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Perceptual experience: The world within our brains

Engineering design is about the objectives of a system and mechanisms for accomplishing those objectives. However, engineering design is also about the experience that is created by a system. Whether an operator or user, or those otherwise affected by a system and its operations, the experiences created will determine whether objectives are met, and how well they are met. Technically, a system may provide the mechanisms to achieve its objectives, yet due to confusion, frustration, annoyance, fatigue or other effects, the system may fail. While key facets of a system may operate as designed, there may also be unintended effects. For example, artifacts associated with simulation-based trainers may result in learning that proves counterproductive when students must function within real-world settings. To successfully engineer systems that accomplish their stated objectives, it is important that designers attend to the experiences that are created by these systems. Furthermore, there are opportunities to engineer experiences that will produce more positive outcomes than would be expected, given only the mechanics of the system. Within many contexts, a functional system that meets the basic operational objectives may be readily achievable. However, by also attending to the experience created by a system, there is a differentiating opportunity to create a level of satisfaction and subsequent desire that will translate into high regard and loyalty toward one's products.

Our brains recreate the world around us within our heads. Everything that we experience is an abstraction that arises through transduction as energy flows from sensory receptors, through intermediate neural circuits and eventually, results in an integrated internal representation of the external world. This is perception, at least from our brains' perspective. Perception concerns the processes whereby we experience the world around us based upon our creating an abstract representation of the external world within our head. It is worth noting that the majority of this experience may never enter into our conscious awareness. However, whether experienced at a conscious or unconscious level, one's experience of a system, and its design, will arise through their perceptual processes.

Traditionally, from an engineering perspective, perception has been mainly discussed with respect to the capacity for a human to effectively sense, process and use various information to achieve task objectives. Certainly, effective task performance is essential to achieving system objectives, and there are many excellent accounts of the principles underlying effective information presentation and display (Boff & Lincoln, 1988; McBride & Schmorrow, 2005; Salvendy, 1997). However, in the following sections of this chapter, there will be little emphasize on engineering information displays for task performance, with the primary focus placed on engineering design that engages perceptual processes to create certain experiences within operators, users and others effected by a system. Each of the following sections discuss general principles concerning the mechanisms and organization of perceptual processes within the brain that determine to how systems will be experienced and the resulting efficacy with which people will operate within those systems.

Our mind attends to a small slice of what our brain senses

At some time, we all learned about the five senses: sight, hearing, taste, smell and touch. This idea of five primary senses is a simple practical means of teaching children about how our body uses specialized organs to sense the world around us. These are also the senses that dominate our conscious awareness. This is particularly true for vision and audition, as our conscious experiences tend to be dominated by these two senses.

I recall the day my daughter came home from school and told me that they had learned about the five senses. I could not help myself and pointed out to her that there were at least three other senses that she should know about. First, there is proprioception, which concerns the movement of our joints. Second, there is kinesthesis, which concerns the movements of our muscles. And third, there is equilibrium, or our sense of balance. Then, I pointed out that there are probably at least forty other distinct senses.

It is unknown exactly how many senses we do have. This is partly due to disagreement about the definition of a sense. However, in addition to the eight mentioned here so far, you can add: temperature with heat and cold being separate senses; nociception or pain due to either nerve damage or tissue damage; and chronoception or the sense of time. There are also a number of senses that respond to the internal state of the body. For example, pulmonary stretch receptors in the lungs help to control the rate of breathing and sensory receptors in the urinary bladder and rectum give us the sense of being full with the need to go to the bathroom. There are still other senses that respond to the molecular concentration of specific chemicals. For example, there are sensory receptors that respond to the relative concentrations of carbon dioxide and oxygen within the brain, and are responsible for the sense of suffocation when carbon dioxide levels become too high.

While our conscious awareness is focused on the sights and sounds around us, our brain is having a substantially richer sensory experience, although it is primarily occurring at an unconscious level. Consequently, it is a common sensation that we experience some sensation such as the wind blowing against our face or the aroma of a certain spice and it triggers a memory from long ago. We may or may not make a conscious connection between the immediate sensory experience and the memory that has been triggered. Nonetheless, it is important that we understand that our experiences involve sensory sensations that go well beyond our conscious experience, and include much more than sights and sounds. This can be important when attempting to create a high-fidelity representation of an actual system for simulation-based training. For instance, subtle sensory sensations such as the smell of a straining engine and the saltiness of the ocean air may be important cues that the student must learn to correctly interpret key events. Likewise, in entertainment, there is the opportunity to enhance experiences by reproducing subtle sensory sensations or to confuse and disorient the audience by introducing unexpected sensory sensations. There has been relatively little research exploring the use of alternative sensory channels to affect experiences at an unconscious level, however based on fundamental biology, there should exist numerous opportunities to produce richer sensory experiences, while leveraging unique channels of communication to create more engaging experiences.

Our judgment is shaped by unconscious sensory experiences

In the previous chapter concerning conscious awareness and the preceding section of this chapter, I have made the point that a tremendous amount of sensory information is relayed to the brain and is processed at an unconscious level, yet very little enters our conscious awareness. This raises the question, “Does sensory information processed at an unconscious level affect our judgments?”

A series of studies reported by Josh Ackerman and colleagues indicate that our judgments are not only affected by unconscious sensory processes, but affected in ways which we may have no conscious awareness (Ackerman et al, 2010). In one study, subjects were asked to watch videos of individuals participating in a job interview and afterward, asked to rate each job candidate on a number of attributes. Subjects were provided a clipboard with the sheets they were to use for their ratings. One group of subjects was given a relatively heavy clipboard, whereas a second group was given a relatively light clipboard. Those subjects receiving the heavier clipboard, on average, rated the job candidates as being more serious and more interested in the job. Similarly, in a second study, subjects were asked to read a story involving a social interaction. Then, they were asked to assemble the pieces of a puzzle. For one group, the puzzle pieces had been given a rough texture, whereas the second group was given puzzle pieces with a smooth finish. Afterward, subjects were asked to rate the social interaction with regard to various attributes. On average, the subjects given the puzzle pieces with a rough texture rated the social interaction as being harsher and less pleasant than the subjects who had been given the smooth puzzle pieces. Ackerman and colleagues noted that their findings mirror common expressions that occur in everyday language. For instance, weight is associated with seriousness in expressions such as, “thinking about weighty matters” or “the gravity of the situation.” Similarly, roughness is associated with difficulty or harshness in expressions such as, “having a rough day” or “coarse language.” These expressions reflect implicit associations that under certain circumstances may affect our judgments, without our having any conscious awareness that largely irrelevant sensory experiences have had an effect upon our thinking.

In a somewhat different study, researchers considered how sensory experiences associated with environmental surroundings affect our judgments (Woods et al, 2010). Part of the sensation associated with eating potato chips derives from their crunchiness. Subjects wore headphones and ate potato chips in one of three conditions. In one, there was silence, in a second there was soft white noise and in the third, there was loud white noise. On average, when asked to rate the tastiness of the potato chips, those in the loud condition gave lower ratings than subjects in the quieter conditions. This suggests that there is a sensory experience that is associated with eating potato chips and that if other sensory experiences interfere with this experience, the overall experience is diminished. In this case, there is no direct association between the level of background noise and the flavor of the potato chips. However, when the background noise overshadowed the expected auditory sensations (i.e. the crunchiness of the chips), the overall experience, including the flavor of the chips, was less satisfying.

Within design, unconscious sensory experiences can be used to affect judgment. These unconscious sensations offer an alternative channel of communication. For instance, the information display of a device may serve as a primary mode of communication that is task oriented. At the same time, the shape and feel of the device may be used to convey an overall sense of seriousness, or a sense of whimsicalness. Similar effects may be accomplished through the design of the environment. This is not a new idea. However, a consideration of unconscious brain processes suggests mechanisms for more systematically achieving such effects. The studies discussed above address two mechanisms. The first takes advantage of semantic associations. The language used to describe sensory sensations carries with it associations to other attributes. Heaviness is associated with seriousness. Its opposite, lightness, is associated with airiness and freshness. Second, there may be unconscious sensory experiences that we have learned to associate with unrelated positive experiences. For instance, there may be no direct link between a product's packaging and its quality. However, a well-packaged product may be assumed to be of higher quality than a product that is not as well packaged. If some event interferes with our unconscious sensory experience (e.g. someone else removes the packaging of the otherwise well-packaged product for us), without that association, the overall experience may be critically diminished.

Perception is multisensory

As is true with other animal species, our perceptual systems are specialized to sense stimuli that are biologically significant for a given mode(s) of survival, within the context of a certain environment(s). There is considerable debate surrounding the environment(s) and mode(s) of survival that most shaped the development of humans as a species (Potts, 1998). Furthermore, some senses are more primitive than others (e.g. internal senses associated with basic life functions such as respiration), as evidenced by their being largely the same in many diverse species (Hodos & Butler, 1997). Yet, for any given sensory system, there is a range of stimuli for which the human sense organs and associated neural circuitry is most responsive.

One perspective explaining the differential emphasis placed on different senses points to the energy demands associated with sustaining sensory organs and associated neural processing (Niven & Laughlin, 2008). Sensory systems with broader ranges and/or higher levels of acuity exact a greater cost than those that are sensitive to a smaller range of stimuli and/or provide lower levels of acuity. It is asserted that the specialization of sensory systems within any given species reflects a balance between the costs of sustaining a sensory capability and the benefits derived from that sensory capability. These pressures may be combined with trade-offs imposed by basic anatomical and physiological characteristics. For example, the frequency range of sounds for which humans, as well as other mammalian species, are most sensitive corresponds to the range of sound affording the optimal localization of sounds given the size and shape of our head (Masterton, Heffner & Ravizza, 1969). It has been said that, "the brain is not a well-designed machine, but a magnificent compromise" (Krubizer, 2007). This principle is reflected in the relative emphasis that is placed on different sensory systems and for any given sensory system, the relative sensitivity to the stimuli to which it responds.

From the perspective of engineering design, human sensory processes have been fairly well characterized (Boff & Lincoln, 1988). This is particularly true for vision, audition and touch, with somewhat less data existing for the chemical senses (i.e. taste and smell) and secondary senses such as proprioception and equilibrium. Given the available resources (e.g. MIL STD 1472G, 2012), there is little excuse for the design of products that do not accommodate the basic strengths and weaknesses of the human sensory systems.

Design may go beyond merely matching the sensory signals used to communicate information to the relative acuity of different sensory systems. An alternative perspective sees design as the creation of a sensory ecology. Analogous to ecologies in nature where different animal and plant species co-exist by occupying and exploiting different niches, one may similarly think about sensory signals as different species and the various sensory systems as different niches. Applying this analogy, different sensory signals may exist side-by-side, each exploiting a different channel of sensory communication. For instance, as we visually navigate our surroundings, auditory signals may be used to both entertain and communicate important information. This presents the opportunity to create rich, multi-faceted sensory experiences that communicate and engage individuals through a variety of mechanisms, some which operate at a conscious level and others at an unconscious level.

In practice, design of a sensory ecology should begin by considering the impressions a designer hopes to make upon users, operators and others affected by a system. The clearest examples occur with environmental design. In the design of a grocery store, the intent may be to create the sense of freshness, which may be addressed through air exchange and ventilation. To create a sense of quality, items may be neatly stacked and well-organized. Clean floors, shiny surfaces and bright lights may be used to create the sense that meats and produce are fresh and free from contaminants. Well-constructed carts that roll easily across the floor suggest efficiency. Happy, perky music evokes a sense of impulsiveness. The shopper may only be consciously aware of the immediate tasks of remembering and locating what they need to purchase, making selections, deliberating over costs, etc. However, the sights, sounds and smells of the surroundings and physical sensations associated with their actions impinge upon their senses and create an overall sensory experience. A shopper may be totally unaware of the various aspects of the environment that are shaping their experience. Yet, if something changed or they went to another grocery, they would likely sense that something was different, although they may not be able to say exactly what it was.

