Requisite Variety in Mechanical, Biological, and Social Systems
An Introduction

The concept of “requisite variety” (RV) is a cornerstone of the contributions of cybernetics to the rigorous study of systems. To understand RV is to be able to characterize the “variety” of a system — its capabilities and capacities to achieve its goals — and therefore also its limitations. This short paper serves to introduce RV as precursor to applying the concept to design of products, services, and teams.

This paper builds on the standard model of first-order cybernetic systems by adding the concept of variety to their components.

1. Goals

As observers, we say that certain systems are organized to act effectively in their environment in order to achieve a goal.

We say that a physical system, such as a heater with a thermostat, has the goal of maintaining the temperature in a room. On observing a biological system, such as an animal, we may say that it has survival as its ultimate goal. And a corporation, one type of social system, has the acknowledged goal of making enough money to survive, no less to thrive.

In order to achieve a goal, a system must be able to sense its environment, compare what it senses (current state) to a model of its goal (desired state), and to act in a manner that moves closer to the goal. An observer may restate this process as the environment causing a change in the system’s model of the current state, which causes a comparison to desired state, which may cause a change in action… which, in turn, may cause a change in the environment. The process does not end with a single excursion around this loop; it is necessary to continue (to recursively transit the loop) in order to check the result as well as maintain vigilance when conditions change.

As a shorthand, we refer to systems that are so organized —that are “circular causal” systems — as “cybernetic systems”.

In general terms, a system experiences disturbances from its environment that move it away from its goal. The system must be able to respond so that it can achieve its goal *despite* the disturbance. **The goal of this short paper is to discuss an approach for considering the *limitations* of a system in relation to achieving its goal.**

2. Essential Variables

***Essential variables* are those parameters of a system's operation that must be kept within strict limits for the system to achieve its goal.** The alternative is a system that is ineffective at achieving its goal, or even dying or being destroyed.

In the case of a thermostat, the essential variable is the temperature of the room; if kept close to the set-point of, say, 70º F, we say the system has maintained its essential variable. In the case of an animal, there are many essential variables: oxygen in the blood, body temperature (at least for warm-blooded animals), and many other chemical levels. The general term for this regulation in the body is *homeostasis*.

If one or more essential variables go beyond certain limits for a certain length of time, the thermostat has broken or the animal has died. Social systems also have essential variables, which is discussed below.

3. Variety

The capabilities and capacities of a system to overcome disturbances and to achieve its goal must be measurable, if design is to be explicit. Of course, it is always possible to try more-or-less random changes until something works. This wastes resources by “just trying things” instead of converging efficiently and purposefully. In addition, such random attempts increase the risk of system failure between now and (possibly never-attained) success.

One way to measure a system’s capabilities is in terms of the *number* of different possible responses that the system can have to what it senses in the environment. In the case of a simple thermostat, the system has 2 possible responses: turning the heater on or turning it off. (It is amusing to note that “turn” is a figure of speech that derives from on/off switches rotated by the fingers, but it is an equally apt metaphor for steering a cybernetic system with a rudder.) In the case of an animal being chased by a predator, there are many choices of action but the cybernetics remains the same: the number of different responses that the system could take is a measure of the overall capacity of the system to overcome disturbances. Put another way, the smarter and more powerful the animal, the more options it can think of and also execute physically, giving it a better chance to survive. Later we will see how this applies to social systems.

Using a number to reflect the range of capabilities of a system is particularly mechanistic and quantitative, but valuable as a starting point. (See Chapter 11 of *Introduction to Cybernetics*, W. Ross Ashby,1956, available for download at http://pespmc1.vub.ac.be/ASHBBOOK.html, for a rigorous application of this means of measuring systemic capacity.)

We call the range of possible responses embodied in a system its *variety*. In the course of software or service design, a simple numeric measure of the total number of responses may seem too simplistic. But there is great value in thinking about—and explicitly designing for—the variety of the systems we create and then evolve. Just as the scope of cybernetics extends from mechanical to biological to social systems, so does the concept of variety.

Next we expose the benefits of explicitly incorporating awareness of variety in the design process, first by declaring a general rule and then by looking at examples.

4. Requisite Variety (RV)

If a system possesses enough variety to achieve its goal, we say the system has *requisite variety* (RV), that is, it has the variety required to succeed in achieving its goal.

For a system to have requisite variety, the system must possess *at least as much variety* as the environment that is the source of the disturbances. This is called Ashby's Law of Requisite Variety, after W. Ross Ashby, a psychiatrist and cybernetician who established it.

RV is always a relationship between a system and a proposed environment. While the system's variety changes only when the system is changed, RV is judged to be present or not depending on a comparison between a measure of system variety and a measure of the variety of an expected environment.

It is incorrect to refer to “adding to a system’s requisite variety” or “giving the system more requisite variety”. Either the system has RV or doesn’t; it is a binary relationship between system and environment, not a quantity.

