Chapter 5: Strengths and Weaknesses

You have just received a new board game. It is called, “The Mind Game.” The instructions state that the objective of the game is quite simple. You must solve problems to allow you to get things and to do things that bring pleasure, while avoiding pain and discomfort. Reading further you see that all work is done within a workspace that can hold seven items, although sometimes you can squeezes in one or two more and other times the workspace will only hold five or six items. It depends on the complexity of the items and other factors that might enhance or detract from your performance. Items come into the workspace one at a time and if you do not take steps to maintain them, they exit the workspace, generally without you knowing it. Most of the time you can only do one operation at a time, although there are some occasions in which you may be able to simultaneously do a couple of operations. In solving problems, you will use items stored within a warehouse. The warehouse has an infinite capacity for storing items, although when items come out of the warehouse, they are often not quite the same as when they went into the warehouse. Furthermore, your ability to find a specific item in the warehouse will vary. Sometimes it is easy. Sometimes it is hard. And at other times, if you wait a little while, an item you are currently unable to find can be easily found.

The Mind Game reflects the daily challenges faced by all of us as we make our way through life. There are some things that brains do remarkably well, yet there are other ways in which brains are quite limited. The limitations of the brain are well illustrated by a study in which subjects were placed in a room with lights embedded in the floor and they were asked to find which of twenty lights was the target for that trial (Longstaffe, Hood & Gilchrist, 2012). Subjects were given no clues as to which light was the target and could move freely around the room selecting lights. In this case, the problem was to find which of the twenty lights was the target, however after making an incorrect guess, subjects had to remember that selection so that they did not choose the same light again. Consequently, performance depended on their ability to remember which lights had and had not been selected. However, there were two other factors introduced that affected their performance. First, some of the lights flashed on and off, making them more salient. The subjects were attracted to the flashing lights and tended to choose them, even though the likelihood of a light being the target was the same for flashing and non-flashing lights. Furthermore, on some trials, subjects were given a five-digit number to remember. The five-digit number would have consumed much of their workspace. Likewise, to the extent that the flashing lights captured subjects' attention, this would have consumed more of their available workspace. Results showed that when subjects had to remember the five-digit number, they were much more susceptible to the allure of the flashing lights. Yet, the allure of the flashing lights vanished when either subjects did not need to remember the five-digit number or did not need to remember which lights they had already selected (i.e. lights were no longer illuminated after being selected).

This study illustrates the limitations of the brain's workspace and how our susceptibility to external factors (i.e. the flashing lights) varies with the demands being placed upon the workspace. The demands the experimenters imposed on the subjects in this study are analogous to those faced by individuals working in many occupations. This could be a radar operator who must allocate their attention to different contacts or a forensics analyst who must divvy up their time as they investigate different cases or an instructor who must decide which of their students gets their assistance. In any of these situations, there is a need for one to remember how they have distributed their attention and where it may be needed. However, they may also face the equivalent of the flashing lights. Some items may have a natural tendency to attract their attention, whereas others may tend to drift into the shadows. For example, in a classroom, some students may be naturally gregarious drawing much of the instructor's attention and if charismatic, may also be favored, with the additional attention coming at the expense of more reserved students. Furthermore, there may be additional demands that have the effect of making the flashing lights more difficult to resist. When struggling with a malfunctioning piece of classroom equipment, it is likely that the gregarious student is the only one that will receive any of the instructor's attention. In each of these situations, individuals must struggle to cope with their ability to only focus on a few items at any given time, while contending with various extraneous factors that make it even more challenging.

The strengths and weaknesses of the human brain are most apparent in the conscious thought processes that underlie everyday problem solving. It may be argued that the greatest strength of the human brain is the seemingly endless capacity for storing information within memory. This applies to our capacity for remembering factual knowledge, or what is sometimes referred to as declarative knowledge. This capacity is evidenced when playing games of trivia that call on players to recall obscure facts, many of which they have not thought about for years. With respect to life experiences, or our episodic memory, we do not retain a perfect record, but do retain enough information from our everyday experiences that we can easily reconstruct countless episodes from our past. We are constantly acquiring new skills as we engage in activities or familiarize ourselves with new devices. On average, a five year old English speaking child has a vocabulary of approximately 1,500 words that by adulthood, will balloon to around 10,000 words and continue to grow as they get older. Finally, our perceptual knowledge encompasses all of the various objects, people, places, etc. that one can distinguish, whether they have had direct perceptual experience or the experience has occurred second hand (e.g. books, television, movie, etc.). Each of these examples illustrates the seemingly endless capacity of the human brain to store information attained during a lifetime that while often not perfect, can be later retrieved and applied in solving current problems.

The inverse, or most prominent weakness of the human brain, is the limited capacity for conscious awareness. Granted, the vast majority of information processing that occurs within the brain occurs at an unconscious level. However, information processing that occurs at an unconscious level is largely inaccessible. It may impact our decisions and affect our reaction to different situations, but we generally have no awareness of what information has been processed or how that information has influenced our conscious thought processes. Our capacity for conscious thought, whether this involves our attention to the world around us, our deliberative problem solving or our voluntary control of bodily activities, is severely limited. As we all know, we can closely attend to only one thing at a time and our attention quickly wavers when there are distractions. Likewise, we know that we can only keep a limited number of items immediately accessible in memory, and some level of effort is necessary to sustain the immediacy of items within memory for more than a few seconds. The effort required to retain items in working memory increases as one attempts to retain more items, with this increased effort evidenced in increased activation of prefrontal, executive regions of the brain (Rypma & D'Esposito, 1999).

Unless an activity is well-practiced (e.g. driving an automobile), it is difficult to do more than one thing at a time. While our brains are constantly active responding to a broad range of stimuli, we have an extremely limited capacity to voluntarily engage and intentionally direct our brain processes, whether the goals involve mental or physical activities. It is difficult for our brains to do more than one thing at a time and we sometimes struggle doing one thing when it is complex and we are distracted.

How to cope with the inherent weaknesses of the human brain

Consider what happens when we call upon our memory. The areas engaged when recalling information from memory are distributed across many different regions of the brain. A given memory may encompass different elements that include location, people, time, activities, and perceptual and emotional experiences, with each element of the memory associated with neural processes that are centered in different areas of the brain. These localized neural processes involve the synchronous oscillations of brain cells within a given area of the brain. Our experience of a memory in which all the various elements are integrated into a coherent recollection requires that the different regions of the brain oscillate in a coordinated fashion (Watrous et al, 2013). The extent to which there is coordinated activity of the different brain regions appears to underlie whether or not we are able to successfully recall what we are trying to remember. A successful recollection corresponds to the activity of assemblies of brain cells within diverse brain regions oscillating at approximately the same frequency, or some harmonic of one another, with the transfer and integration of information facilitated by the coherence of the oscillations. The successful operation of the brain requires that many different elements operate in coordination with one another. Consequently, it is easy to imagine how the slightest disturbance (e.g. an emotionally significant event) can upset the balance rendering our capacity to access our memory stores ineffective. Many people have had the experience of going blank when facing the stress of taking an important test or presenting in front of a large audience. Yet, generally, the brain is remarkably robust successfully calling upon memory on a moment-to-moment basis as we accomplish various activities. More often than not, the brain gets it right and does so in an efficient manner making human memory the envy of scientists and engineers who long for the capacity to duplicate its capabilities in similarly compact computer hardware.

How do we cope with the inherent weaknesses of the brain, and in particular, our inability to attend to more than a slender slice of the world around us at any given moment? In general, we play to our strengths, with perhaps our greatest strength being our seemingly endless capacity for memory. There are many mechanisms, most of which we rarely think about due to the extent to which they are embedded in our everyday behavior, and in some cases, institutionalized within the cultures in which we live. The following sections describe some of these mechanisms.

Routines or habits – often without realizing it, our lives can become so routinized that we hardly have to think about what we are doing. It is not until something breaks up our routines that we can truly appreciate the extent to which our life consists of a series of well-learned patterns of behavior. Within a region of the brain known as the basal ganglia, there reside the neural circuits that underlie the ritualistic behavioral routines seen in many animal species (e.g. the courtship dance of a bird or the depositing and fertilization of eggs seen in fish). In humans, these same circuits are co-opted in the formation of habits (Graybiel, 2008). Except, in humans, the routines arise and adapt to ongoing circumstances with tremendous fluidity. Furthermore, in humans, routines can go beyond simple motor routines to include habits of thought, or the tendency to gravitate toward a certain cognitive perspective or problem solving strategy. For example, within engineering domains, one regularly encounters the habit of thought characterized by the expression, "a hammer looking for a nail," which describes the tendency that once one has a clever technical solution to one problem, there is an inclination to overgeneralize and apply the same solution to other less applicable problems. Here, a pattern of thought has become a routine, not unlike the route taken driving to work each morning, and the individual applies that same pattern of thought, regardless of its appropriateness to the immediate situation.

