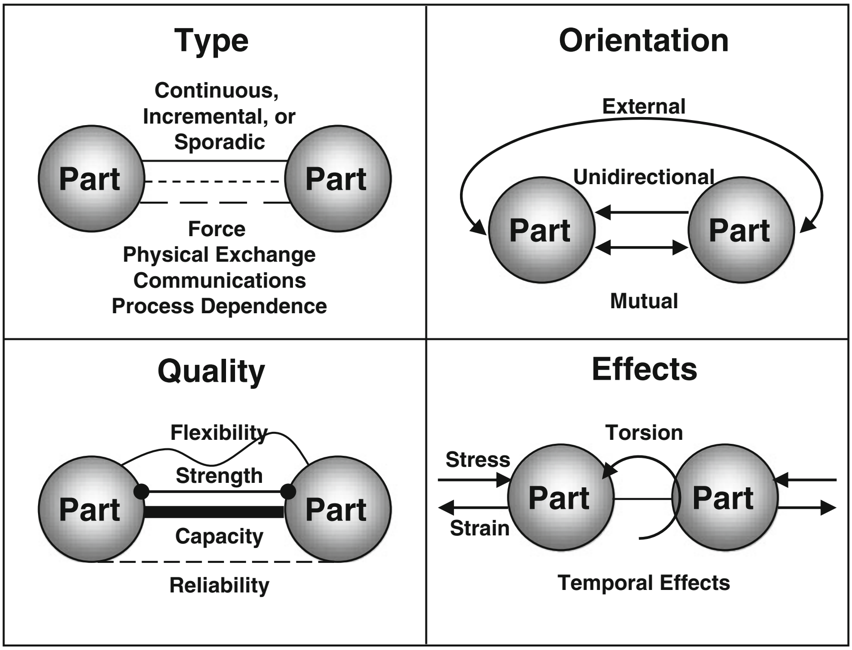

Fig. 2.12 Describing association characteristics

could pass data from one computer to another. And a factory worker could start his/her work, which depends on other people's work, by merely following the directions provided and looking at the clock. In the latter case, the workers are linked together by a process and do not necessarily have to communicate with one another.

The links between parts do not have to enable continuous force, material, and process data exchange. Incremental exchanges are still definable as links. At which point, the nature of the increments, such as time between engagements and duration of interactions, become additional characteristics. Further, the link could form only as needed and break in a sporadic manner depending on the dynamic state of each part. Human players working as a group and adapting to an unpredictable and changing environment will often form and break ad hoc associations as needed. Based on the number of link types and exchange types, there are 12 combined types of associations between parts. Two parts can yield more than one of these 12 association types, and the types can change as a form of dynamics. Sporadic links can suddenly become continuous, and incremental links can gradually become more sporadic. The flow of material between parts could stop while the communications continue, and the communications could stop while the process that associates the parts endures.

If there is any kind of link between parts, the flow of force, material, information, and/or awareness can be in just one direction or both directions. Unidirectional associations often create a subordinate relationship between parts. Beyond these link orientations, a link between two parts can also be external. In other words, the forces, material, information, and process controls can pass from one system part into some element of the environment that passes them to some part in another system. For example, when we are on the Internet, there is not a direct communications link between our computer and the web application server on the other end. Instead, information on both sides are sent out in packets with protocol layers that tell routers throughout a vast global network on how to direct the movement of the packets along adaptive paths. The optimization of the Internet than controls the flow of countless packets so that millions of users all think that they have direct lines of communications. Looking at the Internet example, we can also consider external link orientations as mostly dependent links on system controls, as it is difficult to imagine a simple environment redirecting the paths of forces, material, information, and awareness. In contrast, direct links can be facilitated by a simple medium, such as pipe, wire, paper, etc., or no medium at all.

With link type and orientation, the next set of characteristics is for describing the quality of the link. The quality characteristic of flexibility is how the link can be changed while still remaining intact. The change can be initiated by changes in the dynamics of one or both parts, or it can be due to changes in the medium or mechanism that enables the link. For example, parts that are moving or changing in properties might require the link to also change in order to be viable. If the medium enabling a link, such as air for the passing of sound, water for the shipping of containers, and wire for the passing of electrons, is damaged or altered, then the link characteristics might have to flexibly respond.

The quality characteristic of strength in a link is simply how much opposing force can be withstood by the link based on the reference frame of the link. The opposing force for a link based on forces or physical exchange could act directly on the forces in the link or transport mechanisms enabling the link. Alternatively, the opposing forces could act at each end of the link on the parts. The opposing force for communication links could be false information; the opposing force for process links could be opposing processes.

The quality characteristic of capacity is simply the level of throughput for each type of link. How much force is applied? How much material can pass at one time? How many bytes of data can be transmitted per second? Links based on process might not have a capacity, but the number of procedural steps enabled by the link per second in the process could also be interpreted as capacity in some cases. Finally, the reliability of the link is slightly different than strength in that reliability accounts for the effects of time. A link can be strong initially but become unreliable due to the course of change. Also, the association can simply be unreliable from the beginning as an inherent quality. Not the same as sporadic links, which are known to break and reform, unreliable links fail to meet their objective level of endurance against time and forces. In designed relationships, reliability can sometimes be improved like strength and capacity. Ways to improve reliability include increasing strength, maintenance, backups, and redundancies.

The last set of characteristics for the association of parts is the effects of time, environment, and other parts on the association. Using a physical mechanistic analogy, the effects on an association can be regarded as: (1) stresses; (2) strains; and (3) torsion.

Stresses are things external to the association that seek to force change in the association. In mechanics, stress is the force that presses inward. In a communications link, external stress can be other external communications causing the intended communications to be more difficult. In a physical exchange link, external stress can be checkpoints and detours along a road that chokes the shipping of goods. In a process link, external stress can be other laws and regulations that the process might have to comply with. In mechanics, strain is the force that seeks to pull apart the link. In a communications link, external strain can be parts moving further apart and into areas where the communications infrastructure is less robust. In a link for physical exchange, external strain can be a breakdown of transport vehicles and reduction of delivery personnel. In a process link, external strain can be people unwilling or unable to conform to the process. Finally, torsion is a force that seeks to change orientation. In the case of links between two parts, external torsion might flip the direction of forces, communications, and physical exchange. In a process, torsion might shift the flow of the process. The reason I have added torsion is as a reminder that external forces can affect association in complex ways.

The study of associations given the general characteristics described is separable into the understanding of existing associations and the prediction of future associations as well as changes in associations. In the study of current associations, we first start with whether there are deterministic ways to describe the association—ways that explain cause and effect and ways for the capture of absolute behavior. At times, deterministic definitions of associations are possible because associations are not as diverse and complex as parts. To be specific, the ways to describe parts are unbounded. System parts can be almost anything and anyone, and human components in a system are beyond complex, almost impossible to adequately define. In contrast, the association between even the most complex parts cannot be as complex as the parts themselves. Instead, a subset of the parameters that define the parts will govern the association. Thus, if we can isolate the subset parameters and isolate the nature of the linkage, we might be able to formulate a behavior for the association.

An example for deterministically defining an association is when the force, physical exchange, and/or communication that join two parts follow a wave pattern. Wave patterns are describable by formulas, and the cycles, peaks, and contours can match the association characteristics. Some common wave patterns for incremental links include square waves, sawtooth waves, rectified half waves, and surge and release waves, as shown in Fig. 2.13. Square waves reflect a cyclical flip between two states, such as times when products are moving from Part A to Part B and times when there are breaks. This cycle is definable as a discontinuous function. Sawtooth waves reflect a cyclical rise and decline with discontinuous changes at peak and nadir. This wave/cycle can be used to describe interactions between Part A and Part B that reverse directions based on an upper and lower limit. For example, Part A pours water into Part B until a certain level, and then Part B pours the water back. The link overtime will look like a saw tooth. Rectified half waves reflect a cyclical pulse and a corresponding rest portion. This wave cycle can be used to represent associations based on periodic events with ramp-up start and ramp-down end. Finally, surge and release waves reflect a buildup to a point of sudden release like a capacitor. This release can be periodical discharges of energy that go from Part A to Part B to create an association.

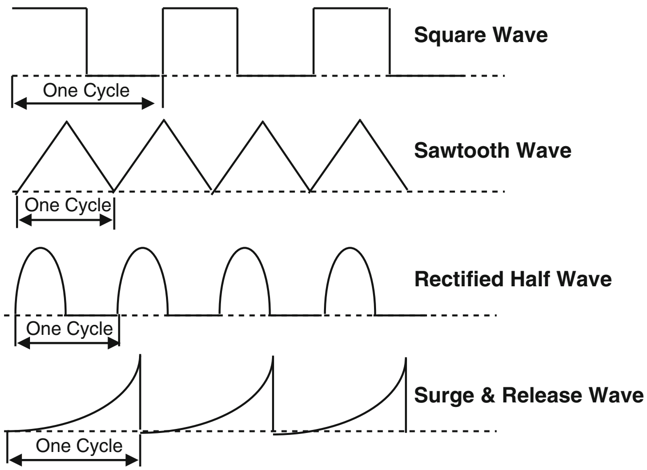

Fig. 2.13 Wave form types for incremental links

Continuous links between two parts with changing characteristics are better expressed as continuous wave functions. These waves can vary in amplitude and cycle overtime, and the patterns of variations for links transmitting energy have been the basis for modern coded communications. In communication links, where a large amount of data encoding is desired, we want shorter waveforms and higher frequencies for modulation. In the links of forces, such as planets in elliptical orbits around the sun, the strength of the forces can vary by distance and other factors to create very long waves. Continuous links do not always have to vary overtime. Instead, the characteristics of the parts joined by a link could change. Thus, there are link dynamics, part dynamics that drive link dynamics, part dynamics, and part dynamics that are shaped by the links.

The types of associations that lend themselves to precise determination of behaviors are, in many cases, a part of designed systems. In natural systems, the associations might be difficult to identify and difficult to quantify. For a particular type of association, the qualities might vary dramatically across a large number of samples without clear causes. Given a defined sample set, we might nevertheless be able to determine the probability of each level of quality occurring and graph the probability of all the quality levels, as shown in Fig. 2.14. If the graph shows a standard probabilistic distribute curve with a dominant mean and most samples falling within the standard deviation, then we are led to consider that there is coherence in the effects upon the association type. If there are multiple clusters of peaks, then we are led to consider that the association type is split by other characteristics and effects to include shifting behaviors over time. For example, people taking a test to become employed in an organization/system will have varying scores depending on individual capabilities. However, we should expect the common test and people's common understanding of the questions to create the coherence and standard distribution of results. The test can then be viewed as a process link between people and the organizational system. If the test is poorly written so that half the people will read the questions differently than the other half,

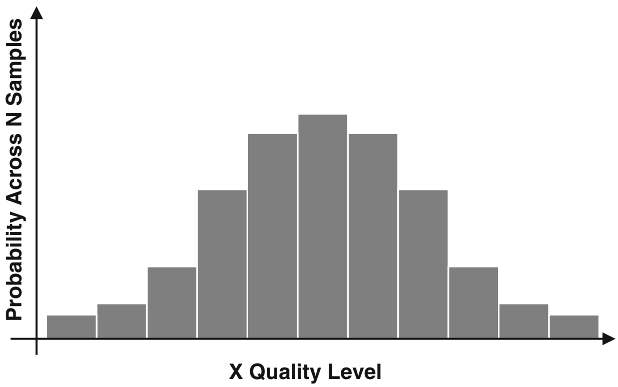

Fig. 2.14 Distribution of probabilities for a coherent association

then the results will be split and the process will be broken. This initial understanding might help us find linkage issues prior to full understanding and look for the interrelationships between the characteristics of associations to discover causes and effects.

In associations between parts where there is a known group of mutually exclusive types, a pie chart, as shown in Fig. 2.15, can be used to show what percentage of the total number of associations is dominated by each type. The percentages can then be determined by studying large data sets. While we may not have enough understanding to determine which type of link will result when a new association forms, the distribution will provide some insights regarding occurrences in large samples. For example, an organizational component may have multiple choices for sending packages to another organizational component, such as by government mail, commercial shipping, private courier, or employee tasking. While the decision process for selecting the link between sender and recipient at each occurrence of sending a package is highly complex, if the components and conditions remain relatively stable over a time frame in which a sample set is established, then we can build the pie chart. If a shift in the components, such as arrival of new decision-makers, or a shift in the association type, such as price changes, can be specifically identified to enable a new sample set to be collected, then we can study dynamic changes in the association.

If different associations in a system have common but not well-understood characteristics, then the overlap of characteristics between different associations are expressible in a Venn diagram, as shown in Fig. 2.16. This visualization of simple set dynamics can help us focus on the most import groupings of characteristics in a complex system. While the overlaps between three associations are quite simple to see, diagrams involving many associations and sets of characteristics might be visually complex. In this complexity, the human mind might be able to see centers of gravity, hidden stresses, and driving characteristics. If the characteristics being explored also have probabilities of occurrence, then the diagrams can be connected to probability theories for examining the system.

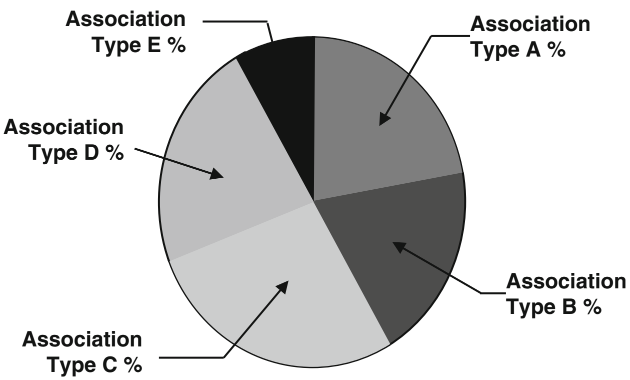

Fig. 2.15 Pie chart breakdown of association types between specific parts

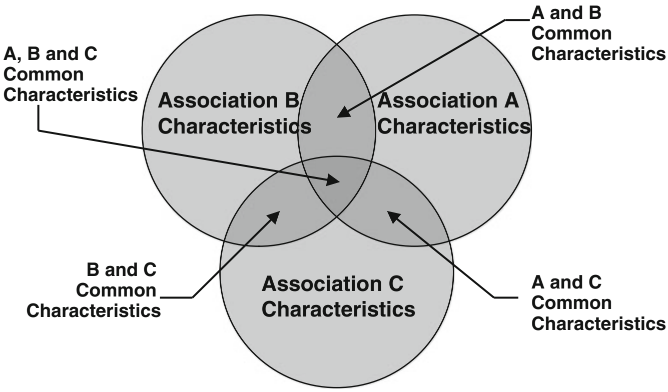

Fig. 2.16 Venn diagram of association characteristics

The use of probabilities to define associations is an acceptance that individual behaviors of elements in a sample population are too difficult to measure. We know that there are commonalities in the elements that drive the determination of probabilities for given behaviors/associations, but we do not know exactly how an element will choose to behave at any given point. The most obvious elements of this type are human beings with our incredibly complex mental processes making decisions based on past experience and thousands of environmental factors. Despite this complexity, people as a whole are remarkably predictable when the population state is measurable and the environmental stimulus is quantifiable. The modern advertising industry is completely based upon this fact. When a test market group of people that is traceable to the profile of the general population is shown a commercial, their probability of reacting in specific ways and forming specific associations are translatable to the overall consumer population. The success of population studies by statistics has extended to medicine, city planning, organizational management, military strategies, and all other missions of human society. The success of statistics has further been extended to other types of populations such as microbes, wild animals, and even environmental phenomena. However, if any of these populations have internal structures of associations/links, statistics will offer limited understanding.

Giving up on understanding how parts in a system will individually behave in achieving associations is contrary to the idea of studying how systems form. Statistical descriptions of association behaviors do not yield true system models if one does not believe that there is true randomness in system behaviors. Even for systems with massive amounts of associations that seem impossible to individually measure, the exact outcome of every association/interaction are predictable if all the conditions in the system and surrounding environment can be modeled. Thus, the notion of a stochastic system can be viewed as merely an abstract concept for coping with the inability to model behaviors or the impractically of modeling individual behaviors. Regarding impracticality, what if the actions of that one specific person or part matter? What if one relationship or one broken relationship can change the outcome of the whole system? For example, a drug company might only care about the total number of acceptable fatalities in the user population for a new drug. However, if the few people with fatal side effects include promising scientists, leading artists, and/or key political leaders, then the whole world is in the balance with only a few associations. I am not arguing about the value of new drugs, and we all understand risks. However, from this perspective, is it not worthwhile to see if specific associations/interactions can be modeled through new explorative techniques? In the case of new drugs, is it not valuable to be able to isolate people who would have adverse reactions through systems analysis?

When deterministic definitions cannot be discovered, and when stochastic assumptions are not enough, there is a series of uncertain reasoning techniques that can be used to explore associations between parts in a system as well as between parts and the environment. Some of these techniques are discussed below, and most of these techniques are being actively explored in research communities. Again, I cannot do justice to these techniques for which researchers have devoted years of effort in developing algorithms and computer models. However, using the concepts for advanced techniques might at times help even novice problem solvers think about the world with its many parts, associations, and systems.

2.2.1 Discovery by Fuzzy Logic

This technique, as shown in Fig. 2.17, treats variables as vague but not random. A fuzzy variable can belong to different sets with varying levels of enclosure. The

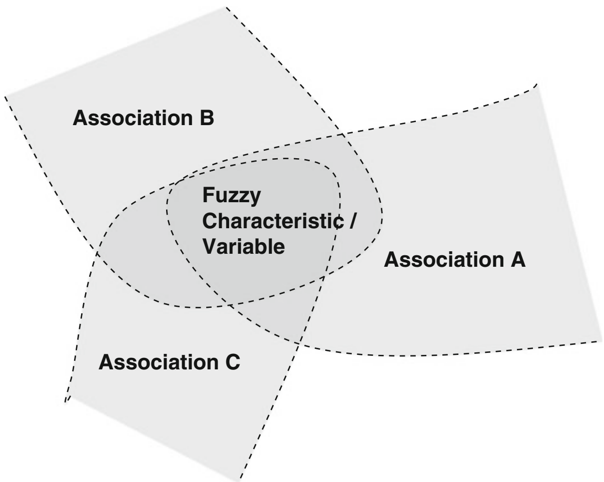

Fig. 2.17 Fuzzy logic connection between characteristics and associations

boundaries of these sets are, therefore, elastic, and the logic for determining enclosure is more driven by degrees instead of simply true or false outcomes. Algorithms with binary outcomes (i.e., If X Then Y) are, therefore, not well suited for fuzzy logic analysis. Instead, fuzzy logic algorithms allow outcomes to have degrees of truth (If Very, If Somewhat, If Not Much, etc.), and the degrees can shift with iteration against changing influences.

The concept of fuzziness has been mathematically explored throughout the twentieth century, but the terminology of fuzzy logic did not become formalized until 1965 [10]. With advancements in computer technology, fuzzy logic has been used to try to mimic complex processes, such as in artificial intelligence, and cope with complex interactions, such as controlling unstable objects. However, at the fundamental level, fuzzy logic is about figuring out associations that are not fully defined but not random in nature. This is most definitely true for interactions based on the human mind as well as all the countermoves to match shifting environmental forces on unstable objects. In both cases, mimicking or modeling outcomes might be easier than figuring out specific associations. Therefore, we might need to find a simpler example of how fuzzy logic can be used to understand associations as a step in understanding how systems form.

That example could be undetermined protein activities as parts in a cell. We know that many complex proteins have a multitude of functions and associations in the course of supporting cell dynamics. When these associations have been isolated, the protein's role in the system can be simply mapped. However, what should we do with protein characteristics that are not clearly tied to associations? Iterative analysis using fuzzy logic and many instances of data might gradually enable us to narrow down the nature of the primary associations (characteristic sets) connected with the uncertain protein characteristic. If we put aside the purest view that fuzzy variables must remain fuzzy, then this technique could move understanding from degrees of belief to near certainty.

2.2.2 Discovery by Bayesian Networks

This technique, as shown in Fig. 2.18, uses a node and link network to propagate a behavior, such as the formation of associations, based on the probability of each uncertain step in the propagation moving forward in one direction or another [11]. The use of probability in this case does not imply automatic acceptance that the entire system is stochastic. Instead, the probability can be used to describe the uncertainty as patterns of belief. These patterns can provide us with insights regarding the accumulated consequences of formed associations. After multiple steps in propagations, we might see propagation paths cross one another, initially dominant paths shift into obscurity, and unrealized ranges in outcomes. The theory in studying associations with such networks is that simple courses of action might lead to complex results over many steps of interaction and association formation.

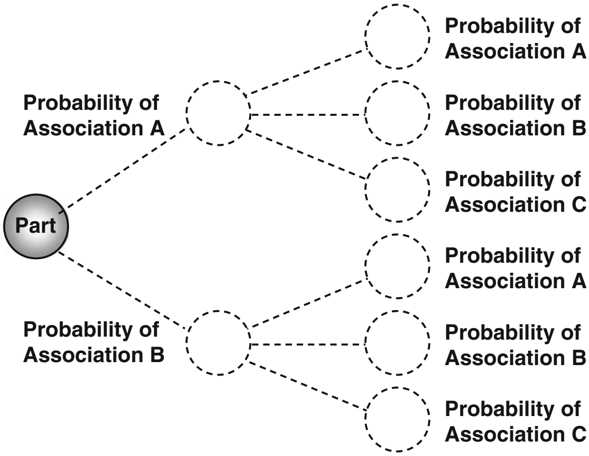

Fig. 2.18 Bayesian network projections of association propagation

An example of parts in a system dealing with a limited course of actions is people in an organization starting to work together to confront a specific crisis situation. The organizational environment and operational procedures provide some constraints on the ranges of people's actions. The emerging crisis creates a degree of uncertainty for people's actions. And different types of people will have different probabilities for choosing the ways to work with others as the crisis progresses. The result is a natural network diagram of associations and evolving associations. Associations that are temporary or enduring can be uniquely identified to portray possible end states. Similar network diagrams can be used to track the status of one person in moving from one action to the next. In either case, we are not examining large populations and assumed randomness. What we are looking for are configurations, patterns, ranges, and overlaps.

2.2.3 Discovery by Rough Set Theory

This technique, as shown in Fig. 2.19, starts with data, such as association characteristics, which clearly falls within specific sets and data, such as uncertain characteristics, which falls within the region between sets [12]. Then, a reductionist approach is used to determine how to be lenient with inconsistent data and to create rough boundaries. For the approach, information is decomposed down to indiscernible elementary granules of knowledge that can form elementary sets (concepts). Elementary sets can then integrate into compound sets, which are then classified as either crispy sets or parts of rough sets. This operationally intense technique meant that robust application did not start until the 1990s as computer processing capabilities increased. In application, the technique crosses from data mining to machining learning that involves large data sets.