As stated above, environmental design offers tremendous opportunities to structure the sensory ecology so as to achieve certain experiential effects. However, most designers are only tasked with development of specific elements or components of the overall environment. For example, a designer may only have responsibility for a single electronic device that is to be combined with several other electronic devices within a vehicle's electronics console. In this case, the designer likely has no control over the totality of the sensory ecology. Their device is analogous to a single species that must find a niche where it may flourish alongside other species that are filling adjacent niches. In such a situation, there exists the potential for conflicts where multiple devices compete for the same limited resources. Recently, I was talking on my cell phone in a busy airport where there were many different sounds occurring all around me. My phone beeped to warn me that the battery was running low. I heard the sound, but failed to recognize that it came from my phone. Consequently, I continued my phone conversation, ignoring two additional warnings, until the battery could no longer power the phone and I was disconnected. In this case, there was a clearly discernible signal, yet because there were other simultaneous signals in the same range of frequency and intensity, I failed to correctly localize the source of the signal, and therefore, failed to recognize the relevance of the signal. In this example, several signals are in competition for a limited resource (i.e. the range of audio frequencies for which my hearing is sensitive). While the low power warning on my phone was detectable, I failed to distinguish it from other similar audio signals. It is unlikely that this would have been the case had the audio signal been combined with a brief vibration creating a compound stimulus for which there were no comparable competing stimuli.

Within the brain, the processing of sensory input for a given sensory modality follows a progression from lower to higher levels of detail. For example, at the lowest levels of visual processing, analysis of visual signals involves the detection of features such as the color and orientation of visual stimuli. Similarly, the lowest levels of auditory processing distinguish features such as sound frequency and pitch. As processing progresses from lower to higher levels, there is both an integration of low level features (e.g. features are combined and distinguished from the surroundings for the detection of objects) and increasing influence from top-down processes or expectations (e.g. a round object in the context of a child's room takes the form of a ball). Accompanying this progression from lower to higher levels of processing, there also occurs an integration of input from different sensory modalities, as well as the modulation of input from one sensory channel based on input from other sensory channels. This serves to disambiguate input from a given sensory channel, enhancing the clarity of the signal.

The capacity for effective sensory integration has been linked to attaining superior levels of performance within certain domains. For example, Vuillerme and colleagues (Vuillerme, Teasdale & Nougier, 2001) compared expert gymnasts to individuals who had attained notable levels of performance in other sports using a task that required subjects to stand immobile. As subjects attempted to maintain a stationary posture, proprioceptive input from the ankle was disrupted by applying vibration to the tendon. Gymnastics requires an ability to effectively integrate proprioceptive with visual, kinesthetic and vestibular input to establish and sustain balance. This enhanced skill was evidenced in the gymnasts being able to recover faster and being less affected by the disruption in proprioceptive input. Further research has demonstrated that with expert gymnasts, the multisensory processes associated with sustaining balance demand less attention as evidenced by the gymnasts exhibiting faster reaction times while simultaneously balancing on one leg (Vuillerme & Nougier, 2004). Similarly, it has been shown that with dancers, there is an enhanced capacity for the integration of visual and proprioceptive input, as evidenced by performance of manual tasks with and without disruption of sensory input (Jolla, Davis and Haggard, 2011). This research does not imply an intrinsic superiority for the integration of input from diverse sensory channels. However, it does point to a differential capacity for sensory integration, with individual differences manifested in measurably higher levels of performance for tasks placing similar demands on the capacity for sensory integration exercised during gymnastics or dancing.

Our conscious awareness is generally focused on the dominant sensory modality for a given type of signal. For example, during conversation, our awareness is primarily focused on the sounds being produced. However, at an unconscious level we are also processing visual signals, whether the movement of the speaker's mouth, or their gestures and facial expressions. All the while, the brain is combining all of these signals to produce an integrated perceptual experience. This is illustrated by the *McGurk Effect* (Massaro & Stork, 1998; McGurk & MacDonald, 1976)). If watching a person speak the syllable "ga" while hearing an audio recording of the syllable "ba," the listener will likely report having heard the syllable, "da." Similarly, if watching a speaker say the expression, "My gag kok me koo grive" combined with an audio recording of the expression, "My bab pop me poo brive," a listener will likely report having heard the expression, "My Dad taught me to drive." In both cases, the listener consciously attends to the audio recording. Yet, at an unconscious level, they are processing the visual signals from the speaker's mouth movements and combining the auditory and visual input to produce a conscious experience that is the integrated product of inputs from the two sensory channels.

Traditionally, it was believed that in higher cortical areas of the brain, input from brain regions responsible for processing specific sensory channels converge, with higher cortical processes integrating signals from multiple sensory modalities. These regions of the cortex have been referred to as sensory association areas. Numerous regions of the brain's cerebral cortex have been attributed with this function (Baylis, Rolls & Leonard, 1987; Desimone & Ungerleider, 1986; Lewis & Van Essen, 2000). Additionally, there are subcortical areas with functional connections to higher cortical areas, such as the thalamus and amygdala, where sensory integration also occurs (Mesulam & Mufson, 1982; Turner, Mishkin & Knapp, 1980).

Yet, the integration of input from specific sensory channels is not limited to higher-level cortical processes, but also occurs early during the initial low-level processing of sensory input. It has been shown that there are projections from areas responsible for low-level processing of auditory signals to areas responsible for low-level processing of visual signals (Ettlinger, 1990; Falchier et al, 2000). Through these connections, the brain is able to use auditory input to signal visual processing areas regarding the likely presence of important visual cues. Likewise, low-level projections from visual cortex, as well as somatosensory cortex (i.e. regions responsible for processing signals from tactile, or touch, sensors) to auditory cortex have also been demonstrated (Schroeder & Foxe, 2002). With our visceral senses (i.e. those associated with the internal organs of the body), integration occurs at an even lower level within the spinal cord, with the sensory signals reaching the brain having already undergone some degree of integration (Cervero & Tattersall, 1987). These observations of integration at nearly every level of sensory processing suggests a conceptualization of the brain wherein input from different sensory modalities may enter the brain through separate pathways, yet almost immediately, the brain begins to construct a multisensory representation of the world. Limitations on the amount of processing that can occur at a conscious level may bias our awareness to emphasize one or more dominant sensory modalities. However, at an unconscious level, the brain is experiencing the world as an integrated fabric combining input from all of our sensory systems to create a multisensory representation.

The brain responds more strongly to some stimuli, than others

While at a low level, the brain may exhaustively process the stimuli impinging upon sensory receptors, relatively few stimuli provoke a pronounced response. While registered, most stimuli merely serve to fill in the background. To elicit a strong enough response to distinguish a given stimulus from the background of accompanying stimuli, it is not sufficient to merely be detectable. A conspicuous signal must be distinct from its surrounding environment Enquist & Arak, 1998).

As previously discussed, a given signal exists within a sensory ecology and competes against other signals, with some provoking a more pronounced response than others, and some provoking a sufficient response to capture one's attention and enter into their conscious awareness. Within nature, there are various approaches employed by different species to enhance the conspicuousness of the signals they produce. For instance, stimuli that sharply contrast with their environment tend to be more conspicuous. This is evidenced in the evoked response of the brain to visual stimuli of varying levels of contrast measured using EEG. In particular, the overall amplitude of the brain's response tends to be greater for higher contrast stimuli (Campbell & Kulikowski, 1972).

Viewed at a finer level, the response of the brain to stimuli of varying levels of contrast reveals an interesting property of the brain. It is a misnomer to think of the brain as either being active or inactive because there is constant activity throughout the entirety of the brain. In the absence of a prominent stimulus, this activity takes the form of spikes that arise at varying locations, with waves of activity emanating from these spikes that diminish as they travel further from their origin (Nauhaus et al, 2008). This produces relatively constant, yet somewhat diffuse levels of activity. When presented a stimulus, diffuse activation patterns are transformed with their being pronounced activity localized to areas involved in processing the stimulus (Nauhaus et al, 2008). This transformation and the subsequent localization of activity varies in response to stimulus contrast with their being a greater disruption of diffuse activation patterns and heightened localized responses with increasing stimulus contrast. Thus, the brain's response to a conspicuous stimulus does not involve a generalized increase in activation, but instead an increased coordination of activation.

While the contrast between a stimulus and its background may be the key to its conspicuousness, there are many mechanisms for achieving contrast. For instance, visual stimuli may vary in size, shape, intensity and color, as well as other more complex dimensions such as flicker and frequency gratings. In nature, it has been observed that signals that elicit varied responses tend to be very different from one another, and are often much more distinct than necessary for them to merely be discriminated from one another (Brown, 1975). Darwin referred to this observation as the *Principle of Antithesis* (Darwin, 1872). This principle is consistent with the fact that when processing a given stimulus, generally, the brain simultaneously analyzes the stimulus with regard to different dimensions. For instance, with visual stimuli, orientation, color and location are simultaneously processed somewhat separately and later integrated to form a coherent visual representation (Hubel & Wiesel, 1959; 1962). This opens a range of opportunities for designers to take advantage of different stimulus qualities as a basis for creating contrast between the stimulus and its background, and thus, enhance the conspicuousness of the stimulus. This may be realized through signals that vary along multiple dimensions. For example, auditory signals may vary with respect to their pitch, tone, volume, rhythm and cadence, as well as the sound source. Variation along each of these dimensions should serve to heighten the contrast between the stimulus and its surroundings.

Another method that may be used to enhance the conspicuousness of a signal involves the simultaneous activation of multiple sensory modalities. For instance, alarms often combine a flashing light with a loud sound. Certain combinations of stimuli will elicit a more pronounced response from the brain than any one stimulus by itself. Furthermore, this response may be parlayed into enhanced behavioral performance. For example, it has long been known that faster reaction times occur for a visual stimulus if the stimulus is combined with an auditory stimulus (Todd, 1912), with similar facilitating effects having been reported for the combination of auditory and tactile stimuli (Loveless, Brebner & Hamilton, 1970). Furthermore, sensitivity to stimuli that are slightly below the normal threshold for detection may be enhanced if there is simultaneous stimulation of another sensory modality (Frassinetti, Pavani & Ladavas, 2002). To achieve these effects, the stimuli must be synchronized in a manner that allows them to merge into a compound stimulus. Where visual and auditory stimuli are combined, a brief offset in the time the two stimuli are presented and/or the location of the two stimuli will lead to a diminished effect, with the effect no longer occurring once there is sufficient separation of the stimuli (Stein et al, 1989). Thus, stimulus facilitation effects are contingent upon stimuli being merged such that they are perceived as a single compound stimulus.

The response to multi-sensory signals is modulated by attention with a more robust response to attended stimuli, than unattended stimuli. Using auditory and visual stimuli, EEG measures indicated a larger amplitude response to multisensory stimuli that were the focus of attention, as compared stimuli that were not the focus of attention (Talsma & Woldorff, 2005). This effect occurred from the very earliest stages of the response, beginning within 100 msec of the stimulus presentation. Furthermore, the facilitating effect may not occur with non-congruent stimuli (i.e. stimuli that one would not expect to occur together), with the overall response often being of a reduced magnitude. For example, in an fMRI investigation of sensory integration with taste and smell, Small et al (2004) found that unexpected combinations (e.g. vanilla and salty) produced less activation, with the incongruity producing an apparent suppression of the brain's response. Within the midbrain, the superior colliculus is a structure that possesses receptive fields for multiple sensory modalities including audition, vision and touch and functionally, with the superior colliculus largely involved in directing our attention to focus on significant stimuli. It has been observed that within the superior colliculus, cells responsive to each sensory modality overlap and that when there is simultaneous stimulation of multiple senses, there is a pronounced amplification of the overall electrophysiological response (Stein & Meredith, 1993). This amplification may be as much as 12-fold, as compared to the activation observed when the same sensory modalities are activated one at a time. The response is often greatest when the intensity of sensory stimulation is relatively low suggesting that the response amplification may serve to facilitate our reaction to somewhat weak, yet potentially significant, sensory signals. Furthermore, the response amplification diminishes with separation of the stimuli in space and/or time, with there being response depression once there is a sufficient degree of separation between stimuli (Kadunce et al, 1997). Consequently, under certain conditions, the opposite effect may occur with one stimulus actually suppressing the response to a second stimulus. While other brain regions involved in sensory integration do not show as distinct of a response as the superior colliculus, in general, there is an enhanced sensitivity to multi-sensory stimuli, particularly with respect to capturing and orienting our attention toward certain sensory events. From a design perspective, if a multi-sensory stimulus is designed correctly, it can trigger a marked response that elevates it conspicuity. However, any disparity in the timing or other facets of the multi-sensory presentation can diminish the response and under certain circumstances, actually produce the opposite effect (i.e. signal suppression).