The link between the expression of habits and the basal ganglia lies in the specialization of these neural circuits for iteratively evaluating situations and matching situations to known sequences of actions or cognitive operations (Graybiel, 2008). I once had a subject matter expert with many years of experience in assault teams with the military and law enforcement use the analogy of a rolodex (i.e. a card holder where one can rotate through a series of cards to find the one with the desired information). He said that when he was presented a situation, he quickly surveyed it to gain a general sense of the environment, characters and events that had transpired and once he had seen a pattern, it was like flipping through the rolodex to find the card that contained the instructions for what to do in that situation. This analogy offers a nice depiction of how the basal ganglia operates, with our everyday lives consisting of a series of situational appraisals occurring both consciously and unconsciously. Our reliance on routines plays to the capacity for our brains to store vast collections of routines, with many continually evolving to become increasingly more elaborate over time. This relieves us from the in-depth moment-to-moment analysis that would otherwise be required. The result is that our brains are freed to attend to other considerations, or perhaps merely daydream. It is through our basal ganglia, and its capacity for quickly sizing up a situation and identifying the corresponding pattern of learned behavior that is most appropriate for the situation, that routines and habits offer a mechanism by which we play to the strength that our brains have a seemingly endless capacity for learning and retaining sequences of behavior and cognitive operations.

Conventions – when presented a new device or placed in an unfamiliar situation, the conscious effort required to recognize and learn the appropriate behavior, whether sequences for activating controls, or expected or generally agreed upon activities, can be all-consuming, preventing one from doing anything else, or sometimes, even enjoying the experience. Within nearly every human endeavor, there are conventions that serve to assure consistency of expectations and behavior. Depending on the country, everyone travels on either the right or the left side of the roadway, with this convention extending to pathways, stairways and escalators. With devices, one expects that turning a control knob to the right should increase whatever feature the knob controls. Within the home, there may be conventions such as where different items are placed within the refrigerator or how to make a certain type of sandwich. As with routines, our brains have an unlimited capacity to learn various conventions, and often, does so implicitly with little conscious effort. Then, once one has learned the conventions, there is little need to devote much thought to what to do. The conventions become deeply engrained and exercised almost reflexively. Yet, conventions not only free cognitive resources, they also create efficiencies and enable possibilities that would not be possible otherwise. I believe that the power of conventions is perhaps best illustrated by the German autobahn. German drivers seem naturally inclined to rigorously adhere to the rules of the road. It is through this compliance with agreed upon conventions that I believe it becomes possible to have roadways where there can be a 40-50 mile per hour difference in the speeds of vehicles driving in adjacent lanes, with surprisingly few accidents.

Vocabulary – whenever one must operate within a new domain, whether an occupation, sport, academic discipline, etc., one cannot hope to be effective until they have learned the vocabulary, or jargon, of the domain. Jargon has the capacity to capture complex ideas within a single word or phrase. This can be similarly seen with acronyms, where a complex title or phrase is reduced to letters spelling a word that can be easily recalled. The chunking that occurs with both jargon and acronyms serves to allow individuals to communicate, as well as to think, using units that have a much greater information content, or density. As a result, those familiar with the jargon of a given domain are able to communicate more efficiently. I have observed this in research conducted with colleagues at Sandia National Laboratories where we found that experts in a given domain tend to communicate substantially less (i.e. number of utterances and duration of utterances) than novices (Lakkaraju et al, 2011). Communication generally consumes much of our conscious awareness making it difficult to effectively do anything else. By achieving more efficient communication through the use of jargon, which relies on the capacity to learn and retain an extensive vocabulary, one lessens the demands imposed by communication, freeing resources to focus on other activities.

Symbols and Icons – pictorial representations, such as the icons used to depict the location of a restroom or the computer's trash folder, operate similar to jargon in that they allow complex information to be engrained within an image. Similarly, the result is to achieve a relatively high level of information density. They also benefit from their familiarity, especially icons that attain some degree of universality such that most people can look at them and recognize their meaning. With a familiar icon, once one has learned the symbol, this knowledge translates across situations, devices and often, cultures, with the associated conceptual knowledge becoming engrained within the perceptual representation (Barsalou et al, 2003).

Retrace steps – in getting around the world, people can often be creatures of habit. Once one has found a route taking them to a destination, it is not uncommon that they will continually retrace their steps, following the same route on subsequent journeys, without considering whether there is a more practical option. Interestingly, in navigating the Internet, as well as computer software interfaces, the same behavior occurs. A person will follow the same sequences of links that they followed when they first found a webpage, as opposed to taking advantage of the ability to go directly to the webpage by bookmarking it or using the automatic fill-in feature of the browser's address bar. Similarly, once a person has found a useful feature within a software user interface that is several layers below the surface, often, they will continue to navigate through the menu layers to find it, instead of using shortcuts that would allow them to go directly to the feature.

When navigating physical or virtual space, our brains construct a map with the route and various landmarks encountered along the way (Ekstrom et al, 2003). It can be demanding to contemplate the physical layout of a city, park or building to identify and assess alternative routes for traveling from one location to another. Then, once one has set out on an unfamiliar path, there is the need to confirm that the route being taken corresponds to the intended route. Furthermore, there may be unexpected obstacles along the way, forcing one to rethink their route. In contrast, while perhaps not optimal, by retracing your steps, there is the opportunity to rely on your memory of a given path. Thus, there is no need to devote resources to route planning and since you have seen everything along the way at least once, the presence of familiar landmarks and surroundings serve to verify that you are on the intended route. By taking a familiar path, one is freed of the cognitive demands of tracing a new path, as well as the uncertainty of an unknown route and the accompanying need to monitor progress along the way and potentially, reassess the route if faced with unexpected obstructions.

Favor the Familiar – while stimulating, novelty can be demanding, particularly when it is necessary to make choices. Furthermore, in making a novel selection, one inevitably incurs some risk. Thus, it is not surprising that people adopt routines in which they return to the same restaurants or stores and are often reluctant to venture out to try new establishments. With any business, or product, one of the greatest challenges involves spurring potential customers to come in for the first time or to make the first purchase. Most of us are quite familiar with the experience of driving by a restaurant that seems interesting from its external appearance, yet never actually stopping to try the restaurant. People naturally favor the familiar, often accepting suboptimal returns to avoid the risk of the unknown. While favoring the familiar allows one to avert risks, it also lessens the cognitive demands associated with an activity. When one visits a familiar restaurant, skims the menu and selects a favorite dish, they are freed from the demands associated with studying an unfamiliar list of options and weighing these options to make their selection. When one shops for groceries in another country where there are the same products, but none of the same brands, it can be like going grocery shopping for the first time. You may know what you want, yet it takes some mental effort to match these wants with an array of unfamiliar products. In our everyday lives, we are constantly drawn to familiar products, establishments, people etc. and in doing so, we rely on our memory for past experiences to make our choices easy and allow us to focus our cognitive resources on other facets of our lives.

Infer Rules – with most endeavors, there are simple rules or heuristics that one may learn to make their experience more efficient and productive. For example, by leaving thirty minutes later, one may encounter substantially less traffic on their way to work. By delaying one's purchase of a new product, there may be the opportunity to avoid many of the defects that will be discovered and corrected during the first few months after the product's release. We are constantly assessing situations to try and deduce rules of this nature. The result is that once an effective rule has been identified, thereafter, it may be applied without much further thought. While the optimal solution may be to assess situations anew on each occasion, having a rule that regularly provides a satisfactory solution, although perhaps not the best, frees one from the demands of considering the unique circumstances of each occurrence and the subsequent demands of coordinating a strategy tailored to the immediate circumstances.

