Modularity in perception
its relation to cognition and knowledge[Chapter] Goldstein, E.bruce
Blackwell handbook of perception.
Handbook of experimental psychology seris (pp 737-759) Malden MA
Blackwell Publishers

Chapter Twenty-Three

Modularity in Perception, its Relation to Cognition and Knowledge

Ken Nakayama

> Nature has contrived to have it both ways, to get the best out of fast dumb mechanisms and slow contemplative ones, by simply refusing to choose between them.
> (Fodor, 1983, p. 4)

Although, as lay people, we take it for granted that perception offers us sure knowledge of the world, perception is deficient in some rather fundamental ways. It doesn't reveal *all* that we know about the world. Unaided, it says very little, for example, about the microscopic structure of matter. Perception can also be mistaken at the scale of the everyday, showing a host of well-known errors, so-called illusions. Yet, these obvious limitations do not shake our confidence in perceptual experience. Seeing is believing and we take perception as a reliable source to bolster our most deeply held beliefs.

Yet, this seemingly natural acceptance of perception as corresponding to "reality" has not gone unchallenged. Descartes (1649) began his foundational approach to philosophy with the posture of radical doubt, raising the possibility that the material world might not exist at all, that our sensory experience could be the conceivable handiwork of a malevolent demon, cleverly constructing what we sense for some evil purpose to fool us. In a more scientific vein, a different though related question continues to be of importance. Does perception inform us directly or is perception a construction, mediated not necessarily by Descartes' demon, but by our own and possibly flawed mental apparatus? Berkeley's *New Theory of Vision* (1709) addressed the critical issue of perceived size and distance and argued that the various cues to vision, accommodation, convergence, etc., required learned associations with motor and tactile feedback to get the correct impression of distance. For Berkeley, the process of vision from such cues was analogous to that of deriving meaning from language. As we learn the meaning of words from their association with objects and events in childhood, so do we learn the distances of objects from their association with our motor activity and various associated kinesthetic sensations.

Seventy years earlier, Descartes and followers argued for a different answer, assuming that by some form of innate calculation, distance could be immediately derived. For three-dimensional vision, Descartes suggested that we can know distance (as does the blind man in Figure 23.1a) using some form of geometrical reasoning. Assuming that we can sense the length of our eye muscles (Figure 23.1b), the calculation of distance is a straightforward problem in trigonometry.

Berkeley's and Descartes' ideas have survived very well in this modern age. Berkeley's thinking suggests the continuity of perception with thought in general, citing the analogy of perception to language, whereas Descartes' views suggests that perception is pre-