Finally, there is a class of stimuli that have been referred to as *supernormal* stimuli. A supernormal stimulus is one that compared to other comparable stimuli, produces a disproportionate response. With a supernormal stimulus, there is some facet of the physical properties (e.g. combination of size and shape) of the stimulus for which there is an unusual sensitivity with the propensity to produce an amplified electrophysiological and behavioral response. Supernormal stimuli were first observed in animals (Enquist & Arak, 1998). Specifically, researchers discovered that sometimes animals would respond more strongly to the dummies used in their experiments than to the natural objects being mimicked by the dummies. For example, in a study of egg recognition in a species of bird known as the ringed plover, it was observed that birds preferred higher contrast dummies that were white with black spots than their actual eggs, which were brown with dark spots. Similarly, with another bird, the herring gull, it was observed that chicks pecked more enthusiastically at a rod with three white bars at the tip than to a realistic replica of the parent's bill and head.

In contrast to animal studies, there has been surprisingly little research to identify supernormal stimuli to which people respond. Human infants seem to find low frequency murmuring sounds to be calming. In a study by Hutt and colleagues (1968), infants were presented artificially-produced murmuring sounds that had a specified structure (i.e. square wave) and low frequency components. The skin conductance of infants was measured, which provided an indication of the infants' emotional response to the tones. It was observed that the artificially-produced tones produced more responses than an actual voice. Another example of supernormal stimuli in humans involves facial features. Humans are uniquely sensitive to faces and within the human brain, there is a region known as the fusiform gyrus that exhibits a specialization for processing images of faces, and face-like, stimuli (McCarthy et al, 1997). Our sensitivity to certain facial features was illustrated in a study that presented subjects with facial caricatures (i.e. cartoon-like drawings). To produce the caricatures, an average or prototypical face was obtained based on statistical analysis of numerous faces to derive a model containing twenty different physical dimensions along which human faces differ from one another (Brennan, 1985). A caricature was created by taking a drawing that faithfully depicted the facial features of former U.S. President Ronald Reagan and exaggerating specific features corresponding to dimensions from the model. When subjects were shown either a drawing with a relatively accurate representation of the facial features and the caricature, they were faster and more accurate recognizing the caricature than the drawing of the actual face (Dewdney, 1986). This study suggests that the face processing area within the brain is unusually sensitive to exaggerated facial features. Similarly, related studies have demonstrated a heightened sensitivity to other human physical features. For instance, men have been shown to exhibit preferences for females whose physical characteristics vary more significantly from the average male form, and vice versa with females preferring males whose physical features vary more strongly from the average female form (Ridley, 1993). In general, supernormal stimuli are based on naturally occurring, biologically-significant stimuli (e.g. the sound of a mother's voice, facial expressions or the physical form of a potential mate). For designers, there is an opportunity to emulate these physical forms as a means of creating contrast so that certain features of design standout from the surroundings. The key lies in appreciating which physical features of the naturally-occurring stimuli are essential to the brain's perceptual representation of the stimuli and the associated dimensions along which these features may be exaggerated to produce an amplified response. Then, the stimuli must be placed within an environment where the exaggerated features contrast with the physical features of other surrounding stimuli. It should be noted that this contrast is important because the exaggeration of physical features is relative, and if the environment is crowed with similarly exaggerated stimuli, the response to any one of these stimuli will be diminished.

Vulnerabilities arising from our perceptual processes

The previous sections have described how designers may use the physical properties of stimuli to enhance our sensitivity to those stimuli. These same properties may also be applied from an adversarial perspective. It is often the intent to avoid being conspicuous and conceal one's signals so that one does not draw attention and may go unnoticed. The same mechanisms that may be used to enhance the contrast between a signal and its surroundings may be applied in reverse to minimize the contrast so that a stimulus blends into to its surroundings. We see this with camouflage where there is an attempt to match the color, patterns and other physical properties of the surroundings. Likewise, if attempting to conceal a signal, one should avoid the properties discussed in the preceding sections that enhance sensitivity to a stimulus, such as engaging multiple sensory modalities or exaggerating key dimensions that underlie the sensitivity to a particular stimulus.

The exception occurs with mimicry. With mimicry, there is a known, or mimicked, signal that is either assumed to be harmless, or is associated with danger and is generally avoided. The known, or mimicked, signal may be quite conspicuous, as often occurs when it is associated with danger or some other hazard. The objective is not to avoid detection, but to deceive. Mimicry may be found in nature where to avoid being attacked by predators, one species assumes a form that resembles another species that is either poisonous or known to taste bad, or is dangerous and threatening. For example, with certain butterflies, black spots on their wings make them visually distinct. However, this coloration serves to repulse predators due to the black spots resembling eyes, creating the appearance of an owl or other large predator.

Internet phishing attacks can take mimicry to extraordinary lengths in an effort to confuse intended victims and induce them to inadvertently download nefarious software. In this case, the objective is to recreate the properties of a signal that would generally be considered harmless, and potentially, even helpful, or to disguise the phishing attack as a signal that would otherwise be trusted. Likewise, the same occurs with cyber social engineering where an individual presents themselves in a manner that convinces the victim that they can be trusted, or that they are harmless, and uses this trust to gain access to computer systems and facilities that they would not otherwise be allowed to access. In each of these cases, the secret lies in recognizing the critical properties of the signal being mimicked, which may be both physical (e.g. the corporate logos and layout of a phishing email or the appearance or demeanor of the person being mimicked) and social (e.g. the language used in a phishing email or the solicitous dialogue used in assuming the role of a dutiful computer network administrator), and faithfully recreating, and potentially exaggerating, those same signals.

One means of mimicry is to assume the identity of someone that would otherwise be trusted. In a study of email phishing, college students' social networks were combed to construct phishing email disguised to be from people within each student's social network (Jagatic et al, 2005). Students responded to 72% of the email that had been sent from the spoofed address of a friend, as compared to only 16% in a control group who received email from an anonymous individual. This finding illustrates the level of trust placed in personal relationships and how susceptible one can be when an adversary has the capacity to mimic an individual or group that would otherwise be trusted.

An analysis of phishing attacks reported to the Phishing Archive of the Anti-Phishing Working Group revealed a variety of approaches that take advantage of perceptual processes and have been used to deceive email recipients (Dhamija, Tygar & Hearst, 2006). These approaches included: (1) "typejacking" where the letters of a web address are substituted with letters that appear similar (e.g. in www.paypa1.com, the letter "I" may be replaced with the number "1"; (2) images masked as text where what appears to be text linking to a website is actually an image of that text with the image linked to a different website; (3) images mimicking windows where an image is presented that looks like a window or dialog box with buttons, menus and/or links, but the image is actually a surreptitious link; (4) windows masking underlying windows where an illegitimate browser window is spawned and appears either adjacent or overlaying the legitimate window; and (5) deceptive look and feel in which the user is presented a replica of legitimate logos or websites, which may contain links to download nefarious software, or data entry fields where users may voluntarily enter personal information.

Dhamija et al (2006) conducted a study in which they presented subjects either spoofed versions of actual websites or authentic websites and asked whether they believed the websites were real or illegitimate. They found that on average, subjects were fooled about half of the time, with there being no relationship between the likelihood of being fooled and the reported number of hours using a computer or experience using Internet browsers. It is particularly striking that the best spoofed websites fooled 90% of the participants, with one of these spoofed websites being that for a bank. This research illustrates the extent to which people are vulnerable to relatively simple mimicry within the context of their everyday lives. It should also be noted that this occurs despite mechanisms meant to lessen user's vulnerability to deceptive activities. For example, Dhamija et al (2006) reported that 68% of their subjects ignored pop-up windows warning them a website appeared to be fraudulent.

Decoys are a variant on mimicry. Often, a decoy may serve as a source of distraction. For example, in sports, an offensive team may want to confuse the defense by using a decoy that causes the defense to focus their attention on the wrong person. A common technique used in American football involves the quarterback faking a handoff to one of his running backs who runs at the defense drawing them away from the quarterback. As this occurs, the quarterback, who still has the ball, drops back pretending they are no longer part of the play, and then, once they have spotted a receiver who has run past the defense and is open, pulls out the ball and throws it to the receiver. In martial arts and other sports involving sparring, an important skill is to be able to execute an effective feint. A feint involves pretending to attack (e.g. pretending to throw a punch) and once the opponent moves to defend against the feigned attack, the attacker takes advantage of the resulting opening with their actual attack. For a feint to be effective, it should not only have the same perceptual properties as a real attack, but may exaggerate those properties to help assure it gets the attention of the opponent and ideally, elicits a reflexive reaction. In Shaolin-style Kung Fu, which is a sport in which I have participated for many years, one of my favorite techniques involves feigning a sweeping ridge hand to the side of the head. I execute the ridge hand with my lead hand as a big circular movement so that it not only can be readily detected, but draws their attention to the side. Then, my real attack comes from the rear hand and involves a reverse punch (i.e. palm of fist facing upward) to the abdomen, which the opponent usually never senses, since my decoy (i.e. the ridge hand) has drawn their attention away from their midsection. I have always believed that the key to the effectiveness of this technique lies in the exaggerated movement associated with the ridge hand. This example illustrates that a decoy may be made more effective by not only presenting the perceptual cues that normally trigger a response, but exaggerating those perceptual cues in a way that may begin to take the form of a supernormal stimulus.

What does the brain see when presented with a decoy? Essentially, it sees the same thing it would see if presented the object being mimicked by the decoy. In a study of the early stages of visual processing, Rees and Heeger (2003) presented subjects images of gratings composed of contrasting dark and light tiles that either did or did not contain an embedded figure. As subjects viewed the images and indicated whether they believed a figure was or was not present, fMRI measurements of their brain activity were recorded. Analysis of the fMRI data allowed the researchers to distinguish the patterns of activation in the visual cortex that corresponded to trials in which a figure was present (i.e. hits) from trials in which a figure was not present (i.e. correct rejections). The researcher then considered trials in which subjects made a false positive response meaning that they said a figure was present when the image did not actually contain a figure. In these trials, the pattern of brain activation matched that observed in the trials in which the subject correctly responded that a figure was present. Thus, from the perspective of the brain, there appeared to be no distinction between images in which an actual object was present and images in which an object appeared to be present, yet was absent. It may be conjectured that in the trials in which subjects exhibited a false positive, there were some elements of a figure present (e.g. a few tiles arrayed in a configuration that resembled a figure), but not the entire figure. In these trials, once the brain had detected a few cues that a figure might be present, it filled in the remaining details creating the sense that the figure was actually present. This same principle may be expected to apply with decoys. If the brain is presented with a few essential cues, it has the propensity to fill in the missing details creating the sense that the actual object is present, when in fact, it is merely a decoy.

Perceptual processes the brain does well

The preceding sections have addressed perceptual mechanisms that can cause an individual to misinterpret situations. Yet, with respect to perception, there are some activities for which the brain is surprisingly adept. In the following sections, I describe several of these innate aptitudes.