Chunking – If transporting apples, one could handle them one apple at a time, or put them in cases and move them one case at a time. Similarly, much of the information that people contend with on a day-to-day basis can be processed one item at a time, or in larger chunks. A familiar example occurs with counting. It is much more efficient to count by 5's or 10's than to count one item at a time. Throughout various activities, opportunities exists to process information in chunks, with individual chunks involving some level of abstraction, or casting aside unnecessary details. One relies on memory for knowledge that each chunk represents a certain set of individual items, with it being much less demanding to operate with chunks than to individually process each item.

These are only a few of the mechanism that people regularly employ to minimize the demands for real-time cognitive processing. In each case, there is a reliance on memory. The primary mechanism by which people cope with their limited ability for real-time cognitive operations is to play to their strengths, their primary strength being an essentially boundless capacity to store information in memory.

In the design of systems, through careful analysis of the tasks to be performed, situations may be identified that impose demands upon real-time cognitive processes. Left to their own devices, operators will devise their own mechanisms for coping with these demands, with it likely that these coping strategies will involve derivatives of the mechanisms described in the preceding sections. Some of these solutions may be quite awkward. For example, a control room may be littered with ancillary electronic devices (e.g. handheld calculators) that allow operators to perform tasks using equipment and software products for which they are familiar. Within the design of any relatively complex system, there will be points that exceed the capacity for operators, users or customers to cope through real-time processing. Thoughtful design acknowledges this reality and accommodates the mechanisms people commonly employ to cope with demanding situations.

The majority of activities in which a person engages may be organized into a few categories and systems designed around these categories. This provides opportunities for the formation of a basic set of routines that encompass most activities. For example, clerical workers may repeatedly receive the same requests. Routines may be facilitated through forms that capture the essential information for each requester in a common format, procedures that allow common requests to be processed similarly and the layout of offices to accommodate sequential activities and segregate unrelated activities. Invariably, people will establish routines to aid them in performing frequent activities. Recognizing this fact, designers may incorporate mechanisms to accommodate and facilitate these routines.

Most designers are attentive to common conventions (e.g. controls should rotate clockwise to increase a quantity, people walk and drive on the right in the U.S. and many other nations). However, within the home and workplace, people regularly adopt idiosyncratic conventions that represent their on preferred organization of objects and activities.

One of the insights that arose during my personal experience in designing and assessing systems for which there exist the potential for critical, high consequence events is that not all activities are created equally, or should be treated equally. For some activities, there is no tolerance for variability from one instance to another. In these cases, it is important that the activity be performed the same way every time. Often, through various engineering design solutions, the opportunity for deviations in the performance of these activities can be essentially eliminated, with written procedures and training used to further assure compliance. For example, a mechanical stop may be inserted to reduce the potential for over tightening bolts and crushing critical components.

With most actions, there is tremendous tolerance for variability. It may not matter if workers perform a set of steps in varied sequences, people layout items differently or each individual uses their own unique vocabulary. In this case, no matter how a competent person conducts the activity, it is unlikely that the outcome will differ in any way that is significant. Where there is tolerance for variability, it can be assumed that people, and often, teams, will develop their own idiosyncratic conventions. For example, workers may carry their own preferred set of tools in their work belt and organize them in the way that makes the most sense or is most comfortable for them. For these situations, where safety and operational performance do not depend on conformity, design may accommodate individual variability. Shelves, storage containers, workbenches, etc. may be made adjustable, or perhaps portable. Within software, users may be allowed to arrange the desktop however they wish and create their own shortcuts. Businesses may allow customers to wander freely and checkout at a time and location that is most convenient for them. People will expect adherence to certain conventions, but where there is tolerance for variability, there is an opportunity to allow individuals to experiment and adopt the conventions that make the most sense to them.

Design features that allow, or encourage, personalization enable idiosyncratic conventions. This can be seen with music playlists that allow a user to select the songs they want to hear in combination with one another and in the order in which they want to hear them. It suits the taste of the individual who created the playlist, and perhaps others who share their musical preferences, but may not generalize beyond a relatively small group of individuals. Many activities occur within social contexts that vary in their acceptance of idiosyncratic conventions, and particularly, idiosyncrasies that deviate from the norm. For many activities that occur within a social context, effective communication is vital to their success. Idiosyncratic conventions often occur in the vocabulary and symbology adopted by individuals and teams, which may directly affect communication. An individual may refer to a certain operation or activity that is unpleasant, but necessary, as "taking out the trash," with this reference subsequently adopted by other members of their team. However, others will not understand and may misinterpret the expression. In fact, learning the idiosyncratic vocabulary and symbology (e.g. hand gestures) of a team may serve as a barrier to newcomers, delaying their effective integration into the group.

Vocabulary and symbology both serve communicative functions. As discussed earlier with respect to conventions, within a given operation, there will be varying tolerance for variability in vocabulary and symbology. There will be points where effective communication requires that there be essentially no variability with everyone using exactly the same vocabulary, and perhaps even verbal inflection, and the same symbology. Likewise, there will be other points where there is tolerance for variability and little or no loss in efficiency associated with the idiosyncratic use of terms and symbols. As with routines and conventions, a vocabulary and symbology will naturally emerge. It is important for the designer to recognize those points where there is little or no tolerance for variability and those points where individuals and teams may develop their own terms and symbols. Where there is no tolerance, the vocabulary and symbology should be consistent throughout every facet of the operation (i.e. labeling, written procedures, training, etc.). In contrast, where there is tolerance for variability, it may be desirable for the material elements of the system to be consistent so there is a common reference (e.g. physical labels), yet adherence to a common vocabulary or symbology should not be a requirement for the system to function effectively. For example, the software algorithms used with search engines often employ some degree of fuzziness so that when a user enters one term (e.g. home repair businesses), the search returns results for related terms (e.g. plumbers, electricians, etc.).

Similarly, fuzziness may be incorporated into the design of organizations. Several years ago, I read a story about a company in Silicon Valley where the President had instituted a policy whereby the employees were expected to create their own job titles. While some chose titles that were silly, even narcissistic, most of the job titles described meaningful roles and responsibilities that also corresponded to the culture and unique ways in which the company operated. Here, the system could tolerate individual variability and used this opportunity to allow employees to create a vocabulary that was meaningful to them.

While it may not be optimal for one to retrace their steps, people will inevitably do so and there are measures that designers can take to facilitate retracing a previous path. This is true whether one is traveling through physical space or the virtual space of the Internet or software products. One approach is to capture a history of traversals through a system, with this history then serving as a reference when later retracing one's path. This occurs within Internet browsers that highlight links that have previously been selected. While the highlighting does not explicitly map the path previously taken, it does offer landmarks that can be used to reconstruct the path. The designer has fewer opportunities within physical space. However useful landmarks may be provided by placing distinct memorable features at key junctions and locations. This is done in the parking lots at theme parks, such as Disneyland, where otherwise indistinguishable sections of the lots are named for memorable characters from their movies. In buildings, hallways may be painted different colors. Within buildings, parks and cities, signs may be regularly placed along frequented corridors that indicate one's current location and the direction of other recognizable destinations. It is assumed that when a person initially travels from one location to another, they will construct a mental map that contains information concerning the path taken and key landmarks along the way. The designer can facilitate the construction of a meaningful map and the later use of that map to retrace one's path by situating distinct, memorable landmarks at key locations.

In some circumstances, the designer will want to create a sense of familiarity and take advantage of the tendency to favor the familiar. In other cases, the designer may be concerned that allowed to follow familiar routines, people will become complacent or bored, with there being the need to encourage people to explore new ideas and consider different choices. People will not only favor the familiar, but asked to rate alternatives on some valued attribute (e.g. which Chocolate bar is tastier or which city has the most people), people will select the most familiar option (Gigerenzer & Todd, 1999). Where it is advantageous for people to favor the familiar, the designer must assure that their product is recognized and associated with familiar experiences. This can be accomplished through distinguishable packaging and placement, the use of memorable names and slogans and recognizable features such as layouts, menus, uniforms and procedures. With popular fast food restaurants, a comfortable familiarity is created through a distinct, yet consistent exterior and interior design, menus that look similar and contain the same selections, and the procedure for placing an order, receiving an order and paying being the same from one location to another. On many occasions, I have personally made the decision to eat at a restaurant knowing that I would not get a great meal, but having some certainty that my meal would be satisfactory. The end result may have been less optimal, but by favoring the familiar, I assured myself some degree of predictability, and incurred less mental effort.