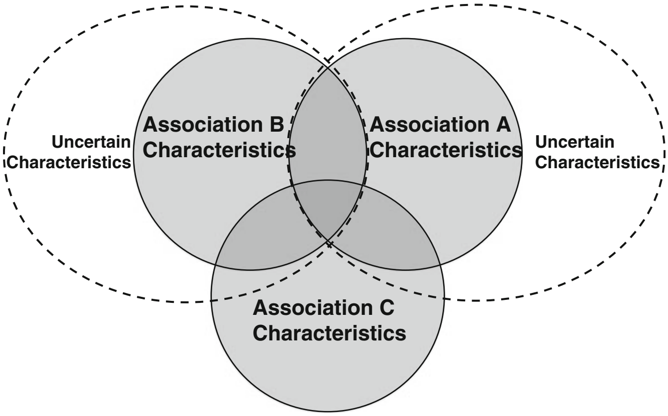

Fig. 2.19 Rough set theory of association characteristics

In discovering associations that are a part of existing and potential systems, rough set theory can be used to filter out system associations in a sea of other types of interactions. For example, in human society, there are countless associations/ relationships between people each with characteristics. Suppose one wants to find out what structure of relationships in the mass of relationships indicates the activities of a terrorist organization, what is the path of discovery? Using this technique, one would take all the characteristics that are from undetermined associations and break them apart, such as a person buying a gun and a person going to the gun store on his birthday. Then, these granules will start to coalesce around association types, such as the person is planning an attack or the person is buying a birthday gift. Granules from other undetermined associations, such as another person interacting with this person and another person buying a gun, might start to shift the set boundaries in favor of specific types associations. When conducted on a set of "Big Data" for population behavior, this type of assessment might produce complex networks of possible associations for indicating hidden systems. In some cases, we may not even wish to start searching for a specific system but, instead, allow the rough set associations to lead us down paths of discovery. Serendipitous discovery can sometimes be highly important in complex system dynamics.

2.2.4 Discovery by Genetic Algorithms

This technique, as shown in Fig. 2.20, leverages evolution theory and uses algorithms that compete candidate search approaches against large data sets [13]. Through comparing fitness parameters connected with the search approaches, a selection using search results is made regarding the best approach to undergo alteration for the next generation of searches. In altering the fittest approach, genetic

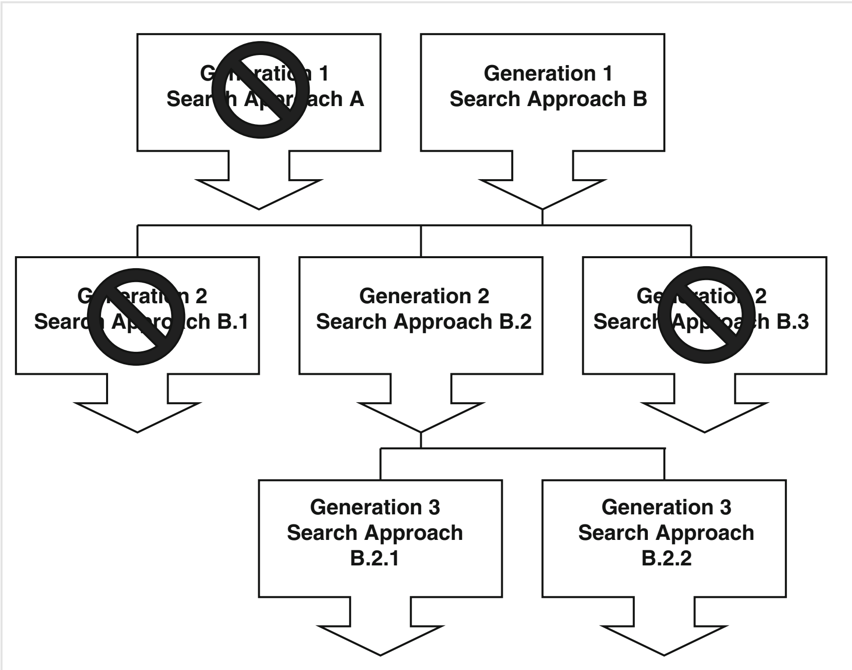

Fig. 2.20 Generations of improving search approaches with genetic algorithms

operators are used to adjust/deviate key instructions in the searches. These operators can also pull positive elements from other search approaches to create hybrid search approaches. The result is a new generation of search approaches based on controlled variation from an evolutionarily successful parent. The goal is to obtain the best search outcomes, even though the initial starting point of discovery may be way off target. In theory, this discovery process will become increasingly intelligent or refined overtime. After generations of searches through complex data environments, one might be able to narrow down the critical pieces of data, which is like finding a needle in the haystack.

Genetic algorithms can clearly be used to search for highly obscure associations without many identifiable characteristics. For example, the early stage propagation of a rare disease with minimal initial symptoms but hugely damaging long-term effects might merit this type of search. How the disease connects with people as hosts, how it proliferates in the host, and how it passes to other people can all be very undetermined at the start of the search. Then, as each victim is discovered, the search can be refined for other victims and more specific propagation paths. This type of discovery is similar to the human process of a detective deductively considering his or her options and pressing forward with each step of an investigation. However, when automated through high-speed computing and sophisticated search evaluation and refinement approaches, the search can quickly advance through hundreds of generations of refinements and a complex path through the data space.

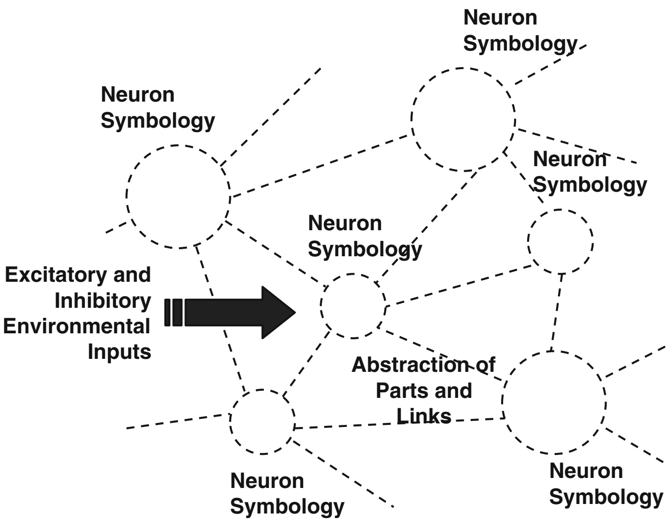

Fig. 2.21 Neural network representation of uncertain association dynamics

2.2.5 Discovery by Neural Networks

This technique, as shown in Fig. 2.21, uses a layered interconnected network of subsymbolic (no rigidly defined symbolic meaning) elements known as neurons to abstractly model a problem space or network of associations [14]. The neurons are defined to have weights as well as connection strengths and can receive positive (excitatory) and negative (inhibitory) inputs from the environment, which induce changes. Therefore, we are attempting to study the dynamics of associations without clear understanding of the parts and the links between parts. After studying the dynamics over a period of time and across a range of conditions, we might then be able to add more specificity to the definition of the neurons and the morphing network structure. Neurons and neuron types that do not fit with clearer definitions can be eliminated. Links that are turning out to be not a part of the system dynamics can also be dropped from the topology. In the opposite direction, increasing dynamic knowledge may cause us to add neurons and links as well as to leave the total topology of the network unbounded. The environmental inputs upon the network that is a stimulus to change could also be initially not well defined. Additionally, the network might have a pattern of change independent of the environment. Deeper understanding of both these change patterns will further contribute to environmental understanding.

Neural networks have been used to study organically formed associations and systems across the World Wide Web. We can track network traffic, identify the ends of communications, and model the dynamics of information flow. However, understanding the people and groups who are communicating and the nature of the communications that form associations can be very challenging. Social networks are often self-organized and rapidly changing. Thus, using a neural network model could reveal the characteristics of nodes and links and discover the extent of associations.

2.2.6 Discovery by Agent-Based Modeling

This technique, as shown in Fig. 2.22, requires the use of an explorative modeling tool that enables us to create agents for representing actors, system components, and environmental elements [15]. Agents are defined through a series of logical behaviors that describe what each agent will do when confronting other agents in the modeling environment. The resulting associations and broken associations over time with many interacting agents might be complex, even though each agent is simply defined. In practice, we want to design agents to be abstractions of real-world entities with the behaviors focused on the associations and system dynamics that we care about. We cannot and should not try to build perfect software replicas of real-world entities. After designing the agents, complex system theory then argues that simple behaviors can interact in complex ways when executed across a large population and/or extended time. The results can reveal hidden patterns, unforeseen consequences, and latent forces.

Agent-based models can be effective at studying organic systems with self-adapting, self-organizing, and self-replicating associations. Obvious organic systems of many actors include ant colonies, bacterial infestations, herd migrations, and other animal groups. However, humans under tactical situations and machine/software codes allowed to freely operate in an environment can also exhibit simple organic interactions. For example, if we use an agent-based model to see how our troops will work with one another and engage enemy troops on a battlefield of

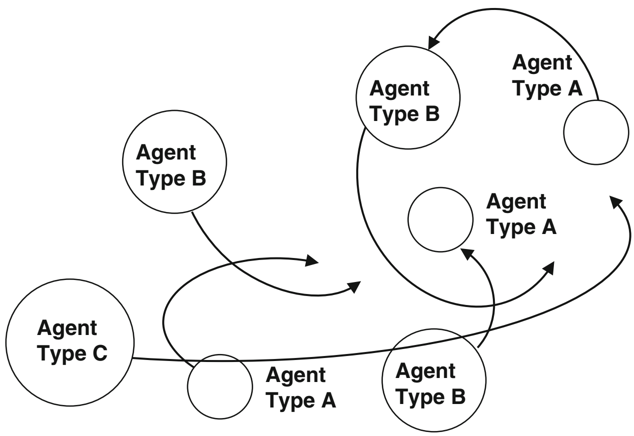

Fig. 2.22 Agent-based model of organic associations

evolving environmental conditions, we might be able to discover new vulnerabilities, unrealized ranges of potential outcomes, and tactical opportunities. The difficulty in such models is that they can only offer ranges of possible futures and not specific projections of outcomes. So the results are difficult to validate against measured data and often not trusted by strategic planners. Yet, when analysts and researchers are confronted with unbound systems and overwhelming complexity, this technique can narrow down the problem scope, help us determine where to find the key associations, and enable us to visualize the dynamics of systems and interacting systems.

In our discussions, I have often used humans and human organizations as examples of complex associations and resulting systems. Therefore, it is worthwhile to discuss the two dominant approaches for simulating human cognition/rational thought. For the past many years, researchers of the human mind have focused on either classical decision-making or naturalistic decision-making.

In classical cognition theory, our rational thought is modeled as a hierarchical tree structure of possible actions and further actions. The theory then argues that the human mind weighs the pros and cons of each course, considers the consequences/outcomes, and determines follow-on actions until the mind discovers an acceptable path to take. In complex situations, strategic planners have tried to organize our choices first by major strategies and then by the tasks for implementing the strategies in different ways [16]. Leaders wishing to follow a disciplined approach for making decisions have enlisted methodologies, such as the Analytical Hierarchical Process, to help them think through the strategies and tasks in a consistent ways [17, 18]. In other words, if they prefer Strategy A over Strategy B and they prefer Strategy B over Strategy C; then the methodology will tell them that they should prefer Strategy A over Strategy C. Classical decision-making can be simulated by computer algorithms as a rules engine that determines what rules to execute based on situational inputs. As such, it could be quite useful in bounded problem spaces and where the choices as well as the logic connected with the choices are clear.

In naturalistic cognition theory, our rational thought is modeled as a comparison of our current situation with similar situations of our past. Using a complete image of a past reference frame or several past reference frames, we then decide what to do in the current situation based on commonalities and differences [19]. The theory is that this process enables our minds to make instant decisions under complex situations, such as soldiers on the battlefield. In support of this model, it can be shown that we can make rapid decisions that are neither random choices nor a path-by-path weighing of options. To simulate naturalistic decision-making, we need to establish a large collection of mental reference frames, rules for how situations are connected with reference frames, and approaches for how decisions can be made based on comparisons.

Regardless of which cognition modeling approach we prefer, it is quiet easy to see that humans are perhaps the most complex and uncertain parts of systems, and systems based primarily on humans without the constraints of clear enforceable rules might be difficult to shape and control. Even the single association of one person to another person can have a multitude of dimensions. So the structure formed by such associations reveals the complexity and dynamic intensity of systems. System structure is, therefore, the natural next step in our exploration of how systems form.

2.3 Structure: All Parts and Associations in the System

Up to this point, I have not really talked about systems formation because I wanted to start with the building blocks of systems: parts and associations. We can see that the dynamics of the parts will translate into the dynamics of the system, and how the system will behave depends on how the parts work together as defined by the associations. Systems can be divided into those formed by man and those formed in nature. Manmade systems, to include systems composed of people, can be precisely designed, controlled in self-formation by people, or uncontrolled in self-formation by people. Because all systems are parts working together, they will each have some type of structure that is defined by specific parts and specific associations. Some systems have common associations from part to part, and some systems have associations that link the parts in step-by-step processes.

In studying system structures, we can start from the individual parts and move up to the total system. Alternatively, we can start with a total system, which has an abstraction of the parts and associations, and progress down to the specificity of parts and associations. If the system is extremely large in the number parts and associations or complex in the behavior of the parts and associations, the abstractions can focus on macro-dynamic behaviors first.

In thinking about macro-dynamic system behaviors, we can envision four types of general system structures as shown in Fig. 2.23: firm and fixed structures, clustered and morphing structures, dynamically linking structures, and dynamically influencing structures. The best way to understand this breakdown is to explore examples, as we will do below. But first, let me say that real-world system structures are not always cleanly divided. Some systems are actually a system of systems with different types of structures at each level and/or region of the overarching system. Some structures may be hybrids, exhibiting qualities of multiple types. These realities raise the questions of system boundaries and system content; both of which we may not fully understand in initially studying a system's structure. The next section is devoted to discussing system boundaries. In regards to system content that are not deliberately simplified in models to study macro-dynamics, there are two strategies for finding missing parts and associations.

The first strategy for content analysis is to assume that the missing parts and associations reside within a bounded section of the system where some level for macro-dynamic behaviors can be measured or modeled. This bounded section can then be treated as a control volume, as shown in Fig. 2.24, with defined inputs and outputs [20]. Based upon matching the inputs and outputs as well as taking into account any known parts in the control volume, research efforts can then theorize

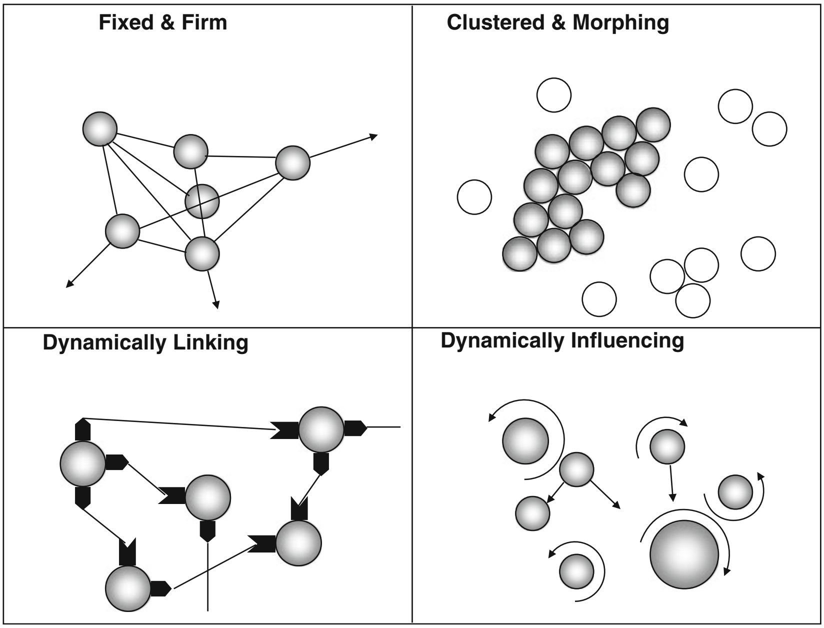

Fig. 2.23 Types of system structures

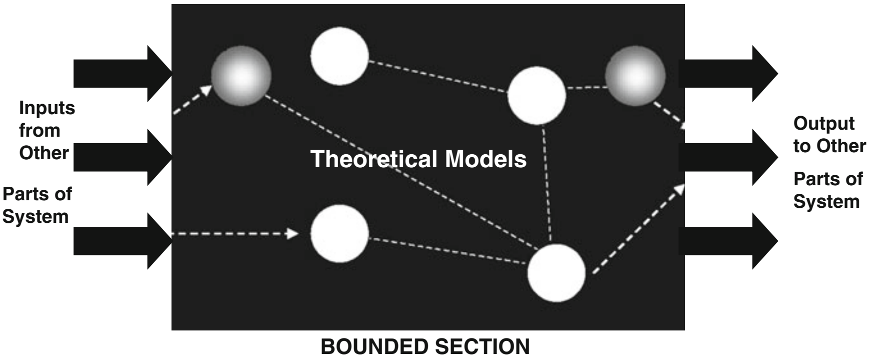

Fig. 2.24 Control volume analysis of unknown system content

and test options for structures inside the control volume that will meet the input and output profiles. In this strategy of bounding the unknown, highly complex input and output profiles make it challenging to formulate theoretical models. However, successful models will be better validated to garner higher confidence.

The second strategy for content analysis is to look across the known parts and associations of a system to see if there is a void, as shown in Fig. 2.25, where links should go into. Indicators of this void could be missing functions and even missing

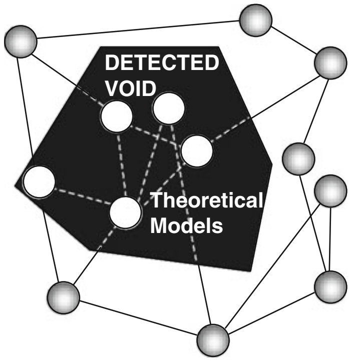

Fig. 2.25 Black box analysis of unknown system content

parts. Once we believe that a void might exist and that there are possible links or starting points for links on the surrounding parts for going into the void, research efforts can then treat the void as a "black box" for theorizing and testing possible structural options inside the void [21]. In this strategy of finding holes in the known, the larger voids in densely populated systems are the easiest to find but perhaps the hardest to theorize in regards to internal structures. Small voids could, alternatively, wedge themselves between parts and associations to create perceived disconnects in the associations. Instead of perceived broken links, maybe a void has slipped in.

We need to always keep in mind that the system we perceive may be quite different than the system that exists in the real world. Clearly our perception might have missing awareness of content that hinders our understanding of system structure. However, even with defined structures, our understanding of the details within the parts and associations could reach limits. Doctors a thousand years ago studying the organs of the human body did not understand that they were composed of cells. Doctors a hundred years ago studying cells, discovered in 1665 by Robert Hooke, [22] did not understand how they were controlled by DNA, discovered in 1953 by James Watson and Francis Crick. Even when we think we understand everything within a system, we may not understand all the forces, energy, substances, and communications interacting with the system. This is because not all the associations/links made by parts are necessarily with other parts in the system. Associations between parts and the environment and between parts and other systems could greatly affect system structure and system dynamics. Such associations are specifically discussed in the following sections on interaction and integration.

Instead of getting too far ahead, let we define the four types of system structures and let us explore examples that explain the merit of each definition. People have devoted entire lifetimes to studying each of the example systems, and each course of study has resulted in specific theories, models, and formulas. Our exploration at this stage is not to debate the current research or use current research to control specific systems. Instead, let us think about how systems are similar at conceptual and structural levels before we start to study how systems are unique.

2.3.1 Fixed and Firm Structures

System structures can be considered fixed if the associations between parts endure for extended periods and the characteristics of associations remain unchanged. These structures are then firm if they can maintain their fixed configuration under internal and external forces. The limits of this definition depend on how long the structure has to be unchanging in order to be considered fixed and how much force the structure has to resist in order to be firm. Typically, in order for the structure to be fixed, the associations have to be well-defined links between set parts. One way for this definition to emerge is if the links between parts form a connected process. This process then creates dependencies between parts and the strength of each part's ability to sustain its link impacts the total firmness of the structure.

Structures can have all common associations, which often means that the parts are also similar. In such cases, the dynamics of the system resides primarily in the changes moving across the links and not with the characteristics of the links. For example, all the links in an electrical power grid delivering electrical current from power station to power station are similar and the system looks static from the perspective of the infrastructure. However, the system is dynamic because of the power that flows through it. In contrast, the parts of a mechanical clock are all moving in perfect synchronicity. The dependencies and the dynamics are all visible and clear.

Many fixed systems can have highly volatile dynamics within the links and the parts/nodes. Parts in fixed systems typically cannot change orientation or motion independent of other parts. For example, all the gears of a clock must turn together. And parts typically cannot change the type of inputs and outputs as well as their internal structure and surface features. However, parts can accept changing levels of force, energy, substances, and communications. If these changes in the connection of the parts are too fast or exceed maximum or minimum limits, the internal stress can cause a part to break away from the system, reorient, move, or compositionally change in a way that causes fixed links to break or change. The continuous links in a strong fixed system should resist stresses and strains, as discussed earlier. The ways to resist are to have strong connections in how links join parts; have enough capacity to sustain the dynamic flow of forces, energy, substances, and communications; and have high reliability. Nevertheless, internal dynamics can place great stresses and strains on the structure just as external forces can push and pull upon the nodes. Systems that look very firm can, therefore, be on the brink of sudden collapse.

Fixed systems can expand in size by adding parts and links to the systems. This expansion, however, has to be a planned build or growth event in moving from one fixed state to another fixed state. If the expansion is continuous, then the system is not fixed. In a build event, parts are either acquired from outside the system or constructed by the system using external supplies. If the system has to use salvaged resources to build parts, such as other failed parts, then the structure is not very fixed. In a growth event, parts can self-generate new parts either by division or reproduction. Either way, external inputs will be required to sustain the growth. Noncontinuous growth usually occurs according to fixed cycles. At each cycle, the parts can grow throughout the structure, in specific regions or around the surface. Following the cycle, the structure then goes through a transition period where new links are established and system structure is extended.

The following examples reveal the prevalence of fixed systems in our natural and man-made world. In fact, these systems are so common that we often overlook their constrained system dynamics until something goes wrong.

The Body as an Example of Fixed and Firm Structures: We, human beings, are organic systems with fixed subsystems centered on primary organs held together by the skin and skeleton of the body. The subsystems include respiration and circulation enabled by the lungs and the heart; digestion enabled by the stomach, liver, and intestines; thought and sensation enabled by the brain and sensory parts; movement enabled by muscles and tendons; liquid waste management enabled by the bladder and kidneys; and reproduction enabled by the sex organs [23]. Each part of the subsystems is composed of building blocks called cells, which are by themselves complex fixed systems. From the perspective of the body, the subsystems and their organs work together with complete interdependency, and the system will break if any organs/parts fail. The organs interact with one another through the passing of red blood cells (erythrocytes) to carry oxygen and remove carbon dioxide, nutritional substances directly through cell membranes, protein structures for intercellular and intracellular communications and control, and hormonal type chemicals like adrenaline for organ level control. Further, the nervous subsystem uses chemically driven electrical impulse for thought, organ regulation, and control of the overall body system. Although this is an extremely simplified description of the highly complex human system, it clearly shows how a fixed system can succeed in nature. The complexity of nature allows this type of fixed system to vary greatly across different types of animal life and even more greatly between animal and plant life. The complexity of nature further allows the human system to vary slightly between person to person to allow for diversity and individual success across the human species.