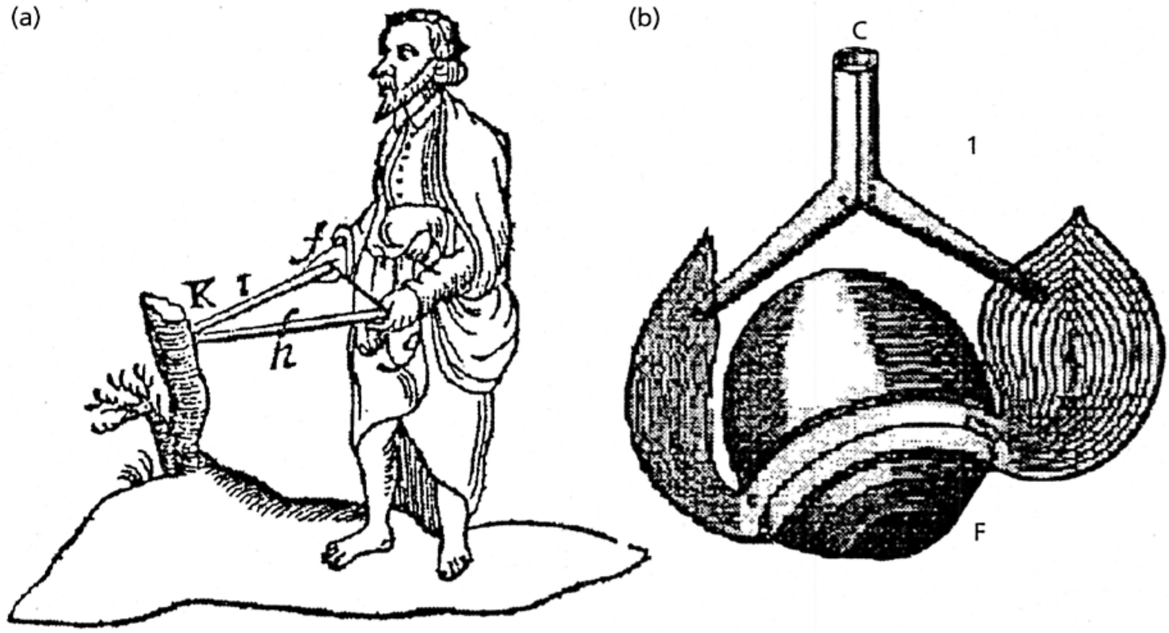

Figure 23.1 (a) Blind man obtaining information from the distance of a point in the environment using trigonometry, utilizing the known angle between the sticks which are hand-held (from Descartes, 1649). (b) Eye muscles as described by Descartes (Treatise on man).

ordained, more machine-like, and very different from thought. As we will see, current ideas about perception tilt more in favor of Descartes and this in turn leads to the following question. If perception is more machine-like and distinctively different from thought in general, what happens when the results obtained from perception contradict knowledge of the world obtained from other sources mediated by thinking?

In this chapter I argue that errors from perceptual mechanisms are almost inevitable and are very likely. On the other hand, consequential, that is, life-threatening or even inconveniencing errors of perception are rare in real life. This might be regarded as surprising because perceptual experience can make such a strong impression on us and the long history of research in perception contains a catalog of errors and illusions. To address this seeming paradox, we take a wide tour. In brief, we argue that perception can be regarded as modular in Fodor's (1983) sense. Then we identify some unusual situations where modularity can lead to consequential error. The singular nature of these situations implies that perception's modularity leads to no particular problem under normal circumstances. Perception's distinctly close coupling to the real world and its selectivity renders any error as inconsequential. We conclude this chapter on a cautiously ambitious note, suggesting that the characteristics of perception's modularity are such that a greater understanding of perception offers particular benefits for the study of cognition and psychology more generally.

Modular Systems

To begin this discussion, I suggest we reflect on the seminal essay by Jerry Fodor (1983), *Modularity of the mind.* Although many disagree with the specific assertions made (see later), this short book, more than any other, has articulated the agenda for contemporary cognitive science. In *Modularity*, Fodor suggests that we resurrect faculty psychology, that we create a modern version of Gall and Spurzheim's phrenology. Fodor's point was that we need to think of the mind as a distinct set of units or modules, each of which is complete in itself, fully devoted to a specific function. Fodor was emboldened and inspired by the Chomskian revolution which assumed innate structures for the processing of speech and language. Using language as his main example, Fodor suggested that speech processing uses dedicated hardware that is specific to the language task, that this hardware is not shared by other cognitive systems. Furthermore, it is activated in an automatic and obligatory manner. Thus for speech in a native speaker's language, utterances are automatically processed as speech, with each word individuated. Because speech processing is obligatory, native speakers always process the sounds of their language as speech; they cannot hear their own language as the continuous stream of sound experienced by the foreigner.

According to Fodor, such modular systems as exemplified by human language are likely to have very specific characteristics. Modular systems are (a) domain specific, (b) encapsulated, (c) obligatory, (d) have shallow outputs, (e) are rapid, (f) are generally inaccessible to consciousness except at their outputs, (g) have a characteristic ontogenetic course, (h) have dedicated neural hardware, and finally, as a consequence, (i) have characteristic patterns of breakdown.