However, with predictability, there can also be complacency. This is particularly worrisome where safety is an issue. When activities become too familiar, there is the tendency to consciously disengage, resulting in a failure to recognize signs of impending dangers. For example, the ferry operation that makes the same routine transit on numerous occasions everyday may fail to recognize a gradually worsening fuel leak or may fail to adjust their speed in response to reduced visibility on a hazy or stormy day. There is an analogy to skiing or sledding. Going down a snow covered hill, ruts will begin to form and one will naturally be drawn to those ruts. While the snow is plentiful, this can be ideal for a fast, effortless glide down the hill. But as the snow thins, rocks or other hazards may become exposed within the ruts, yet until one makes an effort to carve out a new path, they will be continually drawn to the path with the ruts and accompanying hazards. A familiar operation can be like ruts in the snow. Once learned, it may be the easiest and most effective way to do things. However, due to this familiarity, one may ignore developing hazards, or even disregard them, as they enjoy the mental disengagement that comes with familiarity.

It is a challenge for the designer to balance the trade-off between the efficiencies that come with a familiar routine and the risk of complacency. With facility security, this is often accomplished by regularly rotating assignments. An individual may often work at a given checkpoint, but rotate between different checkpoints on a daily basis. Consequently, the experiences of security personnel vary somewhat from one day to the next. While care must be taken to avoid incurring undue risks, in general, it can be beneficial to occasionally introduce circumstances that force workers or operators to step outside of their daily routines. The logic for accomplishing key tasks may be essentially the same, but altering the surrounding circumstances removes the elements of familiarity that make it easy to disengage.

Through their experiences using a product, users will infer certain rules for achieving effective or satisfying outcomes. These rules may not correspond to the optimal solution for achieving a given objective, but if they are good enough, users will come to rely on them. In system design, it is important to facilitate the user as they infer the rules they will rely upon to accomplish their objectives by masking non-essential complexity, while exposing the user to the essential logic underlying the operation of the system. For example, an electronic device may offer users a relatively straightforward set of functional capabilities, yet also contain the logic for various specialized operations, personalizing the device along different dimensions and performing troubleshooting operations to diagnose malfunctions. Exposure to the latter functions makes the experience of the user unnecessarily complex, interfering with their ability to infer a basic set of rules for achieving their objectives. Ideally, a user would be provided immediate access to essential functions while non-essential functions would be available, yet somewhat below the surface. Analogously, in architectural design, there may be many paths for traveling from one point to another, yet if these paths mask the essential spatial layout of a facility, individuals may find themselves continually disoriented.

If users and operators are going to infer rules, a system must operate in a consistent manner. Unpredictable behavior, or at least, seemingly unpredictable behavior, will be disregarded and dismissed as bugginess. Rules will be learned based on those facets of a system that appear to operate consistently from one occasion to the next and from one situation to the next. Consequently, if a designer wants to facilitate acquiring a set of rules for achieving various objectives, the system behavior on which this learning will be based must be consistent. I have observed this working with kids teaching them robotics. Often, the simplest solution for programming a robot will involve basic dead-reckoning where the program tells the robot to go a certain distance, at a certain speed and turn a certain amount to reach the intended destination. However, the kids have been frequently confounded because a program that works one day does not work another day or a program that works on one robot does not work on another robot. These difficulties are rooted in less power being delivered to the motors as the charge on the batteries diminishes and subtle differences in the motors. These inconsistencies serve to complicate the basic programming rules the kids are trying to learn and as a result, they often become frustrated, assuming there to be no rhyme or reason to the behavior of the robot, when they had actually inferred a reasonably good working knowledge of the logic of the robot programming. In this case, the rules are straightforward and not hard to infer, but due to the inconsistent behavior of the system, the kids conclude that the system is buggy and incapable of consistently achieving their objectives.

Our daily lives are filled with examples of chunking. A six-pack container for carrying beverages allows us to operate in units of six, as opposed to one. The combination meal at a fast food restaurant allows us to combine an entrée, side dish and drink into one unit. Music playlists allow us to create different mixes of songs, each being a separate unit. It is common practice for retail merchants to analyze the purchase behavior of their customers to identify patterns in which the same items tend to be purchased in combination. This data affords chunking, allowing items frequently purchased together to be placed in proximity to one another, or even sold as a package. With existing systems, through behavioral data collection, opportunities may be identified to employ various mechanisms to effectively chunk individual items or activities. In system design, some patterns of behavior may be anticipated, but often users and operators will adopt patterns that cannot be anticipated. Consequently, there is the need to build flexibility into the design to later accommodate chunking, once reoccurring patterns of behavior have been identified. For example, the design of a facility may emphasize modular construction providing flexibility in the physical layout, and multi-use components such as work surfaces and storage areas that can be assigned a variety of purposes. In contrast to dedicated spaces that cannot be readily adapted to alternative purposes, these design features enable the facility to be adapted in various ways to accommodate recurrent patterns, or chunks, of behavior.

Earlier, it was stated that the brain compensates for its limited capacity for real-time processing by relying on its seemingly endless capacity for memory storage and retrieval. The preceding sections have discussed the mechanisms by which this occurs and various design approaches that facilitate this process. Within the design process, at any given point, it is pertinent to ask what activities should be the object of the limited capacity for real-time processing of users and operators. Once this question has been answered, the designer may consider what mechanisms may be introduced to facilitate formation of memory representations, and subsequent reliance on these memory representations. This may consists of procedures that promote the formation of routines, conventions that encourage consistency, vocabulary that captures complexity within jargon or other approaches. Furthermore, as a user or operator gains experience, these same mechanisms provide opportunities to translate experience into improved efficiency, whether the mechanisms focus on primary, secondary or other activities. Accordingly, through experience, an individual should amass more and more knowledge within memory allowing them to function at increasing levels of abstraction, while freeing resources for real-time processing to better focus on the most essential aspects of the activity.

The Google effect and the symbiosis between the brain and technology

A prominent trend within much of human history has been an increasing reliance on physical artifacts to enable us to exceed the inherent limitations of our brains. Perhaps, the accumulation of knowledge in books is the most pervasive example. But, there are countless other examples including devices for counting and numerical operations, calendars, maps, etc. In each case, the demands that would otherwise be placed on the brain (e.g. memory for events, mathematical operations), are off-loaded to an external object freeing the brain to focus on other activities. Where these artifacts have been widely adopted (e.g. books), a symbiosis may be observed between the brain and the artifact. For example, with reading, functional circuits within the brain provide the basic capability to interpret text. Then, through extensive practice, these circuits are refined and expanded to enable greater efficiency and sophistication. A symbiosis arises where the technology allows the brain to accomplish more than it ever could in its absence while the brain adapts to become better equipped to realize the benefits afforded by the technology.

A recent illustration of this trend may be observed with the vast stores of knowledge available through the Internet and associated software products for locating and retrieving specific information. Sparrow, Liu and Wegner (2011) first described what has been termed, the "Google effect." These researchers conducted a series of studies in which they presented subjects with various questions that they might ordinarily turn to an Internet search engine to find the answer. In one study, they presented subjects with either easy or difficult trivia questions. For example, a difficult trivia question might be "how many countries have only one color in their flag?" They then measured reaction time to various words, some of which were related to computers and Internet search. After receiving a difficult question, compared to general words, the subjects showed a faster reaction time to the computer-related words. This suggests that when posed a difficult question for which the subjects did not know the answer, they were primed to think about computer technology.

In a second study by Sparrow, Liu and Wegner (2011), subjects were given facts such as, "An ostrich egg is as big as its brain." Subjects were asked to type the facts into a computer with half of the subjects told the computer would retain this information and half told that the information would be erased. Subjects were then asked to write down as many of the facts as they could recall. Subjects told that the computer would retain the information recalled fewer facts than the ones who believed that the information would be erased. This suggests that when there is a belief that information will be available later, there is less inclination to process the information in a manner that would facilitate its later recall. In a third study, subjects were given a series of statements and after each statement, a message appeared indicating that the statement had either been saved, saved to a specific folder on the computer or erased. Afterward, subjects were presented the statements, but with some statements, the wording had been altered. When subjects were asked if statements were the same as those presented originally, they were more accurate recognizing statements if they believed the statements had been erased than if they believed the statements had been saved on the computer. In contrast, when they were presented statements and asked if the statement had been saved, saved to a certain folder or erased, they were more accurate for statements that they believed had been saved or saved to a certain folder.