Associations between perceptual form and the actions afforded by an object

The brain has a natural capacity for recognizing how an object might be used based on its perceptual form. The association between an object's perceptual form and the actions made possible by the object is referred to as an affordance (Gibson, 1979). After standing for a long time, one may look around and recognize that any one of a number of surfaces offer a place to sit down. It might be a rock, a tree stump or a concrete divider. Each of these objects has physical characteristics that afford sitting. In particular, they are solid, have a relatively flat horizontal surface and are elevated from the ground enough to accommodate a seated posture. None of them are designed to be a chair, yet given the impetus to sit down, any surface with the right characteristics will be recognized to afford sitting, whether or not they were designed for this purpose. In fact, architects often incorporate these features into buildings or landscaping (e.g. slabs of concrete may be placed near ground level outside a building where people are expected to spend time milling about). Likewise, by observing the unintended uses of certain architectural features, it is often evident what unanticipated needs are being addressed by people in an ad hoc manner. For example, impromptu foot paths in otherwise grassy lawns suggest points at which designers did not appreciate the most efficient flow of foot traffic and provide suitable walking surfaces. As a result, seeing a surface that afforded walking, people created their own shortcuts. Within the brain, the motor cortex issues commands to the musculature of the body to enable us to carry out various actions. For common actions, memories form within the motor cortex (i.e. motor programs) that consist of the corresponding neuromuscular commands. It has been observed that when presented an image of an object that affords certain actions (e.g. a hammer), there is activation of the motor cortex comparable to the activation that would occur if the person was actually using the object (Buccino et al, 2009). Furthermore, merely looking at a picture of an object is sufficient to trigger activation of motor cortex. Through this activation, perceptual processes have the ability to prime the motor cortex readying an individual for the potential actions that an object might afford.

Affordance-based priming extends beyond physical actions to also occur through language. Costantini and colleagues (Costantini et al, 2011) showed subjects 3-D pictures of various objects. Afterward, the subjects were presented a verb and asked to indicate if the verb was appropriate for the object. The verbs either conveyed a function, a manipulation or an observation. For example, shown a drinking glass, the function verb would be "to drink," the manipulation verb would be "to grasp" and the observation verb would be "to look at." They found that subjects responded fastest to the manipulation verbs suggesting that images had primed the corresponding motor actions enabling the subject to respond slightly faster to these verbs. Interestingly, this effect was strongest when the 3-D objects were presented at a reachable distance, as compared to their being presented at a distance that was slightly out of reach.

Fischer and Dahl (2007) demonstrated that affordances can affect performance for tasks that bear no relevance to the actual affordance. Their subjects viewed a coffee cup that rotated so that the handle came in and out of view. Subjects were asked to indicate when a dot changed color. The dot was always at the center of the image and was always visible, despite the orientation of the cup's handle. Subjects responded fastest when the cup's handle was in view, as compared to periods when the handle of the cup was obstructed. These findings suggest a top-down influence in which the recognition of an affordance produced more efficient processing of perceptual features that had no relevance to the affordance.

The propensity for the brain to recognize and respond to affordances provides an opportunity for designers to use perceptual features as a means to both ready individuals for forthcoming actions, as well as to attain higher levels of task engagement. Affordances are a wonderful tool that used judiciously, can enhance design by engaging users through the triggering of unconscious perceptual-motor processes. Affordances may also provide a basis for influencing the behavior of an adversary. For instance, by providing a forum that facilitates and encourages communication, accompanied by an admiring audience, one might be lured into divulging sensitive or incriminating information. This can be seen in situations where criminals are identified as a result of their having boosted of their deeds within the context of an online community. In other cases, an affordance may serve as a distraction. For example, in the design of medieval fortifications, often passageways were designed in a maze-like configuration where paths often double-backed on one another as a means to delay an adversary's assault and lure them into traps or ambushes. While an affordance may not always be sufficient to elicit the desired response from an adversary, often the mere suggestion should be sufficient to cause indecision, and in the right circumstances, achieve an effective misdirection.

The brain orients toward moving stimuli

The capacity to recognize moving objects is one of the most basic mechanisms by which perceptual processes contribute to the survival of many animal species. We are uniquely sensitive to movement. With vision, our eyes are automatically drawn to moving objects. Similarly, a moving sound source or tactile stimulus can readily elicit an orienting response. Moving stimuli are not merely detected, but there is a special significance assigned to them that often results in their entering our conscious awareness, even if for a fleeting moment (e.g. the fleeting awareness of an insect flying past our face), while equivalent stationary stimuli go unnoticed.

Our heightened sensitivity to movement allows us to quickly recognize those facets of our environment that are dynamic and changing, and consequently, may signal the need for an imminent response. Furthermore, movement is interesting and stimulating. Adults and infants will preferentially turn their attention to a moving object, with multiple independently moving objects being more interesting than a single moving object or multiple moving objects that move in unison (Rochat, Morgan & Carpenter, 1997). There is a specific region within the visual cortex that may be distinguished from surrounding regions due to it sensitivity to moving stimuli (Watson et al, 1993). However, the brain does not merely respond to movement, but there are areas that differentially respond to objects moving at different velocities (Orban, Kennedy & Maes, 1981). The visual perception of movement is quite complex due to the timescale at which the neural circuitry of the brain must operate. Specifically, in the 30-100 msec required for cells in the retina to convert light energy into neural signals and the subsequent relay of those signals from the eye to the brain, an object may move a considerable distance. This problem is resolved through mechanisms that allow both the cells of the retina, as well as the visual cortex, to anticipate the direction of an object's movement producing a minimal delay in their response (Berry et al, 1999). Yet, the perception of movement goes beyond the immediate psychophysics of the stimulus. Moving stimuli can evoke activation of brain regions associated with inferring the intent and mental state of other individuals (Castelli et al, 2000). Thus, embedded within our perception of movement, there is an appraisal of the relevance of the movement to one's self based on attributions concerning associated intentions and causation.

Movement can be used to make design more engaging. For example, with computer screen savers that cycle through a series of pictures, the software feature that simulates a camera panning across the images has an effect that is surprisingly compelling. In this case, the object of the picture does not move, but instead, the perspective changes, which often creates an illusion that the object in the picture is moving. Likewise, I have seen the animation features within PowerPoint used with tremendous effectiveness to illustrate the dynamic aspects of a topic (e.g. the flow of information through a system or an organization). However, movement for the sake of movement can often backfire. I cringe when I see a presenter use animation to make the content of their PowerPoint slides enter and exit like performers coming on and off stage. Movement not only captures an audience's attention, but can be quite compelling when it emulates something that actually does move through space. However, when movement is attributed to objects for which movement is not an inherent characteristic (e.g. bullet points on a PowerPoint slide), the movement is distracting, and an annoying source of unnecessary sensory stimulation.

Movement suggests something is changing. From an adversarial point of view, it forces the opponent to pay attention. Movement can serve as a source of distraction, drawing attention away from more critical activities. Following an extended period of inaction, it may be assumed that sensitivity to movement will be at its greatest. This is particularly true if the movement occurs within a context of uncertainty. Perhaps, more importantly, movement may or may not be of significance. As discussed previously, a good decoy captures the attention of an opponent.

However, an even better decoy sustains their interest. Movement may cause an opponent to attend to a decoy, but if the opponent must then devote additional resources to ascertain whether the movement is of significance to them, the decoy has occupied the time and resources of the opponent, and distracted them from other activities. However, the ultimate decoy not only sustains attention, but misleads the opponent, causing them to infer false patterns or intents, based on a sequence of movements. The key is to tap into the brain's unique sensitivity to movement and predilection to see movement, sometimes any movement, as a signal that something of importance has changed.

Certain stimuli have a biological significance

A previous section discussed supernormal stimuli which are a class of biologically-significant stimuli that are marked by their capacity to evoke a disproportionate response, relative to other comparable stimuli. Biologically-significant stimuli involve objects or actions that have been ascribed special significance due to their criticality to the survival of an animal species (e.g. a gosling's capacity to imprint upon its mother). There are various stimuli that seem to have a biological significance to humans and thus, we exhibit an innate capacity for recognizing corresponding patterns of sensory stimulation.

Many of the stimuli that might be classified as biologically significant involve objects that evoke fear, or a general unease. For example, the experience of a physical drop-off or cliff presents a somewhat universal approach-avoidance dilemma. There is a curiosity and allure to experiencing an expansive view of the surroundings, but an accompanying uneasiness that may be accompanied by mild dizziness, weakness in the knees and even, heart palpitations, as well as mental images of going over the edge and falling to one's death. In a recent paper, Stefan Bracha (Bracha, 2006) described four types of fear-related brain circuits that are each rooted in different stages of human evolution and highlight separate classes of biologically significant stimuli. The first type is the Mesozoic or mammalian-wide fear circuits. These are the most deeply rooted and presumed to be shared by all mammalian species. The fear of heights falls into this category, with there being extensive evidence accumulated since the original visual cliff experiments (Gibson & Walk, 1960) to establish that this fear is manifested in the absence of prior learning experiences (Poulton et al, 1998). While it has been noted that some individuals exhibit a capacity to effectively operate in high places (e.g. skyscraper construction workers), the apparent absence of a fear of heights seems to run in families and is difficult to acquire by non-blood relatives. Throughout the centuries, there have been examples where people have taken advantage of the human proclivity to fear long drop-offs by constructing fortifications on high mountain tops where an aggressor would be forced to mount their assault on precarious terrain, confronting their fear of heights at every step.

While we generally think of separation anxiety within the context of young children, it has been argued that it reflects a deeply rooted emotion-motivation system that influences behavior throughout a lifetime. Specifically, Fisher et al (2002) described three such emotion-motivation systems that are each mediated by a different corpus of neurotransmitters within the brain: (1) lust, which evokes courtship behaviors; (2) attraction, which steers one to appropriate mates; and (3) attachment, which leads to greater parental involvement in caring for children. Bracha identified separation anxiety as a Mesozoic mammalian-wide fear circuit pointing to the evidence of separation anxiety in the young of mammalian, and even marsupial, species.

However, as discussed by Fisher and colleagues (Fisher et al, 2002), separation anxiety can be seen as the avoidance end of an approach-avoidance continuum that serves to promote enduring bonds. Conceived of as an approach-avoidance continuum, each of the three emotion-motivation systems described by Fisher et al may be leveraged as either a means to promote certain behaviors and at the same time, diminish the likelihood of other behaviors. For example, in relation to attachment, online social media sites such as Facebook promote the development of communities and through “friending” and “liking,” allow users to cultivate and sustain enduring relationships, and at some level, satisfy their needs for affiliation. In contrast, a popular mechanism being used by spammers inserts a message onto a webpage altering the user that they have been “unfriended” by several individuals. Rejection, and its extension to banishment and exile, evokes profound emotions in people. The spammers use these emotions to capture the attention and lure their victim offering the promise that they can find out exactly who has rejected them. The ability of these mechanisms to elicit a reaction in individuals, many of whom may not even participate in online communities, illustrates the capacity to provoke a behavioral response through signals that trigger brain circuits underlying the emotional and motivational foundations of attachment.

The second type of fear circuit is the Cenozoic or simian-wide fear circuits. These fears are shared by all of the great ape species (i.e. gorillas, orangutans, chimpanzees), as well as lesser apes (i.e. gibbons) and many species of monkey. Included in this type is the fear of snakes and reptiles. The innate propensity to fear these animals was demonstrated in studies by Cook and Mineka (Cook & Mineka, 1989; 1990) which used laboratory-bred rhesus monkeys that had never had any experiences outside of the laboratory. One group of monkeys observed a video in which other monkeys exhibited a fear response to either a toy snake or a toy crocodile. Later, when presented with either the toy snake or toy crocodile, these monkeys reacted fearfully. In contrast, a second group of monkeys were shown a video in which other monkeys exhibited similar fearful responses to either a toy rabbit or an artificial flower. After observing this video, the monkeys did not behave fearfully when they were later exposed to the same toy rabbit or artificial flower. These studies reveal a biological preparedness to recognize and fear certain animals. Related to this fear, Bracha (2006) also includes the preparedness to respond fearfully to teeth and being bitten. With most primates, the primary means for attack involves biting, which is also true for many of the animal species that might prey on humans. Consequently, an image of sharpened teeth and fangs has the capacity to evoke an emotional response, and similarly, showing one's teeth serves as a universally recognized expression of aggression (Ekman, 1993).

Cenozoic or simian-wide fears also include fear of the dark and fear of confined spaces. While the human visual system is not well suited for nighttime activities, our response to the dark seems to go beyond mere practicality. This is evidenced in the connotations associated with darkness. Darkness is associated with evil, as in "the Dark Lord," and misfortune as in "these were dark times." The color black carries the same connotations. It might be said that someone has "a black heart." Likewise, black attire has traditionally been used to convey a sinister quality. For instance, adversarial hackers are referred to as "Black Hats." The discomfort that is often experienced in response to confined spaces has been linked to the sensation of being trapped and having nowhere to escape (Kendler et al, 2001). Within a confined space, flight is not an option. Similarly, this fear also manifests itself within our common language. We talk about “the world closing in on” someone that has run out of options or a person being “trapped” and having “nowhere to go.” These expressions tap into a universal recognition that darkness and confined spaces, which may often occur together as with a cave, basement or prison cell, present danger, and should be avoided.