Color and Classical Stereopsis as Modules

Foundational studies on the visual system began many years before Fodor's *Modularity* and still provide its best examples. Consider color vision which can be seen to be in easy accord with Fodor's modular system's concept. It is (a) domain specific as it processes only visual stimuli, in particular wavelength as it has been broken down into three broad bands by the receptors. It is (b) encapsulated in that it is impervious to thinking or to other high-level cognitive processes. It is (c) obligatory insofar as we cannot turn off color vision at will. When we view a scene at photopic levels, we *always* see it in color. We don't have the option of seeing the world as shades of gray, as in a black and white movie. It has very (d) shallow outputs in the sense that it does not supply information as to its own inner workings or the results of intermediate processes. We have no conscious knowledge of the tristimulus values, the excitations of each cone type. This is consistent with the view that the workings of the color system (e) are generally inaccessible to consciousness except at their outputs. Furthermore, the chromatic system has a (f) characteristic ontogenetic course, particularly evident at the earliest stages. Specific pigment molecules are confined to different classes of receptor (Baylor, 1987) and the anatomy of the visual system appears to contain (g) dedicated neural hardware devoted to color. Color vision shows very (h) characteristic patterns of breakdown. Each photoreceptor loss is associated with subtle color deficiencies which form distinct classes (protanopia, deuteranopia, tritanopia). Profound and often total loss of color vision can accompany circumscribed lesions in extrastriate visual cortex in the case of cerebral achromotopsia (Cowey & Heywood, 1995). This cortical deficiency reinforces the "shallow output" nature of the process because *primary* visual cortex with its rich supply of color selective cells is intact in these patients. Yet, color vision is absent. As such, there must be a higher cortical area (beyond the striate cortex) which must comprise the critical output portion of the color module upon which the conscious perception of color depends.

So closely does color vision conform to Fodor's modularity that it is probably its best documented example. Yet binocular depth perception might qualify as a plausible second. With classical stereopsis as in Wheatstone's original demonstration, tiny differences in image distances between the two can lead, when fused, to the vivid perception of three dimensions (Wheatstone, 1838). This became particularly evident with the invention of the random dot stereogram (Julesz, 1960). With Julesz's stimulus, the perception of depth is ineffable, not further analyzable through introspection. We are completely unaware of the differences in disparity in this figure and simply see a square hovering in front of a background. Further support for a specialized binocular system comes from neurophysiology with the discovery of disparity-specific neurons tuned to various degrees of binocular image alignment between the two eyes (Barlow, Blakemore, & Pettigrew, 1967). In addition, there is a characteristic breakdown of binocular depth perception with damage to this early visual cortical system as evidenced by the case of strabismus, where eye misalignment prevents the normal development of binocular neurons in the visual cortex.

Although these examples from low-level vision are evident examples of modularity they do not come as much surprise to those who have spent their careers in the field of visual perception. At either an implicit or explicit level, vision was thought to be special, not explainable by more general laws of psychology, like, say, conditioning. Thus the Gestalt psychologist rejected the associationist foundation of vision, suggesting that perception was autonomous with its own laws. The single unit revolution of visual neurophysiology beginning back in the 1950s only strengthened this view, showing unforeseen structure and regularities within the visual system. Neurons in the retina of the frog were detectors of bugs and looming objects (Barlow, 1953; Lettvin et al., 1959). Neurons in the cat visual system were arranged in a hierarchy such that LGN cells coded local aspects of an image with concentric receptive fields and this was elaborated with cortical processing, showing several stages of integration where cells here were sensitive to oriented lines, to motion, to binocular disparity (Hubel & Wiesel, 1962).

Building upon these success stories in early vision, a larger challenge of the modularity thesis is to see whether more cognitive visual processes would be similarly constituted. Would higher-level visual processing, obviously requiring experience and learning, be understood as modular systems as well? Here of course the objects of study would be much less known and the establishment of modularity would be more difficult to accomplish. Yet recalling Fodor's speculation that such systems would be modular at least to "an interesting extent," it is clear that very recent research has been very supportive of the modularity, extending it in new directions.