The Cell as an Example of Fixed and Firm Structures: Cells are the building blocks from animal and plant life and represent the total system for single-celled prokaryotic life in the categories of bacteria and archaea and eukaryotic life in the category of protists. Cell structures vary greatly between prokaryotic cells, which do not have a nucleus to protect the circular DNA control structures, and the eukaryotic cells of animals and plants. Animal cells, with soft membranes, further varying greatly from the firm structured plant cells in their internal chemical reactions to sustain life. Finally, animal cells even in the body of one animal will vary greatly to serve different functions in the body.

Nevertheless, each cell is a very fixed system, which only changes according to the mitosis reproduction cycle across the S and G2 phases of cell life. However, this cycle is slowed or suspended for cells in bodies that have achieved adult status where further growth in size is no longer necessary. Bacteria and archaea cells are less stable in that they are continuously reproducing through mitosis and expressing mutation effects from environmental chemicals and radiation as well as from the DNA of other systems. The parts of an animal cell include the DNA blueprint organized into linear chromosome molecules, nuclear membrane that protects the chromosomes, ribosomes with RNA structures that support protein synthesis, mitochondria that support energy generation, vesicle for material transport and storage, and Golgi apparatus for protein packaging. As noted, this discussion is not to make us cell experts but to show how nature has been successful in designing fixed systems. In the case of the cell, the system can enable the formation of larger more organized fixed systems like the organs of the body or it can enable single-cell life that work together under other system constructs to be discussed.

The Government as Example of Fixed and Firm Structures: It might seem quite strange to jump from human physical systems to government systems, but the nature of people living together is to start forming structures of leadership and control. The structure of government from the earliest tribal chief is perhaps the oldest human-created system. Since the goal of government is to sustain a stable society, government structures should be fixed and firm. The simplest way to achieve a firm government is to crown a king with central control authority and designate appropriate nobles to manage the affairs of regions. Because absolute power can be abused, the monarchical structure of government can be constrained by constitutional laws, such as the Magna Carta [24]. In complex societies, in which the people are educated and have achieved economic prosperity, the people may demand participation in government through democratically elected representatives and direct approval of key decisions through a popular vote. The goal of democracy from our perspective should be to sustain a firm system of government where leadership change does not collapse the system.

Regardless of the specific form in government structures, all stable governments are a fixed system with typically hierarchical structures of responsibilities. The management can be based on regions, core societal services, population groups, or a combination of all three. However, the links need to be clear for those in government and those being governed. The society being governed can, in contrast, be a dynamic entity with economic fluctuations, introduction of new technologies, and migrations of the people. The society can alternatively be simple with one core marketable product and all other resources acquired through trade. Regardless of the dynamic properties of society, the firm government system must integrate into it to exert effective control. The challenges of system integration will be discussed in a later section. However, I must note that effective control has been a topic of political and economic theories and debates for many years.

Military Forces as an Example of Fixed and Firm Structures: Military force structures emerged almost as early as the first government structures. Force structure refers to the organization of people to fight as a coherent group to increase total combat power. This includes recruiting, training, a hierarchy of command, equipping of soldiers, procedures for roles in the structure, a process for promotions, and capability to treat the injured. In modern combat, the soldiers must adapt to the chaos of the battlefield, adversary strategies and tactics, environmental stresses, and the risk of unforeseen events. While the coordinated behaviors of soldiers could resemble other types of system structures to be discussed below, the dynamics of war actually emphasize the importance of maintaining a firm force structure, a clear way to deal with chaos. When parts are damaged and associations are broken, there must be a way for the system to repair the structure. If new parts and associations cannot be established, the system must have a way to collapse down to another firm configuration. The reference frame in which a military force structure is fixed is not the physical terrain but the information terrain. Soldiers in combat could suddenly be hundreds of miles away. But as long as the communication links are maintained and all sides recognize the responsibilities, the associations and parts are firm. The military can consume supplies in a variety of patterns depending on the status of conflict. But as long as the supply lines are maintained, then only the flow is changing across the links. Based on historical examples, a well-organized military force structure might be able to maintain its stability even after losing more than 50 % of its parts (soldiers and weapons) [25]. I will return to discussing the military in exploring system interactions and how systems fail.

Companies as an Example of Fixed and Firm Structures: For-profit companies are societal structures organized by people or the state to gather wealth through integrated work activities. These work activities can lead to products, services, and/or the manipulation of existing wealth. The integration of work activities is typically based on established processes and procedures enabled through a firm system structure. In highly volatile markets, processes can be designed with flexibility and responsiveness. However, the structure of the company should still be firm to anchor the processes. For example, select people in a company may be given great latitude to make individual decisions against market forces, but these people must still recognize their reporting chain and who can disapprove of their efforts. Otherwise, there will be no alignment of processes, control of integrated work, or reliable associations to sustain the system. A bunch of people working successfully each in their own way does not automatically make a company. A company must have a structure of control. This control can be purely hierarchical with the hierarchy to include positions such as president and CEO, C-Level officers, division vice presidents, directors, managers, and employees. Alternatively, this control can be a matrix of horizontals, such as with regional vice presidents in charge of markets, and verticals, such as vice presidents in charge of product lines and capabilities being delivered to the markets. Further, the company control structure can be very flat, with few layers of management and a lean organizational structure. Alternatively, the company can have extensive controls across layers of management for enabling continuous oversight. The best or firmest (most resilient) structure for a company, therefore, depends on what is being sold, how things are produced, and the market forces.

Educational Systems as an Example of Fixed and Firm Structures: Parents have been teaching children and masters have been teaching apprentices since the first tribal societies. Formal educational systems, with structures of management, professors, and levels of students, emerged in Europe based on the Cathedral Schools of the Middle Ages [26]. Though the medieval schools were to serve the nobility and to supply churches with educated clergymen, large educational systems would later emerge across the world to supply companies and the government with skilled workers in the industrial and information ages. The educational systems at the grade school and high school levels have become prevalent across modern societies because all workers need a core body of knowledge and skills. Then, the students can proceed to universities, colleges, and trade schools to prepare for specific career paths. The structures of the educational systems are so fixed that many have endured for centuries even as the courses taught are undergoing continuous change. Pictures of generations of chancellors are hanging on university walls. Statues of famous university affiliates are occupying campus lawns. And stories of university accomplishments are passed to the student and alumni population. Walk into any school today, from high schools to universities, and one will see the instruments for strengthening system structure. The system instills traditions, recognizes the best in each generation, enforces links and paths, celebrates group accomplishments, and welcomes back those who have graduated.

Mechanical Machines as an Example of Fixed and Firm Structures: The design of machines is man's commitment to the power of fixed systems. From the creation of the wagon to modern day jet planes, machines designed by man have parts that must be made precisely, assembled into a physical system, and work synchronously to achieve the intended dynamics of the system (i.e., to transport goods along roads, fly people across continents, and manufacture goods). Some machines, such as robots, can have a wide range of motion and functions. What is fixed and firm in the structure of machines is the association of the parts to one another. Even if a part can change associations based on operating conditions, that ability to change must have been designed into the mechanical system. To preserve the fixed state of machines, a process for replacing aging or broken parts is often incorporated as an element of the design to extend system life. In more and more cases, sensors are further embedded into machines to detect part failures. Current mechanical systems cannot self-replicate like organic systems. There are no ways for system components to gather more raw materials from the environment and the mechanical systems still cannot fashion raw materials into parts to build copies of themselves. 3D printing technology might move machines toward self-replication [27]. For now, all machines have a life cycle, and all machines will need to be retired unless so many parts have been replaced that one is getting a new machine. How machines fail will be discussed later in this book.

Infrastructure Systems as an Example of Fixed and Firm Structures: Modern human societies are sustained by electrical power, water supply, sewage, fuels, fiber communication networks, and broadcast networks. Our homes literally sit on top of these infrastructure components, which consist of mechanical machines, computers and electronics, devices such as valves, and nondynamic parts that facilitate transport. As I have mentioned earlier, infrastructure systems, excluding orbiting telecommunication satellites, can appear static in the physical world. However, the dynamics of energy, material, and information flow across the system are what make infrastructure a system. The firmness of the system or resilience against disasters, such as hurricanes, earthquakes, bombs, and blizzards, depends on (1) the system's ability to resist or avoid damage; (2) the system's ability to be repaired once damaged; and (3) the system's ability to reorganize flow to minimize the impact of damage. Modern communication networks with dynamic routing of information are highly able to reorganize information paths. Well-managed city departments have crews that are ready to repair downed power lines and broken transformers. And some water supply and sewage systems are designed to redirect floodwaters. As people and systems used by people in urban environments depend heavily on the infrastructure, the failure of this firm system has serious consequences.

Electronics and Computer Hardware as an Example of Fixed and Firm Structures: Systems that depend on electrical supply include a variety of electronic and computer devices. Today, computer processors have become so versatile that most electronic devices from the television to kitchen appliances all have embedded computer controls. When we look inside an electronic device with all its components and wiring, it is clear that it is a fixed system carefully designed to route, amplify, and utilize electrical power. However, when looking at a computer board with all the complex electrical pathways and embedded microchips, it can be difficult to understand what is fixed. The heart of the computer resides in the capabilities of the microprocessor and random access memory (RAM). These and all integrated circuits have millions of tiny transistors inside interconnected by a complex web of semi-conducting material. The semi-conducting material can be as thin as tens of nanometers and still carry electrical current. The microscopic transistors then control the routing of the electrical impulses to enable computing functions [28]. This elementary presentation is only to point out that the designs of integrated circuits are still fixed though extremely complex. In fact, the complex structure is packed so tightly that the integrated circuit chip typically either survives as a whole or fails as a whole. Over the past few decades, computer chips have mostly been discarded as obsolete technology long before they have reached the point of failure.

Software Applications as an Example of Fixed and Firm Structures: The purpose of computer hardware systems is to sustain software that supports all functions in society and most devices that we use. The question, however, is whether software, as merely an interlinked series of commands that operate on data and external inputs, constitute a system. The commands are in the form of a programming language for people to create software. Then, the developed code is either compiled into the binary-number-based language of the computer processors in advance or interpreted in real time as the software is executed. Either way, software is a linear series of codes that can be printed on paper. These codes can be changed by the programmer to correct bugs/programming error, but they are fixed except when codes are designed to self-modify. When stored and inactive, software does not have the dynamics to represent a system. However, when a piece of software is executed by the computer, it becomes a system that gathers and outputs data, organizes and stores data, computes data to create metadata, and controls physical systems based on computed results. This process, which can be highly interactive with users and the environment, will appear adaptive and constantly changing. However, the information is actually moving about a coded system of controls. Parts of the system may never be utilized, but the software of current computers is a system that seeks stability. The level of stability or firmness depends on how easily the codes can get corrupted due to errors in operations, exploited by software virus, and accessed by computer hackers.

Moving on, I have clearly not covered all the countless fixed and firm system structures in the world. Nevertheless, the presented examples have hopefully shown that firmness is often a dominant state but not an absolute condition. Under the right stresses and strains, fixed systems can break or transform into other structure types. The formation of this dominant system structural state is, therefore, about tightly connected processes, dependent parts, and resistance against damaging effects.

2.3.2 Clustered and Morphing Structures

System structures can be considered clustered if the associations between the parts are close based on the primary reference frame in which the system is being measured. Closeness does not have to mean distance but is often tied to the time of interaction from one part to another. This closeness can be caused by the nature of the parts and/or links. However, it can also be caused by the forces that travel across the links as well as external forces pushing the parts together. Clusters can be small, having a few parts as long as the number is more than two. Clusters can also be huge, having millions of parts. A cluster of parts that do not shift their associations with one another is simply a densely formed fixed system. However, many clusters with close associations have enough forces and/or links keeping the cluster together that individual associations can change without breaking apart the system structure. These changes enable the structure to morph as the parts remain together. By this definition, a clustered structural type is the only one that cannot enable a distributed system structure with parts spread far away. A distributed rigid structure will be difficult to sustain and perhaps difficult to redirect motion, but it can exist as long as the links are strong enough. Dynamically linking and influencing structures can be distributed to the extent the links can reach or the parts can travel. This leaves the idea of clustering and distributing as directly opposite concepts.

The ways that associations can enable the clustered system structure to morph is to have flexibility and/or incremental properties. In a cluster, flexible links enable parts to shift positions relative to one another in the structure without breaking the links. The links can reorient and stretch, but there is enough strength and pull in the links to keep the parts together. In contrast, incremental links will break as parts shift, but new links will form fast as the parts get into new positions. The incremental links in a cluster cannot all break at once. Instead, the structure must always be held together by some links as the other links are reforming. Finally, a morphing structure can have a mix of flexible and incremental links or links that are both flexible and incremental. In the latter case, the links will try to stay connect until parts shifts beyond a certain point. Then, old links will break as new links form.

Based on the above definition, clustered and morphing system structures typically cannot have uniquely defined associations and process components. The uniqueness of the links and the specific dependencies across the structure encourage fixed states, thus making redefinition of relationships among many parts difficult. This does not mean that all the associations in morphing structures must be the same. Complex parts might be able to support a variety of situationally dependent associations, and parts with self-control or even self-reasoning capability can build highly complex networks of varying links in morphing structures. For example, people living in close proximity to one another might form a clustered system based on their relationships. This system is different than people in a company with clearly defined roles and dependencies. However, the social structure can still have many types of local associations and highly complex group dynamics. What keeps the structure together are common characteristics in the associations such as the need for friendships, the search for spouses, and the sharing of social resources. Using social clusters as an example, we see that fixed structures with elaborate processes can exist on top of morphing structures such as specific job responsibilities for people in a social cluster. We also see that fixed structures with elaborate processes can be threatened by self-formed associations between the parts that will break the structure down to a morphing system. What if the workers in a factory organize into a social structure that pushes against the defined workflow and conditions? We then see two systems fighting to exist with the same parts or overlapping parts. I will save this discussion for the section on integration.

Returning to the consequences of morphing structures, the volume of a system in its reference frame is governed by the number of parts and closeness of the associations. However, the structure can morph into many shapes because of internal and/or external forces and because of the functions in the system. When morphing is a reaction to forces, there should be an inherent level of resistance before structural changes start. Thus, the structure will be fixed once the forces stop. In morphing as a part of system functions, the parts and links could shift in the course of working together or due to some level of centralized control. The system might morph to evade, invade, engulf, pass through, or block.

Clustered and morphing systems can expand or contract continuously as well as in phases. Expansion can be through pulling parts into the system, creating parts in the system, or loosening the closeness of links. The ability to rapidly form links in these structures enables high rates of growth. The ability to shift links to other parts further allows the system to cope with high rates of parts breakdown. These changes in parts can work in conjunction with the morphing of the total system. In case of system damage, the morphing and growth can help restore weakened regions and overall parts density.

The following examples reveal the immensity of some clustered system structures and the intensity of forces involved in structural changes. Most of these systems are found in nature, as not many designed systems with man-made parts have adopted clustered self-organizing dynamics. This could change with advancements in nanotechnologies [29], micro-robotics [30], and automated swarming weapon systems [31].

Climate System as an Example of Clustered and Morphing Structures: The weather patterns of planet Earth form a complex system that includes effects from the Sun, Moon, Earth's rotation, and Earth's revolution. The gravity of the Moon causes high and low tides at where the ocean meets the land. The thermo energy from the Sun powers the circulation of the air. The position of Earth on its rotational axis and about its orbit yields the seasons. Water from the oceans, seas, and lakes fuels the clouds and transfers thermo energy to create storms from hurricanes to blizzards, and mountains and rivers capture precipitation to feed the oceans, seas, and lakes.

The Earth's climate system is powered by thermo energy along with changes in temperature states. However, water and air are its primary parts. Therefore, if we observe water and air molecules across the planet, we see a massive clustered and morphing system structure that moves and passes force as well as energy through close interaction of the molecules. The system on a molecular level is actually quite simple, even though air is composed of oxygen, nitrogen, carbon monoxide, argon, and green house gases. Green house gases include carbon dioxide, nitrogen oxide, methane, heavy oxygen in the form of ozone, and chlorofluorocarbon. It is the interaction of these molecules across the planet that creates complexity beyond the ability of current computer models to precisely predict. Thus, we get incorrect weather reports and the climate change debate [32].

The debate regarding whether the Earth's climate system is failing to support a stable human society is centered on the increase of atmospheric green house gas that can be traced to worldwide deforestation and burning of carbon fuels. Green house gases are important for maintaining surface temperature, but an increase in these gases that trap solar radiation could cause temperature increases and climate instability. The debate is that we know that human endeavors such as over farming can cause dust bowls and over burning of fuels can cause city smug. However, there is still a lack of direct traceability between increases in green house gases and temperature change. The Earth had gone through many major temperature-change cycles long before human effects; thus, the level of human effects relative to Earth's own climate dynamics is still uncertain. If the effects of man are small compared with the Earth's own climate shifts, the world might still be heading toward a climate oscillation and ice age due to melting polar ice. Unfortunately, in such a case, closing down factories and using clean fuels will not prevent this reality.

Terrain Systems as an Example of Clustered and Morphing Structures: A much slower system than the Earth's climate is the terrain/surface features of the Earth and other solid planets. Nevertheless, forces are continuously moving across the Earth's solid mantel layer that sits on top of the molten outer core. As a result of these forces that pass across the clustered material structures of the ground, mountains rise, valleys form, rivers start, and bodies of water emerge. Sudden shifts between surface plates and the sudden collapse of the surface structures can cause earthquakes. And lava from the molten outer core as well as water heated by lava can burst their way to the surface in the form of volcanoes and geysers.

Even ignoring sudden tectonic disturbances, the surface of the Earth is highly morphing when measured across millions of years. This surface is composed of localized material structures such as rock formations, sand and soil, and even crystalline elements, which can all be viewed as system parts. When we remove a part from the Earth, it is just a simple object. When we look at the Earth in human time frames, it is just a static platform for architectural endeavors. Therefore, we care about this system primarily for the sudden disturbances that result from thousands of years of gradual change. Once an earthquake, volcano, geyser, or rockslide occurs, the power of this morphing system is realized. The power in some cases can be triggered by human error such as incorrect mining practices, poor construction decisions, and deforestation. Therefore, nations, companies, and city planners all have a vested interest in understanding the dynamics of terrain systems.

Bacteria Growth as an Example of Clustered and Morphing Structures: I have introduced bacterium as a fixed single-cell organic system, but the reproductive growth of bacterium through mitosis cell division can rapidly form clusters of bacteria that constitute greater morphing systems. A cluster can invade nearby cell structures in a host organism or dominate a nutrient-rich environment such as food. In the spreading of the bacteria cluster, the association between bacteria cells might be minimal. However, bacterium can communicate with one another through chemical signals known as quorum sensing [33]. In this communication, bacteria in a cluster can coordinate their movement and growth activities to increase their success at overwhelming host's defenses. One key coordinated action is for the cluster to wait until it is large enough before launching a major assault on the host. Another coordinated action is determining which chemical should be produced by all the bacteria. As an invasion progresses, the bacterial growth and spread can be along key pathways in the host. The bacteria can simply eat away at surrounding tissue in the host, but a pathway would be for the bacteria to travel along the blood stream and attack specific organs in the host. Some bacteria regulate their growth to achieve symbiotic existence with the host body. This symbiotic existence can benefit the host as in the case of bacteria in the human intestine that aids digestion. However, symbiotic existence can also degrade the host by taking away nutritional content, continuously battling the immune system, and causing low-level cell damages.

To defeat an invading clustered and morphing bacterial system, one can kill off individual bacterium faster than their growth rate, kill all the bacteria by exploiting a common weakness, disrupt their chemical signals to weaken coordinated attacks, and/or manipulate their chemical signals to break apart the system. In the open environment or on the surface of bacteria-infected wounds, antibacterial substances, such as alcohol or hydrogen peroxide, will kill the cell structures of bacteria. Inside the body, antibiotics such as penicillin can either kill bacteria or inhibit their growth process. However, bacteria evolve quickly. For every bacterium that has been exposed to antibiotics but is not killed, there is the chance that its mutated characteristics will survive to form strains of antibiotic-resistant bacteria. So the story of bacteria is one of competing systems, which will be further explored later in this book.

Population Migration as an Example of Clustered and Morphing Structures: I have described the infrastructure and organizations of societies as fixed systems, but the people in society do not have to be trapped by these fixed systems. In times of danger or in search of opportunities, people have been known to cluster and migrate. This behavior is very different than people gathering to watch a ball game where there is minimal association between people to yield a system. Instead, when people are moving toward an opportunity, such as the wagon trains going to the American west, they band together to help one another achieve a common purpose. The collaboration can be as simple as forming defensive circles when under attack or as complex as the exchanging of vital resources.

When people are moving away from a threat, such as running from a forest fire, they must at times coordinate with one another to prevent gridlock and chaos. The coordination can be as simple as some people directing the flow of traffic and as complex as continuous exchanges of situational awareness across the cluster. Humans have not always worked well together. So this type of system can have very high transformability but very weak cohesion in the cluster. People might start to move faster as panic increases, and the cluster might break apart as individual fears take precedence over group survival instincts.

Mob Actions as an Example of Clustered and Morphing Structures: The natural condition for forming a strong human cluster is, sadly, when everyone shares a common intense emotion, typically anger, and wants to take action. The emotion creates tight bonds between people, then the cluster/mob will morph once one person starts to take action. This morphing might be an assault on a section of the city when people, without centralized guidance, help one another tear down statues, burn buildings, spread graffiti, and vandalize stores. Because of the lack in centralized control, mob-type systems are difficult to confront. People in mobs can still be adaptive and clever in their attacks, and the aggressiveness of the attacks will not dissipate until the emotional intensity dies out. The associations in mobs can span the range of human communications and communication devices. Sometimes, it is the simplicity of communications and the localized rallying of actions that make a mob effective.

Strategies to deal with a mob system include disbursing the people enough with law enforcement or troops so that cluster dynamics break down, eliminating the causes of emotional intensity through negotiations, terrorizing mob participants into inaction through greater violence or arrests, and attacking all the mob participants. Generally, the sequence of events in dealing with a mob is attempts at negotiation and disbursal followed by individual arrests and broad attacks. The latter actions might cause society-wide backlash if other people are also sympathetic to the cause of the mob.

Close Quarter Troop Engagements as an Example of Clustered and Morphing Structures: Successful human clustered and morphing systems are, at times, created through training. A tightly formed group of combat troops is one such system. Even in modern warfare, combat in jungle and urban environments might require troops to work together in a cluster to engage enemy forces. The cluster might not be large, but high-tempo operations depend on coordinated tactics and common understanding of set procedures. For example, communications when enemies are near might rely upon hand signals, flashing codes, text messages, and special sounds. Once the system is in action, the morphing pattern can be to move in one direction, cover multiple paths and angles, surround the enemy, divide the enemy, sneak up on enemy, hide and evade, regroup, or retreat. For highly trained troops that can act independently and fight in coordination, a clustered system can remain effective even under heavy losses. As the cluster components are trained to maintain the cohesion of the cluster, the system is far more difficult to break apart than mobs.

The few examples of clustered and morphing systems presented reveal great diversity among this type of system structure with the power of transformation. Many system structures can morph. However, the morphing of a cluster of system parts is the most obvious. The cohesion of the cluster adds strength to the transformations and the size of the cluster increases the power of the total system.

