

## 9 – Requisite Variety

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### Ashby's Law of Requisite Variety

In discussions about the quality of *control* (or consistent with the themes in this blog the quality of muddling), Ashby's *Law of Requisite Variety* is often raised. Basically, this Law states that

*for full control, the variety of the controller must be at least equal to the variety of the process or situation being controlled.*

In this context, the opposite of *variety* is constraint. So, an alternative statement of Ashby's Law is that:

*for full control the controller must not be more constrained than the process or situation being controlled.*

A synonym of variety that is typically used in the motor control literature is *degrees of freedom*. Thus, a third statement of Ashby's Law is that:

*for full control, the degrees of freedom of the controller must be at least as large as the degrees of freedom of the process or situation being controlled.*

The gist of Ashby's Law is that if the controller is more constrained than the process being controlled (i.e., has less variety or fewer degrees of freedom), then there will be states of the process that cannot be reached by the controller. In other words, the controller will not be free to access all process states.

Note that failing to satisfy Ashby's Law does not mean that the controller can't achieve satisfaction with respect to controlling the process (e.g., achieve certain goals or avoid catastrophe). It simply means that there are limits to where the controller can take the process. In other words, there are some states of the process that cannot be reached due to constraints in the controller. So, if the controller is more constrained than the process being controlled, then it cannot do anything or everything – there are limits to what states can be achieved and or limits to what process changes can be countered (or maybe even observed).

Typical reasons that a controller might not satisfy Ashby's Law might reflect constraints on perception (observability) or constraints on action (controllability). The control system might not be able to discriminate certain process states from other process states. Or the control system's motor coordination may be too gross to

perform the precise moves required to achieve certain state transitions.

## Scaling up Variety to meet the challenge of Complex Problems

The natural world is *complex* or *messy* and many of the problems that humans or sociotechnical systems must solve in order to survive are *ill-structured* or *wicked*. Relative to Ashby's Law, the implication is that the variety associated with these problems can be extremely high.

So, it is quite fortunate that humans are also complex (e.g., the brain has a high degree of freedom), that humans are diverse, and also that we have the ability to use complex technologies. Thus, the variety of an organization of diverse humans and technologies (i.e., a sociotechnical system) can also be extremely high. Although the demands of many complex problems may exceed even the large capacity of the human brain, it will generally be possible for organizations of diverse humans and technologies working together to meet the challenge of Ashby's Law with respect to complex problems. And in many cases the variety of the sociotechnical system may exceed the variety of many complex problems.

On the positive side, exceeding the demands of requisite variety opens up the possibility of full control and also the possibility of redundancy and flexibility offering multiple solutions to control problems. On the negative side, the excess variety within the sociotechnical system may also be a source of 'noise.' That is, the variety within the sociotechnical system may reflect conflicts (e.g., differing values) that make it difficult to coordinate actions to achieve skilled control of the situations. An organization with many degrees of freedom is difficult to manage – like herding cats. Thus, the excess degrees of freedom within the organization (e.g., differing opinions) can add variety, increasing the computational demands on the control system.

While satisfying or exceeding Ashby's Law means that complete control is possible, it does not guarantee that complete or even satisfying control will be achieved. The variety of the controller (or the degrees of freedom or constraints) must be structured to reflect the variety of the process being controlled. In other words, the constraints or structure of the controller must be organized in such a way that it can meet the demands associated with the process. Another way of saying this is that the controller must have a valid *internal model* of the process. This does not necessarily mean a conscious mental model, but it means that the degrees of freedom in the controller must be tuned appropriately to the demands of the process being controlled.

## Degrees of Freedom Problem

In motor control, the tuning of degrees of freedom in the human body to the demands of physical control problems (e.g., playing winning golf) is typically referred to as the *degree of freedom problem*. While playing winning golf is a high variety problem, each of the different shots required for winning golf are fairly low dimensional problems. But different shots are associated with different types of demand. The requirements for driving a golf ball long distances and staying in the fairway are different than the requirements for chipping a golf ball to a nearer smaller target, which are different than the requirements for putting a ball into a hole.

While the human motor system has adequate degrees of freedom to satisfy the demands of each different shot, it is necessary to use different degrees of freedom (or different constraints) for each type of shot. To be successful at the highest levels, a golfer needs to be able to organize the degrees of freedom of the motor system into different *smart mechanisms*. Each mechanism reflecting the requisite variety of different situations (e.g., driving, chipping, or putting). In creating these smart mechanisms, different degrees of freedom are 'locked out' (constrained) to reduce the complexity of the control problem.

Thus, for the golfer a key to skilled performance is to lock out unnecessary degrees of freedom (potential sources of noise), leaving a few degrees of freedom that are well matched to the demands of a particular type of shot.

In an analogous fashion, in designing sociotechnical systems focus needs to be on identifying the situational demands of various work functions and creating constraints (e.g., locking out degrees of freedom) to create smart mechanisms for addressing the demands of those functions. This involves setting lines of authority and communication and designing appropriate procedures and representations so that the the organization is well tuned to the problem constraints (or requisite variety). In work domains where the demands are changing – it also becomes necessary to support organizational learning, so that the organization is capable of self-tuning the degrees of freedom to adapt to the changing problem constraints.

## Identifying and Designing Constraints

For cognitive systems engineering – an important implication of Ashby’s Law is that the focus of work analysis is on identifying the problem *constraints*. Understanding the problem constraints is a first step toward designing organizations that can achieve satisfying control of complex situations. From the perspective of design – satisfying Ashby’s Law is achieved by matching constraints or degrees of freedom. Rasmussen’s Abstraction Hierarchy (AH) is one way that cognitive systems engineers try to visualize the constraints in a work domain. Each level of the AH is associated with different classes of constraint (e.g., values, physical laws, regulations, organization, physical function, and physical form).

Diversity within an organization is critical to meeting the requisite variety demands of complex work domains. However, this diversity can also be a source of noise that can make skilled control difficult. Design thinking involves introducing the appropriate constraints to channel this diversity along productive paths reflecting the requisite variety of the problems to be solved (e.g, the shots to be made).

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