Face Recognition as a Module

Face recognition emerges as a very strong candidate for modularity with probable genetic constraints. Higher primates and especially humans are inherently social animals and there is no question that faces have been both important and ubiquitous throughout recent phylogeny and over the course of an individual's development. As such, it is plausible that a specialized face processor emerges during development with help from mechanisms which have been bequeathed by evolution (Johnson & Morton, 1991). This important idea has been underappreciated partly because faces can be recognized by a variety of routes, not exclusively connected to a specialized face processor itself. For example, we can recognize faces from the presence of a defining feature such as a peculiar-shaped mustache or, say, a birthmark. Yet, it is becoming more evident that there is something more characteristic about face processing that enables us to recognize familiar persons under very different guises, after they have shaved off their beards or had changes in hairstyle or cosmetics. For such familiar faces, it is clear that we can recognize faces with great certainty and under a wide variety of conditions (see Tong & Nakayama, 1999) but often we as "perceivers" or "knowers" cannot analyze our knowledge about faces with any more insight from introspection than we did for stereopsis or color. We are certain of a friend's identity even if the face is stripped of all features that can be verbally described. The process remains ineffable and immediate and we don't have conscious insight as to what underlies our knowledge. This is consistent with the notion of face recognition as mediated at least in part by a Fodorian module with shallow outputs.

Some of the most striking evidence that face recognition is a module comes from clinical cases, particularly those sets of findings which constitute a double dissociation. Prosopagnosia, the absence of face recognition (Meadows, 1974), can occur in observers whose ability to do object recognition is largely intact. Such patients often have lesions in the ventral occipital regions, just where more recent evoked potential and fMRI studies show activation to the presentation of faces (Allison, Ginter, McCarthy, & Nobre, 1994; Kanwisher, McDermott, & Chun, 1997). Second is the converse phenomenon, a situation where a patient has an almost total loss of ordinary object perception but is normal or even above normal in the identification of faces (Moscovitch, Winocur, & Behrmann, 1997). Their patient CK is particularly informative because his remaining abilities reveal a putative face module in isolation, uncontaminated by other recognition systems available in persons with an intact visual brain. For example, when CK was shown the unusual paintings of Giuseppe Archimboldo (Kriegskorte, 1990) where faces are composites of vegetables (Figure 23.2), he was easily able to identify them as faces, presumably because his face module was intact. Yet because of the shallow output of this putative face module and his lack of any other recognition abilities, he could see the face only but *not* its vegetarian constituents. A very recent case study of prosopagnosia due to very early damage (infantile encephalitis) in this same cortical area (Farah, Rabinowitz, Quinn, & Liu, 1999) suggests that the dedicated neural hardware responsible for face recognition is likely to be constrained by genetic factors.

Modules Without Genetic Specification? The Case of Written Language

All of these cases (color, stereo depth, and face recognition) subserve functions that would have been beneficial over the course of evolution. As such, they do not challenge Fodor's strong claim that modules are to some extent innately specified. Each of course requires some degree of environmental input and the higher one goes in the visual system, the more obvious is the likely dependence. Thus, for faces, it seems self-evident that one needs to be exposed to a specific face to recognize it. Yet, the existence of and the importance of learning does not indicate that genetic factors are not at play. Each of these functions is likely to have a long evolutionary history with genetic specification aided by additional learning. So, all of these examples fulfill more or less all of the specifications listed by Fodor for modular systems, including the important property of having a characteristic ontogenetic course.

There remains the possibility, however, that Fodor may have been unnecessarily specific in indicating the requirement for strong genetic control. It has been suggested that modules having many of the characteristics of Fodor modules may indeed exist but that they are more likely to be the result of a developmental process, that modularity *increases* as a consequence of experience (Karmiloff-Smith, 1992).