Bracha (2006) mentioned two additional Cenozoic or simian-wide fears, both of which harken back to an earlier section of this chapter concerning the breadth of our senses, including the capacity to sense the internal states of our body. One of these fears is triggered by elevated carbon dioxide or CO^2 levels in the body and is associated with the sensation of suffocation. This fear is somewhat related to another simian-wide fear discussed by Bracha, the fear of being immersed in water. Again, there is a remarkable approach-avoidance spectrum where at one end, there is a strong attraction to water with respect to play and bathing, yet many rituals involve having one’s head dunked in water, in some cases symbolizing the act of cleansing (e.g. Christian baptism) and in others, the act of drowning (e.g. hazing-related activities). Furthermore, waterfalls convey a unique symbolism in that they simultaneously portend the experience of being swept away in a rapid rush of moving water and falling over the edge of a steep cliff. Still, despite having all the ingredients to evoke a fearful reaction, large dramatic waterfalls are an enormous attraction for tourists throughout the world.

The second of these internally-based simian-wide fears is induced by lactate accumulation resulting from extended physical exertion. In certain individuals, high lactate levels can trigger a panic attack with profuse levels of anxiety and associated physiological reactions (e.g. sweating, accelerated heart rate). While lactate-induced panic attacks are somewhat uncommon, most people are familiar with the sense of helplessness that accompanies conditions when the body reaches a level of physical exhaustion such that it is impossible to continue with activities.

The next class of fears identified by Bracha (2006) is believed to have arisen late in the evolutionary history of the human species and is referred to *Homo Sapien*-specific. These fears would have arisen following the split of humans from the other great apes and reflect conditions that uniquely affected early humans. Bracha discusses the fear of blood-letting as one illustration. People are unusually sensitive to bloody images and often exhibit anxiety in association with receiving a shot or having blood withdrawn that exceeds what would be proportionate to the actual pain experienced. Modern horror movies highlight graphic depictions of bloody violence and it is generally this quality of the visual imagery that distinguishes relatively tasteful depictions of violence (e.g. the battlescenes in Peter Jackson's Lord of the Rings trilogy, which featured few images of human blood) from depictions of violence that many find senseless and unnecessarily horrific (e.g. the gorier scenes from movies by Quentin Tarantino). Likewise, common folklore highlights occurrences in which otherwise strong individuals succumb to vomiting and feinting. For example, the story of William Kemmler, who was the first person executed in an electric chair, tells of the unexpectedly intense convulsions resulting from the initial unsuccessful application of electrical current and how trained medical observers vomited and had to leave the room.

Also included in the *Homo Sapien*-wide fears are those implied by certain compulsive behaviors that occur with unusually high frequency within individuals seeking clinical care for obsessive-compulsive disorders and certain phobias. It should be noted that in most of these cases, the compulsive behavior involves an exaggeration of a behavior that otherwise, is highly adaptive. Bracha (2006) identified the following examples of unusually common compulsions and phobias:

- *Compulsive lock-checking* – barriers and security have a special significance for people and there is a profound sense of violation associated with the experience of someone, or some creature (e.g. wild animal) intruding upon one's domain. Stove-checking is another common compulsive behavior that similarly emanates from anxiety associated with the security of one's dwelling.

- *Compulsive washing/cleaning and obsessive fear of contamination* – human excrement has been a common mechanism for the spread of disease within human populations, historically, as well as in modern times. Consequently, a deeply rooted concern for cleanliness and a common reaction of disgust in response to the smell and sight of human excrement would seem natural.

- *Compulsive hoarding* – human archeological sites reveal that hoarding appears to be a long-standing pattern of behavior in humans. For example, human Paleolithic sites often contain large hoards of stone tools and axes that exceed what would actually be needed, based on the estimated size of the group inhabiting the site (LeBlanc & Register, 2003). This pattern of behavior has been linked to the prevalence of warfare in ancient humans. With regard to the hoarding of food and other objects essential to daily survival, hoarding may represent an otherwise adaptive pattern of behavior in response to past and anticipated shortages. Whether the hoarding of weapons, as is more common in men, or the hoarding of food and clothing as is more common in women (Samuels et al, 2002), hoarding is an intrinsic behavioral response that is prone to arise in response to certain conditions (i.e. suspected threats or potential shortages).

- *Irrational fears of insects and mice* – as noted above, the hoarding of food is adaptive as a means of preparing for anticipated shortages. However, food caches generally attract insects, and mice and other small rodents. These animals drawn to human food caches are also prime mechanisms for the transmission of disease. Thus, a distaste for insects and small rodents reflects a response to conditions that might undermine one's own health and that of their family.

- *Irrational fears associated with social situations* – the fear of being in the presence of strangers or the fear of meeting new people lies at the root of commonly reported social phobias. Within human history, the experience of

> being in the midst of a large group of non-blood related individuals, especially individuals who differ from one's self, while being observed and scrutinized by them, would generally warrant some degree of anxiety. However, in modern civilized societies, this same anxiety may be amplified to the point that it becomes a source of dysfunction.

Other research has addressed biologically significant stimuli that are not linked to fear circuits and approach-avoidance continuum, at least not to the extent of those identified by Bracha (2006). For instance, it has long been established that humans are uniquely sensitive to the visual patterns associated with a human gait and can easily distinguish a pattern corresponding to someone walking from other seemingly similar patterns (Johansson, 1973). Similarly, there is pronounced sensitivity to looming stimuli consistent with a rapidly approaching object that has been demonstrated at very early stages of development (Schiff, 1965).

From the perspective of a designer, there is the opportunity to incorporate biologically significant stimuli into design as a means to shape behavior associated with one's product. This is particularly true for the biologically significant stimuli discussed by Bracha (2006) in that these stimuli imply approach-avoidance continuum. The fears that are somewhat universal across human populations emanate from stimuli that have a shared significance, accompanied by privileged access to the neural circuitry underlying our experiences of fear, anxiety and uneasiness. At the same time, many of these fears present an inverse that lies on the approach end of the continuum, which may be employed to enhance the attractiveness of a product. For instance, objects placed at the center of a mass, as opposed to being positioned next to an edge, convey the sense that the object is solidly supported. In contrast, a sense of tension may be created by placing objects adjacent to an edge, particularly where there is an extended drop-off.

Likewise, within social settings, whereas one is easily put off by situations that involve forced interactions with strangers, this can be alleviated through mechanisms that highlight the similarities and common interests of individuals (e.g. common uniforms, mechanisms that indicate shared acquaintances or similar backgrounds).

We adjust to the habitual, and become sensitized to the provocative

In my office, I have a speaker and docking station that allows me to continuously play music from my IPod. I always have the speaker set to a relatively low volume so my music does not disturb the people in the adjacent offices. On a daily basis, I have an experience that never fails to amaze me. I will step out of my office to pick up print outs from the printer down the hall or talk to a colleague, and when I return, I will be unable to hear the music coming from the speaker. Then, after waiting a minute or so, I'll start to hear the music again. There are continuous background noises in my office from the fluorescent lights and ventilation system. This background noise is sufficient to drown out the music coming from the speaker. However, it takes only a minute or so for me to habituate to the continuous background noise and once my auditory system has habituated, I can once again hear the sounds coming from the speaker. This example illustrates a basic principle of the human sensory systems. There is a propensity to habituate to continuous stimuli, particularly when those stimuli convey little or no meaning.

When a stimulus occurs repeatedly (e.g. auditory tone, visual pattern), it begins to trigger less and less activation of cortical regions associated with processing the stimulus. For instance, when subjects are shown a visual pattern repeatedly, there is a reduction in the activation observed within the occipital, or visual, cortex (Hakan et al, 2000). Interestingly, this reduction in cortical activation is accompanied by an increase in activation of the thalamus, a region of the brain associated with early processing and subsequent relaying of sensory information. Hakan et al (2000) suggested that the thalamus might operate to modulate the activation of upstream cortical circuits in response to redundant stimuli. Yet, despite there being a muffled response to redundant stimuli, the brain continues to process the stimuli and is sensitive to unexpected changes (Naatanen et al, 1989). When the brain is presented a redundant stimulus (e.g. a recurrent tone of a specific volume and frequency) and unexpectedly, there is some change to the stimulus (e.g. the tone becomes louder or switches to a higher or lower pitch), there is a pronounced wave of activity that extends across much of the brain. This phenomenon has been referred to as mismatch negativity and it has been reported for many different types of stimuli. The brain appears to both habituate to redundant stimuli, but at the same time, it is unusually sensitive to any change in a stimulus. Furthermore, it has been shown that habituation not only occurs with perceptual processes, but there is also habituation in brain regions that underlie the formation and retrieval of memory, specifically the hippocampus (Grunwald et al, 2003). This habituation is manifested in a similarly diminished response following repeated exposure to cues triggering memory retrieval. However, habituation within the neural circuits that give rise to memory manifests on a much slower timescale than habituation associated with perceptual processes. Consequently, stimuli that one may no longer respond to at a perceptual level may continue to trigger activation of neural circuits associated with memory and become incorporated into the memories that are being established of corresponding experiences.

For the designer, it can be assumed that there will be habituation in response to features of a product that are relatively insignificant. However, this will only occur if the features remain constant. Any change in these same features will not only evoke a response, but will trigger an orienting response that calls attention to the feature. For example, this often occurs as features of a product begin to wear down due to age or excessive use. Thus, straps, mountings and supports that go unnoticed throughout the early lifespan of a product may break, loosen or become discolored and as a result, become a focal point and potential source of discontent with the product. I have had this experience with a camera for which the wrist strap began to periodically become loose. For most of the time that I have owned the camera, I never thought about the wrist strap. However, once it became loose, every time I used the camera I would instinctively tighten the wrist strap, until eventually, the strap fell off and I lost it. In this example, I never thought about the wrist strap. But, once it became loose, it became a source of annoyance and I constantly attended to it.

The inverse of habituation is sensitization. With sensitization, there is an amplified response following repeated exposure to a stimulus. The distinction between habituation and sensitization primarily lies with the significance of the stimulus. Habituation occurs when a stimulus is relatively insignificant (e.g. the background noise in my office). In contrast, sensitization occurs with stimuli that are somewhat meaningful. For instance, there will be sensitization in response to stimuli that produce pain or discomfort. A piece of clothing that does not fit well or chaffs will become increasingly uncomfortable over time. A person who has irritating habits will find that others are less and less tolerant of them as they become increasingly sensitized to the annoying behavior. In general, following repeated exposure to a stimulus, the brain becomes increasingly less responsive to stimuli of little significance, while it becomes more responsive to stimuli that are significant.

Much of the research concerning sensitization has concerned stress and addiction. With stress, as has been often described in the context of Post-Traumatic Stress Disorder, one becomes sensitized to stimuli associated with a traumatic experience and as a result, those same stimuli, or similar stimuli, elicit a disproportionate response within the brain (Stam, 2007). In addiction, there are various cues associated with the addictive behavior, with addicts becoming sensitized to these cues. As a result of this sensitization, the cues that the addict has associated with their addictive behavior are amplified to the point that they become difficult to ignore, leaving the addict unable to resist the urge to satisfy their addiction (Robinson & Berridge, 1993). For example, an individual attempting to recover from a gambling addiction might find that merely being in the vicinity of a casino, with the surrounding context, is enough to squash their willpower and overcome their intentions to restrain from further wagering.