This suggests that when there is a belief that information will be retained, there is a shift in emphasis from remembering the information per se to remembering that the information has been saved and will be available later. Finally, subjects were tested on their recollection of statements as compared to their recollection of the name of the folder where the statement had been stored. It was found that when subjects believed the information had been stored in a specific folder, they exhibited better recollection for the name of the folder than for the statement itself.

In combination, these findings illustrate how experience with Internet technology has shaped the manner in which information is processed and memory is utilized. When we believe that technology will be there to support our memory processes, the emphasis shifts from the specifics of the information to the specifics of how to retrieve the information. In this case, brain processes have adapted to the affordances of the technology, and it may be conjectured that with extensive experience, those brain processes engaged by the technology will become increasingly efficient and effective at carrying out these operations.

Once a task has become automated, conscious control can be surprisingly effortful

In almost any domain where an individual repeatedly performs an activity, over time, the activity becomes increasingly automated. This automation involves establishing routines within memory such that once the routine is triggered, it will then execute without the need for much, if any, conscious attention to the activity. The propensity for automation of routine activities is a key mechanism whereby the brain copes with its limited capacity for real-time processing. By shifting to a reliance on sequences of learned actions stored within memory, attention may be turned to other activities, as the brain mindlessly performs the activity that has been automated.

While beneficial, and perhaps necessary, for many of our daily activities, this propensity for automation of routine activities carries a cost. Specifically, once an activity has become automated, it becomes less accessible to conscious attention. A common example involves familiar songs where the words and melody are stored in memory as a sequential unit, and when recalled, we essentially replay the elements in sequential order. Consequently, if asked to recall the words to a familiar song, it is easy to start from the beginning, but very difficult if you are asked to start from a point midway through the song.

When learning a sequence of actions, there is a differential engagement of brain regions as one progresses from the initial exposure to intermediate and proficient levels of performance. Initially, there is involvement of the cortical regions associated with executive control of movement (i.e. prefrontal cortex and supplementary motor area) and the cerebellum, which is associated with the detailed timing of activities in relation to movement kinematics (Hikosaka, 2002; Penhune & Doyon, 2002). During the intermediate stages, cortical mappings between motor and sensory representations develop and these mappings serve as the substrate for recalling and executing the routine. Then, with more practice, there is a migration from cortical control to control through the circuits of the striatum. This migration involves a shift from cortical circuits that are readily accessible to conscious awareness to subcortical circuits that are largely inaccessible to conscious awareness. In practice, the learning of sequences can occur either explicitly where there is conscious intent or implicitly through casual exposure to repeated sequences of actions or sensorimotor experiences. It is interesting to note that while explicit learning tends to rely on cortical processes, implicit learning has been attributed to the activity of the subcortical basal ganglia (Destrebecqz et al, 2005). Furthermore, the extent of implicit learning has been correlated with the level of activity in the basal ganglia and related striatal regions of the brain (Rauch et al, 1997). Thus, the brain circuits that are largely responsible for incidental learning of sequential actions that occurs with repeated exposure are closely associated with the circuits responsible for the eventual automation of sequential learning.

A key implication of automation, and the brain processes whereby it occurs, is that once an activity has become automated, it can become largely inaccessible to conscious thought processes. This can be seen in experts within many domains. Often, while the expert can perform a task flawlessly, and at a clearly superior level of performance, it may be difficult for them to explain exactly how they do it. When conducting expert elicitation, one must be aware that many of the activities of interest have become automated to the point that the expert no longer thinks about what they are doing, and may not really be cognizant of how they do it. Consequently, expert accounts may often consist of accounts of what they consider best practices and retrospective interpretations of past events, and may say very little about the mechanics that underlie their ability to outperform those with less experience.

A second downside of automation is that once a routine has become automated, it is often less malleable to corrections and refinements, or variations in response to unusual situational factors. Trainers and educators are continuously confronted with the challenge of how do you get someone to unlearn an inefficient or ineffective behavior. I have found a useful measure of the extent to which a behavior has become automated to the point of being outside the realm of conscious control is to try and perform the activity in mirror-reversed conditions. Anyone who has spent most of their life driving on the right side of the road and finds themself in a situation where they must drive on the opposite side of the road can appreciate how foreign an otherwise well-learned behavior can seem. For myself, after having driven on the right side for sixteen years, the first time I drove a car in Australia it felt like I was driving for the first time.

With automated routines, to restore conscious awareness, one must intentionally focus attention on their performance, or modify situational factors in some way that either interferes with the automated routine or provides cues to deviate from the established routine. For me, driving on the left side of the road meant that I had to take a moment prior to every turn to think about which lane I should steer the vehicle. To illustrate how cues might be used to help restore attention to an automated routine, occasionally on my way to work in the morning, I need to leave mail at the mailbox about a half mile from our home. My routine for going to work in the morning is so deeply engrained that without taking special measures, it is highly unlikely that I will remember to stop at the mailbox. Thus, my solution has been to place the mail on top of the steering column of my truck so that it makes it awkward to drive and serves as a continuous reminder.

In system design, one must be aware of how elements of design promote the development of automated routines, and the need to sometimes interrupt this automaticity. One example occurs with routine checklists where an individual must go through a series of identical checks repeatedly in the same order. Such an activity is highly conducive to automation with the individual carrying out a behavioral routine without much conscious attention to what they are doing. A hallmark of automaticity is the act of looking without seeing. One may follow through with the behavioral act of looking at the item to be inspected, but this does not mean they see it. Input enters the brain and activates visual circuits, yet there is little or no conscious attention to the visual input. One way to re-engage conscious attention is to employ an approach that operates similarly to the example explained previously that involved using a mirror reversal. In this case, the structure of the activity is altered in some way that while be essentially the same and relying upon the same skills, it forces the individual to think about what they are doing. For example, a series of visual inspections may be performed in reverse, or in an otherwise altered order. Another approach would be to periodically request that some additional information be recorded with every visual observation. Another effective means to re-engage conscious attention when activities have become subject to automaticity is to take advantage of circuits within the brain that naturally respond to stimuli that are surprising or in some way out-of-context. For instance, stimuli may be occasionally inserted that are unexpected, or in some way out of the ordinary. For instance, a tag might be placed adjacent to a part that is being inspected or an unexpected item inserted into a series of identical pieces. The basic point with each of these approaches is to introduce a stimulus that captures the person's attention while minimally interfering with their productivity, and as a result, pull them out of the inattentive state into which they may have lapsed.

Are we multitaskers, or merely good task switchers

We commonly engage in multiple simultaneous activities. For instance, I frequently talk on the phone while doing the dishes or folding the laundry. Often, multitasking involves the introduction of some form of stimulation (e.g. music or television) as a means of keeping our minds engaged as we perform a mundane, otherwise boring, activity. Multitasking becomes a concern when there is a risk associated with individuals having their attention split between the primary task and one or more secondary tasks. For example, great concern has been expressed for the dangers of talking on a cell phone while driving. Yet, multitasking is common, and it is difficult to say there is any greater risk incurred talking on a cell phone than toggling through the radio dial or even engaging in a spirited discussion with other occupants of the vehicle. Furthermore, it is unrealistic to believe that attention is generally focused singly on driving given the routine and often monotonous nature of most automotive excursions. Driving is highly prone to automaticity, as well as accompanying mind wandering, and one might question whether a cell phone discussion is any riskier than daydreaming. The point is that multitasking is a regular part of our day-to-day lives and if it is broadly defined to include activities such as listening to music while running or walking, combining a business discussion with lunch, rehearsing a presentation while waiting one's turn to speak, etc., we may spend as much, or more, of our waking hours multitasking as we spend committed to a single activity.

Charron and Koechlin (2010) devised an experimental method to assess how the brain copes with multitasking situations. In their studies, subjects were presented two series of letters. Each time a letter appeared, their task was to indicate if the current letter was the same or different than the last letter in its respective series. In essence, the subjects were asked to simultaneously perform two tasks, although the tasks were identical. This activity was challenging, but subjects had little difficulty coping with the demands and performing the task with reasonable levels of success. As subjects performed the task, fMRI recordings provided an indication of their ongoing brain activity. When the two tasks were equivalent, there were relatively equal levels of activity in the left and right hemispheres of the subjects' brains. Next, the experimenters introduced a differential monetary reward such that each successful performance of one task produced a substantially greater reward than the other. With the differential reward, activity in one hemisphere increased, while activity in the opposite hemisphere decreased. Then, when the differential reward was reversed so that a large reward was received for successful performance of the task that had previously produced a small reward, and the task that had produced the large reward gave a small reward, the differential activity of the two hemispheres reversed. These findings suggest that subjects coped with the two tasks by devoting one hemisphere of the brain to one task and the other hemisphere of the brain to the accompanying task. It was particularly interesting to see what happened when a third task was introduced. In this condition, subjects performed at chance levels for the third task. These findings imply that the brain is quite capable of performing two simultaneous tasks and accomplishes this feat by allocating one hemisphere of the brain to one task and the other hemisphere to the other task. However, there are no further resources available when there is need to perform a third task.