The characteristics of our visual recognition of written language argues this point. Writing is an instructive case because the adoption of written language is a very recent development on the scale of human evolutionary time. Skills in writing and reading cannot have played a role in human evolution because mass literacy emerged only within the past century and is still incomplete. Yet, despite its recency, the processing of written language shows many of the characteristics of a Fodorian module. For example, the reading of the written word is automatic and mandatory. Like speech, it is not a matter of choice as to whether we will process written words as having meaning. This has been amply confirmed

Figure 23.2. A face by Giuseppe Archimboldo (Kriegskorte, 1990) composed of vegetables. Patient CK (Moscovitch et al., 1997) sees such paintings as faces but is not aware of the vegetables.

by the well-known Stroop effect where the meaning of a presented word can interfere with ongoing tasks despite the greatest efforts to ignore the words or their meaning (MacLeod, 1991).

Neuropsychological studies on the recognition of written words reveal some unusually specific patterns of breakdown with brain damage. For example, Caramazza and Hillis (1990) show that left parietal lesions can selectively impair word recognition in surprisingly characteristic ways. In these patients the first (left) portion of a word can be identified but not the right. Yet, it is not simply a portion of the visual representation of the word that is selectively degraded. The damage is more subtle and reveals that the representation of words is more abstractly represented. Thus if the words are presented vertically or left right reversed, the deficit is still confined to the second half of the word. The findings indicate that specific brain lesions can lead to very characteristic breakdowns in the processing, occasionally revealing the characteristics of underlying modules.

In some forms of acquired dyslexias, patients cannot read the letters of words or word-like non-words (Coltheart et al., 1993). Yet they can read whole words and understand their meaning. This indicates the existence of a "whole word" module which makes available the identity of the word but not its constituents, strikingly similar to the case of face recognition (Moscovitch et al., 1997) where patient CK sees the faces but not the constituent vegetables. Further studies of word recognition under conditions of backward masking also reveal the "shallowness" of the outputs of a putative word recognition module. Words with upper, lower, or mixed case letters are correctly recognized, yet subjects are unaware of such changes and variations of case.

Given these examples of modular processing in the absence of obvious genetic constraints, Fodor's modularity idea has been strongly criticized (see Elman et al., 1997; Karmiloff-Smith, 1992). Yet, even the severest critics leave much of Fodor's speculative framework intact, differing mainly on the single issue of nurture vs. nature. These commentators take great pains to dismiss the likelihood that these modular systems are inborn, relying on learning mechanisms as could be realized in connectionist networks. Yet, they concede, and in fact embrace, much of Fodor's program, arguing that if modules can be built during development and if they are highly over-learned, they will exhibit many characteristics that Fodor reserved for inborn systems (Karmiloff-Smith, 1992).

This example of written language suggests that Fodor's postulation of innateness for modular systems might be overly rigid, missing possible systems that are modular to "an interesting extent," particularly if we seek explanations as to the underlying characteristics of higher visual processes. It suggests that there might be many more modules, somewhat unsuspected, and not as easily identifiable as, say, for reading, but that have many of the properties outlined by Fodor and followers. It also suggests that it is the outcome of module formation that is important, that the mechanism of formation of a module is less important than its operation.

From the examples we have given so far, it is clear that modular systems exist and they clearly have some decisive advantages in their ability to deal with domain-specific material in a very rapid and effective manner. This array of "fast dumb mechanisms" (Fodor, 1983) is at odds with Berkeley's now dated view of perception as a general associative process. We should note, however, that there is plenty of room for association too in modular processing (Hebb, 1949; Linsker, 1990) but it seems that it is carried out over a restricted range of inputs, "within" a domain. Thus for visual surface perception, it has been argued that the associations are not domain general but restricted to local visual surface information within vision (Nakayama, He, & Shimojo, 1995).

Yet in reflecting about behavior and mind as a whole, it seems unlikely that modular systems by themselves can provide a full explanation as to the function of the mind and brain. Much of our mental life seems too varied and rich to be subserved only by such arrays of specialized sub-systems. Furthermore, our behavior seems wielded to serve more general goals; it is not simply the result of smaller piecemeal activities, acting independently. For this reason, it is important to think about what else may be necessary for the mind and brain to act as a whole.