With sensitization, there is an amplified brain response to stimuli that extends over broad regions of the brain. In a study conducted by Hugdahl and colleagues (Hugdahl et al 1995), subjects participated in a standard classical conditioning paradigm in which a tone was presented in combination with an electric shock. Once subjects had learned the association between the otherwise neutral tone and the aversive stimulus, the electric shock, mere presentation of the tone was sufficient to elicit broad activation of the right cerebral hemisphere of the brain. As a result of the electric shock, the subjects had become sensitized to the tone and exhibited a pronounced response that engaged many different regions of the brain. Sensitization appears to be largely rooted in the arousal mechanisms of the brain. A stimulus for which one has become sensitized activates neural circuits associated with perceptual processes, but additionally, activates arousal mechanisms within the brain. This has been demonstrated through research showing differential activation of regions of the brain stem associated with arousal in situations involving sensitization to pain (Lee et al 2008). Thus, with sensitization, due to the influence of arousal, activation associated with perceptual and other related neural processes is intensified.

Generally, sensitization is associated with negative consequences and is something that a designer would seek to avoid. Consequently, where one might anticipate there being discomfort, displeasure or pain, a designer might seek to isolate aspects of the design for which they have responsibility so as to minimize formation of associations with the unpleasant experience, and the resulting sensitization. Such association can doom a product or experience. With sensitization, individuals may become hypersensitive and any annoyance, whether related or unrelated to the product or experience, may be sufficient to evoke negative feelings.
However, sensitization may also be used to achieve design objectives. For instance, where there are experiences that are known to be enjoyable, one might expect to see some degree of sensitization for stimuli associated with those experiences. Thus, certain peripheral experiences become part of the pattern of behavior that leads to the sought after experience. For example, going to an amusement park or sports arena is generally associated with positive, enjoyable experiences. By placing one's business such that it is on the path of those visiting these venues and can become a peripheral part of their routine, there is an opportunity to capitalize off of the positive experience. As a result, a certain satisfaction may be attained by simply going through peripheral parts of the routine (e.g. eating at the restaurant or having a drink at the bar that is on the way to the ballpark), even if one does not actually intend to visit the park or attend an event.

A second means by which a designer may apply sensitization to achieve design objectives relies on the arousing properties of stimuli for which there has been sensitization. Stimuli for which one has become sensitized evoke a generalized arousal. This can be effectively put to use in situations where one wants to get peoples' attention or assure people are alert. For instance, a standup comedian, or any other presenter, might begin their presentation with a provocative assertion. The comedian may care nothing about the assertion and it may be irrelevant to their subsequent material, however it serves to get the audience's attention. While such techniques can quickly become ineffective, if used sparingly, and with care, one can take advantage of topics for which there is considerable sensitivity as a means to get people's attention and assure that they are alert.

We fill in the pieces and see the whole

The term *Gestalt* has become incorporated into common vernacular to convey the idea of seeing the whole of any object or situation, rather than the mere collection of its parts. More formally, this idea has been expressed as a collection of principles that describe various perceptual phenomena (e.g. the *Law of Proximity*, which says similar objects that are close to one another will be perceived to constitute a group). Yet, in general, it is a basic property of the brain that when presented various pieces of a recognizable figure, the brain fills in the missing pieces and perceives a whole figure.

One of the most common illustrations of the Gestalt principles of perception involves what is referred to as a bistable figure. A classic example is the Rubin vase which depending on one's perspective, the figure appears as either a vase or two faces looking toward one another. Within the brain, fast frequency, gamma band activity is associated with active perceptual or cognitive processing. When the Rubin vase, or other bistable figures, is rotated, there is an orientation at which the vase or faces are seen most clearly. Within the visual areas of the brain, gamma band activity increases when the figure is in the vertical orientation that most clearly affords seeing either the vase or the two faces (Keil et al, 1999). This indicates an increased coordination of fast frequency neural activation when the figure appears at an orientation at which specific objects are perceived, in contrast to other orientations of the figure in which no discernible object is perceptible. Furthermore, as demonstrated using the Kanizsa square (i.e. a figure with four darkened circles arranged in a grid with slices removed from each circle so as to suggest the image of a square), the increased coordination of activity is combined with an amplification of activity in response to perception of the square (Hermann & Bosch, 2001). This research demonstrates that given perceptual ambiguity, the brain tends to separately process the various elements of a scene, but once the brain is able to put the pieces together to form a recognizable object or shape, there is both an amplification and coordination of the corresponding neural activation.

Where the common experience of an object involves multiple sensory modalities (e.g. the sight and sound of an object), the propensity to fill in the missing pieces spans the relevant sensory modalities. In a study reported by Meyer and colleagues (Meyer et al 2010), subjects were presented video clips without sound of objects that produce distinct sounds. It has been demonstrated that within the auditory regions of the brain that process sound, the memories for the sound of objects from certain categories of objects are localized to specific areas. For example, memories for the sounds made by different animals will be grouped together within a distinct area of the auditory cortex. Likewise, the sounds associated with different musical instruments will be grouped together. For this study, the researchers used three categories: animals (e.g. howling dog, mooing cow, crowing rooster); musical instruments (e.g. violin, bass, piano) and general objects (e.g. chainsaw cutting wood, glass vase shattering, coin being dropped). Each of these categories of objects could be distinguished on the basis of their activating a specific area of the auditory cortex. When subjects viewed the video without sound, it was observed that there was activation in the region of the auditory cortex that would ordinarily have been activated in the presence of the corresponding sounds. For example, when watching the muted video of the dog howling, there was activation in the area that would have been active had the subject been presented the sound of a dog howling, without the video. Here, the brain had expectations that spanned multiple sensory modalities, and when only one modality was presented, the brain filled in the missing pieces.

There is a risk for the designer in that pieces that inadvertently suggest certain patterns may be connected to give rise to perception of objects or symbols that are not relevant to the actual design, and may serve as a basis for distraction or misinterpretation, or even offend the sensitivities of some. For instance, there is almost no limit to the objects that have been attributed phallic symbolism due to their shape and there are frequent occurrences in which it is pointed out that architectural features contain patterns that resemble the Nazi swastika.

On the other hand, there is an artistic allure to designs that imply, yet do not actually depict familiar symbols or patterns. Yet, perhaps more practically, the capacity of the brain to fill in missing pieces offers an opportunity for economies in design. This is well illustrated with simulation-based training where to reduce costs, the key features of a system are replicated, but many details are omitted. For many occupations, there is a desire to train individuals in conditions that closely resemble actual operations, however while actual operations may be simulated with tremendous fidelity, this comes at a great cost. By using low and medium fidelity trainers that do not replicate many details of an actual system or actual operations, training may be offered at a much lower cost. I have often been asked to comment on the importance of fidelity, or the extent a simulated system matches the real system or actual operations, in simulation-based training. Speaking solely from the perspective of our knowledge of the brain, I can say that there is a propensity for the brain to fill in the elements missing in low and medium fidelity simulators. However, the key point is that the trainee must have sufficient experience with the actual system to expect those elements that have been omitted in the simulator and fill in the missing pieces. This suggests that for experts, there may be little effect on training benefits with low and medium fidelity simulators because these individuals know what to expect and their brains fill in the missing pieces. In contrast, the novice does not know what the experience of the actual system should be and will be unable to fill in these missing elements. As a result, the novice is more likely to be surprised when their experiences with the actual system do not correspond to the experiences they have had during training using a simulation-based trainer.

Brains naturally categorize

If every object was distinct and it was necessary to appraise every object individually, this would make our everyday lives intractable. The brain has greatly simplified the problem through categorization. If an object can be recognized as the member of a known category, then all the knowledge that has been accumulated concerning this category can be attributed to the object. Suddenly, seeing an object for the first time, one may draw upon all the knowledge of the object they have acquired over their lifetime. For example, birds are common objects for which almost everyone has some familiarity. When we go to the zoo and see a species of bird that we have never seen before, we know what to expect. We know that they have wings and can fly, and that they lay eggs and raise their young in a nest. Actually, it is the exceptions to the category that generate interest (e.g. birds that do not fly) and we take notice of evolutionary vestiges, like the wings possessed by chickens and other birds that have lost the capacity for flight.

When presented a familiar object, there is activation within the brain corresponding to the neural circuits that underlie our knowledge of that object. Generally, this activation is quite diffuse spanning broad regions of the brain. However, using brain imaging techniques, it may be observed that brain activity tends to be most intense within specific areas. There have been numerous reports that illustrate that areas may be isolated that are activated by specific categories of objects (See Thompson-Schill, 2003 for review). For instance, in one of the earlier studies (Spitzer et al, 1995), subjects were shown pictures of different items from one of four categories (i.e. furniture, fruit, animals or tools) and asked to name each object. When comparing the brain regions that were most active, it was found that there was a somewhat different pattern of activation for each of the four categories. The regions activated varied for each subject, with this attributable to life experiences having differentially shaped the brains of each individual. However, during tests administered on different days, the areas activated by a given category were essentially the same for a given subject. Other studies have reported similar findings comparing activation to living versus non-living objects (Mummery et al, 1996), animals versus tools (Martin, et al, 1996), and animals, tools, faces and houses (Chao, Haxby & Martin, 1999). These findings indicate that the brain not only distinguishes between objects, but makes distinctions based on the similarity of objects with regard to known categories, with these distinctions evidenced through there being somewhat localized activation of brain regions associated with different categories.

More recent research has suggested that the dimensions along which categories of objects differ are reflected in the organization of the brain areas activated by these objects (Connolly et al, 2012). In one study, fMRI was recorded as subjects viewed images of 6 different species of animals, with two each from the subordinate categories of primates, bugs and birds. In a second study, there were 12 species with four each from the categories of mammals, reptiles and bugs. When the regions activated by each subordinate category were compared, there were two primary dimensions. One spanned from primates to bugs and the second spanned from mammals to bugs. Interestingly, primates and mammals were close to one another and closer to areas found to be associated with animate or living objects. In contrast, bugs were more distant and closer to areas found to be associated with inanimate objects. Thus, a primary dimension along which categories of objects differ seems to involve the degree to which we think of the objects as a living being similar to ourselves, as opposed to being more like an inanimate object.

Within the brain, the organization of different categories of objects is somewhat dynamic and reflects learning that occurs over the course of a lifetime. These categories embody both the perceptual properties of objects and their semantic relationships to similar objects. The propensity to form categories and then, differentially respond to the world in relation to these categories is an intrinsic property of the brain. Furthermore, it is an ongoing work-in-progress with new categories being formed and existing categories revised, with a continuous reorganization of the corresponding neural circuitry (Linden, Turennout & Fernandez, 2011; Carlson et al, 2012).

Placed in a given environment, an individual will invariably cope by calling upon their categorical knowledge of the world. They will look at objects, people and situations and relate them to categories that are already known and react to them accordingly. Yet, at the same time, they will update and revise their knowledge of the world based on these experiences. This may entail the formation of new categories, or the refinement and elaboration of existing categories. From a design perspective, our understanding of systems, products and experiences has an underlying categorical organization. However, in the earliest stages of design, the product has not been realized making it necessary that the designer imagine the ways in which people will interact with their design. Ideally, design would embody the mental model of the designer and that mental model would both correspond to the mental models of the people interacting with the product and people would not see the product in ways that do not comply with the mental model of the designer. In reality, the categories people use to organize the world may not comply with those of the designer. Furthermore, the ways in which people engage with a design may vary from that imagined by the designer resulting in their developing a mental model of the product that is contrary to that of the designer. Through their interactions with a product, people will infer relationships and sense patterns, and based on these relationships and patterns, form an understanding of the product that will guide their beliefs, expectations and interactions with the product. Furthermore, over time, this knowledge will become increasingly crystalized to the point that it may become difficult to see the product in any other way.

What can the designer do? First, one might leverage existing commonly-shared categorical relationships. For example, stores are generally organized so that there are separate sections for men's, women's and children's clothing, which leverages the fact that in our homes, families usually keep their clothes separate. Second, one might structure design to facilitate formation of certain categorical knowledge, while discouraging formation of irrelevant categorical knowledge. Within a graphical user interface, related functions may be grouped together and non-related functions separated requiring the user to open a new window or menu to access those non-related functions. This serves to tell the user that these items are of the same category and these other items are different. Third, where practical, people may be allowed the opportunity to customize the design in a way that makes sense to them with respect to how they use the product. For example, the desktop environment of most computing systems allows users to place the objects they want on the desktop and organize them in a way that makes sense to them and corresponds to how they use the system. Finally, there is much to be said for keeping the design simple so that one minimizes both the need and the potential for the development of complex and diverse, and perhaps inappropriate, categorical understandings of a system.