5. Effective design

“Effective design” is defined as a process whose result is a build-able system that achieves the goals ascribed to it by its designers, in the context of their expectations of the context of use. Context of use always includes the situations in which the system will be placed, the conditions that the system may meet. While a complete discussion of effective design would include considerations (or even constraints) of money, time, risk, and reliability, for our purposes here we consider only what is needed to discuss RV.

6. RV in Mechanical Systems

Effective design of a mechanical systems in the context of RV requires defining expectations for the disturbances that may come from the environment. To counter these disturbances, capacity for the system to respond must be built into physical components comprising the system.

Just as a system’s ability to sense, compare, and act in the course of interaction defines its capacities and capabilities, so does it define its limitations. One way to look deeper into the sensing and acting phases is by focusing on:

- **resolution:** to what level of granularity can the system detect or *sense* feedback? To what level of granularity can a system respond or *act* in order to get closer to its goal? In the case of the thermostat, this would be the sensitivity of reading current temperature, say within 1° F, and to controlling the heater, which may be no more than simple on or off.

- **latency:** how long does it take for the sensor to get a new reading and how long does it take for the actuator to change? For a thermostat again, this may reasonably be once per minute for each sensor and actuator, because the rate at which the temperature in a room changes is slow. (As always, there is a relationship between the environment that the system is attempting to regulate and requirements of variety for the system to do so effectively.)

- **range:** for what span of a given variable can the system sense and act? A temperature sensor that operates between 0ºF and 120ºF would be more than sufficient; a heater that can keep a space at 75ºF when outside temperature is between 30ºF and 80ºF would seem sufficient for San Francisco but not for Boston

Of course, a system's capacity also depends on the system's ability to perform the comparator function. Here again, we can expose limitations as well as opportunities for improvement:

- **correction:** what are the limits of the system's ability to *compare* a current state to a desired state, to "detect error" and to create a vector—direction and scale—of corrective action to be taken?

To repeat, all these aspects combine to define—and delimit—the variety of a system. They suggest a means to measuring the system's limitations as a first step to re-designing the system in order to eliminate those limitations.

If a physical system fails—if it does not achieve its goal—it lacks RV. Variety can be increased by adding range or resolution or shortening latencies or improving the comparator function. Such increases may bring the system closer to achieving RV. This is a re-design and re-implementation of the system, an evolutionary action performed by a designer (a.k.a. an external observer of the system-and-environment loop). The designer incorporates her own loop of sensing, comparing, and acting—external to the sensing, comparing, and acting of the system under scrutiny—and makes adjustments to the system in order to increase its variety and, hopefully, to achieve RV.

7. RV of biological systems

Effective design of a biological system is description applied by an observer to the generation-upon-generation of reproduction in which a species' genes are re-mixed to create alternative "designs". **Each individual organism in each generation has a given variety, which may or may not be sufficient for the individual to survive and reproduce in the environment it experiences.**

Survival depends on the encounter between the organism's variety and the variety of the disturbances that come from its environment.

In the course of the organism's lifespan, limitations may arise in sensing, comparing, and acting in its environment. These may be modeled more easily as a continuum of possibilities rather than a discrete number of responsive actions; however, the concept of *variety* still rigorously applies.

In contrast to physical systems, even if an individual organism fails (dies) because of insufficient variety, other **individuals of the species may succeed because they possess RV—sufficient variety—as a result of a different mix of genes resulting from a different evolutionary path**, due to the partially-random mixing of genes during reproduction. The individuals who die are "selected out" by disturbances from the environment because they lack RV. This in turn "makes room" for others who do.

8. RV of social systems

A human social system comprises cooperation and collaboration in the form of teams, organizations, or governments that are actualized (instrumented, embodied) in conversation. (See Dubberly, Edmond, Geoghegan, Pangaro 2002, *Notes on the Role of Leadership and Language in Regenerating Organizations*, available at http://www.dubberly.com/articles/notes-on-the-role-of-leadership-and-language.html.)

Effective design of social systems begs the question, “what are a social system’s essential variables?” Put another way, what are the critical parameters that assure the system's survival and the achievement of its goals?

"In social organizations, ‘essential variables’ are the ‘shared truths’ of an organization—perturbed by the environment, regulated by [human] actions, and carried in its language." (See Geoghegan and Pangaro, *Design for a Self-regenerating Organization,* 2004, available at http://pangaro.com/ashby/.)

This says that **the survival of an organization—maintenance of its essential variables—relies on what the members of an organization believe.** This is because the sensing, comparing, and acting performed by a social system takes place in the context of the belief structures of the people who comprise the organization:

- sensing: it is through the filter and mechanism of beliefs that some inputs are perceived (selected), understood, and heeded, while others are not.

- comparing: beliefs give structure to the conversations that determine how the inputs are processed and compared to goals (which are also formulated as beliefs). Again and in turn, proposed actions are considered appropriate and acceptable within the belief systems of those developing plans of what to do.

- acting: here the decisions taken above are carried out, often in the form of communication and agreements, whether verbal or written, that are couched in language and therefore bound by underlying beliefs.