The findings of Charron and Koechlin (2010) suggest that our brains are well-equipped to perform two tasks, although it may be noted that the experimental tasks used in these experiments are not excessively demanding or as potentially life-threatening as driving or other similar activities. Today, with the proliferation of electronic gadgets, it is common to see multitasking go well beyond a pair of simultaneous tasks to involve numerous simultaneous tasks. Ophir, Nass and Wagner (2009) reported that among students at Stanford University, on average, they simultaneously used three devices. A typical scenario might involve a student working on their computer as they periodically shift attention to their cell phone for messaging, while they play music in the background. To study the effects of chronic multitasking, students were identified who were categorized as either high multitaskers meaning that they regularly combined four or more tasks and light multitaskers who on average, only combined two tasks. In one study, subjects were presented an array of blue and red rectangles. Their instructions were to focus on the red rectangles, with the blue rectangles being distractors. An array was shown to the subjects and then after a brief pause, a second array was shown in which one of the red rectangles may or may not have been rotated. The subjects' task was to say if any of the red rectangles had changed orientation. As the number of distractors increased from 0 to 2, 4 or 6, there was no drop-off in performance for the light multitaskers, yet a substantial drop-off in performance for the high multitaskers. This finding was interpreted as evidence that the high multitaskers were less effective in ignoring the distractors, with the result being that they performed less well on the primary task.

Ophir, Nass and Wagner (2009) extended this research to consider the effects on memory. They used a procedure known as the N-back, where subjects are presented a series of letters and their task is to say if each letter was the same as or different from a previous letter. The difficulty of the task can be varied by requesting that subjects compare the current letter to either the letter that preceded the current letter by one, two or three positions. To successfully perform this task, a subject must be able to retain the immediate sequence of letters in memory, without becoming distracted by intervening letters. The researchers found that the high multitaskers performed less well than the light multitaskers. Interestingly, the high multitaskers performance was highly sensitive to both the frequency of occurrence for a given letter and the number of different letters used. As the frequency with which a given letter appeared increased, it proved to be more distracting preventing these subjects from making accurate comparisons. The researchers concluded that in the high multitaskers, their capacity for managing their memory resources had been lessened. As new information came into memory, they had a diminished capacity to clear old information that was no longer needed from memory and consequently, it served as a distraction.

In another study, these researchers considered the performance of high and light multitaskers with regard to their ability to effectively switch from one task to another. It was presumed that if there was any skill for which the high multitaskers would exhibit an advantage, it would be one that required an individual to frequently shift between different tasks. For this task, subjects were presented a combination consisting of a letter and a number. Prior to seeing the letter-number pair, they were presented a cue indicating if they should focus on the letter or the number. If the cue was for letters, their task was to say if the letter in the letter-number pair was a vowel. If the cue was for numbers, their task was to say if the number was even. On successive trials, the high multitaskers were significantly less accurate than the light multitaskers when there was a transition from letter to number or from number to letter. This indicated that the high multitaskers had a harder time discontinuing one task and switching to the other. However, the high multitaskers were also slower in responding on trials in which the task did not switch (i.e. a letter trial was followed by another letter trial or a number trial was followed by another number trial). This implies that even on the non-switch trials, the high multitaskers have a difficult time not thinking about the other task.

Finally, the researchers used the classic study discussed in a preceding chapter in which subjects are shown a video of several people passing a ball and asked to count the number of passes. In this study, at some point, a person dressed in a gorilla suit steps into the scene, does a few distinct movements (i.e. pounds its chest), and steps out of the scene. Most people viewing this film for the first time do not see the gorilla because their attention is focused on counting the number of times the individuals in the film pass the ball back and forth. This was true for the light multitaskers, who on average, did quite well counting the number of passes, but generally, failed to see the gorilla. In contrast, the high multitaskers performed poorly counting the passes, yet were more likely to say they saw the gorilla. In this case, the inability of the high multitaskers to filter out the irrelevant stimuli (i.e. the gorilla) allowed them to avoid the inattention blindness that characterizes the performance of most of the people who watch this film. In short, if the objective is to detect irrelevant, yet critical stimuli, high multitaskers are likely to be quite effective. However, this will come at the cost of diminished performance on almost every other activity.

The researchers point out that many organizations have adopted policies that either explicitly or implicitly establish the expectation that employees will multitask. For example, companies may require that employees keep a chat window open continuously on their computer with the implication that they will regularly interrupt their work to respond to messages from their co-workers. Similarly, policies have been implemented that require employees to respond to all email within a certain time period. These policies have the effect of demanding that employees regularly shift attention from one task to another, with the potential outcome that they will become increasingly susceptible to distractions, similarly to the high multitaskers in the studies of Ophir, Nass and Wagner (2009). Whereas these examples involve obvious interruptions to ongoing activities, in many systems, similar, yet not so obvious, interruptions occur, with the effect of forcing users and operators to continually shift attention. This may occur with open office spaces where workers are surrounded by activities such as conversations, phones ringing, people coming and going, etc. Whether a worker actively or passively attends to these activities, their presence serves to draw attention away from their primary task forcing them to continuously task switch. The same situation may arise where workers are exposed to periodic announcements, or warnings and alarms. Each instance forces workers to suspend attention to their primary task and then subsequently, restore it.

In system design, it is important to be aware of the moment-to-moment allocation of attention, whether shifts in attention occur as a part of normal operations or due to periodic disturbances. Where task switching is essential, mechanisms may be employed to facilitate the shift in context from one task to another. For example, this might involve capturing, and potentially, allowing playbacks of the sequence of activities that occurred immediately prior to an interruption. Another mechanism might entail capturing cues concerning one's activities that may be carried from one context to another. The level of multitasking assumed by different individuals is likely to differ, as well as the susceptibility to distractions. Thus, design must accommodate individual differences allowing users to control the extent to which they must cope with interruptions and distractions. Likewise, over the course of a day, individuals may differ, with their being periods in which there is a desire for uninterrupted solitude and other periods when the disruptions are welcomed as a source of stimulation, when activities have grown monotonous or frustrating. In summary, with system design, one should be aware of the potential effects of multitasking, understanding that interruptions and distractions are forms of implicit multitasking. Furthermore, while individuals may choose deleterious levels of multitasking, the designer should be careful to not intentionally or unintentionally impose such unfavorable multitasking conditions upon users.

Brains reflexively respond to exceptions

Imagine you are gazing at a large screen and on that screen, a large circular disc flashes briefly every second. You are instructed to tap your finger on the table in front of you each time that you see the disc. After several flashes, your tapping is in time with the rate at which the disc is being flashed and you have begun to anticipate the flash. In fact, if the activity of the motor cortex of your brain was being recorded, a readiness potential would be evident. This is indicative of preparatory processes whereby given awareness of an impending action, the brain readies its response, enabling a minimum response delay. Then, when the sequence of flashes is interrupted by an unexpectedly long delay, for instance, the one second delay between flashes is extended to three seconds, there is a momentary surprise, associated with heightened attention to the task. Similarly, many of us have participated in the group activity where the leader claps their hands at a constant rate and you are asked to clap in rhythm with the leader. Then, unexpectedly, the leader does not clap. Invariably, a few in the group will be unable to suppress their response and will clap. Yet, everyone experiences the same sense of surprise in response to their expectations having been violated.