2.3.3 Dynamically Linking Structures

Systems can also have loose structures that are formed by temporary associations. Such associations are formed by the changing orientation, motion, and/or composition of parts. The surface conditions of the parts, to include input and output interface standards/openings, then governs how the links are established and when the links will break. For example, if the content of a part exceeds a specific level, the internal stresses might force a link to form with another part to transfer content and lower stress. Alternatively, a part might have a content deficiency that compels it to establish links with sources of available content. The key difference between dynamically linking structures and clustered structures is that the links are not formed by proximity between the parts or forces pushing the parts together. Therefore, the links must have functions that keep parts together, but the links can stretch and shift across substantial distances, as long as the functions of the links are sustained.

Dynamically linking structures can cover a vast space and expand or contract significantly within space. Parts can be expelled from the system when links are no longer required and parts can be added to the system when links are justified. Further unlike clustered structures, complex processes can form across the parts and links with high degrees of uniqueness throughout the process flow. In such cases, the uniqueness of the parts and links will control the dynamic behaviors of the system, the rate of system expansion or contraction, and the realignment of the structure. The capabilities of the system enabled by dynamic links can yield highly self-organizing and self-adapting properties. This organization and adaptation can concur through the autonomy of the parts or through centralized control. However, if the system processes across the dynamically linked structure are complex, then the controls within the parts or across the links must match the complexity.

Dynamically linked structures typically have no baseline size. Therefore, system expansion and contraction is an inherent characteristic and has no special meaning. Parts can proliferate or be built inside the space of the system. However, the parts will not belong to the system structure until a new role or repeated role has been established through dynamic association. This definition creates a challenge in establishing system boundaries, which we will further explore in the next section. For now, the simplest way to describe the challenge is the question of: If parts are dynamically linking to one another, how do we know what links are between parts in the system structure and what links are to parts in the environment? The answer will require an assessment of commonalities and differences between specific parts and links for a defined system. Based on the assessment, a practical system boundary can be drawn that does not include every single element/part that interacts with one another.

The following examples show how dynamically linked structures are observable in nature and incorporated into human activities. In studying the structural behaviors, the uncertain reasoning techniques for identifying linkages, as discussed on the previous section, might yield greater insight. We tend to think of dynamics as links forming fast and/or often. However, it might be the slowly formed links that are the most important and most difficult to study. For systems that have slowly forming links, key parts within the system might exist in plain sight but not be revealed for decades. To illustrate, a sleeper agent/spy planted in an enemy's organization would be a key part of an opposing system. Yet that association and role will not be visible until the agent is activated through a triggering link.

Insect Colonies as an Example of Dynamically Linking Structures: Some insects, such as ants, will work together as a distributed system centralized on a nest or hive housing the queen. For ants, the workers then move out from the nest in search of food and building materials. The male ants with wings also fly out to mate with other queen ants. When foraging in the environment, worker and soldier ants can individually wander far away. However, they will still circle back to communicate with one another to coordinate actions. Hundreds and thousands of ants can quickly gather to bring food back along a transport column once a food source has been identified. The soldier ants will organize for an attack when another insect species, such as termites, is encountered. In the nest, the ants will work together to dig caverns and construct living spaces. Thus, the status of the ant colony system largely depends on communications between ants, the immediate needs of the colony, threats facing the queen, and opportunities in the environment. The ability of each ant to act independently and form associations as required is what makes the colony a dynamically linking system. The system is not held together by the links but by each ant/part's commitment to the system. Even when disconnected from the whole, the ant will perform its responsibilities for the system and seek to return to the system. When necessary, worker ants will even sacrifice themselves for the system. This is why a dynamically linking system can still be very strong.

Protein Interactions as an Example of Dynamically Linking Structures: Proteins are complex amino acid molecules organized into polypeptide chains. These chains are produced by organisms to perform a vast variety of functions [34].

Different folding protein structures support functions such as DNA transcription, catalyzation of cell chemical (enzyme structures), intercellular communications/ signal transduction (structures like insulin), cell defense (antibody structures), material transport (specific protein binding sites), and cell integrity (fiber proteins). Thus, the bodies of living things are filled with proteins working together to sustain life. Proteins do not have intelligence but, instead, a complex range of behaviors based on molecular structure, folding dynamics, and surface binding sites. When these molecules are outside of the body, they are merely nutritional elements for the body to use in energy generation and cell construction. Within the environment of the body, however, proteins are responsible for most of the dynamics within cells and between cells. Proteins' associations with one another include passing components and triggering reactions. Yet, the most important association is perhaps a common anchor to the cellular reference frame. In this reference frame, the cells of organisms control the production and types of proteins released as well as the retirement of proteins. It is through this control and the suitability of proteins for specific functions that system cohesion is achieved.

Social Networks as an Example of Dynamically Linking Structures: I have placed computer infrastructure and the worldwide network of fiber optics and cell phone towers as fixed systems. However, the information on these systems, as well as the activities of people in generating, consuming, and manipulating this information, is far from fixed. Generally, a social network is enabled by a web-browser-based software application that allows people to share information based a set of rules and constraints.

The first set of rules governs role-based information access, which is supported by user identity management [35]:

- Who can sign on the application?
- How is the information shared among people with different access privileges?
- What information can be gathered by all participants on the application?
- What information can be used by the application admin for purposes such as advertising?
- What information is searchable on the open worldwide web?

The second set of rules governs the type of information that can be shared: lengthy text, short text, photos, videos, web addresses links, links to content on application, etc.

The third set of rules governs the quality of content such as filters against adult material, filters against political opinions, filters against harassment-type activities, and filters against copyrighted content.

There may be many other rules that govern associations between people, but it is clear that social networks are dynamically linking structures that can grow and shift rapidly across the population. People are joining and leaving networks all the time. The information that people share changes with life experiences, emotional states, and social interactions. The links people make change base on friendships, personal interests, and professional needs. Social networks are spawning new product markets, inciting revolutions, enabling criminal activities, generating media stars, facilitating commerce, reporting on news events, promoting friendships, and causing interpersonal conflicts. Yet an entire network can collapse overnight as people move on to better products and better communities. Such is the nature of dynamically linking system structures.

Terrorist Organizations as an Example of Dynamically Linking Structures: Terrorist organizations can be viewed as social networks held together by a common violent purpose. Such networks have learned to leverage Internet-based applications for communications and organization. However, a terrorist network can use any means of communications to include carrier pigeons. Like other social networks, terrorists join and form local groups within the dynamically linking system. Unlike other social networks, however, leaving the terrorist organization can be quite difficult, as it will be viewed as a betrayal that requires violent response. The ability of terrorist groups to take action without clear central authority makes this system difficult to stop. The ability of participants to secretly hide within the general population of society further makes this system difficult to find. If one terrorist is captured or killed, multiple new recruits might fill the gap. If a terrorist group/cell is broken apart, other groups might extend links to absorb surviving members. If individual terrorists or groups are captured, links can be quickly broken to protect the total system. Essentially, links between terrorists are constantly adapting to support the survival of the organization and the achievement of violent actions. As the only hard rule for associations is a commonality of violent purpose, terrorist systems are exceedingly difficult to destroy. One can attack the commonality of purpose or the integrity of the system parts. If all terrorists start to have doubts about the organization, then the system will weaken. If one terrorist is not sure whether another terrorist is a traitor, then the system will weaken. Otherwise, this dangerous system can stretch out to all the societies of the world and hide in the most obscure places.

Crisis Response Activities as an Example of Dynamically Linking Structures: My last example for dynamic linking is the system of first responders, military forces, government officials, and the general population all work together to respond to a crisis event. Under great threat or disastrous outcomes, the normal processes of society will stop. Then, the survivors will try to reorganize into a dynamic system to increase the odds of continued survival. If attempts at reorganize through new dynamic links fail, the people might either disperse or engage in conflict for resources and shelter. Advance planning and the training of people for roles during and after crisis can increase the ability of the survivors to form a new social structure. New associations need to be formed based on the evolving conditions of a crisis. For example:

- How should the police and fire department coordinate against each type of crisis?
- Under what conditions should military forces be called into action?
- Who in the government has relevant responsibilities?
- Where should people go as the crisis event changes?

These are all decisions that can be supported through studying representative crisis scenarios and determining potential courses of action. With knowledge of an appropriate step-by-step response, the people as parts of the new dynamically linked system can focus on precisely forming and breaking links. Breaking links is necessary at times when the capabilities of the parts are limited and/or the needs of the parts have different priorities. First responders must focus on those in greatest need. Government officials cannot take all phone calls. The people must sometimes focus just on personal safety. Therefore, the societal structure during and after a crisis is delicate. However, being able to reform a structure is incredibly important, as the imperfect structure is the foundation for building the future.

2.3.4 Dynamically Influencing Structures

Finally, some systems do not have any kind of lasting structure at all. This means that the parts do not have any permit or short-term dependencies on one another, and enduring processes cannot stretch across the parts. However, the parts still work together through interactions. Momentary associations that do not form links can still pass force, energy, substance, and/or information from one part to another. What makes these parts a system is then either some commonality of purpose among the parts that synchronizes with interactions or some connection of the parts to a common reference frame for basing behaviors. Through the constant interaction of parts, we can then say that the structure is completely dynamic and based on the parts influencing one another.

Parts influencing one another do not have the mutual pull to keep systems from breaking apart. Therefore, the parts have to independently anchor themselves to the spatial region of the system even as they reorient, move, and change their composition. In some cases, the environment for the parts will provide a boundary in which systems behavior can form. In other cases, the parts have independent controls that keep them within the proximity of one another for interactions.

Interactions among parts in a system can pass information that allows parts to coordinate behaviors, substances that allow for operations and proliferation, and energy that sustains operations. One part can also push or drag another part with a force appropriate for the reference frame of the system to get the other part better aligned with system behaviors. For example, if one part hits the boundaries of the system's environment, it can translate that force toward hitting other parts to prevent all the parts from crowding along the boundaries.

Thus, despite the lack of permanent and temporary links, influence-driven system structures can still reach stable states of dynamics. However, instability can emerge with increasing number of parts, intensity of movement among the parts, concentration of parts in one area, and deficiency of part interactions in other areas.

Virus Growth as an Example of Dynamically Influencing Structures: The effectiveness of viruses is that they travel far in the body and from the body. An airborne virus in the environment is potentially more contagious than one transmitted by fluid contact. Viruses that survive longer in the environment and viruses that infect multiple animal species are also potentially more contagious. In the body, the objective of all viruses is to invade cells and use the cellular components to replicate countless more viruses. As viruses are DNA or RNA strands surrounded by proteins, they are not fully formed life in the external environment. Therefore, viruses should not have any ability to form associations with one another to create a dynamic system. However, once a virus has invaded a cell, the cell components then become a part of the virus lifecycle. At that point, systems thinking would pose the question of whether associations can emerge. We would still expect these associations to be links between viruses, but can viruses in the cell control activities such as protein generation to influence the behaviors of other viruses? Research in this case is ahead of system thinking because the study of propagation rates and patterns in the vaccinia virus infecting monkey liver cells conducted by Geoffrey Smith's team shows that the viruses bypass cells that have already been infected by other member of their group [36]. Thus, the vaccinia virus is spreading faster than initial predictions. Apparently, the virus protein structure recognizes changes in surface protein characteristics for a cell infected by their fellow virus. This is, therefore, a classic example of a dynamically influencing system structure.

White Blood Cell Activities as an Example of Dynamically Influencing Structures: In the body of animals, the purpose of white blood cells is to identify, destroy, and consume enemy invaders and the infected cells of the body. Of the white blood cell types, the B type lymphocytes produce antibodies that identify abnormal entities, the T type lymphocytes recognize the abnormal entities and kill them, and the phagocytes to include the large macrophages finally consume the abnormal entities. Like viruses in the body, the white blood cells travel far and fast along the blood stream to go to points of infection. Therefore, they influence one another through the execution of their individual functions. Yet, there are no direct links between the cells as they can be far apart. The totality of dynamic influences, based largely on antibody signals, is the body's immune system. The power of this system is that all the parts are anchored to the reference frame of the body and guided by the conditions/signals of the body. As long as the body is viable and enables the production of more white blood cells, the system will fight on.

Nanotechnology as an Example of Dynamically Influencing Structures: Nanometer-size man-made molecular structures are categorized as nanotechnology. The potential of these structures in performing mechanical functions in a variety of environments to include the human body is being explored in scientific research [37]. The size of nano-devices does not permit elaborate communications capability to form long-range links. However, these devices can integrate into a fixed system construct through contact and they can cluster to create material properties. A more effective use of nano-devices could rely upon their ability to influence one another through contact and spread out across the environment like white blood cells. Nano devices can perform different operations, such as changing an organic molecule in the body or an inorganic molecule in the environment. Each type of device can build upon the accomplishments of other nano-devices. In this manner, nano-devices can, in theory, self-replicate if the raw materials for building themselves are available in the environment. By mimicking the behaviors of organic systems, systems based on nanotechnology parts can grow to immense complexity.

Democratic Political Process as an Example of Dynamically Influencing Structures: The process of electing leaders in human society is a dynamically influencing system because each eligible voter in the society must be given the freedom to make a personal choice. Direct links between candidates and voters, such as the buying of votes, and direct links between voters, such as pre-election day commitment of votes within groups, are strictly prohibited. Therefore, the only associations that can officially exist between the parts/voters are that of influence. If the parts are polarized and committed to candidate positions, then the system is not dynamic and the influence is not effective. The outcome of elections is, thus, dependent on the size and commitment of each side. If there are parts that are open to arguments and new ideas, then the system can be dynamic with influence pushing voters from one candidate to another. For this type of dynamically influencing system, the number of parts is limited by eligible participants, the range of associations is governed by laws, and the purpose of the system is to satisfy a defined process. The complexity in this system resides in ways to influence the possible outcomes of elections. One approach for studying these associations is through statistics. However, we can also try to understand the specific associations through uncertain reasoning techniques, as discussed in the previous section. Is it possible to understand the causes and effects on individual system parts? And is it possible to control the proliferation of effects across system parts?

In the first two sections, I focused on ways to find and study the parts and associations that go into systems. In this section, I focused on showing the breadth of system structures that can be formed by the parts and associations. The generalized examples presented should not be mistaken for the specificity of real-world systems. When faced with a real-world system problem, we can start with finding the parts and associations to formulate the structure and system dynamics. Alternatively, we can start with a general understanding of system structural type and then seek to discover the behaviors of the specific parts and associations. Neither of these paths will be simple if the system has poorly understood boundaries, intense interactions with the environment or other systems, and/or dramatic shifts in its form. This then leads us to the next three sections on the qualities of complex systems and the final section that summarizes how systems form through integration.

2.4 Boundaries: How to Define the System

The first statement about system boundaries should be that all boundaries are artificial constructs to make the study of systems more manageable. As a result of boundaries, the total system that is the universe is broken down into chunks within chunks so that the capabilities of man can measure, study, and perhaps control.

Each chunk can be regarded as a defined system or a subsystem of a greater system depending on one's perspective. Some chunks have obvious fixed boundaries, such as a mechanical device. However, one can still wonder whether the real system should include the person using the device as well as the entire operations the person is supporting with the device. Other chunks have boundaries that are expanding or contracting, absorbing or expelling parts, and spontaneously present and not present.

Although the structure of a system drives the nature of the boundaries, it is important to note that there does not have to be a direct correlation between the type of structure and the boundaries. For example, all four structural types discussed in the last section can be within a fixed boundary. Even when the system parts are only dynamically influencing one another, the range of dynamics can be within a boundary that is rigidly defined. Parts hitting the boundary, such as the surface of the body that contains white blood cells, might literally be prevented from escaping.

The other point to note before we jump into boundary types is that there is a difference between systems to which establishing boundaries is impractical and systems to which we have not yet figured out the boundaries. Many complex systems have boundaries that are difficult to determine, but this does not mean that they are truly unbounded systems. In our exploration, I will propose that unbounded is a specific boundary type that is diametrically opposite to a system with fixed boundaries. Between the bounded and unbounded system, there are other boundary types worth discussing.

In the effort to understand the boundaries and behaviors of systems, this section will further explore the utility of different research philosophies and associated methodologies. We will see how the definition of boundaries can change our perspective on system dynamics. And we will see how the definition of boundaries often depends on the reference frame in which we want to study the system. A system in one reference frame can have a completely different boundary type than the same system in another reference frame. Thus, we might care about one reference frame for control and another reference for understanding collateral effects.

The first type of boundaries, as shown in Fig. 2.26, is a boundary that sets a maximum range for the system structure by using a measuring point within a reference frame for system parts and associations. Thus, this boundary is fixed and the parts are bounded relative to the reference frame. The whole system along with the measuring point can move in the reference frame, but the boundary will remain the same as long as the ranges from the measuring point stay the same. If the system has a fixed structural configuration, then the boundary is simply the outer most parts of the rigid structure. Depending on the reference frame, the parts along the boundary might be the only parts within the system that interact with the environment or another system. This determination of which parts are interacting across the boundary with elements external to the system is perhaps more complex and important for systems with clustered, dynamically linking, and dynamically influencing structures. In the case of dynamically linking or influencing system structures, the level and nature of dynamics as well as the commonality of characteristics between parts may be what determines whether associations are within

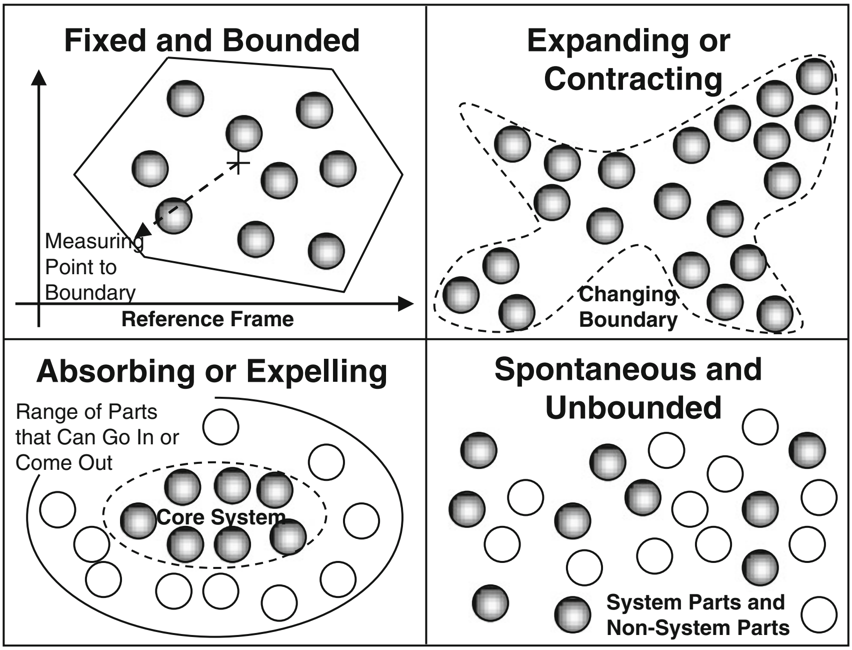

Fig. 2.26 Types of system boundaries

the system boundary or extending past the system boundary to parts that are not in the system. If a part is in the system, then a fixed boundary will prevent the part from moving beyond the maximum range. In some cases, the boundary is an actual barrier for containing the system, and the barrier might be a part of the environment, such as an ecological system being contained by the boundary of a lake. In other cases, the barrier is simply a behavioral rule of the parts where the parts will self-limit their dynamics at a specific range.

The second type of boundaries is a boundary that expands or contracts because system parts are pushing or pulling the boundary past fixed states. This expansion or contraction might only change the system's shape in a reference frame, or the volume might also be changed to create more distance between parts. The fluidity of the boundary and the level of resistance against initial change are system characteristics. Clearly, fixed and firm system structures will promote fixed boundaries that resist expansion and contraction. If an expansion or contraction is forced upon a fixed structure, then the system will typically want to settle down to another fixed structural and boundary state. For other types of system structures, a fluidic boundary can serve a variety of purposes. In a clustered and morphing system, the boundary might reflect how the system will engulf other entities in the environment or move around obstacles. In a dynamically linking system, the boundary might reveal how the system will expand to gain dominance. In a dynamically influencing system, the boundary might show the impact of increasing or decreasing dynamics. Sometimes, measurements and research will initially reveal more about the behaviors of the boundary than the structure of the system.

The third type of boundaries is a boundary that is absorbing and/or expelling system parts. This boundary results from systems whose structure is in a state of transformation or flux. All four types of system structures previously discussed can shed parts or take in new parts to change their structural configuration. Depending on the nature of the parts and associations as well as the structure of the system, parts can be removed or added to the system at specific rates and to specific sections. The porous boundary can, therefore, change shape as the system changes or maintain its shape to force the system into increasing or decreasing its density. The rules regarding which parts are going in and come out of the porous boundary are characteristics of the system. Parts can be pulled in or pushed out by existing links with the system structure. Parts can force their way in or out by creating links with the system structure. Further, parts outside the structure and parts inside the structure can have natural pairings that promote integration.

The forth and last type of boundaries is a boundary that is spontaneous and temporary. Parts can be associated with the system or outside the system at any time depending on dynamic conditions. As the system is essentially unbounded, this type of boundary is often not effective at describing system constraints. However, the boundary can describe system states. There may not even be a process for parts to cross the boundary in joining or leaving the system, as the unbounded system may not have a core set of parts. All four system structural types can be unbounded if the structures are prone to collapse and reorganization. However, dynamically influencing structures are more suited for unbounded characteristics. For example in the case of virus propagation, one boundary could be the entire environment of an infected body. However, the virus is designed to spread from body to body as well as from species to species in some cases. So other boundaries could be clusters of outbreaks, regions of epidemics, and national borders. The viral propagation system in this perspective can be viewed as an unbounded system where the spontaneous boundaries are our constructs to contain the virus. The virus then mutates in attempts at breaking past these boundaries.

The artificial definitions of boundary types above are established to help us understand the nature of system boundaries. Unfortunately, the actual determination of boundaries for real world systems can be challenging as systems tend to not fit cleanly into bins. There are two interrelated strategies for a real-world boundary definition. First, we can establish boundaries to match our objectives and methods for controlling the system. For example, we break down national voting in the democratic system of the United States by states, congressional districts, and precincts. Second, we can discover natural points where boundaries can be defined by studying the behaviors of the system. For example, a bacteria growth system might be naturally constrained by the extent of a nutrient rich growth environment. The results of the first strategy should not conflict with natural boundaries, and the results of the second strategy should also help us with control. The challenges come in when neither of the two strategies work or when system behaviors extend into other reference frames to yield collateral effects and hidden consequences. When boundary definition strategies do not work, it generally means that the controls are not effectively controlling the system or that the natural divisions are not really clear and lasting divisions. When system behaviors in a different reference frame are yielding dramatic consequences, it generally means that the initial dimensions in measuring the system were not broad enough. Parameters thought to be irrelevant actually have impact or there are unknown parameters as well as parametric ranges in the problem.

To wrestle with real-world systems with unclear boundaries, researchers have at times declared such systems initially as all unbounded to facilitate unconstrained searches for system parts and associations using techniques previously discussed in Sects. 2.1 and 2.2. For example, agent-based models can test the dynamic ranges of system parts to see where unknown parts to the system are hiding in the real world. This search, however, can become overwhelming when dealing with systems, such as human society, with millions and billions of parts. Thus, other approaches for assessing the system from a macro perspective have been adopted by researchers in different fields. Though each field will advocate for its specialized methodologies, we can place these methodologies in a general systems framework to understand their value and limitations. Three dominant methodologies are discussed below.