How to trick, confuse and otherwise baffle the brain

The objective with system design is generally to recognize and orient human-systems interactions to take advantage of the intrinsic strengths of the perceptual systems and avoid interactions that rely on activities for which human perception is ill-suited. It is worthwhile to consider the inverse. One might ask, "How might I present a signal that is well within the bounds of what the human perceptual systems can sense and recognize, yet will likely go unnoticed?" In other words, setting aside the earlier discussion of decoys and mimicry, how can one take advantage of the weaknesses inherent to human perception?

Imagine the intent is to conceal an auditory signal. For example, one may want to signal their presence and intent to an ally without an adversary knowing about it. First, if the same sound is being emitted from different locations, it becomes difficult to distinguish one instance of the sound from another. Likewise, if there are different sounds being emitted from the same location, it may be difficult to separate the sounds and recognize the one that is serving as a signal. Both of these mechanisms take advantage of limitations in the ability to segregate sensory stimulation. It can be confusing when the same sound comes from different locations or when the sound for which one is listening must be distinguished from other sounds that are all originating from the same location.

Second, one can assume that an adversary is sensing patterns, whether this is occurring at a conscious or unconscious level. Thus, as the predictability of a signal increases, it will become more easily recognized. Yet, to successfully conceal a signal, one must strike the right balance. The presence of a discernible pattern within a stimulus will draw attention to the stimulus. However, an unpredictable signal, within the context of an otherwise predictable background, will also draw attention to the signal. Consequently, the regularity in a signal should mimic the regularity naturally present within the background such that the regularity in the signal is indiscernible.

Third, people are sensitive to boundaries. Boundaries demarcate the beginning and end of meaningful units. Distinct stops and starts within a signal serve as boundaries and alert a listener to the beginning and end of something that may potentially be meaningful. To conceal a signal, continuity, with there being no distinguishable starts and stops, will deny the listener the boundaries that would otherwise facilitate their ability to recognize the presence of a signal. Similarly, the presence of dead spaces where there is little or no stimulation creates a contrast against which any signal that intrudes will be particularly noticeable. Thus, the broadcasting of a signal should be timed and placed so that it does not coincide with a dead space. In this regard, one might also create continuous background noise that has the effect of eliminating the presence of any dead spaces.

As previously noted, it can be difficult to isolate a specific signal when similar sounds are being emitted from multiple sources. Likewise, a moving source can be difficult to discern. Distinguishing the “what” of the signal and the “where” of the signal involve somewhat different perceptual mechanisms. In challenging situations, while it may be possible to discern one, it can be difficult to simultaneously discern both. Consequently, when the signal is emitted from a moving source, conditions may arise where distinguishing the location of the source prevents recognition of the content of the signal, and vice versa.

Finally, when an individual is distracted and faced with other perceptual and cognitive demands, it becomes more difficult to recognize a signal. Many years ago, I had the opportunity to work with one of the major automobile makers. We were experimenting with technology that would use data available on the car to recognize when the driver was in a challenging driving situation (e.g. changing lanes to overtake another car or merging onto a busy highway). One of the ideas being considered was to lower the volume on the radio when the driver was in a difficult situation so that this did not serve as a source of distraction. There was an unusually profound effect that when driving, one did not notice that the volume had been reduced and subsequently returned to its original setting. However, as a passenger, the automatic volume adjustment was quite apparent. This example illustrates how task demands can affect our sensitivity to perceptual input. This suggests that if a signal can be timed to coincide with periods in which an adversary is distracted by other task demands, then the adversary should be less likely to recognize the signal.

These are a few means by which an auditory signal may be concealed. This does not speak to what may be accomplished given technology to augment human perceptual processes, but assumes the adversary must recognize the signal using only their perceptual systems. This example has focused on concealment of an auditory signal. With other sensory modalities, these mechanisms may be more or less effective, and there may be other mechanisms that can be used. It is important to recognize that the human perceptual systems have certain strengths that can be leveraged in design. Likewise, the human perceptual systems have certain weaknesses that can be leveraged in adversarial situations.

Perception is not a continuous process

Historically, there has been a tendency to conceive of human perception as a continuous ongoing process in which bottom-up processing of stimulus information gives rise to perceptual experiences, which then feed into cognitive processes. The assumed continuity is understandable given that our conscious experience is continuous and free of periodic disruptions. Likewise, we have extensive experience with machines and electronic devices that function on a continuous basis, whether a gear that rotates at a speed that is proportionate to the energy supplied from the drive train or an electronic device that produces transmissions that are proportionate to the input signal. However, these experiences can be misleading when trying to understand the functioning of the human brain. Take for example vision where our experience is of a continuous stream of visual input corresponding to the world around us. The reality is that the visual signals from the eyes are intermittent, coming and going with the saccadic twitches of the eyes, yet the brain fills in the holes to produce the continuous experience that we all know. Perception is best described as a multi-phase process, with the operations at each phase being subject to ongoing modulations of the corresponding neural circuitry, and the results manifested through variability in our moment-to-moment performance on tasks reliant upon perceptual processes.

Using EEG-based electrical recordings of the activity of the brain, the coordinated activity of neural circuits can be observed in the frequency characteristic of the EEG signal. If variations in the amplitude of the signal over time are charted, these variations will form waves with recognizable peaks and troughs. Frequency describes the number of waves that occur within a given timeframe. For example, if the time between the peak of one wave and the peak of the next wave is 100 msec, then in the period of a second, ten of these waves will occur. This signal would be said to have a frequency of 10 Hertz (Hz). When looking at the signal emanating from a given recording site, there are generally many different frequencies simultaneously present within the signal. However, often there will be a dominant frequency with the signal strongest for this frequency. This is indicative of their being a large population of neurons that are pulsing in a coordinated manner. Research has shown that the timing of a stimulus relative to the dominant waveform impacts the likelihood that the signal will be detected and the subsequent salience of the signal (Wyart & Sergent, 2009).

When at rest, the rear region of the brain, which is largely involved in visual processing, is dominated by activity with frequencies of approximately 10 Hz. In research by van Dijk and colleagues (2008), it was shown that the amplitude of this activity correlated with the likelihood that subjects would detect a visual stimulus for which the intensity of the stimulus was near the threshold for detection. Faint stimuli were more likely to be detected if the populations of neurons within the visual cortex were pulsing, or oscillating, in coordination with one another. Furthermore, the likelihood that a faint stimulus would be detected correlated with the degree to which there were coordinated oscillations.

Subsequent research has considered the timing of the stimulus relative to the specific phase of the dominant frequency (Busch, Dubois & VanRullen, 2009; Mathewson et al, 2009). In other words, at the time the stimulus was presented, was the waveform rising toward its peak or falling toward its trough. These researchers have reported that when the amplitude of the waveform is lowest, or the wave is on its downswing, subjects are less likely to report having seen a faint stimulus. Comparing the phase of the waveform with the greatest likelihood of detection (i.e. the upswing) to that with the lowest, there was 12-16% difference in the likelihood of detecting the stimulus. This same effect has also been shown for auditory stimuli in studies that have used transcranial direct current stimulation (tDCS) of the brain to manipulate frequency characteristics, and accordingly, produce increased or decreased likelihood of detecting an auditory stimulus through direct manipulation of the waveform (Neuling et al, 2013).

In the design of systems, one must constantly contend with the variability in performance that is intrinsic to human operators. The research described here points to one source of variability. Specifically, the human brain undergoes continuous fluctuations and these fluctuations may translate into moment-to-moment variations in performance. Perhaps more importantly, this research highlights how the variability that is intrinsic to human performance can affect recognition of stimuli that are near the threshold for detection. The human brain is unlike a machine that operates in a continuous manner. Instead, the human brain is in continuous flux. Consequently, there will be a certain range of variability in the performance of operators that cannot be eliminated through training or other related mechanisms. This suggests the need for systems to be designed so that they are tolerant of a range of variability in the performance of human operators, with this being particularly true when systems require that operators function near the limits of their capacities.

Perceptual processes may be flexibly adapted to circumstances

Chapter 2 discussed the inherent plasticity of the human brain and made the point that through experience, we continuously shape our brains over the course of a lifetime. With perceptual processes, plasticity is evidenced in the expansion of brain regions following extensive practice with an activity that relies on a particular sensory modality. For instance, in individuals who are blind, there is activation of regions of the brain normally associated with vision during performance of a task that requires the sense of touch (Sadato et al, 2002). This activation of visual areas during a tactile task was not observed in normal seeing individuals. Furthermore, the extent to which visual areas were engaged by the tactile task was much greater in individuals who lost their sight prior to the age of 16 years, as opposed to those who lost their sight later in life. Similarly, in the deaf, it has been shown that visual stimuli activate areas of auditory cortex that would ordinarily be responsive to sound stimulation (Finney, Fine & Dobkins, 2001). Thus, in extreme cases, processing of one sensory modality can encroach on brain regions associated with the processing of other sensory modalities, taking over the associated neural circuits.

Somewhat less dramatic illustrations of brain plasticity associated with perceptual processes have been described in musicians. When one plays a musical instrument, they engage sensory processes linked to fine motor control. Research has demonstrated anatomical differences in the brains of musicians as compared to non-musicians with areas involved in listening and producing music being more extensive and showing denser connectivity (Gaser & Schlaug, 2001). Yet, in addition to the anatomical differences, it has similarly been shown that musicians' brains function somewhat differently exhibiting extreme sensitivity to minor variations in stimuli associated with musical performance (Russeler et al, 2001). With trained musicians, when notes were off by a mere 20 msec, a response was triggered within their brains that would normally occur with an unexpected, surprising or deviant perceptual stimuli. At 50 msec, non-musicians responded to the mistimed performance, however at 50 msec, the brain response of the musicians was still much more pronounced than that of the non-musicians. These studies illustrate that the experience one attains within the course of extensive practice produces measurable differences in both the structure and functioning of the brain.

Many activities for which individuals may gain expertise involve brain functions that are somewhat unlike those activities that would have naturally occurred prior to the advent of modern technology. For these activities, the intrinsic functional capabilities of the brain may be harnessed and adapted to fulfill the new roles. This often involves co-opting brain circuits that had originally specialized for other functions. This was recently demonstrated in a study of 8-10 year old children who had expressed intense levels of interest in Pokeman cards (James, James & Swain, 2012). When these children were compared with other children who did not share this interest, fMRI recordings revealed pronounced activation of the fusiform gyrus, an area linked to human face recognition. These children had co-opted the areas of the brain that would normally be employed in the recognition of human faces for the processing and recognition of the images found on the Pokeman cards. When adult experts in Pokeman were studied, they showed the same pattern of activation of the fusiform gyrus face recognition region of the brain as the child experts. In fact, the level of activation associated with the Pokeman cards in both the child and adult Pokeman experts was greater than the activation of the face recognition region when actually viewing faces. These findings suggest that with expertise, the brain applies neural circuitry relevant to the activity (i.e. in the case of Pokeman experts, this was the neural circuitry associated with recognizing faces) and these neural circuits may become finely tuned to the trained activity, even to the extent that brain regions respond more robustly to the trained activity than the activity for which they are presumed to be specialized.

The brain is remarkably flexible and can adapt to a broad range of activities, many of which would not exist if it were not for the demands of modern technology. The brain does not develop new functional capabilities, but instead, applies existing capabilities, perhaps in new ways, and then hones and elaborates those capabilities to attain increasing levels of skill. The designer might ask "what perceptual, cognitive and motor skills are essential to successful performance within the context of a system and what existing skills might be leveraged in developing these skills?" Understanding that face recognition might be leveraged in recognizing abstract symbols or that language skills might be leveraged in learning and remembering otherwise meaningless codes (e.g. computer passwords), the design can then accommodate the ability to leverage these functions. Assuming the designer has found a good match, the brain can then be relied upon to facilitate this process through adaptation and specialization of the corresponding neural circuits, enabling skills to emerge that have little precedent within any of the person's previous activities.