Both of the examples in the previous paragraph illustrate the basic capacity of the brain to infer patterns within everyday events and based on these patterns, establish predictions or expectations of forthcoming events. In a classic series of studies Emanuel Donchin and Michael Coles (e.g. Coles et al, 1985) established that there were distinct physiological responses within the brain associated with anticipation, and violations of expectations, that occur within specific timeframes, relative to presentation of a stimulus. For instance, in a reaction time study, different letters were presented that served to prime an impending response (Gratton et al, 1990). However, the letters varied with respect to the probability that the stimulus would immediately follow (i.e. for a given letter, there was either a 20%, 50% or 80% likelihood that the stimulus would follow the prime). There was a wave of activity that peaked approximately 300 msec following the letters that served to prime the impending stimulus with the amplitude of this activity correlating with the probability that the stimulus would follow the prime. Furthermore, there was a recognizable readiness potential in anticipation of an impending stimulus with there being a correlation between the probability of stimulus occurrence and the magnitude of the readiness potential. These studies demonstrated that the brain anticipates the relative likelihood of forthcoming events and not only generates a preparatory response, but modulates this preparatory response in regard to the likelihood the anticipated response will actually occur.

Whereas the P300 described by Donchin and Coles is indicative of the brain's anticipation and response preparation, a second distinct pattern of activity occurs in response to an unexpected stimulus. This activity, referred to as *Mismatch Negativity*, consists of a wave of activity that is present when a predictable series of stimuli is interrupted by an unexpected stimulus (Naatanen, 1992). The unexpected stimulus has been referred to as an *oddball* and a typical research paradigm might involve auditory presentation of a series of letters such as "s,s,s,s,s,s,s,s,s,s,s,s,d,s,s,s,s,s,s,…," with the "d" serving as the oddball. The response occurs whether or not a person is paying attention to the stimulus and it has been demonstrated for both auditory and visual stimuli. Furthermore, the mismatch can involve either the physical characteristics of a stimuli (e.g. loudness, color, etc.), as well as the identity of the stimulus. It has been suggested that the P300 and mismatch negativity reflect two distinct functional circuits with the P300 emanating from higher-level cognitive control functions and the mismatch negativity arising from bottom-up perceptual processes (Ritter et al, 1999).

At an unconscious level, our brains are continually processing the array of sensory input being received from the environment, comparing ongoing events to known patterns of events and piecing together and inferring new patterns. Then, when events diverge from the patterns we have come to know and expect, there is a response triggered that has the effect of capturing our conscious awareness and directing our awareness to the anomaly. We experience this process through the surprise that occurs when something deviates from our expectations. Surprise is generally mild as occurs when we hear someone use a word in an unusual fashion or we notice that a friend has re-arranged their furniture. On occasion, surprise can overwhelm our thoughts and emotions as occurs when we receive unexpectedly good news or an unexpected, but much appreciated, gift. It can be argued that surprise is what makes life interesting. For instance, a basic mechanism by which jokes make us laugh is through shifting from one context to another in a surprising manner (Coulson & Kutas, 2001). Consider the joke, "When he told his mother about having gone to a topless bar, she asked, "What do they do when it rains?"" Much of the humor, as well as popular fiction we enjoy, builds upon unexpected shifts or mixing of contexts that evoke surprise within the brain. Similarly, the aesthetic quality of music has been linked to the extent to which it establishes and diverges from predictable patterns (Abdallah & Plumbley, 2008). This accounts for the appeal of live music (Sloboda, 2000). The adept live musician is able to perform a familiar song, but with each performance, they introduce slight unexpected variations within the overall structure of the song.

There is an important distinction to be made. It is not novelty that elicits a response from the brain, but instead, it is the violation of expectations. For instance, Vachon, Hughes & Jones (2012) showed that as subjects listened to voice narrations, variations in the information content did not evoke a response, yet an unexpected change in speakers did so. However, this response diminished as the listeners learned what to expect. Thus, generally, random comments are not funny, and disjointed stories are not entertaining. Likewise, the joke that elicits a laugh the first time you hear it does not do so the second time or the drama that is shockingly surprising loses its impact after watching it once or twice.

Within the foregoing, there are lessons for engineering entertaining or aesthetically pleasing experiences. First, there is the need to provide a recognizable structure. This may involve evoking a familiar storyline (e.g. the downtrodden individual who is completely down on their luck). The structure may arise from a common process or procedure (e.g. the sequence of steps that are associated with going to a restaurant and ordering a meal). Likewise, structure may exist in the spatial layout of a building or outdoor facility. Next, there must be elements that given the structure, are readily predicted. The downtrodden individual may experience a series of disappointments or indignities. On entering a restaurant, there may be a waiting area where the hostess greets diners at a podium and there are benches to sit while waiting to be seated at a table. The passageways of a building may be orderly and symmetrical. Much of the art in designing experience lies in attaining the appropriate degree of predictable regularity. There must be enough to not just create expectations, but to leave little doubt that anything is going to be any different than would be predicted on the basis of those expectations. However, one must also know when enough is enough so that do not become too monotonous and unpleasantly boring. Finally, one must introduce the unexpected. Again, it cannot merely be random. The unexpected element of the experience must be reasonable given the structure that has been created, yet unpredicted given associated expectations. Within the story of the downtrodden individual, it would seem weird, if they inexplicably got into a luxury car and drove away. However, the story might work if someone recognized that they possessed a hidden talent and through this unappreciated talent, they were able to change their fortunes. In the restaurant, it would merely seem strange if one was handed a toolbox and told they must assemble their table. Yet, one might find it a curious change of pace if they were handed a spatula and led to an open grill where they cooked their own meal. Within a building, one would find it odd if a hallway widened and narrowed for no apparent reason, yet be pleasantly surprised if a long hallway opened into a spacious atrium. In each of these examples, the designer has taken advantage of basic brain circuitry whereby we unconsciously recognize structure and predictable patterns within our environment and then, assess ongoing experiences against these predictions, experiencing surprise, perhaps even wonder or fascination, when our expectations are violated.

There is a related facet of the brain's reflexive response to violations of expectations that is also worth mentioning. This occurs when we are carrying out some activity where there is a known relationship between our actions and the results produced through these actions. For instance, when dialing a friend's phone number, we know the series of actions that will produce the response of ringing their phone. Similarly, when someone asks a question, we know the sequence of verbalizations that will give them their answer. Yet, we have all had the experience that we think one thing, and then witness ourselves doing something different. We intend to call our friend, but catch ourselves dialing another familiar number. We open our mouths to answer a question, but catch ourselves saying something different. In the same way that the brain naturally senses environmental experiences that violate our expectations, our brain similarly monitors our actions and responds when our actions differ from our intentions. There is a measurable signal that takes the form of a wave of activity that travels over much of our brain that has been referred to as error-related or conflict-related negativity. This signal emanates from a structure known as the anterior cingulate cortex and has been shown to be the product of responses that deviate from the expectations for a given situation or our intended actions (van Veen et al, 2001). This research suggests that at an unconscious level, we are not only immediately aware of having committed an error, but that there may be recognition of an impending error prior to our actually having committed the error. Unfortunately, we may be well into the midst of having committed the error before our conscious awareness catches up and we realize what we are doing.

As "pattern-seeking primates," the default condition is to believe

In one of my favorite TED talks, delivered by Michael Shermer, who edits a journal known as The Skeptic, Shermer introduces the term, "patternicity," to describe our tendency to find meaningful patterns within our everyday experiences. As previously noted, the brain is constantly recognizing and often, differentially responding to patterns, with this often occurring at an unconscious level. However, Shermer primarily concerns himself with the conscious willingness to believe that patterns are real, and meaningful. He asserts that by default, our tendency is to believe patterns are meaningful whenever the cost of making a false alarm is less than that of a false rejection. For instance, most superstitious behavior is harmless, with there being little cost in believing that the associated ritualistic behavior has a real effect on the outcome of everyday events. The basketball player who insists on wearing a new pair of socks for every game suffers little for this belief. Likewise, the individual who readily accepts a seemingly outlandish conspiracy theory about purported illicit behavior of government leaders or the surreptitious influence of secret groups may seem odd to many, but can endure without realizing any significant consequences for these beliefs. Furthermore, Shermer emphasizes that patternicity is particularly prevalent when it is difficult to assess the truth. In the case of conspiracy theories, the theories generally involve covert activities for which there either never existed any evidence or all of the evidence has been destroyed, with there being powerful parties with an express interest in concealing the truth. This creates conditions that are ripe for those inclined to believe in such theories to see connections between seemingly unrelated events and infer patterns for which there is no substantiation.