2.4.1 Methodology of Iterating a Conceptual System Model

As noted earlier, Soft Systems Methodology (SSM) seeks to iterate a conceptual model of the system until enough insight and accuracy are gained to affect the system. The general tenet of this methodology is that no system model can be an exact replica of the real-world system and that the act of measuring the real system changes it. Instead, the model is an abstraction with compromises made due to inability to measure the real system beyond a set point, record all possible data associated with the real system, identify all the parts of the real system, and/or avoid disturbing the real system. For example, if one wants to perfectly model a clock, one will have to record the structure of the clock down to the atomic and subatomic levels and identify all the effects on clock from the friction of the gears to the transfer of heat from the environment. One also cannot take apart the clock or even touch it in any way while measuring it. Giving up on perfect, we can create a conceptual model of the clock with the shape of all the gears to show how the clock works. Therefore, the objective of SSM is to create and leverage an effective conceptual model.

The SSM iterative cycle described by Peter Checkland is practical and problem-resolution focused for the business community. We can describe his cycle in a slightly more general perspective and with less advocacy to be one of multiple ways to wrestle with the unclear boundaries and behaviors of real-world systems. The iterative process, as shown in Fig. 2.27, begins with recognizing a complex real-world system. There are existing ways to measure the parts and associations in the system, but these ways might not be able to capture all the structure, dynamics,

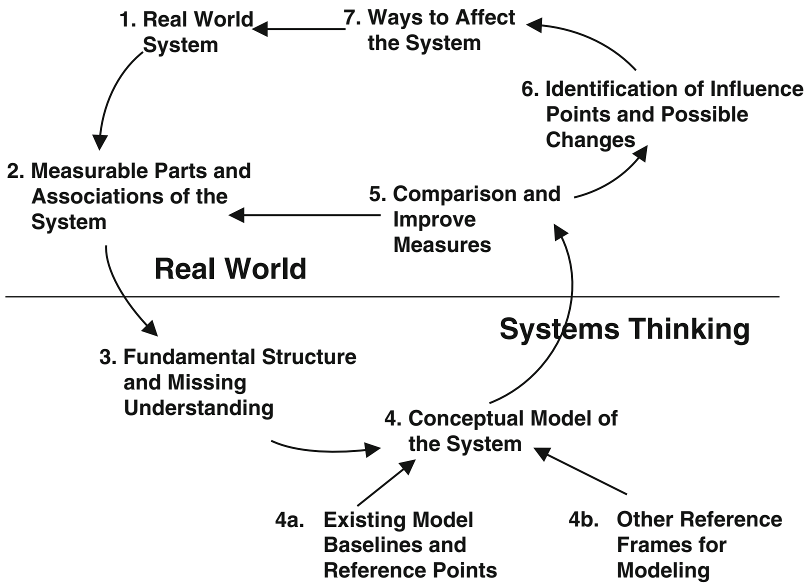

Fig. 2.27 General cycle of soft systems methodology

and boundaries. One can have missing understanding in a reference frame, and one can have completely missing reference frames. From what the real world can provide, systems thinking then projects the structural characteristics of the system and the missing understanding between the measurable and complete reality. The inconsistencies help us to create an initial conceptual model. Based on the system structure, one might be able to find other systems with similar structures to help build the conceptual model through comparative analysis. Similar behaviors in other reference frames can also help define the conceptual model for resolving inconsistencies.

The initial conceptual model can be brought into the real world and compared with existing measurements. This comparison might enable the improvement of ways to measure the system, which then leads to further refinement of the conceptual model. After iteration, the conceptual model might reveal points for influencing the system and ranges of possible change within the system. Using these influence points, we then want to find ways to affect the systems in an understandable manner. This process of interacting with the system will probably not be initially precise. However, one might be able to get to an acceptable level of control through additional measures and additional refinement of the concept model.

We do not have to follow SSM rigorously to apply the method of iterating and testing an imperfect model to understand the hidden nature of a system. In fact, the model can be abstract when there is limited data about the system, and the model can still have value if new ways to measure the system can be gleamed from studies. The weakness of an iterative methodology is that conceptual models that can be easily iterated often cannot be extremely dense in parts and associations. Further, the philosophy that one cannot exactly model reality may cause us to prematurely give up on the idea of more detailed modeling approaches. We need to, therefore, know when to break away from this philosophy and switch to other system modeling approaches once iterative conceptual models have served their purpose.

2.4.2 Methodology of Eliminating Intermixed Boundaries

The alternative to using the temporal domain to enhance systems understanding, such as through iterations, is the idea of studying systems with multiple potential boundaries by eliminating sets of boundaries or making some boundaries more important. This spatial simplification methodology is most commonly found in the study of macro human interactions across the world, as shown in Fig. 2.28. For centuries, the most obvious boundaries around people are that of political states represented by territories controlled through systems of government. However, as

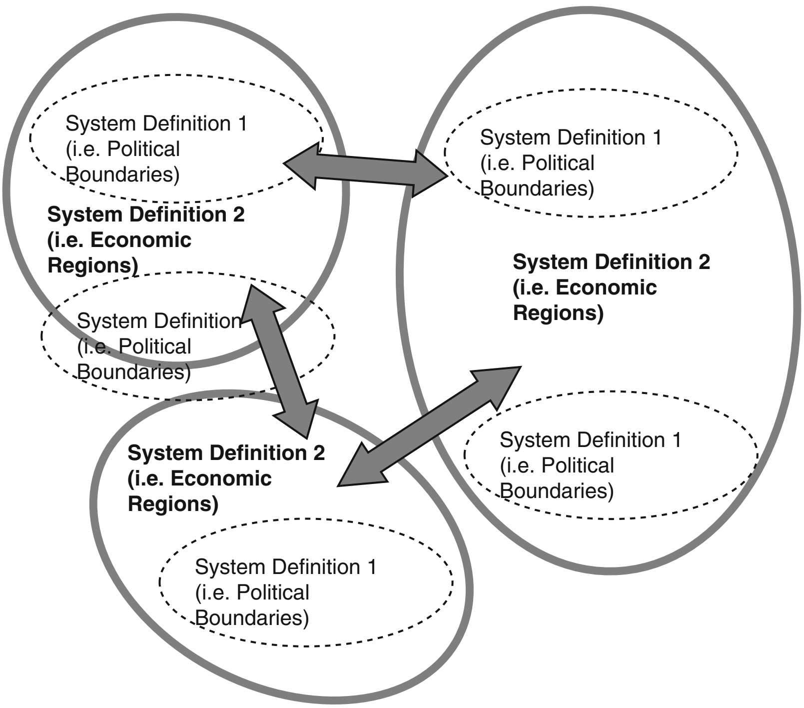

Fig. 2.28 One type of boundaries more dominant than another type

people migrate, companies trade, and banks move currencies across state borders, scholars have wondered whether there are other boundaries around people that are more definitive of systems changing the world. Before discussing this second set of population boundaries, let us first explore the idea of state boundaries and how such boundaries have already displaced older boundaries based on human associations.

From a systems perspective, the nation state is an artificial construct of man to sustain the power of government and the ability to establish militaries for enforcing and expanding state boundaries. The natural parts in state systems are people. The natural associations across the parts that can support or hinder the strength of government are the common ethnicity between people, the shared cultural experience among the people, the people's embrace of prevailing ideology, and/or the people's dependence on an integrated economic system. When state boundaries are aligned with the boundaries of these natural associations, the government tends find a form of stability. When state boundaries divide ethnic, cultural, and ideological boundaries, as in parts of Europe, the Middle East, and Africa, tensions within state boundaries can become very high. Countless political science papers have been written about the tensions within states and the tensions between states due to misaligned boundaries between the government and common human associations. A part of the discussion is how governmental boundaries have been changed through civil war and invasions to achieve better alignment.

The boundaries of human associations can also influence forms of government as well as conflict behaviors. Government boundaries tightly wrapped around ethnic boundaries can promote racist policies. Government boundaries tightly based on strong culture can turn nationalism into a fascist policy of cultural expansionism. Alternatively, many governments are enforced by ideologies and promulgate their ideologies. One of the earliest ideologies for governing is that of a ruling class (nobility) running the government and the head of state (monarch) coming from nobility. A variation of the ruling class system is the ideology of the head of state coming from the religious caste as a member of the clergy. And, more recent in history, is the ideology of representative democracy where the head of state and government officials are elected from the general population. Along this view of government and human associations, there are two ideologies that have not been popularly embraced across human associations but have, at times, been successfully promulgated by the power of government. First is the idea that one single person should have absolute power over the people. Although this idea tends to be rejected by the people, totalitarian governments have formed based on the head of state's grasp of military power. Second is the idea that only the wealthy should have power over the people. Though disliked by the majority of the people without wealth, governments owned by the wealthy have formed based on the politicians' allegiance to money. These last two examples are important from a systems perspective because they show that the boundaries of government artificially established by man can overcome other boundaries among people to be powerful and enduring.

Returning to the methodology of eliminating types of boundaries to focus on the dominant levels of system interactions, the nation state appears to be one logical set of boundaries, as we can treat ethnicity, culture, and ideology as merely forces with the boundaries of states. The interactions between nation states are then governed by political decisions and explored through political science theories. Though greatly over simplified, we can say the *Theory of Anarchy* argues that states brutally compete with one another for survival [38]. The *Theory of Realism* argues that the decision to wage wars must be tempered by rationality [39]. The *Theory of Neorealism* argues for the overcoming of hostilities between states [40]. The *Theory of Neoliberalism* argues that states can achieve limited cooperation [41]. And *Theory of Liberalism* argues that states can collaborate as partners in the global community [42].

Beyond the theories regarding motivations for political decisions, there are theories that argue that political decisions are merely reflections of the needs of system structures within states and between states. The *Organic Theory* argues that states behave like predatory living entities and must seek to devour more territory to survive [43]. The *Theory of Constructivism* argues that states may have an evolving self-identity that governs behavior [44]. The *Theory of Democratic Peace* argues that democratic states are motivated to not wage war against one another, as the people pay the price of wars [45]. And the *Theory of Institutionalism* argues that global financial institutions and corporations are shaping the actions of states [46]. The challenge with all these theories is that, as long as the system is defined by political boundaries, the interactions between the systems are always vulnerable to the irrational and emotional decisions of leaders. At times, psychological profiles of individual world leaders may provide more insight than studying system dynamics.

The dependence of state systems on leadership decisions leads us to question whether leadership decisions are really what shape the dynamics across the global human population. If we eliminate state boundaries, what is the second set of boundaries between people for defining systems? One type of new boundaries is based on global geography. Are there advantages accorded to people of an entire region, which may include many states, due to the region's geography? In response, the *Heartland Theory* argues that the people at the center of mass in a continent will have advantages in territorial reach [47]. So whoever can dominate the heartlands of Asia and Europe will dominate the world. In contrast, the *Rimland Theory* argues that the regions with both sea and land access have the advantage in global reach [48]. So whoever can dominate the rimlands will dominate the world. We can draw boundaries around heartland and rimland geographical areas. However, the *World Systems Theory* makes the argument that a region's economic status is what drives its success in global dynamics [49]. Boundaries must, therefore, be drawn around core regions with advanced technologies, diversified economies, and educated workforce. The core system, according to theory, is then surrounded by buffer semi-periphery regions with industrializing economies and growing level of skilled labor. Finally, the periphery regions are beyond the boundaries of the buffer regions and have nonskilled labor, weak governments, and primarily exploitable raw materials.

Related to world systems are the *Theory of Modernism*, which argues that regions or states advance incrementally to the level of modern society [50], and the *Theory of Dependency*, which argues that regions or states in the periphery are trapped by their dependence on the core [51]. In all these regional theories, if we eliminate state boundaries from consideration and focus on the regions, then we can suggest that all the countries in a region will share similar system structures. Regardless of theories, we should expect to see similar system behaviors and issues in one region and different system behaviors and issues for another region. The debate, however, is whether these boundaries are more dominant than decisions of the state.

In discussing so many theories, I know better than to be caught in passionate debates against advocates. I present the theories to explain an overarching methodology, which may not be recognized by all the scholars advocating theories. That is fine. In order for the methodology of eliminating boundaries to work, advocates of specific boundary types must merely argue that their definitions are the most dominant. This is despite the reality that all the boundaries might be interrelated and all the theories might have conditions where they are not fully relevant. If we are to drop a set of boundaries, then the argument about dominance has to be made and compromises have to be accepted.

Lastly, this methodology does not have to be restricted to human population systems. Almost any group of associating parts that can be defined by multiple types of system boundaries can go through the assessment of which boundary definitions are more important. The key is to not to lose sight of reality, recognize that dropping boundaries is only for the convenience of studies, and understand that all boundaries impact the system.

2.4.3 Methodology of Summarizing Lower Order Systems

For systems that are pervasive in their spatial reach, the boundaries that we care about are the range of fidelity for measuring internal system dynamics and the range of time intervals for taking measurements. The methodology for leveraging fidelity and time interval is to find ways to roll up vast amounts of discrete lower order data into macro-level parameters that describe the pervasive system or to find ways to directly collect summary data based on the macro-level parameters. The economy is an example of a pervasive system. Earlier, I have noted economics as one of four main structures connecting the human population, and I have presented other scholars' theories on dividing up the world into different interlocked economic regions. The global economy can, however, also be viewed as a single system with the research methodology focused on what macro-dynamic parameters and models accurately represent the interactions and outcomes of countless firms, distributors, and buyers, as shown in Fig. 2.29. The range of these macro-dynamic parameters then represents the boundaries of the global system.

To demonstrate the methodology of macro-dynamic analysis, the most important parameter in macroeconomics as recognized by Adam Smith is the capabilities and capacity of the people in producing goods and services of value [52]. Thomas Malthus then recognized that changes in the size of the population impacts economic activities [53], and Ricardo [54] recognized that the ability to specialize and produce in large scale creates a comparative advantage. Marshall [55] further

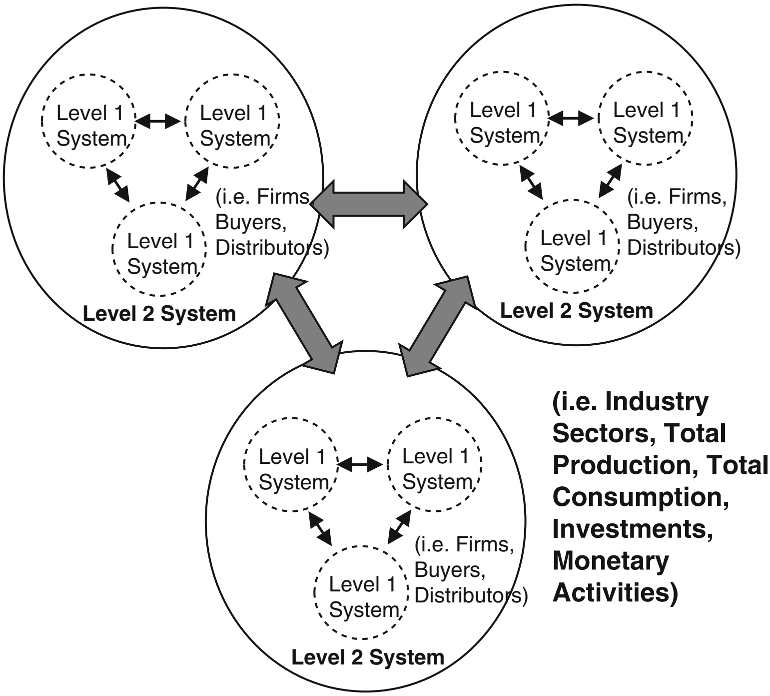

Fig. 2.29 Macro-system based on summation of lower order systems

explained that total production of specific types of goods and services and total demand for those goods and services are interdependent and have dynamic cycles, as long as firms have the freedom to produce and people have the freedom to buy. The dynamic cycles in the economy can be further understood by measuring time for market awareness, time for production, and time for deliveries [56]. The importance of information about market needs and the logistics to match changing market needs are further explained by Von Hayek [57].

Decades of scholarship by economists across the world have led to parameters and processes for measuring the macroeconomic system without having to model all the parts and associations in the economy. Specifically, these parameters take aggregate inputs and outputs from the totality of industry sectors, market segments, buyer population groups, information channels, and distribution networks. The challenges of summarizing the dynamics of lower order systems to bind the macro-system are: (1) whether the range of measured data over decades is enough to identify all the behaviors and potential behaviors of the macro-system; and (2) whether the economy can be effectively influenced through these macro-parameters. These challenges have led to some theoretical debates as further described.

The first debate is over the existence of longer cycles of change in the economic system [58], and the possibility that even the most advance regions of the system is still evolving in structure [59]. In fact, *Evolutionary Economics* has become a dedicated field of study to focus on the natural forces for changing capitalistic economies.

The second debate is over how and to what degree the government should influence the economy to achieve sustained growth. John Maynard Keynes argued that intervention policies are required by the government to reduce the impact of inflationary and depressionary forces in the economy [60]. In contrast, Milton Friedman argued that the economy is more self-correcting [61]. The resulting Chicago School (monetarists) of practice is, thus, focused on controlling the monetary supply as the primary means to stimulate the economy to self-correct.

The third debate is whether there are components of the economic system that are disproportionately concentrating wealth relative to their value. This surfaced during the industrial revolution and might surface again. Karl Marx described this as “surplus value,” [62] but the resulting remedy of communism became a failed form of government. Nevertheless, such imbalances in the economy might still exist, such as the increasing concentration of wealth in the 1 % population of the United States as noted in media [63]. If so, are there any ways to correct possible inefficiencies without abandoning the entire economic structure?

As we consider the debates that still go on in macroeconomics and the periodic inability by scholars to project major economic events, we should remind ourselves that the approach of macroeconomics is just one method for dealing with complex systems. The boundaries of the economic system do not have to be drawn at the current levels. With advances in “Big Data,” we might be able to model economic behaviors from the overall dynamics of the firms directly up to the behavior of the global system. How the actions of one CEO, the performance of one company, and the buyers of one product impact the global economy can be captured in the economic system models of tomorrow.

I close this section with the reminder that system boundaries and the definition of systems are established by those who study them. Some boundaries have been set by academic communities for so long that no one tends to question their limitations and effectiveness. However, we must always be clear about what is reality and what compromises we have made to study reality. When existing boundary definitions are hindering our studies, then new boundaries as well as new methods for establishing boundaries should be explored. The success in studying a system often depends greatly on how the study begins. Toward this purpose, I have only presented some methods for establishing boundaries.

2.5 Interactions: How the System Behaves

Together, we have explored the structure of systems and the boundaries for defining systems. I have further emphasized that systems exist because of their dynamics, the changes between parts and associations for the system, and the changes within parts and associations for the system. These changes can be further studied as a

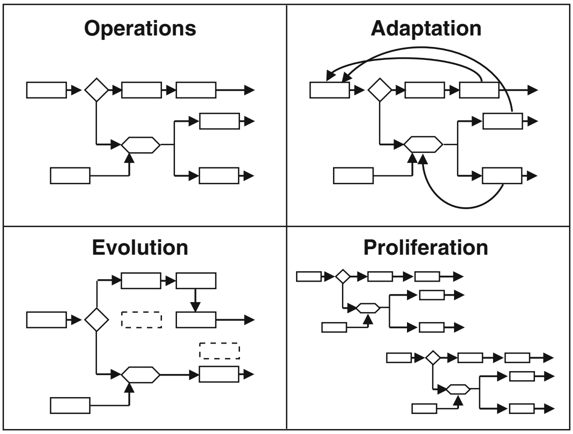

Fig. 2.30 The purposes of system interactions

whole at the systems level assuming that the parts are working together [64]. If the parts are not working together or even influencing one another in an integrated manner, then we do not have a system. If the parts are having problems and difficulties working together, then we are facing concerns about system failure to be addressed in Chap. 3. For now, let us assume that we have working systems that are able to interact with their internal parts, the environment, and other systems. Our next step in exploration is to then look at the ways and proposes of interaction. Similar to the decomposition endeavors of prior sections to find broad sets of system characteristics, system interactions can be divided into four conceptual types, as shown in Fig. 2.30. Unlike the structural and boundary types, which may have unclear divisions but are nevertheless mutually exclusive, the types of system interactions to be discussed can all emerge over the course of a system's life cycle. Further, as we explore the types of interactions, it will be clear that one type of interaction can impact the dynamics of another type of interaction to make system behaviors very complex.

2.5.1 Operational Interactions

At the fundamental level, the purpose of all systems is to operate as defined by allowing the parts and associations to work together. The operations of a system can be captured in an overarching process or series of processes that describe what each group or subgroup of parts and associations is doing. Processes exist even when the associations between parts are changing as long as the dynamics between parts are not random but serve the system's purpose. Processes also exist, even when the parts are being added or removed from the system, as long as the changing of parts across the system boundaries is acceptable based on the design of the process. Finally, processes can be momentary in unbounded systems or systems with incremental as well as sporadic associations. However, there needs to be ways to project when the system will undergo certain processes.

As few systems are perfect by design or through formation, system processes and decisions can contain degrees of variability with cases of lower performance and levels of imprecision leading to errors. Improving the consistency of performance, such as production rates, and avoiding errors that stem from performance, such as product defects, thus, have been matters of great research focus for human designed systems. This is in addition to the fundamental system design challenge of creating structures and dynamic processes that make achieving objective performance and behavioral results feasible.

Assuming that acceptable performance can be maintained and error rates can be kept at acceptable levels, we then have a functioning system that will operate with the purpose of sustaining itself, producing outputs, affecting the environment, and/or controlling other systems. The idea of a system merely sustaining itself seams pointless for human designed systems. However, for systems where the parts have value, such as people in a social system, the simple purpose of processes for enabling parts to live and thrive can be noble. Systems that formed in nature tend to follow one test of acceptable performance, which is survival under harsh environments. To pass nature's test, systems must act with enough consistency and precision to fit within the changing dynamics of the greater natural system. Slight mistakes in action could lead to death. Slight deficiencies in capability could lead to the extinction of an entire species. At the same time, systems in nature work together to help one another survive. Operations support one another and natural processes connect with one another.

Beyond a system acting just to keep itself viable, the processes can produce outputs such as products, raw materials, energy resources, and information resources. For systems in nature, their outputs, such as oxygen from plants, can help other systems to survive. For human designed systems, the outputs often define the purpose of the system. The most obvious outputs come from factory processes, and the most complex outputs might be the terabytes of information generated by software system processes connected across the World Wide Web.

The counterpart to a system contributing something new to the environment is the system performing actions that affect existing components of the environment. These actions include transportation, assembly, alteration, demolition, storage, and consumption. In fact, most systems consume from the environment and contribute to the environment in some way. The counterpart to a system contributing something new to another system is the system controlling or attempting to control another system. These controls include physical changes to the other system, forces upon the dynamics of the other system, instructions to the other system, and parametric inputs to the other system for basing dynamics. If the interactions between the systems are tight enough, then we can consider whether we are studying a system of systems or a system with subsystems.