When essential variables are grounded in beliefs, it also means that **the *limitation* of the system (a.k.a. its ability to respond to disturbances, its variety) is constrained (defined, delimited) by those beliefs.** Furthermore, because shared truths are agreements, and agreements arise in conversation, it is the *capacity to have conversations* that is the fundamental limitation to an organization's ability to respond, to survive, to achieve its goals, and even thrive and evolve.

If a social system fails to meet its goals, but continues to survive—that is, if it is not destroyed but has sufficient structure to continue to operate for a time—**it may be able, *by design of conversations*, to expand a system's variety to match the disturbance and achieve survival and success.**

The design of conversations comes down to two major elements:

1. The variety in a conversation is delimited by the variety of the participants in the conversation. (The circumstances in which these conversations take place—the mechanics of transferring the messages, whether the acoustics of a meeting room or the reliability of an email transport—also may matter, but here the focus is on limits of the conversation not the channel that carries it.) It is not a matter of the size of the team, because adding participants who have the same variety—the same experience, or come from the same discipline, or look at the world in the same way—does not increase the variety of the conversation. Therefore, in a second-order analysis, **deciding on *whom to include in the conversation*,**

based on an assessment of required variety, is key. But, on what basis may required variety be assessed? Who needs to be in the conversation?

2. The situation itself helps guide the selection of the participants to be in the conversation, in order to achieve required variety. At worst, the current participants are able to sustain the current conversation, even if they cannot move it ahead. But clearly this is not sufficient for success. Careful assessment and selection among all possible triggers, leading to a specific focus—an internal failing, an external trend, a new way of framing the situation—may suggest the types of expertise (a.k.a. types of variety) required to move ahead in the conversation, and hence define the requirement for new participants. It is impossible to know the range of variety of participants in advance; to know in advance is to suggest that the problem is already formulated, the direction set, and the solution ready to emerge. But in complex situations, we don't know where the solution will lie. Therefore, **to maintain RV in changing situations, social systems must constantly assess their variety via an evolving determination of who needs to be in the next conversation.**

Summary of Terminology

Cybernetic Systems: Circular-causal systems, that is, systems that recursively sense, compare, and act with their environment, in order to move from an undesirable state to a desired state.

Goals: The desired state of a system; the achievement of specific conditions in the system's environment.

Essential Variables: Parameters that must be maintained within a certain range in order for the system to persist; conditions of success for the system.

Variety: The abilities available to a system to move toward its goal(s); the capabilities and capacities (scope and depth) of possible internal states of a system that may be brought to bear in the pursuit of goals.

Requisite Variety: A system possesses requisite variety if it is able to achieve its goals *within a stated set of assumptions about its goals and its environment.*

Ashby's Law of Requisite Variety: A system must possess at least as much variety as the environment that is the source of disturbances that move the system away from its goals.

Effective Design: Design processes that take measures of variety into account and strive to define systems in terms of requisite variety, that is, the effectiveness of their responses to an expected range of situations (disturbances).

Sense: To take a measure of the state of the environment; to characterize conditions in the environment that relate to a system's goal.

Compare: To identify important differences between initial state and desired state of a system as a precursor to action.

Act: To move toward a desired state according to one or more available options.

Capability: A class of response or specific ability of a system to respond to disturbances in a certain way, in order to move toward a goal; for example, to make a cold room warmer by adding heat.

Capacity: The extent or depth of response a system has to move toward a goal; for example, the amount of heat (BTUs) that a heater can output per second.

Disturbance: Anything at all that an environment presents to a system's sensors; this need not be something unusual, for example, the tendency of a room to get colder in the wintertime is a disturbance to the system, which needs to measure any fluctuations in temperature in order to achieve it's goal of keeping the room warm (say, at 70F).

Resolution: Parameter of a sensor or actuator that characterizes its fineness of measure or control; for example, a thermometer may be able to measure a change of 1 degree F, and a heater may be able to vary it's output between 0 and maximum in 3 intervals (off, low, medium, and high, with corresponding measures of heat output in BTUs).

Latency: Parameter of a sensor or actuator that characterizes the speed at which it responds or acts; for example, a thermometer may be able to take 1 reading every second, and a heater may be able to switch output every second.

Range: Parameter of a sensor or actuator that characterizes its operational scope; for example, a thermometer may be able to measure only temperatures between +5F and 100F; and a heater may be able to produce heat only between 0 and 5000 BTUs).

Limitation: Constraint or shortcomings of an element of, or system as a whole; the boundary of a system's effectiveness.

Correction: Action taken by a system in an effort to regulate its environment, at least in terms of the variables it is sensing; for example, a heating system makes an effort to correct the temperature of a cold room, in order to achieve the system's goal of 70F.

Conversation: Interaction by which an adaptable system can define and evolve goals as well as the means to achieve them; that is, the requisite mechanism for collaboration (definition of goals and means) and coordination (actions to achieve goals by agreed means).

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