The propensity to recognize and believe in patterns varies in response to our life experiences. In research by Whitson and Galinsky (2008), they hypothesized that there would be a heightened willingness to see patterns within otherwise meaningless stimuli when individuals are feeling frustrated or out of control. In such situations, the recognition of patterns serves to impose some order on events at a time when one may feel somewhat helpless to effect critical aspects of the world around them. Whitson and Galinsky presented their subjects with images that consisted of numerous black lines of various lengths and orientations against a white background. For some trials, the image consisted of nothing but randomly placed lines. However, on other trials, there was a line drawing of an actual object embedded within the image. For example, there might be a distinguishable outline of the planet Saturn or an airplane, with randomly placed lines surrounding and intersecting the outline of the object. Subjects were asked to indicate whether or not they believed that images contained an embedded object. On 95% of the trials in which the image actually contained an object, subjects responded correctly saying that there was an object within the image. However, the researchers were particularly interested in those trials in which images did not contain an embedded object, yet subjects responded that an object was present.

In one study, prior to viewing the images, some subjects were assigned a frustrating task in which there was no clear relationship between the rewards and punishments, and their performance. The subjects who had undergone the frustrating experience were more likely to respond that images contained objects, when there was no embedded object. Similarly, in a second study, prior to viewing the images, some of the subjects were asked to recall an experience from their lives in which they had experienced a loss of control. These subjects were more prone to false alarms, saying objects were present when they were not. Finally, a similar result was obtained with business people who reported that they were currently experiencing a stressful situation where they felt they had little control over events. Together, these findings suggest that when people are placed in frustrating situations where they feel that events are outside of their control or that they are being effected by events for which they have no influence, they will be more prone to see associations between otherwise unrelated events and assume and behave as if patterns exist that may be largely constructions of their own mind. This is important to system design because it is common for individuals to experience frustration within the course of everyday transactions, both those that are a direct product of a specific engineered system or merely coincide with their interactions with the system. Most of us are familiar with this experience during our everyday computer use. For some reason, the system may be unresponsive or behave oddly and having no obvious explanation, we may link these experiences with unrelated events. For example, observing telephone technicians with a cabinet open, one might presume the problems they are experiencing with their computer are associated with the telecommunications network. Having just had new software installed, one may blame the problem on the new software. Those using Windows-based systems that receive automated software updates are quite familiar with the experience where their computer behaves oddly at either startup or shutdown. Then, they realize that there were new updates and the anomalous behavior is attributable to the installation and configuration of these updates. In fact, I had an expert in cyber security once comment to me that a substantial portion of the everyday reports of suspected computer viruses are attributable to unexpected system behavior resulting from Windows updates.

The first lesson for the system designer is to appreciate that from the perspective of a user or operator, the patterns that they infer to exist are real, whether or not they do actually exist. In a study by Ress and Heeger (2003), subjects were shown a pattern and then shown blurred images that either did or did not contain the pattern, with the subjects' task being to indicate whether or not the pattern was present within the blurred images. Brain imaging data was recorded from the subjects as they performed this task. It was observed that whether or not the pattern was present, on trials in which the subject indicated that the pattern was present, the activity of their brains was comparable to that when viewing an image with the pattern. This suggests that when the brain believes a pattern exists, regardless of the sensory inputs to the perceptual system, it responds as if the pattern is actually there. A designer cannot dismiss the inferences of users because from the user's perspective, these patterns seem quite real. Furthermore, the users may change their behavior, or do things that may be counterproductive as a result of these beliefs. For example, if a user falsely believes that the sluggishness of their system is attributable to new software, they may uninstall the software. If a user falsely believes that the anomalous behavior caused by a system upgrade is due to a hacker having compromised their system or their having downloaded a virus, they may unnecessarily have their system wiped clean and rebuilt. These actions are unnecessary, but from the perspective of the user, given their beliefs, seem logical and essential.

Obviously, the best way to avoid situations of this nature in which users or operators attribute system malfunction or lack of reliability to unrelated factors, and then behave in accordance with these beliefs, is to design systems that perform consistently. However, given that this may not always be possible, there are steps that can be taken to minimize the tendency to make erroneous associations. First, to the extent that anomalous system behavior can be anticipated, there is value in warning the user or operator. Such warnings provide an immediate link between the anomalous behavior and normal operational routines so that there is less of an inclination to search for alternative explanations. Where practical, another approach is to shield the user or operator from the anomalous behavior. For example, an alternative workspace may be supplied that while it does not offer full functionality, will behave in a reliable manner. Frustration will only heighten the tendency to infer extraneous causes for anomalous system behavior. Thus, steps may be taken to minimize frustration. For instance, the user or operator may be allowed to control when the system operations producing anomalous behavior occur so that while being unable to avoid the experience, at least the user or operator can control when it happens. Likewise, steps should be taken to avoid the potential loss of ongoing work or data so that once the system operations causing the anomalous behavior have passed, at a minimum, the operator is at the same place they had been, and have not lost ground. All of these measures serve to establish connections between normal operations of a system and the occasional anomalous behavior of the system, and by establishing these connections, minimize the opportunity for users and operators to form spurious connections. Furthermore, these methods serve to transfer some sense of control to the user or operator as a mechanism to avoid the frustration and stress resulting when one is negatively impacted by events beyond their control.

While everyone appears to be susceptible to “patternicity,” as described by Shermer, and this susceptibility varies in response to ongoing circumstances, it has been observed that there are individual differences in this susceptibility (Krummenacher, et al, 2010). Krummenacher and colleagues described the propensity to see patterns with regard to signal-to-noise ratios. Thus, those with a greater propensity to report patterns, with a corresponding higher incidence of false alarms, would be considered to have a low signal-to-noise threshold (i.e. more likely to report the presence of a signal and likewise, more likely to mistake noise for a valid signal). In contrast, those who are less likely to report patterns, with a corresponding high incidence of false rejections, would be considered to have a high signal to noise threshold, being more likely to reject valid signals as noise.

There are a collection of traits that characterize those with a greater propensity to see patterns that include being more creative, more willing to believe in the paranormal, more prone to psychotic illnesses and a lower sensitivity to negative feedback. In contrast, there is a somewhat opposite collection of traits associated with those who are less prone to see patterns that include being more analytic, more skeptical, greater susceptibility to depression and a greater sensitivity to negative feedback. Interestingly, these traits seem to be linked to either intrinsic levels or sensitivity to the neurochemical transmitter dopamine. Dopamine is a primary substrate mediating the reward systems within the brain such that increased dopamine is associated with positive, rewarding experiences. In the research reported by Krummenacher et al (2010), it was shown that by manipulating the level of dopamine, the experimenters could shift individual subject's signal-to-noise threshold (i.e. propensity to see patterns). This led the researchers to conclude that the opposing traits they had observed were linked to the functioning of the dopamine-mediated reward circuits of the brain. Thus, those with an intrinsically high dopamine response are more prone to see patterns, whereas those with an intrinsically lower level of dopamine response are less likely to see patterns.

In applied settings, these findings have important ramifications. First, it can be assumed that the members of a workforce will vary in their intrinsic responses to dopamine and show varying propensities to see patterns. Furthermore, some professions are likely to attract those with a lower signal-to-noise threshold (i.e. higher intrinsic dopamine response). In particular, these are likely to be jobs and professions that hinge upon creative processes (e.g. concept design, marketing, the various arts, etc.). These are positions that demand a willingness to suspend concern for critical judgment and explore unproven ideas. However, in these situations, the associated insensitivity to negative feedback could promote the pursuit of unproductive paths and an accompanying unwillingness to accept critical appraisal. In contrast, professions attracting those with higher signal-to-noise thresholds would include those involving intense analytic analysis (e.g. engineering analysis, hazard and risk assessment, accounting, etc.). These are positions where one must be wary of unproven ideas and keen to the various ways in which things can go wrong. However, in these professions, one must be concerned with the tendency to be excessively skeptical and the stagnation that can result when one is overly sensitive to potential negative outcomes. Within an organizational setting, these opposing forces may sometimes collide. Conflict can result due to those who are blind to risks wanting to move forward while others resist and find it difficult to do anything but the most incremental steps due to their fixation on potential risks. This is a perpetual conflict that exists within many organizations and I do not believe there is a remedy, yet may reflect a healthy balance of opposing traits deeply rooted in the basic circuitry of the brain. Perhaps, the primary point to be made here is that these traits may not be particularly malleable and represent manifestations of fundamental mechanisms underlying the operations of our brain, contributing to an overall healthy range of individual differences.

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