Central Systems

Fodor's speculative psychology in *Modularity* has been prophetic. The study of modular systems is today's most dominant research agenda. So popular has the idea of modularity become that its scope has grown enormously. It is suggested that there are modules for a wide range of functions, rivaling Gall's original phrenology with jealousy organs and cheating detection organs posited by advocates of evolutionary psychology (Cosmides & Tooby, 1986), and theory of mind modules posited to account for aspects of development and autism (Baron-Cohen, 1997). These are recent additions, taking their place alongside color vision, face recognition, etc.

In contrast to these recent developments, Fodor took a surprisingly different stance on the applicability of modular systems to cognition in general. Fodor made much effort to indicate that modular systems are *not* the whole story about the mind. He argued that the mind must also contain in its essentials central systems which have the opposite characteristics of modules; they need to be widely distributed, flexible, slow, accessible to consciousness, etc. These aspects of Fodor's (1983) essay have been largely forgotten, amidst the rapid progress in identifying modules. Yet his point bears closer examination because he makes an extreme, yet lucid argument about the relation of perceptual modules to cognition more generally.

To distill the essence of this boundlessness and flexibility of central systems, Fodor claimed they are (a) isotropic and (b) Quinean. By isotropic, he means that the sources of belief for central systems can come from *anywhere*; they are *not* domain specific. Any information in any domain can influence the outcome, can contribute to the knowledge possessed by central systems. As such, information in central systems is not encapsulated.

By Quinean, Fodor refers to the fact that no specific sorts of sensory information (experience) are decisive in affirming or contradicting a belief. This derives from Quine's (1953) attack on the foundations of logical positivism and its assertion that there is some special identifiable sense data that can validate or invalidate a scientific theory.

> The totality of our so-called knowledge or beliefs, from the most casual matters of geography and history to the profoundest laws of atomic physics or even of pure mathematics and logic, is a man-made fabric which impinges on experience only along the edges. Or, to change the

> figure, total science is like a field of force whose boundary conditions are experience. A conflict with experience at the periphery occasions readjustments in the interior of the field. . . . the total field is so underdetermined by its boundary conditions, experience, that there is much latitude of choice as to what statements to reevaluate in the light of any single contrary experience. *No particular experiences* are linked with any particular statements in the interior of the field, except indirectly through considerations of equilibrium affecting the field as a whole. (Quine, 1965, p. 42, italics added)

This describes science or at least its quest for empirical knowledge. By analogy, Fodor considers science to be the mind writ large, or at least the central systems of the mind. Thus in distinction to modular systems which have enduring or at least lawful characteristics, central systems are essentially holistic, capricious and unknowable.

Seeming to take unusual delight in a gloomy prognosis regarding the understanding of central systems, Fodor asserts that modular systems are the *only* valid topic of inquiry. The extent to which the mind is modular is the extent to which we will understand it. Central systems are just too capricious, contingent on countless random factors and must forever lie outside the bounds of science. Cognitive science is stuck with the study of modular systems and when that task is complete, the enterprise will have reached its limit. By implication, any statements about central systems are off limits, at least as scientific discourse.

The argument here is implicit and indirect. Rather than examining the properties of the mind's central systems (which by his definition are essentially unknowable), he uses science itself and its history as a metaphor for the growth of knowledge in the mind. Thus "knowledge" at any given era in science is prey to remote and possibly tiny causes. There are no laws of scientific discovery and there are no privileged domains of relevant experience. In the field of astronomy, the Copernican outlook denied that the earth stood still, and asserted that it moves around the sun. As such, it became evident that the palpable perceptual experience indicating that the earth is stationary, with the sun making its daily path across the sky, was suspect. This indicated that our perceptual apparatus is too insensitive to rule on the motion of the earth, challenging perception's privileged position regarding the fixation of belief.