Years of researching systems operations have led to a series of methodologies and techniques for managing the operations of human designed systems. One popular methodology, which focuses on identifying and improving core measures,

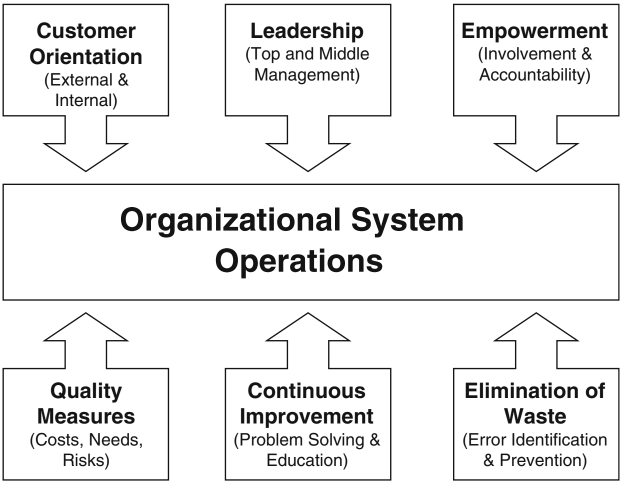

Fig. 2.31 TQM based view of operations management

has been Total Quality Management (TQM). TQM, referenced earlier and shown in Fig. 2.31, recognizes the importance of both leadership and participating workers in a modern corporate organization. At all levels, employees need to understand that they are producing in response to the needs of customers internal to the corporation so that processes connect. Further, the total production must respond to external corporate customers, which is the bottom line.

The involvement of leadership and workers in the processes of operations enables the system itself to focus on operational measures to improve and sustain quality. Performance issues in satisfying processes should be continuously identified and resolved. Then, the members of the organization/corporation need to be trained or educated to prevent performance issues from reemerging. Through this empowerment of the system to achieve optimum operations, end products will, in theory, have better total quality. Continuous identification and prevention of component and assembled product errors will lead to the elimination of waste. TQM was popularized in American manufacturing in the late 1980s and early 1990s to reduce defective products. Later, as organizational processes became more agile with computer-driven design, production, and coordination, management focus appears to have shifted from metrics centric approaches to process capture and change based techniques such as Lean Six Sigma, which was also referenced earlier. Lean Six Sigma, for example, relies on external experts (Black Belts and Master Black Belts) to map the processes, isolate statistically verifiable performance issues (Six Sigma standard is over 99.99 % error free), design/test corrective actions, and improve the entire process flow (lean design of processes). Such techniques not only optimize operations but can lead to a transformation or evolution of the system to be discussed. Employees can be removed or added, business units can be changed, and processes can be completely replaced.

2.5.2 Adaptive Interactions

Beyond a system merely operating against a set of processes, the operations of the system can be adaptive. In other words, the processes allow for changes in rates, procedures, outputs, and interfaces depending on the feedback received from system performance results as well as interactions with the environment and other systems. I use the term adaption in this context to represent responsive changes in the way the system operates but not changes in the structure of the system. For example, human beings are remarkably adaptive systems compared to other animals, even though our bodies are rigid systems in a similar manner. What allows for human adaptiveness is largely the superior brain that receives sensor inputs, records past experiences, and learns to act based on past experiences to optimize the human condition. From the learning process comes the body of human knowledge built and shared across the centuries. From the desire to improve the human condition comes innovation, discovery, and construction to control the human environment. Over the centuries, the human condition has gone from hunting and gathering to survive to traveling into space and underneath the sea. We have discovered medicines to alter the performance of the human system, and we have invented devices to enhance the capabilities of the human system. However, it is only recently, with the mapping of the human genome and developing of DNA modification techniques, that man can change the structure of his own system. Before we explore evolution, however, let us first delve deeper into the purpose of adaption.

On one level, the purpose of adapting through system interactions is to improve the performance of the system. The performance of the system is then tied to the mission of the system. In the case of companies, for example, the general mission is to gain higher market share, increase profits, and grow intellectual property and other assets. The mission of an organic system is to survive, reproduce, improve quality of life, and satisfy emotional and/or intellectual needs. The mission of military systems is to defeat adversaries, defend against threats, capture and control territory, and deter potential aggression. The ability to adapt might be critical to system operations if the operational environment is highly unstable or unpredictable. This would prevent processes from being designed to rigidly interact with the environment and other systems in the environment. Instead, the processes must be designed to adapt to unpredicted events, new drivers, and shifts in environmental conditions. The human mind is ideally suited for this type of unbounded system interaction. Artificial intelligence research and learning systems based on cognition theories are starting to move computers toward higher levels of adaptive capability.

In seeking to control system adaptiveness, the modern military concept of tactical operations as captured in the Observe, Orient, Decide, and Act (OODA) Loop created by US Air Force Colonel John Boyd is a good reference frame [65]. Although the OODA Loop was designed for combat in highly dynamic and often unpredictable environments, it can be used to describe the cycle of system processes required to adapt to any performance conditions. This expanded use of the OODA Loop is shown in Fig. 2.32. Essentially, in order for a system to adapt, it must

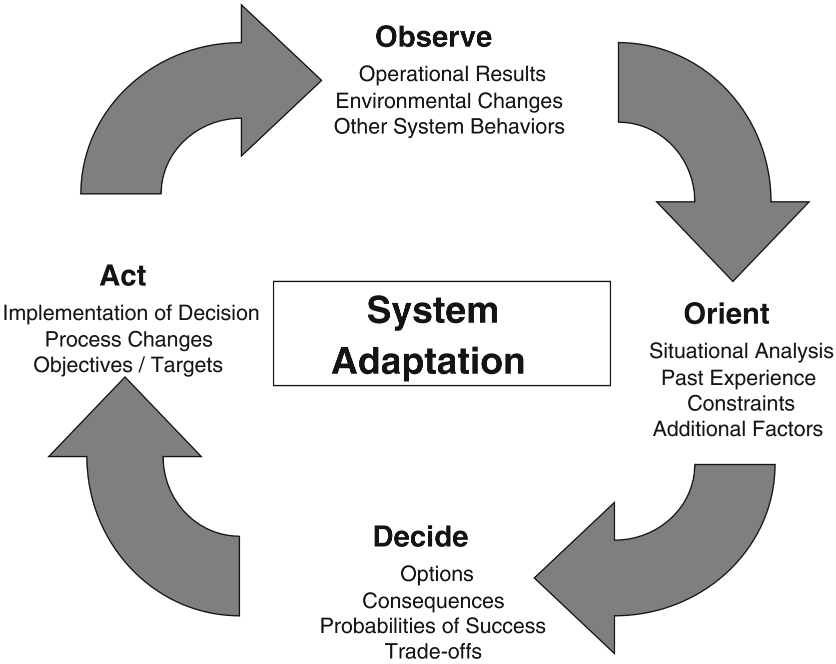

Fig. 2.32 Adaptive cycle based on military OODA loop concept

observe and establish an understanding of what to adapt against. This understanding can be achieved through feedback on operational results, changes in the environment, and the behaviors of other systems in the environment. For nonhuman systems or systems that enhance human capabilities, the sensors and metrics for enabling observations are the starting point of adaptation. Speed, cycle time, and fidelity of observations are then driving factors. With observations, the system analyzes the situation to determine a conceptual model, compares the model with past experiences consistent with Naturalistic Cognition Theory, and determines other factors as well as constraints that would affect decision-making.

The actual decision process would start with the adaptive options associated with the conceptual model of the situation, the understanding of consequences associated with each option, and the assessment of probability for success associated with each option. Before an adaptive action can be taken, the system must first decide on which option to take based on trade-offs. The challenge of the trade-off process is that few conditions have clear answers. In most cases, options carry negative consequences as well as risks of negative outcomes beyond just the potential benefits. The human mind is quite skilled at navigating through these opposing factors, but it is nearly impossible for rules-based computer programs to cope with the unpredictable aspects of operating environments that require adaptation. Thus, uncertain reasoning techniques and artificial intelligence is the path that must be taken.

The actual act of adapting is the last part of the response cycle, and all actions must have clear objectives and ways in which processes are adjusted to achieve the objectives. If the actions are perfect and complete, then the adaptation can stop, and the system might be able to achieve a new steady state level of operations. However, adaptation is often an iterative process where the system must interact with the shifting situation. Actions must be taken, and the outcomes must be observed so that the system can reorient further adaptive actions.

In an interaction involving two or more opposing combat systems, the OODA Loop is continuously executed on both sides. Often times, victory is dependent on the speed of this adaptive cycle and the accuracy of the actions. Getting within the cycle of the enemy can disable the enemy's ability to respond, as one is adapting faster than the enemy's ability to reorient and act.

Adaptive actions can be centrally controlled within the system or be taken individually by system parts. This depends on the structure and boundaries of the system and the ways in which the system interacts with the environment as well as other systems. Central control allows for the power of concentrated system-wide knowledge, situational awareness, and computation to be applied to actions. So the adaptive actions can be complex with deep understanding of total potentials and consequences. Adaptive actions by the parts can be faster in response to environmental situations, harder to counter because of many decision points, and highly complex as a result of mutual coordination. Even the human body has localized reflex actions that do not require commands from the brain. However, it is centrally commanded and locally responsive human systems that pose the choice of selecting the approach that is more adaptive. For example, some companies embrace the delegation of adaptive capability to highly trained frontline employees. Other companies want employees to rigorously follow the commands of leadership who will decide how to adapt. The right approach is probably situationally dependent, and the most adaptive company/system might be the one who can switch the control of adaptive actions based on needs.

2.5.3 Interactions to Evolve

As noted, all types of system structures and system boundaries, though not all systems, can be adaptive in their behaviors. Likewise, all types of system structures and boundaries can evolve. Evolution involves the changing of the parts and associations enabling system dynamics. This change can be within the structure and behaviors of parts and associations, and this change can involve the replacement of parts and associations. Evolution can be caused by external and internal forces, and changes might not always be advantageous to the purpose and mission of the system. Positive evolution is an adaptive event, but systems adapting through evolution might not be adaptive when they are not evolving. In contrast, adaptive systems might not be able to evolve. Negative evolution is a reflection of weaknesses within the system at the levels of parts, structures, and/or boundaries. Vulnerabilities to forces might cause the system to change to a state with less structural integrity and less ability to successfully operate.

Natural selection is a theory suggesting that, through random changes in the system and letting these evolved systems compete with one another in the environment, the most fit systems will survive in the end to dominate. Systems with poorly evolved features and capabilities will die off. The limitation of this theory is that it takes a step function view of how systems interact with the environment. In this view, what is best in the next step is given priority over what might be better for the future. If systems are intentionally evolved through reorganization to surpass previous systems, then the designers might wish to look at the changing environment and needs across the extended future, not just a series of next steps. One clear risk of a next-step evolutionary approach is reaching dead ends, such as mass extinct events as presented by paleontologists.

The key parameters in system evolution are the rates of change and the levels of change. For systems such as those based on information technology, the rate of technology advances has often driven systems evolution as well as the invention of completely new systems. However, whenever such changes occur, they create learning and adaptation changes for the human users. Therefore, product release cycles and product adoptions have been a major area of study in market research. Replacing systems too quickly or with too few innovations could lead to reduced profitability from prior system investments, user delays in adoption, and/or user perception of lacking value. Replacing systems too slowly or with too major a change could lead to reduced relevance for the existing system that should have been replaced, overwhelming of users, and/or loss of user willingness to change. One can argue that evolution is an inherently high risk but perhaps necessary level of system interaction. When pushing for evolution, both in human systems and human created systems, the process of transition from the current system to the next should perhaps be regarded as equally important as the structures and functions of the next system.

A method of transition is evolving systems in the course of reproduction or replacement. Changes in parts, structures, and boundaries for organic systems and systems mimicking organic characteristics can occur during mitosis and sexual reproduction. Changes in other systems can occur as a part of constructing replacement systems. Some systems can, however, evolve without being replaced, and some types of structures and boundaries are more conducive to changes while the system still operates.

The control of human organizational systems to evolve while continuing operations has been a matter of great research emphasis in management studies. The Fifth Discipline presented by Peter Senge and referenced earlier specifically argued for system thinking in enabling organizational change, and I have already noted that Lean Six Sigma offers techniques for changing the system as a part of changing processes. Because of the complexity in this endeavor and the ongoing research into controlling organizational transformation, I am not going to present any methodological diagrams. For example, the Balance Scorecard, as referenced earlier, argues for change as a cycle of setting Vision and Strategy, Communicating and Linking Performance, Planning and Target Setting, and Strategic Feedback and Learning. However, I do not want to trap anyone in formal steps given the complexity and diversity of system dynamics. A methodology might work for one organizational condition and not the next. So I will present some summary observations already made by other systems and management science researchers.

- Organizational systems are often inherently self-adaptive and self-organization based on organic behavioral properties
- Even with performance issues, a stable system will often resist change, and the resistance will increase with external attempts to control change
- Unstable systems will change in unpredictable ways. Thus, causing change could be easy, but controlling change might be difficult
- Complex systems will change in complex ways with possible untended consequences
- There may be hidden patterns and unforeseen forces that affect one's attempt to control change
- The right control points are, therefore, difficult to find
- The extended effects from a control point can emerge anywhere in the system at any time.

Thus, controlling the evolution of a human organizational system could be a myth. Nevertheless, managers and operations researchers might be able to nudge system changes in better directions. One can redesign to obtain the best processes and hire the best people, but the enduring culture of human organizations might get in the way. Gentle use of control points can yield significant results, and iterative use of control points might hone in on more preferred outcomes. So, when in doubt, systems evolution should perhaps be in small increments.

2.5.4 Interactions to Proliferate

Evolution is a state-to-state type of system transformation. A system can also be designed to dominate through proliferation instead of just through operations, evolved operations, and adaptation. The proliferation that allows a system to dominate the environment is growth in number of system parts and/or high rate of reproduction to yield greater number of systems. Proliferation is, therefore, another form of system interaction. In growth, the system structure or parts of the structure can be replicated to expand the system. The system can also have processes for building structures in evolved ways as it grows. In reproduction, the design of the parent system or integrated design of multiple parents is used to create offsprings. A high number of resulting systems is achieved through having many offsprings in one generation and/or having many succeeding generations.

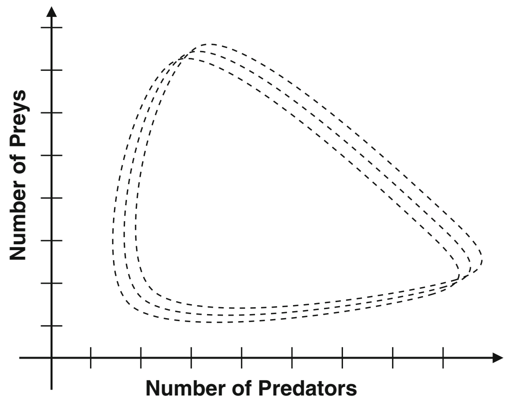

Fig. 2.33 General interactive cycle between predator and prey populations

System proliferation in environments that seek to achieve balance can be an internally or externally regulated interaction. In internal regulation, system growth and reproduction will slow down based on indicators that the environment will not be able to sustain the size and/or population of the system. For example, food and other resources could be dwindling, competition for resources could be intensifying, and environmental conditions could be getting harsher to warn the systems to adjust interactive behaviors. For systems that are not good at internal regulation, such as poorly organized packs of animals, external forces or systems could help to achieve balance. The most well-known proliferation balancing interaction is perhaps the predator and prey model as shown in Fig. 2.33. In this simple interaction, a population of predator animals (such as lions) and a population of prey animals (such as zebras) provide a check and balance in population growth [66]. As the prey population increases to dominate the land, the predatory population will increase to eventually dominate the prey. As the prey population is brought down by the increasing number of predators, the reduced food supply for predators will cause a lagging reduction of population. Once the predator numbers drop blow certain levels, the prey population can grow again in a system-to-system coupled manner.

The cyclical approach to achieving balance in potentially unstable systems can be seen in a variety of system control schemes. For example, when using opposing thrusters to stabilize a spacecraft in a low gravity atmosphere-free environment, one often can only get the stability down to a small wobble called a limit cycle, as the exact force to fix the system's position is not achievable. Limit cycles are common to oscillatory systems when the oscillations are not growing out of control or dying down. When the system is governed by more than two opposing forces, stability and control are more complex. Control science is the discipline of identifying all the dynamic metrics governing a fairly structured and bounded system (such as an aircraft), determining how the metrics associated with one another (typically through partial differential equations), and solving these equations often through computer-based methods to gain control of the system. This discipline does encounter difficulties with systems that are less structured and less bounded.

In environments with less balancing forces, unconstrained system proliferation has, at times, led to massive systems die-off. Bacteria cultures in the lab have demonstrated this behavior where mass growth has reached a point of nonsustainability. Then, suddenly, the population will die off to a level where survival in the environment is again stable. It is still uncertain whether human social systems can internally regulate growth. One can argue that competition for resources and wars between regions in the past has provided some constraints. With a global economy and rapid growth across many regions of the world, how to sustain the system has become a paramount question in the twenty-first century.

Real-world systems can be extremely complex in structure and undefined in boundaries. Therefore, the results of system interactions can be filled with unknown dynamics and effects. I do not want to trivialize the challenges in understanding system interactions in any way, for the book of management history is filled with failed attempts to shape the interactions of human systems. Even in war, with decisive outcomes during most tactical engagements, the consequences of the conflict may not be fully realized for generations. We might create new enemies in the course vanquishing the old. We might adversely change our system/our way of life while trying to adapt to threats and a changing world.

2.6 Quality: Measuring the System

Much of what I have discussed is focused on how difficult it is to fully and accurately define systems. In fact, some have argued that real-world systems can never be fully defined but only understood to a level where we can use influence to obtain specific results. The idea of establishing system-wide quality measures is, therefore, almost a false belief, as the systems will surely stretch beyond these measures. Nevertheless, it is not always possible for us to describe a system by all the parts, associations, and dynamic effects. If we need to make quick decisions regarding systems, it is sometimes practical to simplify our view of complexity, make compromises, and establish quality measures.

Quality measures born from compromises can be helpful in unraveling system characteristics. This is because the measures permit comparative analysis between systems when details are not well understood or when details actually distract us from common characteristics. Despite the differences between systems, common patterns often appear at the macro-dynamic level. For example, some human group behaviors might resemble the patterns of colony insects, and some Internet traffic patterns might resemble the flow of people and goods between cities. In such comparisons, the details of one system might help us discover the details of another system with less understood structures, boundaries, and interactions.

Now returning to the thought of making decisions about systems based on quality measures, reality sometimes calls upon us to choose which systems to monitor for potential failures, track as threats, leverage for opportunities, modify to expand capabilities, mimic in design, and consider terminating. The world is filled with systems and different ways to define systems, so many that we cannot model the world. Therefore, we must choose what to focus on and how to focus. Please note that I, at no point, advocate taking drastic actions based solely on quantity metrics without further studying the systems to be impacted. However, the time needed for studies may not be available during crisis situations. Making the perfect decision at the wrong time is pointless. Thus, I will try to cover a broad enough set of measures to enable crisis decision-making.

To facilitate decision-making, quality measures can be divided into three categories, as shown in Fig. 2.34. The first category is the qualities that enable a system to sustain its intended purpose, which includes the method of operations and objective results. The second category is the qualities that enable a system to compete in order to fulfill its intended purpose. This competition can be in a rules-governed environment, such as the commercial marketplace, or this competition can be an all-out conflict for survival, such as in total war. Finally, the third category is the qualities that enable a system to improve and move beyond its current state. While not all systems must be able to improve, systems that cannot at least improve through replacements and successive generations will most likely become extinct. Systems that endure beyond the need for improvements will often become obsolete.

There may be other ways to categorize or bin together quality measures, and my list of quality measures might not be complete or even properly named. Achieving a

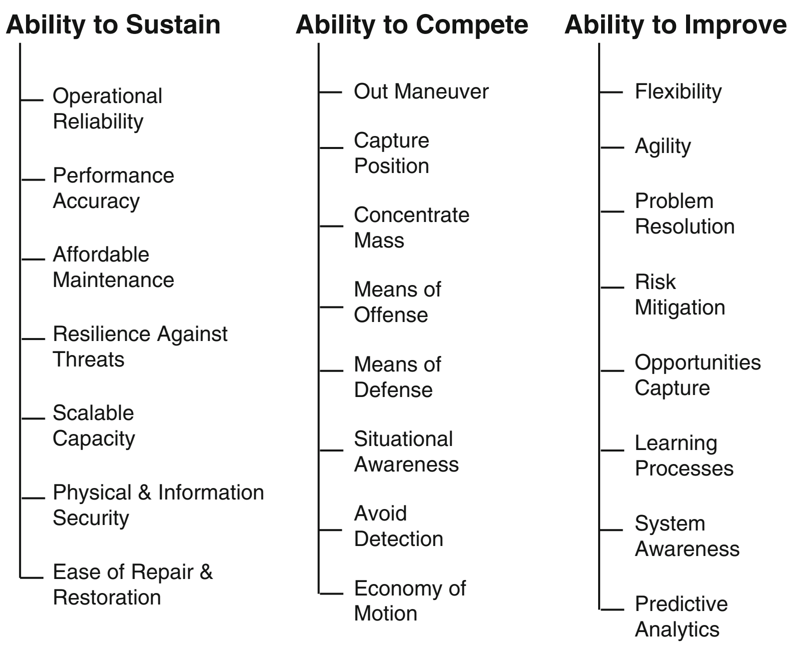

Fig. 2.34 Proposed categories and measures for quality

commonly agreed to taxonomy for measurements has haunted many scientific communities. How are terms different? What does each term cover? And how are all the gaps addressed by terms? These questions typically require long debate before consensus. Since I do not want to spend too much time debating with myself, I have endeavored to select pre-established terms whenever appropriate. If these terms and measures do not feel right for the systems being studied, please do debate to find better terms.

2.6.1 Quality Category 1: Ability to Sustain

Many of the sustainment metrics below come from industrial best practices for assessing systems. Though the scales may be different between physical machines, computer systems, and organic systems, the principles of quality remain similar. Human factors in system operations add a degree of complexity and variability to some of these metrics. Systems with human parts have to take into consideration the risk of unplanned behaviors, the evolving capabilities of people, and the display of secondary system characteristics with people self-organizing while performing functions. I will highlight some of the effects of human involvement in the quality measures below.

Measure: Operational Reliability. The percentage of time that a system will operate within intended parameters is a measure of system reliability. This can be computed by tracking the total time of unacceptable operations or nonoperations within a set period. Reliability standards can also be specified for activities conducted by the system, and the duration for each incidence of system failure can further be tracked. System operations can vary within allowable ranges for reliability. To enable systems to stay within this operational range, the parts can be designed to interact with minimal or no failures, redundancies in parts can be established, and backup parts can be prepared for rapid replacements. Sometimes, operations are adjusted when parts are not in use to minimize disruption and impact on output results.

Parts in a system might exhibit a pattern as they fail, which resembles a bowl-shaped curve. Along this curve, a higher number of parts fail early (infant death) due to manufacturing defects, and a higher number fail after a period of wear (senescence). Infant death in parts can be reduced with advances in manufacturing capability, and parts replacement can be planned after a certain period of use to delay senescence. When the failure characteristics of parts are not well known, the brute force approach for getting higher system reliability is to over-strengthen the parts for their intended functions. People, as parts in a system, add adaptability but present a challenge for determining reliability. Statistical factors in human performance can be affected by many subfactors such as the quality of new recruits, morale of the workforce, and reactions to external and internal events. Rigorous training and clear procedures can reduce variance. However, there are still no guarantees.