External world is replicated within the brain

It is a wonderful gift that our brains are so adept at capturing memories of events that we can later recall, allowing us to re-experience the sensations of our most pleasant experiences. Granted, these recollections are not exact replicas and over time, they diminish in clarity and detail. But still, whether consciously recalled during a quiet moment or brought to life within a dream, the perceptual experiences can be strong enough to trigger many of the same emotions as we experienced during the original event.

When our brain imagines a sensory experience, it re-engages the neural circuitry that would normally be engaged if directly experiencing the same event. For instance, if one is asked to visualize a face, there is activation of the brain regions that would normally be active if attending to someone's facial features (O'Craven & Kanwisher, 2000). Similarly, imagining being in a specific place generates activation of regions of the brain associated with the recognition of places. Thus, the same neural circuitry associated with the original experience is re-engaged when later imagining that same experience. However, the activation that occurs during imagination is not as pronounced as that which occurs during an actual experience. Yet, this is consistent with our common sensation that the imagined experience is never quite as vivid as the actual experience.

The capability for mental imagery has utility that goes beyond our occasional daydreams. Often, in performing tasks, it is necessary that we create an image in our mind as a means to recall specific information about an object or event. For instance, if I am giving someone directions, I might recall my perceptual experience from the last time I made the same journey. Similarly, if I am asked a factual question (e.g. does a turtle have pads on its feet?), I may rely on perceptual recollections to produce my answer. In these situations, performance depends on the ability to accurately recreate perceptual experiences (Kan et al, 2003). It has been shown that the cognitive mechanisms used to perform a task using actual objects as compared to visualization are comparable. For example, subjects were shown faint images and asked to make perceptual judgments (e.g. is the object taller or wider) after having actually viewed the image or only imagined the image. There was more overlap in activation of brain regions associated with making comparative judgments than there was for visual areas of the brain that would have been involved in visualizing the object (Ganis, Thompson & Kosslyn, 2004).

Given that the brain responds to imagined events in the same way that it responds to actual events, imagery offers a mechanism to create richer experiences and perhaps, bolster learning. However, it is worth noting that during imagery, the brain mechanisms involved in performing various cognitive operations may be more engaged than brain regions associated with sensory processes. This suggests that when asked to imagine a given situation, brain regions associated with cognitive operations, whether solving a problem or performing some physical activity, will exhibit the most pronounced resposne. Consequently, it is important when creating experiences that involve some degree of imagination that these experiences ask individuals to actively engage in the situation, as opposed to being mere bystanders.

Activity in the brain, does not mean there was a conscious perceptual experience

If a group of people are placed in a given situation, perhaps a train station, and all are exposed to the same sensory experiences, without there being any distractions or other interference, one might assume that there would be a common perceptual experience. Everyone should be exposed to the same sensory stimulation with there being activation of the associated regions of their brains responsible for processing signals from the corresponding sensory pathways. Within the brain, there may be activation consistent with the recognition of specific objects or recognition of events. However, this does not mean that each individual has had an equivalent perceptual experience. Just because there is activation in the brain consistent with the perception of a given sensory experience, it does not mean that the person has consciously had that experience. For a group of people standing in a train station, exposed to exactly the same sensory stimulation, each having a fully-functioning set of sensory systems, the perceptual experiences for which they are conscious will vary from one individual to another. Each individual will have their own unique perceptual experience, despite having been exposed to exactly the same sensory stimulation.

In research conducted by Moutoussis and Zeki (2002), subjects were presented images of a face and a house in rapid succession for an extremely brief duration. For a given trial, the researchers could tell that subjects had perceptually processed both stimuli due to their being activation in the regions of the brain that would normally be activated if presented an image of either a face or a house. However, due to the stimuli being present for such a brief duration, it was not possible for subjects to consciously recognize both the face and the house. Subjects routinely reported seeing one of the two stimuli, but not the other. Another group of researchers (Pasley, Mayes &

Schultz, 2004) conducted a similar study, except that some of the faces exhibited a distinct expression of emotion (e.g. fear, anger, happiness). Their subjects routinely failed to report having seen the face. However, not only was there activation of the region of their brains responsible for recognizing faces, but there was also activation of a region associated with processing emotional stimuli (i.e. amygdala). In this case, the subjects had no conscious awareness of having seen a face, but the neural circuits of their brains responsible for recognizing and responding to emotional stimuli were triggered.

The fact that one cannot rely on different individuals presented the same sensory experience to have similar perceptual experiences presents a dilemma for the designer, particularly where it is important to the operation of a system that individuals sense and behave in a predictable manner. The situation is different in art and entertainment where the propensity for different individuals to have the same sensory experience, yet perceive it differently, can be used to create a more interesting and engaging product. In situations where there is a need for predictable performance, there are many things that can be done to lessen the extent to which individuals experience a situation differently. For instance, certain stimuli may be made more salient or individuals may be primed to expect and respond to certain stimuli. Similarly, individuals may be engaged in ways that elevate certain stimuli to conscious awareness. Actions may be required that cannot be completed without having consciously processed essential stimuli or mechanisms may be employed that serve to verify conscious awareness of certain stimuli (e.g. it may be necessary to enter a code that cannot be attained without having consciously attended to essential stimuli). On the other hand, one might also ask what can be done to encourage people to experience situations differently. In art, this may be done through ambiguity and abstraction.

The approach used by Moutoussis and Zeki (2002) illustrate another approach in which stimuli are presented in rapid succession such that there is only time to consciously process a subset of the available stimuli. Another approach involves engaging individuals on a personal level so that the experience of each individual is uniquely shaped by their own personal history. The key point is that in designing the sensory ecology that emerges as the product of a given design, there is a need to manage the perceptual experience. This may involve a management strategy that emphasizes the need for consistency and predictability, with the design structured accordingly, or it may involve a management strategy that encourages diversity and distinct individual experiences.

Our brains are specially tuned to the actions of others

Previous sections have discussed our brain's special sensitivity to certain stimuli, particularly those that have biological significance. The actions of people around us have special significance. Another person's actions may have direct bearing on our own goals and actions (e.g. as we are walking across the floor to sit on a bench, someone else may take the seat where we had intended to sit). Gestures and facial expressions may be used to communicate (e.g. someone may motion for us to stay away). Certain actions may be specifically directed toward us (e.g. someone hands us a plate of food). But, perhaps most importantly, it is through watching the actions of others that we learn many essential behaviors. While there has been debate regarding whether there is a particular neural circuit within the brain that is specialized for recognizing and responding to the actions of others (Hickok, 2009), it is clear that the brain is sensitive to the actions of others (Iacoboni et al, 1999). Furthermore, certain brain regions that would ordinarily exhibit activity when performing a given action, display comparable activity when watching another person perform the same action.

The neural circuits that selectively respond to the actions of another person have been referred to as "mirror neurons." Mirror neurons were first identified in monkeys when researchers realized the neural circuits associated with reaching and grasping for objects that were the subject of their studies, exhibited comparable activity when the monkeys observed the human experimenters making similar actions (Di Pellegrino et al, 1992). Subsequently, these findings were extended with demonstrations that the human brain exhibits a similar response (Iacoboni et al, 1999). The activity in the mirror neurons seems to involve a simulation of actually performing the same activity. This is evidenced by findings showing that the progression and time course of the activity is comparable to that that would occur if the observer was performing the action (Gangitano, Mottaghy & Pascual-Leone, 2001). This helps to explain the finding that when a person observes another person perform an activity, the individual is primed to perform the same activity, as evidenced by faster reaction times when subsequently prompted to perform the observed activity, as compared to an equivalent activity that had not been observed (Brass et al, 2000). With respect to learning through imitation, when experimental subjects observed chords formed on a guitar and were either instructed to merely watch or to watch with the intent to imitate the hand positions, there were similar patterns of activation in the brain (Rizzolati & Craighero, 2004). This suggests that the activity within mirror neurons resulting from observing an act, with or without the intent to imitate the act, may serve as a precursor for reproducing the same act.

Placed in the presence of others, as we observe their actions, our brain responds to these observations producing patterns of activation comparable to our performing the same activity.

This primes us to behave in the same way as the people around us. In the design of systems, certain behaviors may be promoted by creating a situation where people observe others performing the desired behavior. On the other hand, where there is a risk of unruly behavior (e.g. during sporting and other live events involving tremendous levels of excitement and emotion), a demonstration of riotous or other undesirable behavior may serve as a trigger to prime and elicit similar behavior from others. A wonderfully benign example can be seen in a YouTube video from Derek Sivers entitled "First Follower: Leadership Lessons from Dancing Guy." This video features an outdoor concert where a member of the audience who stands out due to his being shirtless begins dancing wildly. Shortly, the dancing guy is joined by a couple of others and then more and more until there is a large crowd all dancing together. Sivers uses this video to illustrate the importance of the *First Follower*, or the individual who recognizes someone else has a good idea and joins them in advancing the idea. However, this example also serves to illustrate how watching someone can serve to prime the same behaviors in others. This is a property of the brain that can be applied to achieve productive ends when attempting to steer the behavior of a crowd, teaching various skills, or within the context of entertainment, creating experiences where the audience becomes immersed in events. Yet, the same propensity within the brain to mirror the behavior of others will also be in play in situations where behavior is potentially dangerous, offensive or merely counterproductive.

Our sense of the world is a product of our social environment

Our brains intrinsically sense the actions of others. Yet, does this sensitivity to others manifest in how we perceive the world, and our own actions. The answer is "yes," and the effect may largely occur at an unconscious level. When we see someone yawn, it is often difficult to suppress a yawn ourselves. Likewise, when watching another person laugh, we may find ourselves laughing with them, and at the least, may find it hard to not smile. We similarly mimic the posture and gestures of others. In a group of people, see what happens if you assume a posture that is rather typical (e.g. hands behind the head while slightly leaning backwards), yet is not being exhibited by anyone in the room. It is quite likely that shortly, one or more others will assume the same posture. With babies, it is quite common that after one begins to cry, others will soon also start to cry. Myself, having lived many years of my life in the southern United States, at times I have had a very distinct southern accent, whereas currently, this accent has largely faded. However, I have often noted that after talking to my parents who retain a strong southern accent, hints of my former accent return. All of these examples illustrate the concept of a contagion. A contagion refers to behaviors, mannerisms, gestures, emotions or attitudes that after observing their expression in others, people tend to mimic themselves.

Research by Fowler and Christakis (2008) illustrates the practical impact of contagions on our everyday perspectives of the world. Their research utilized data collected through the Framingham Heart Study, which involved extensive data collection from three generations of participants linked to one another as family, friends and co-workers. Data was regularly collected from over 4,000 subjects for several decades. Included in the surveys, there were several questions that asked individuals to rate various responses concerning their individual well-being such as, "I felt hopeful about the future," "I was happy," "I enjoyed life," and "I felt that I was just as good as other people."

The analysis by Fowler and Christakis found that happiness tended to cluster such that individuals who were happy tended to be associated with other individuals that were happy.

With a given individual, for every happy friend, their likelihood of being happy increased by 9%, whereas every unhappy friend decreased their likelihood of being happy by 7%. Furthermore, the contagion extended beyond one's immediate relationships. On average, an individual was 15% more likely to be happy if they were closely related to another happy person. Yet, they were 10% more likely to be happy if they were the friend of someone who was happy and 6% if one of their friends was friends with someone who was happy. It appeared that happiness operated as a contagion, much like a virus, spreading throughout networks of individuals linked through their social relationships.

These findings point to the influence our awareness of the people around us can have on our perspective of the world. When the people around us perceive the world in a certain way, and act accordingly, there is a certain propensity for us to take a similar perspective. This suggests that close social networks will have a tendency to produce homogeneity in the perceptual experiences of their constituents. In contrast, broader looser networks in which individuals freely come and go, bringing with them diverse perspectives, should result in less homogeneity. Accordingly, to the extent that we structure the world in which we live, choosing to affiliate with certain individuals and avoiding others, we set the stage for our own perceptual experiences. Likewise, in the design and management of systems, we create an environment that may lead to an organization taking on a certain personality, with the rigidity of that personality being a function of the extent to which the organization is highly insular, with few outside interactions, or open to numerous diverse interactions with people from outside the organization.

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