Measure: Accuracy in Performance. The accuracy of a system refers to its ability to achieve a specific set of performance results within very small variances. Like many other parameters, accuracy can be measured as a minimum acceptable threshold and a targeted objective. Accuracy can be achieved by design, or accuracy can be achieved by system adaptation and evolution. For example, the human mind and body are learning systems where the ability to perform tasks can be dramatically enhanced through practice, figuring out what has been done wrong, and making corrections in performance. Beyond mental learning, our muscles also recognize when each must get stronger to meet performance needs. Human organizational systems are also learning systems, as argued by many system thinkers. At the same time, managers of organizational systems still want to instill high accuracy by design. These ways to gain accuracy do not have to be mutually exclusive.

While the human mind and systems that mimic human learning can grow in performance, the advancements of computer control and high-precision mechanical devices have dramatically increased accuracy by design for physical systems. In contrast, accuracy in information systems generally refers to the fidelity of data, appropriateness of data, and lack of junk or erroneous data. Data accuracy in the age of high-capacity computing has launched a dedicated field of study into systematic and non-systematic errors with data as discussed earlier.

Measure: Affordability in Maintenance. If money is not a constraint, then any man-made system can, in theory, be maintained forever. In fact, at some point one will have replaced all the parts. The debate regarding when to stop maintaining the system is, thus, a consideration of affordability. Affordability is a trade-off among the financial, time, resource, and even emotional cost of maintenance versus the consequences of letting the system fail. In some cases, the cost and benefits of new systems with better technology vastly outweighs extending maintenance. In other cases, the risks of transitioning to a new system compel decision-makers to continue relying upon the old.

Systems can be designed for maintainability with features such as modular components, internal failure detection and warning, affordable parts, clear replacement processes, and methods for quick fixes. For organic systems such as the human body, maintenance is often a question of capability and not affordability in first-world nations. With the ability to replace organs, eradicate cancer cells, predict hereditary diseases, and alter the metabolism, the degree on which the human body can be maintained seems to depend primarily on the level of external trauma, genetic flaws, and the natural aging processes. Now even the natural aging process is being investigated and challenged by today's researchers. For organizational systems, maintenance is the cycle of recruiting, training, and assigning new employees as positions become available due to growth and departure of current employees. Some organizations also have processes that drive out less-performing employees to sustain quality and to promote continuous improvements.

Measure: Resilience against Threats. Most systems have some form of interaction with the environment that contributes to the failure of its parts. For the human body, there are carcinogens in the environment that promote cancer. For vehicles, the road wears out tires, and shocks, sun, and rain wear out the body.

For applications on the Internet, there are viruses, malware, and hackers that can corrupt codes, usurp data, and seize operational control. Beyond the continuous dangers of operations, the environment and other systems in the environment can pose specific and targeted threats at the system. A system's ability to maintain a continuity of operations when confronted by such threats is sometimes termed resilience. Thus, the resilience of the societal infrastructure has become a popular metric in disaster response planning [67].

Systems achieve resilience by being able to operate after being severely damaged, being able to prevent or avoid damages, and/or being able to make real-time repairs. To operate when damaged, a system can have redundant parts or have the ability to reorganize through the use of remaining working parts. To prevent damages, a system can have barriers against specific threats, parts that are hardened against specific forces and energies, and/or the ability to counter the mechanisms of approaching threats. For examples, missiles can be shot down, intruders can be captured, bombs can be detected, and computer hackers can be traced. A system's ability to detect threats also means that it might able to avoid the threat through evasion, relocation, or concealment. Finally, a system can make real-time repairs through the ability to adjust operations, switch parts, and reestablishing normal operating conditions. As the duration and nature of threats can be long and complex, systems that are resilient against threats may at times need a combination of the above techniques to maintain operations.

Measure: Capacity to Scale. Some systems have the luxury of operating in a completely steady-state environment. Most environments, however, impose fluctuating, escalating, or declining demands upon systems. For example, systems serving human groups will often face higher demands during peak hours, and systems addressing a popular need might suddenly experience escalating demand through market growth. To handle an oscillatory demand, the system must either have the continuous capacity to handle peak loads or have the ability to scale to adequate capacity during peak hours. To handle a growth in demand, the system must be able to either scale at the rate of growth or scale to the projected level of future demand in advance.

There are several strategies to scale capacity to match growth. The system can grow in size to yield higher volume of output. The system can increase the rate of operations to yield higher output per unit time. And the system can be replicated and coordinated to yield a higher combined volume of output. These scaling strategies have been used to grow information systems to the level of supporting millions of users in an enterprise, and these strategies have also been used in factory operations. Scaling often needs to be considered in conjunction with reliability, accuracy, and maintainable. This is because changes in system dynamics can introduce new stresses and even new vulnerabilities to threats.

While I have referred to capacity as system output, capacity can also be a metric of the communications and transportation to and from systems. With current computers being able to produce data at a rate faster than the rate the Internet can upload and download, network capacity described as bandwidth has been a defining factor in system performance. With the current productivity rate of regions in the global economy, shipping capacity has been a key factor in the world system. The scaling of capacity for designed systems is often a question of cost. How much invested cost to increase capacity can be recuperated through higher rate of sales and/or higher prices? The inability to recuperate such investments has lead to some markets, particularly those in poorer regions, to be stuck with antiquated systems with capacity unable to satisfy demands. The scaling of natural systems is connected with the adaptability of the system and the consequences if a system cannot scale or scale fast enough. By definition, if a natural system has survived, then its capacity is adequate. Adequate, however, may not be comfortable enough for some human conditions. Thus, some human societies across the world have not changed/scaled for thousands of years, and other human societies have gone from using spears to sending people to the moon.

Measure: Physical and Information Security. Security generally refers to the system's ability to detect, prevent, and stop intrusions. This is in contrast to the system's ability to defend against massive attacks. Systems that occupy physical space may require barriers, locks, sensors, and guards as components of physical security. As physical space is three dimensional, barriers need to address all possible directions of intrusion. Barriers provide limited security because for every material there is a tool that can cut through it. Nevertheless, if there is an entry point, then breaking down the door might be easier than breaking through walls. Modern locks have, thus, become very sophisticated in protecting doors. Access can be based on individual unique biological signatures such as retinas and fingerprints, no-replicable keys, and complex passwords. Beyond passive physical security, active means include sensors that detect particulate matter, cameras that detect across the electromagnetic spectrum, automatic weapon systems, traps, and guards who can respond to the actions of actual or potential intruders.

Security in cyberspace in many ways mimics security in the physical world. There are firewalls to block malicious intruders such as viruses, malware, and hackers. There are identity management and access control schemes to let in authorized users. Access control covers entering into an application, such as by password and physical token, and includes user privileges when they are in the application. One can scan for intruders in an application and on the network, and one can monitor for the effects of intrusion. Once detected, intruders can be isolated (quarantined), erased/deleted, or disabled. Intruders, such as hackers, whose physical presence is away from the system can still be traced back to the point of origin and be dealt with by physical means or reverse cyber infiltration. Absolute security is a theoretical impossibility as long as there are evolving and adapting intruders. Therefore, system security should either be considered a mechanism for limiting damages in a sustainment situation or a component of system competitiveness in defeating adversaries.

Measure: Ease of Repair and Restoration. When a system is failing to operate within required performance ranges due to damages, the time, cost, and resources required to repair the system and restore it to normal operations is another quality of sustainability. Time is divided into the period for repairs and the period for restoration. In systems such as a factory, the employees might move on to other jobs if broken machines require weeks to repair. Therefore, even when the mechanical parts of the factory have been fixed, time might still be required to hire and train new workers before the factory can return to normal operational capacity. The time of repair can be slowed by the complexity of labor that cannot be resolved by simply hiring more repair personnel, and the time of repair can be delayed by the finding and delivery of resources/parts. The cost of repair is then the labor cost plus the cost of resources. For every hour or minute that a system is not operating, there is also a cost in lost productivity. For systems and damages that cannot be repaired by man, there may yet be self-repair capabilities within the system. The human body, for example, can self-heal wounds, eradicate diseases through the immune system, and recover lost memory.

Some systems can be designed to facilitate rapid and affordable repairs. However, repairs might not be economical if system functions can be recovered through affordable replacement systems. In fact, the knowledge of when systems are better replaced instead of repaired could drive design decisions. In human organizational systems, repairing people as a part of the organization is sometimes done through counseling and corrective actions. Like physical systems, many companies have found that it is often easier to replace nonperforming employees. When employees have value due to the cost of their training, depth of their experience, and uniqueness of their skills, repair versus replacement becomes a trade-off decision. For example, the military typically has to invest millions to train a fighter pilot. Therefore, the first course of action when a fighter pilot is having performance issues is to figure out how to resolve the issue. In some cases, such as for celebrities, the person's experience and skills can be so rare that the entire system must adjust operations to compensate for the idiosyncrasies of the person just to get that person's benefits.

2.6.2 *Quality Category 2: Ability to Compete*

Competition is either the normal operating state of a system or infrequent events that the system must adapt to or overcome. Regardless of the frequency and intensity competition, the ability to compete can draw its quality measures from the principles of war as explained by Sun Tzu [68], Von Clausewitz [69], and other military strategists. The key feature of competition is that the system is in an environment with other systems. The environment impacts the nature of competition, and competition can further be governed by a mutual understanding of constraints/rules. A misunderstanding of constraints, such as one side's willingness to use a weapon that the other side will not, can lead to defeat but also disgrace for the victor. Also, differences between competing systems that result in asymmetries in engagement can expose vulnerabilities. We will explore the defeat of systems in conflicts to greater detail in Chap. 3 on how systems break. For now, let us see what strategists have taught us about measuring systems competition or conflict.

Measure: Ability to Outmaneuver. A system is largely defined by its interactions. When the interactions must compete with those of other systems and changes in the environment, then the question is how fast, how sharply, and how accurately the system can change its interactions to gain better competitive positions. This ability to maneuver embodies situational awareness, tight operational control, innate dynamic ranges, and sometimes the ability to adapt. In physical combat, a maneuver often involves the speed and radius of a turn, and a fighter jet that gets within the turn radius of the enemy can get an arch of fire. However, in group combat, a maneuver can also be used to change the formation and distribution of the group so that one can place a wedge into enemy forces, surround enemy forces, disperse enemy forces, as well as get behind the enemy forces.

In communications, maneuver is within the war of words where one debater can trap another in an indefensible position through logical arguments. In such a case, a maneuver becomes the speed of reasoning, range of ideas, and accuracy of words. Maneuvers in cyberspace can mimic that of physical space, but the terrain of cyberspace is incredibly complex, and the speed of movement is typically at the speed of light. Therefore, a successful offensive maneuver is about using the terrain to find places to hide, points of vulnerability, and access pathways. Defensive maneuvers in cyberspace, then, are about speed of intrusion identification, speed of code integrity validation, and range of security scans. For all types of systems, the simple rule is that if one cannot maneuver then one cannot win.

Measure: Ability to Capture Position. If a system is to oppose another system or the environment, then the position in which it engages greatly impacts the probability of success. The position can allow the system to attack the vulnerable areas of the adversary. The position can allow a higher rate and level of attack while hindering the adversary's counterattack. The position might simply be more defensible against adversaries. In land engagements, great historical emphasis has been placed on capturing the high ground. The high ground in traditional warfare allows the force to have greater visibility and greater range of fire. The adversary will typically face challenges in charging up the high ground, but the visibility of the high ground might also make it an attractive target for long-range weapons in modern warfare.

Find and getting into the right positions in conflict or competition is, therefore, ultimately about understanding advantages. So position is about the preferred state of the system in the environment relative to other systems. Systems stuck in disadvantageous positions can potentially change to the value of the position by shifting the nature of engagement. For example, a company selling a less desirable product in the market environment can potentially change the value of its position by rebranding the product instead of changing the product. Or, a military force trapped in a cave might find the cave to be a perfect hiding place if aerial bombardment can be brought down upon enemies surrounding the cave. The lessons-learned is that the advantages of positions can change rapidly in the course of competition or conflict. So, capturing positions is a continuous assessment and endeavor.

Measure: Ability to Concentrate Mass. In any engagement, the stronger side tends to win. In attacking specific points, the intensity of force instead of just pure strength tends to do more damage. Strength and ability to project strength are often connected with the concentration of forces to have the effect of mass. In military combat, concentrating mass means the ability of fighting units to come together and coordinate attacks as a group upon the vulnerable spots of the enemy. Long time ago when the accuracy of firearms was limited, concentrating mass literally meant bringing troops physically together. With today's high precision long-range weapons, concentrating mass is often about coordinating fire at a point. However, the idea of swarming for troop engagements in urban environments, as referenced earlier, is being modelled as a new way of combat. In nature, colony insects such as bees can suddenly swarm and attack to confront large adversaries. On social networks, participants can suddenly swarm around one person or event to overwhelm the situation. Awareness of the swarm can spread virally across the network to gather more participants to feed the intensity.

Self-formed masses raise the question of control. Centrally controlled masses can in some cases more easily maneuver and focus the energy of attack. Mutually coordinated masses might have more adaptability and agility against shifting situations. Finally, there is the idea of an uncontrolled and uncoordinated mass, which is essentially a mob. In a mob, each participant acts based on personal awareness, but the totality of the uncoordinated action can yield significant accumulated damage. Because of a lack of control and coordination, mobs can be hard to disburse unless all members of the mob are attacked. As noted earlier, mobs typically die down as the emotional intensity for creating the mob dies down.

Measure: Having Means of Offense. In systems competition, offense constitutes the set of actions and dynamic changes taken by the system to affect the operations, integrity, and performance results of one or more rival/enemy systems. The system can levy these actions directly upon the other systems in overt or covert attacks or upon the environment, which then translates into negative effects on the other systems. Offense brings together the results of situational awareness, capability to maneuver, and advantages of mass. The position then dictates when and whether offensive actions are likely to succeed.

Offense should start with the strategy that focuses on how to achieve the total end state outcome and extend down to the tactics and tasks. This traceability is specifically a part of US military planning as a formalize process. In general, strategies should be straightforward and may be inherent to the nature of the system. Then, the tactics and tasks can be complex with many interdependent adaptive steps as well as many options depending on the engagement situation. Some systems might have only a limited number of ways to conduct offensive actions, such as a single weapon for combat troops. In cases where the means of attack is obvious, tactics are particularly important in offensive success. A part of successful tactics is generally the element of surprise, which hinders the opponent's reaction time and ability to adapt. Other tactically elements include false information, fake maneuvers, withheld forces, timing of moves, and when to stop.

Measure: Having Means of Defense. In systems competition, defense constitutes the set of actions and dynamic changes taken by the system to protect its own operations, integrity, and performance results from one or more rival/enemy systems. Defense can be brought forward to the launching point of enemy attacks and can be established around each potential target of enemy attack. Defending the whole system can be more effective than defending all the system parts and associations, and layered defenses is often a preferred strategy to mitigate risks. When defending parts, one must often divide one's forces, which reduces the ability to overcome focused attacks.

Successful defense requires understanding the opponent's means of offense as well as an ability to predict opponent's strategies and tactics. Getting surprised by the enemy is a key failure of defense. Therefore, in engaging the opponent, defensive actions still need situational awareness, adequate mass, and the ability to adaptively maneuver. Passive defenses such as walls, traps, and automatic weapons can slow down attackers, but attackers must be actively engaged by counterattacking defenders in order for defense to succeed in system competition or conflict. While offense has the advantage of attack, defense has the advantage of home environment. Some environments, such as the Russian winter, are so harsh that they can be exploited by the defender to gain victory over massive forces such as Napoleon's army. Other environments favor defensive positions in engagements and maneuvers. However, defense alone will typically not yield total victory unless the enemies are willing to unrelentingly commit and lose their forces without retreat.

Measure: Gaining Situational Awareness. Both offense and defense require an understanding of the environment, the system's position and dynamics within the environment, and the opponents' position and dynamics within the environment. Therefore, the system's ability to gain situational awareness is a quality measure. The environment, in many cases, includes the physical domain of competition and the information domain of competition. Situational awareness of the physical domain will be in the form of sensory data, research data, data gathered from adversary sources, and interpreted information. However, the information domain of competition or conflict is about the system's dependence on information and the opponent's ability to attack that information to harm the system. If the system itself is composed completely of information and software that executes information, then attacks that erase data, corrupt data, steal data, disable operations on data, block the transmission of data, and generate false data can potentially destroy the system. Situational awareness information in this environment is both a measure of the system's competitive quality as well as a target of attack. Physical systems such as sensors can be attacked to hinder situational awareness. However, actual situational awareness exists in the information domain, and it is a part of the information system.

The value of situational awareness is based on how it enables the mechanisms of offense and defense. In fact, too much extraneous information about the situation can delay response time and decision cycles. This brings up the strategies for gaining situational awareness. One strategy is to sense as much as possible and filter out the data that give insight on how to attack and defend. Another strategy is to model the environment and opponents to find indicators that support competitive actions. Then, the sensor can focus on the indicators that matter in engagements. Finally, sensing can be based on predicting opponent behaviors and testing opponent reactions with probing actions. For example, if predictive models or observations seem to show that the opponents always turn right after an attack, then luring the opponent into a false turn can validate this understanding. These strategies can all be effective under different circumstances. What is most important in situational awareness is not just the right information but the right timing. If decisions must be made quickly, then the challenge of situational awareness is on how to interpret limited and/or imprecise information to allow for the highest probably of success. All those in the field of military intelligence understand the fog of war and the inherit risks in chaos.

Measure: Ability to Avoid Detection. The ability of a system to avoid detection in the physical and information space blocks the enemy's ability to accurately attack and may enable the system to gain the element of surprise in attacking the enemy. In physical space, avoidance can be by stealth technology, which renders the system undetectable to opponent sensors, or by evasive maneuvers, which places the system out of range or away from the angle of opponent sensors. For example, current stealth technology only makes crafts invisible to enemy radars and not to visual sightings. By the time the enemy can visually see the system, however, it will be too late to prevent long-range attacks. Similarly, many directional sensors, such as radars, have a speed of rotation for scanning 360°. A system that can maneuver within the scan cycle of sensors can launch surprise attacks.

Both in the physical and information domain, using the terrain to hide system activities can be an effective way for avoiding detection. Troops use camouflage in the wilderness. Viruses hide in animal cells. Computer worms mix into software codes. When a system has infiltrated the enemy's environment or even the enemy system itself, a means of avoiding detection is to mimic the behaviors and characteristics of enemy systems. For example, terrorists can hide in plan site and disguise their intent to succeed in attacks. When a system cannot completely avoid detection, hiding its more vulnerable parts can reduce the effects of being attacked. For example, organizational systems that are obviously competing in the market place will still have secret projects, false propaganda, and ways to hide activities within market chaos.

The diversity of means to avoid detection suggests that quality should simply be based on one's signature size relative to an opponent's sensors and the time as well as resources it will take for the opponent to figure out one's position and intent. Naturally being completely invisible during competition or conflict is an awesome capability. However, one only needs to be confusing enough to opponents/enemies in offense and defense to succeed.

Measure: Having an Economy of Motion. A system does not have to be efficient in using its dynamic capabilities to win competitions and conflicts, as long as it can overwhelm the opponent with brute force. This means that the system must have far more energy and perhaps expendable parts than the opponent. Unfortunately, a competing opponent that understands the inefficiencies of a much more powerful system can push that system to waste its strength and resources to gain victory. The competition for efficiency is fairly simple. In offensive and defensive activities, the measure is how much energy, time, space, and resources are needed by one side relative to another side in actions and counteractions.

Energy use as a measure of efficiency is straightforward because all physical and informational systems do not have unlimited sources of energy, and many systems operate under tight energy constraints. Fighter aircraft only have a few hours of fuel. A computer's consumption of electricity depends on level of processes. And humans can only work for so long without rest and nourishment. Therefore, efficiency is about meeting objectives with a pattern of dynamics that optimizes the use of energy. What is less obvious is the idea of time and space as measures of efficiency. Time is integral to system dynamics because all actions can be measured by rate and acceleration. The pattern of dynamics can increase or decrease the time a system takes to execute offensive and defense actions. Opponents might exploit delays caused by inefficiencies to gain competitive advantage.

The idea of space as a measure of efficiency is tied to the ranges of maneuver. Extremely large systems with a great deal of potential force might suffer from the inability to efficiently position themselves in competition. Therefore, there is, in many cases, a trade-off between levels of brute force and the economy of motion for accurately applying force. This trade-off is particularly important if resources other than energy are expended in competition. For example, a conflict between systems could result in the destruction of parts and the disabling of links. No matter how much attrition a system can withstand, there will always be a rate of damage that can kill the system. In the days of total confrontational warfare, military forces triumphed based on who has collapsed first from the loss of men and machines. Victory without mass destruction is perhaps the better way. Therefore, a system's ability to find the most efficient way to overcome the operations of an opponent could be the most valuable measure in competition and conflict.

2.6.3 Quality Category 3: Ability to Improve

The third category of quality measures pertains to a system's ability to change its capabilities, missions, and functionalities. In changing capabilities, these measures connect with the measures for sustainment and competition. In changing the functions of the system so that it can address new missions, these measures connect with the raw potential of the system stemming from its structure, boundaries, and interactions. Thus, these measures are either the summation of deeper understanding and predictive results about the system or a representation of goals and possibilities that the system wants to attain. In the latter case, the challenge is to find reasonable indicators for success without the need to wait for deeper systems understanding to manifest. Such indicators can be discovered through comparative systems analysis, historical trends, and connecting macro-system behaviors with the measures.

Measure: Flexibility in Dynamics. The range a system can adapt and evolve is expressed as flexibility. The system may not need to reach the maximum range of adaptive flexibility during normal operations and even during standard conflicts. However, this range helps us understand whether a system can expand its functions and take on more missions. In some cases, a system might be so flexible that it is wasted or poorly suited for its assigned mission. Then, the system's role in the environment should be reevaluated. In system evolution, flexibility can be used to describe the number and complexity of steps required to evolve from one structural and boundary state to another. Although unstable systems are more prone to change, it is really the range of change and the ability to reach objective states that determine flexibility. A system that can suddenly reorganize itself is simply unstable when the outcomes are chaotic and uncontrollable.

In order to increase flexibility during adaptation, a system could test the ranges of flexibility and try to figure out ways to extend the range. Just like stretching the human body, flexibility in other systems might also increase with hard workouts. In other words, the practice of adapting can increase adaptiveness. Another way to increase flexibility is to identify and modify parts and associations that are hindering flexibility. In extreme cases, a part can be shut down and a link can be broken to sacrifice system capabilities for system change. The most obvious sacrifice is to turn off the parts that are vulnerable to adversary infiltration because the threat is often more important than the contribution of the parts. When an objective state for flexibility is determined, the system can then be pushed to evolve to that state. This evolutionary step might be difficult when the system does not want to change. However, the breaking down of resistance will enable easier evolutionary shifts and contribute to achieving objective flexibility.

Measure: Agility in Dynamics. While flexibility is about the range of change, agility is about the speed of change. In the case of adaptiveness, speed applies to all four phases of the response cycle. Agility in observation is connected with the rate in which situational information is gathered. Agility in orientation is connected with the speed of assessing the situation. Agility in decision is connected with the speed of weighing all the options. Finally, agility in action is the speed in which the plan of action is translated into actual results. In the case of evolution, agility can be measured by the number of steps required to get to an objective system configuration and the time it takes to take each step. This time can be delayed due to system resistance and internal dynamic complexities.

To increase agility, the system can try to increase the flow of information and the speed of processing. However, reducing the required information, simplifying the assessments, and narrowing down the decision trees could have more dramatic effects. If such actions reduce the system's capabilities, then there is a trade-off between agility and capability. For example, is it better to fire more times from more angles in combat than to fire with higher accuracy? If the system cannot win the conflict with one strike, then maybe the agility of attacking with many strikes and the fog of war might yield better results. This type of thinking has entered into the software development process, where the idea of trying to get the perfect solution through initial planning is abandoned and replaced with the strategy of getting something working fast and then proceeding with rapid rounds of iterative development to reach a better solution. Agile software development, at the conceptual level, is, therefore, the argument for rapid system evolution as a better quality measure for improvement than all the measures associated with system design and operations. I will not take sides in this debate but will reemphasis that agility very often has trade-offs that depend on the situation.

Measure: Ability to Resolve Problems. If there is a problem with any of the quality measures discussed, then a system's ability to self-resolve the problem is a measure of the ability to improve. Traditional mechanical systems have limited self-repair capability and must rely upon redundancies and backups to deal with operational problems. In contrast, human organizations and systems with human components have problem-solving potential embedded at every layer of human involvement. Turning potential into capability is then the challenge of delegating authorities for making corrections, establishing accountability for empowered workers, enabling coordination to avoid chaos, and providing training to enable problem solving. The balance between centrally controlled correction and distributed real-time fixes is system and situation dependent. However, the fixes can be temporary to keep the system operational until more corrective actions can be taken, restorative so that the system is working as well as before the problem emerged, and preventive in that the system is changed in a way that similar problems are less likely to occur. For all these objectives, the problem-solving approach can be innovative. And innovation is sometimes driven by the necessity of the problem environment such as limited time to react, insufficient resources for repairs, and failure of standard processes.

The advancement of computer control systems has raised the question of how artificially intelligent can computers be at resolving system problems. If a computer can beat the best human chess player, can a computer cope with the unpredicted problems of system operations? By definition, real problems cannot all be predicted because known patterns of system failures can be handled as a part of the design process or system operation procedures. Computer artificial intelligence capability can handle newly emergent problems but might face challenges if the problem space is not well bounded like that of a chessboard. To rival the human mind in making sense of complex situations, computers need to advance beyond linear logic and into the ability to process the total situational information as a whole to match naturalistic cognition as discussed. Even so, that spark of innovation in humans is difficult to quantify and difficult to replicate.

Measure: Ability to Mitigate Risks. A system's understanding of what might happen in operations and competitions can be based on its ability to predict behaviors, learn from past experiences, and model/simulate outcomes of interactions. Predicting behaviors can yield an understanding of potential negative outcomes that have never occurred in the past. Learning from the past can yield an understanding of past negative outcomes that might reoccur in the future. Finally, the modeling and simulation of scenarios for when the system engages the environment can yield an understanding of ranges in potential futures. This understanding can be more than just the possibility of one bad outcome because the future is fluid. Instead, it can be of the possible paths in actions and consequences starting from the current state. Risk mitigation as a quality measure for improving the system is, therefore, not just about reducing probability of occurrence and level of negative impact. Mitigation can also be about shaping the future.

For most systems, the human element is what enables the mitigation of risks because the complexity of risks benefits from human judgment. The earlier discussions about part and association characteristics, system structure and boundaries, and system interactions help us to establish predictions and find ways to alter predictions. We can extrapolate trends while finding ways to stop the progression of trends and games through scenarios while finding ways to shift outcomes. In predicting the complex outcomes of system dynamics, agent-based models as explained earlier are powerful tools. In modeling human decision-making during the competition of systems, Game Theory from the economic and conflict science communities has yielded actionable results. The theory essentially assumes that each person and system will rationally act to preserve its self-interest. The decisions do not have to be perfect nor correct. However, they have to be rational because that is the basis of measure. The outcomes of back and forth rational engagements can reveal hidden patterns of risks. The potential of using complex system models to identify risks is that small adjustments in system operations might lead to vast improvements in risk reduction. Actions taken early will enable effects to proliferate, whereas responses to imminent risks may have to be far more aggressive. It is easier to stop a threat as it is forming, and it is easier to prevent a failure at the first instance of cracks.

Traditionally, analysts have portrayed risk in a reference of probability of occurrence versus the magnitude of impact with high probability and high impact being the risks that should receive the greatest mitigation focus. In the context of measuring a system's ability to self-mitigate risks, this framework can still be used to determine whether all the greatest risks have been properly discovered and mitigated. The term mitigation is used to discuss risks because risks cannot always be eliminated. Sometimes, the probability of occurrence can be brought down, and other times the level of impact can be reduced. If the ability to accurately model outcomes is not available, the mitigation of risks may have to focus on how to recover from the aftermath of negative events.

Measure: Ability to Capture Opportunities. The ability to identify ways a system can improve its structure, performance, and situation relative to the environment and other systems stems from the same capability as projecting risks. Thus, a system needs to understand the consequences of past behaviors, the possibilities of new outcomes, and the potential results of interactions. However, the capturing of opportunities deviates from risks mitigation in that the system needs to have an awareness of what it can become and what it wants to become. In risks mitigation, the system is still focused on its established mission/purpose and how operations, adaptations, and even evolved states can change to increase likelihood of achieving mission.

For a system to seize opportunities, it must have a vision that is beyond the current mission. There should almost be separation between the current mission and the vision because if the system can expand the mission to meet the vision, then the system is only an evolutionary or adaptive path. A system that is self-aware (senescent) can form this vision based on likes, hopes, dreams, and even fears. Then, an opportunity is what occurs in its operations, in the environment, and with other systems that makes a path from its current state to the vision possible. For example, a local store might want to be a global corporation but has no plan. Then, when it sees its products being spread to other cities by passionate buyers, the opportunity for a global brand suddenly emerges and can be captured if the system has the right qualities. Some systems are very good at scaling capacity but have low ability to seize what has not already been laid in as planned. In contrast, other systems can operate without a vision, see what is possible in the changing of situations, form the vision in moments of inspiration, and capture the opportunity to meet the vision. This quality is a corner stone of innovation, and the potential often cannot be predicted for systems based merely on existing capabilities.

The mystery of innovation is perhaps a good place to leave this section on system quality because I want to again emphasize how hard it is to fully understand nonrigid systems. If the system has human participants or is composed of human components, then the element of creativity and inspiration is always a part what the system might become. All statistical measures of human behaviors have outliers, and the outliers are in many cases the ones who change history. Therefore, systems that amplify human behaviors, such as armies, companies, political groups, and even mobs, can do surprisingly great and horrible things.

2.7 Integration: System of Systems

This last section of the chapter on how systems form is named “integration” for both the integration of the previous sections and the understanding of how systems form through integration. In the previous sections, I have taken a step-by-step approach toward exploring systems by starting from their parts and moving toward the system as a whole. Along the way, I have applied the concepts to examples of real-world system types. However, the question of how systems form still has not been clearly answered. This is because the answer extends back to the very origin of the universe and the origin of life. Even if one looks at a simple man-made mechanical system, there is the question of where the materials come from in nature. Then, if one thinks about the composition of each material, it is clear that each is formed from atoms, which are systems formed from elementary particles. The same can be said of human organizational systems because each human part is a complex system that is composed of complex cellular systems.

So as already suggested, all systems are at a level in the total system of the universe. We can then study a piece of the universe by picking a level of system description and a region of systems. Further, we can look below the level of study and above that level to understand how systems are composed of smaller systems as well as how systems belong to bigger systems. Our pattern of study in the prior

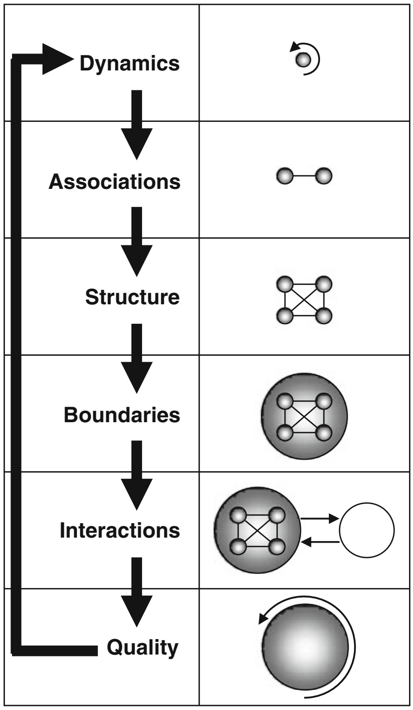

Fig. 2.35 Systems and larger systems

sections can, therefore, be iterated from understanding systems to understanding how those systems are mere parts to other greater systems, as shown in Fig. 2.35. At some point in this process, the details or the scope of study goes beyond our capabilities and perhaps beyond our needs. In fact, most system studies are narrowly focused, and it is only through recent advances in high-speed computational capabilities that researchers can start to model large complex systems.

Four groups of systems within systems can be defined to help us understand the levels we want to focus on in the activities of system formation. These groups are only to help us grasp a universe where systems are constantly being formed and systems are constantly breaking apart. The first group consists of systems formed by nature. The second group consists of systems formed by man. The third group consists of systems formed by nature using man. And the forth group consists of systems formed by man leveraging natural systems.

2.7.1 Natural System of Systems

These systems start with inorganic systems across the cosmos formed by energy and particles in space. The path of system interactions and transformations that has led to the creation of the life sustaining earth environment is still a mystery to scientists. Once the conditions for life exist, however, the second level of systems is the organisms in the environment ranging from virus DNA strands and single-celled prokaryotic life forms to complex eukaryotic multiple-celled organisms and, ultimately, the human system. I am not going to engage in the evolution debate. However, what is obvious is that the earth is teaming with life and that the great variety of life works together to form a biological ecosystem.

Living systems depend on one another for food, hosting, air content, internal biological processes, migration, and other functions. The human body, in particular, depends on bacteria to support digestion, plants for clean air, a great variety of plants and animals as food sources, and domesticated animals for work and transport in early civilizations. To be specific, many human societies would have turned out quite differently without the power of the ox and the capabilities of the horse. The next level of living systems working together is colonies of organisms such as bacteria, insects, and even mammals that form complex social systems. I have discussed some of these colonies earlier, but group behavior among animals can be more diverse and more complex than I have portrayed. When we see flocks of birds in the sky, packs of wolves in the forest, swarms of bees around a nest, and schools of dolphins in the sea, we can now think about how to model their system dynamics during normal operations and when they are threatened.

2.7.2 Man-Made System of Systems

These systems start with the basic mechanical machines that operate based on human, gravitational, electrical, chemical, and nuclear forms of energy and extend to electronic devices that control current telecommunications, computing, and sensing. Together, they form the infrastructure of society with systems all linked together by roadways, fiber optic networks, transmission towers, pipes, tracks, high-voltage cables, and transportation vehicles. Human society came about through centuries of learning, inventiveness, and dedication. Some parts of the infrastructure date back for decades and even centuries while others parts are constantly advancing. For example, some roads in the ancient city of Rome have been in use for the past two thousand years. In contrast, engineers are continuously trying to increase the communications capacity/bandwidth of wireless networks. When we take apart a computer device today, we literally see another world of designed systems within. This complex world is centered on the microprocessor, and if we peel open the microprocessor, we will see countless microscopic pathways and controls.

On top of the societal infrastructure sits systems of information. The earliest system of information is actually currency and currency-driven economic organizations. Currency is an information system because it tracks gained wealth, transfers wealth, and allows wealth to be reused for gains in the society. In the days before computing, paper currency and coinage enabled this information flow by physical transfer between hands and by communications between banks. Computer-based accounting and monetary exchanges then revolutionized system dynamics and now support the modern global economy. Other information systems include education and research, markets and sales, and coordination of social services.

2.7.3 Natural System of Systems with Man

These systems start with social groups formed by people from the earliest tribal societies to the modern social networks on the Internet. Although the Internet has allowed people to break past the barriers of distance and divided communities, the interactions between people have remained largely the same for thousands of years. At the end of the day, people connect to seek friendship, find love, rally against common enemies or concerns, discover common causes, and exploit others. If there is a common cause, which could be as simple as surviving as a group, then the system can become more structured with leadership, roles and responsibilities, and rules and procedures.

While people may see that the way in which we can organize ourselves is based on human rationality and ingenuity, we often forget that our minds are natural products. Therefore, we cannot say that we fully understand human systems because we still do not completely understand the mysteries of the mind (thoughts, dreams, and emotions) and the functions of the brain that sustain the mind.

The system of systems that is perhaps the most challenging to understand are those human networks that have spread across vast regions with millions of participants. Millions of people cannot all know one another nor can a system structure assign individual responsibilities to millions of people. Though the purposes of people interacting may still be simple, there could be layers and layers of self-formed groups and subgroups. One person can belong to a variety of groups that have system behaviors, and thousands of systems can be forming and reorganizing within the overall system of the network. As one might start to wonder whether such vast networks are really whole systems, massive adaptive group behaviors across the world can emerge to surprise researchers.

2.7.4 Man-Made System of Systems Leveraging Nature

Finally, there are systems created by man through the manipulation of natural systems. This manipulation refers to more than just man using materials from nature in simple and sophisticated ways. The first type of natural systems that man can manipulate is the inorganic systems of nature. For example, the atom is a natural system that enables the formation of molecules and materials. Man has long learned how to create chemical reactions that alter the arrangement of molecules, and man has recently learned how to trigger certain types of atomic reactions. However, these are still blunt-force approaches to merely harnessing energy from molecular and atomic level bonds/links. As we start to learn how to control molecular structures to form nano-systems, and, as we start to figure out how to conduct controlled atomic alterations, science will have progressed to truly leveraging nature systems.

Ironically, our ability to leverage organic systems is perhaps more advanced because of the size and coded structure of the DNA molecules. As DNA is the blueprint for all known life, scientists have discovered how to map DNA and how to alter DNA to change the behavior of cells and the production of proteins. Having a map and knowing how to change the map to alter system dynamics is not the same. Thus, much advancement is still required for scientists to fully manipulate organic systems. For example, we can now genetically engineer bacteria to yield useful byproducts, and we can genetically engineer plants to be more disease resistant and have higher yields. Yet the genetic manipulation of complex animal systems is fraught with dangers as well as ethical issues. First, we do not fully understand the cellular reference frame in which DNA codes are applied. Then, the functionalities of many gene sequences are still unknown to us, even though the codes of all the DNA strands have been mapped. If we change a known gene sequence, there could be hidden consequences and proliferated effects as proteins interact with other proteins. To truly design new organic systems, all the ways that DNA sequences can be expressed to enable cellular and intercellular functions must be unraveled. The most challenging organic system or component to design is perhaps the brain. If man can start to design thinking systems, then what are the limits of systems evolution? Will the organic creations of man start to enhance themselves and reason about their existence? Such possibilities are within the scope of systems exploration.

As I close this chapter on how systems form, our exploration of systems and systems formation will continue through the specific study of system failures. The dynamics of how a system will break down can give more insight on how the system was built. For the process of breaking can be treated as a decomposition or destructive test of a system. Sometimes natural systems are so complex or so resistant against probes that their mysteries will not reveal themselves until breakdown starts to occur. Other times, the flaws in man-made systems might not be discovered until the systems are tested to the point of failure. What I have presented so far is only a foundation for systems thinking and systems analysis. Our journey of discovery continues.

References

1. Ren C (2000) Additional factors governing specialized cell dynamics based on deductive systems analysis. Theor Biosci 119(2):95–103
2. Rokach L, Maimon O (2008) Data mining with decision trees: theory and applications. World Scientific Publishing Co Inc., Singapore
3. Alpaydin E (2010) Introduction to machine learning. MIT Press, Cambridge

4. Chen Z (2001) Data mining and uncertain reasoning. Wiley, New York
5. Draper NR, Smith H (1998) Applied regression analysis, 3rd edn. Wiley, New York
6. Piatetsky-Shapiro G (1991) Discovery, analysis, and presentation of strong rules. Knowledge discovery in databases. MIT Press, Cambridge
7. Bailey K (1994) Numerical taxonomy and cluster analysis. Typologies and taxonomies. Sage Publication, Thousand Oaks, p 34
8. Kantardzic M (2003) Data mining: concepts, models, methods, and algorithms. Wiley, New York
9. Knorr EM, Ng RT, Tucakov V (2000) Distance-based outliers: algorithms and applications. VLDB J Int J Very Large Data Bases 8(3–4):237
10. Bojadziez G, Bojadziez F (1997) Fuzzy logic for business, finance, and management. World Scientific Pub Co Inc., Singapore
11. Castillo E et al (1997) Learning Bayesian networks. Expert systems and probabilistic network models, pp 481–528
12. Pawlak Z (1982) Rough sets. Int J Parallel Prog 11(5):341–356
13. Banzhaf W et al (1998) Genetic programming—an introduction. Morgan Kaufmann, San Francisco
14. Bishop CM (1995) Neural networks for pattern recognition. Oxford University Press, Oxford
15. Gilbert N (2008) Agent-based models. SAGE Publications, Thousand Oaks
16. Wickens CD, Hollands JG (2000) Engineering psychology and human performance, 3rd edn. Prentice-Hall, Upper Saddle River
17. Saaty TL (2001) Fundamentals of decision making and priority theory. RWS Publications, Pittsburgh
18. Thaler DE (1993) Strategies to tasks: a framework for linking means and ends. RAND Corp, Santa Monica
19. Storkerson P (2010) Naturalistic cognition: a research paradigm for human-centered design. J Res Pract 6(2):12
20. Van Wylen GJ, Sonntag RE (1985) Fundamentals of classical thermodynamics, 3rd edn. Wiley, New York
21. Bunge M (1963) A general black box theory. Philos Sci 30(4):346–358
22. Stephen I (2003) The forgotten genius: the biography of Robert Hooke 1635–1703. MacAdam, San Francisco
23. Holtzapfel W (2014) The human organs: their functional and psychological significance: liver, lung, kidney, heart (3rd revised ed.). Floris Books, Edinburgh
24. Breay C (2010) Magna Carta: manuscripts and myths. The British Library, London
25. Clark DK (1954) Casualties as a measure of the loss of combat effectiveness of an infantry battalion. Technical Memorandum, Johns Hopkins University, Operations Research Office
26. Riché P (1978) Education and culture in the Barbarian West: from the sixth through the eighth century. University of South Carolina Press, Columbia
27. Easton TA (2008) The 3D trainwreck: how 3D printing will shake up manufacturing. Analog 128(11):50–63
28. Lécuyer C, Brock DC (2010) Makers of the microchip: a documentary history of Fairchild Semiconductor. The MIT Press, Cambridge
29. Drexler E (2013) Radical abundance: how a revolution in nanotechnology will change civilization. PublicAffairs, New York
30. Paprotny I, Bergbreiter S (eds) (2014) Small-scale robotics from nano-to-millimeter-sized robotic systems and applications: first international workshop. Springer, Karlsruhe, Germany June 16
31. Edwards SJA (2000) Swarming on the battlefield: past, present, and future. RAND Monograph MR-1100. RAND Corporation, Santa Monica, CA
32. Maslin M (2014) Climate change: a very short introduction, 3rd edn. Oxford University Press, Oxford

33. Miller MB, Bassler BL (2001) Quorum sensing in bacteria. Annu Rev Microbiol 55:165–199
34. Nelson DL, Cox MM (2005) Lehninger's principles of biochemistry, 4th edn. W.H. Freeman and Company, New York
35. Pohlman MB (2008) Oracle identity management: governance, risk and compliance architecture. Auerbach Publications, Boca Raton
36. Smith GL et al (2013) Vaccinia virus immune evasion: mechanisms, virulence and immunogenicity. J Gen Virol 94:2367–2392
37. Saini R, Saini S, Sharma S (2010) Nanotechnology: the future medicine. J Cutan Aesthetic Surg 3(1):32–33
38. Gilpin R (1981) War and change in world politics. Cambridge University Press, Cambridge
39. Mearsheimer JJ (1995) A realist reply. Int Secur 20:82–93
40. Waltz KN (1990) Theory of international politics. McGraw-Hill Companies, New York
41. Baldwin DA (ed) (1993) Neorealism and neoliberalism: the contemporary debate. Columbia University Press, New York
42. Whelman A (1994) Wilsonian self-determination and the Versailles settlement. Int Comp Law Q 43(1) June
43. Ratzel F (1897) Studies in political areas II: intellectual, political, and economic effects of large areas. Am J Sociol 3(4):449–463
44. Wendt A (1992) Anarchy is what states make of it. Int Org 46(2):391–425
45. Russet B (1993) Grasping the democratic peace: principles for a post Cold-War world. Princeton University Press, Princeton
46. Bull H (1977) The anarchy society: a study of order in world politics, 2nd edn. Columbia University Press, New York
47. Mackinder HJ (1904) The geographical pivot of history. Geogr J 23:421–437
48. Spykman NJ (1938) Geography and foreign policy I. Am Polit Sci Rev 32(1) February
49. Wallerstein IM (2001) The end of the world as we know it: social science for the 21st century. University of Minnesota Press, Minneapolis
50. Rostow WW (1959) The stages of economic growth. Econ Hist Rev 12(1):1–16
51. Larrain J (1989) Theories of development: capitalism, colonialism, and dependency. Polity Press, Cambridge
52. Smith A (1991) [1776] The wealth of nations. Prometheus Books, Amherst
53. Malthus TR (1990) [1798] Essay on the principle of population. Cambridge University Press, Cambridge
54. Ricardo D (1996) [1817] Principles of political economy and taxation. Prometheus Books—Great Minds Series, Amherst
55. Marshall A (1949) [1890] Principles of economics, 8th edn. Porcupine Press, London
56. Rosentein-Rodan P (1943) Problems of industrialization of eastern and Southern Europe. Econ J 53:202–211
57. Von Hayek F (1945) The use of knowledge in society. Am Econ Rev 35:519–530
58. Schumpeter JA (1984) [1942] Capitalism, socialism, and democracy. HarperCollins (Harper Torchbooks), New York
59. Reijinders J (ed) (1998) Economics and evolution. Edward Elgar Publishing, Cheltenham
60. Keynes JM (1989) [1936] The general theory of employment, interest, and money. Harcourt Brace Publishing, Stamford
61. Friedman M, Schwartz A (1963) A monetary history of the United States 1867–1960. Princeton University Press, Princeton
62. Marx K (1992) [1867] Capital: a critique of political economy vol 1. The Penguin Group, New York
63. Khimm S (2011) Who are the 1 percent? The Washington Post, Oct 06
64. Bar-yam Y (2003) Dynamics of complex systems. Westview Press, New York
65. Coram R (2004) Boyd: the fighter pilot who changed the art of war. Back Bay Books, New York

66. Hastings A (1996) Population biology: concepts and models. Springer, New York
67. Woods D (2006) Essential characteristics of resilience. Engineering: concepts and precepts. Ashgate, Aldershot
68. Sun Tzu (reprint 2010) The art of war. Tribeca Books, New York
69. Von Clausewitz C (reprint 1984) On war. In: Howard M, Paret P (eds) Princeton University Press, Princeton

http://www.springer.com/978-3-319-44029-3

How Systems Form and How Systems Break
A Beginner's Guide for Studying the World
Ren, C.H.
2017, XII, 179 p. 47 illus., 1 illus. in color., Hardcover
ISBN: 978-3-319-44029-3