Prior to Newton it would seem that our understanding of celestial and terrestrial motion were separate, comprising discrete encapsulated domains of knowledge. After Newton this division disappeared and all motion was subject to the same universal laws, illustrating Fodor's notion of isotropy. In all of these cases new beliefs were acquired over a long uneven history. Supporting data came from unexpected and seemingly unrelated fields; that is, planetary motion was informed by the properties of terrestrial motion and vice versa. Furthermore, whole frameworks of thought, Quine's "web of belief," were influenced by metaphysical presuppositions (Burtt, 1924). As such, the path delineating the growth of knowledge could not be foreordained or perhaps not understood even *post hoc* (Feyerabend, 1975). So too with the mind, at least that part which corresponds to its central systems. The mind's beliefs are historically conditioned, subject to our individual histories and to the exigencies of the moment. There can be no science pertaining to this aspect of mind and its acquired knowledge.

A Possible Science of Central Systems

Fodor's views about the futility of studying central systems does not seem to have led to the wholesale abandonment of his implied "off limits" areas of psychology. For example, the field of developmental psychology continues to exist, despite Fodor's disinterest and his tacit dismissal of development. Nor has the field of reasoning and decision making, likely to be mediated by central systems, been deserted. Yet, one can discern developments in these fields that are not unrelated to Fodor's main thesis. Topics related to Fodor's central systems have been co-opted by ideas related to modularity. In developmental psychology, there has been a recent emphasis on innate structures, the notion that children are born with built-in primitive knowledge mechanisms to encode and interpret the world and from this base, development unfolds (Carey & Spelke, 1994; Hermer & Spelke, 1996). Second, in the field of thinking and reasoning, there has been the view that reason itself is not as central, logical, and abstract as normative theories of logic would suggest, that it too is domain specific. It is argued that abstract reasoning is a fiction and that we use heuristics, more akin to perception than logic, when faced with the uncertainties of decision making in daily life (Kahneman & Tversky, 1984). These developments indicate an "invasion" of Fodor's territory of central systems by what begins to look suspiciously like modular processing.

Overall we seem to be in a historic period where the study of modules is ascendant, and where other fields of inquiry are less regarded. Curiously, the rapid progress and concomitant optimism about modules has not prompted much effort in thinking of how such piecemeal mechanisms could be functionally coordinated. In other words, there hasn't been a comparably high-profile research program showing the necessity for or characteristics of inter-module organization. The situation is perhaps like the "discovery" of reflexes in the spinal cord a century earlier. Sherrington (1906) indicated that there are reflexes (although he was wary enough to call them useful fictions). He wondered how all of these myriad processes could be wielded together to the smooth seamless behavior observed. A similar problem appears now. How can a finite number of modules, especially ones that are mandatory (many of Sherrington's reflexes were not mandatory), be woven into something that resembles what we consider to correspond to our behavior and mental life?

Some writers have considered this problem at length. Gazzaniga (1985) suggests a kind of autonomous competition between modules such that the orderliness and seamlessness of behavior that we "experience" is actually an illusion, that it is actually rather disconnected, wielded together *post hoc* by our story-telling verbal left hemisphere. This is particularly graphic when actions initiated in the silent and autonomous right hemisphere require a cover story to be told by the left hemisphere, sometimes with bizarre reasons, especially by patients with split brains. In his view, modules appear to rule but there is some kind of *post hoc* mediation function served by language. No doubt, there are many obvious rationalizations afforded by such cases of brain damage (see later). Dramatic as these important findings are, one should be cautious in interpreting such examples from very abnormal brains as illuminating the norm for behavior under ordinary circumstances. Researchers interested in both animal (Tinbergen, 1951) and human behavior (Miller, Galanter, & Pribram, 1960) have postulated broad hierarchical theories to account for the purposive flow of behavior which are not incompatible with rather fixed modules or subunits of behavior. In each case, the animal or person has higher-order goals which activate various subgoals which in turn activate smaller bits of behavioral routines. Thus, for the ethologist Tinbergen (1951), when an animal has a predisposition to nest build, it engages in behaviors appropriate to it, not engaging in competing or distracting behaviors, courtship, exploration, etc.

Baars (1988) in his *A cognitive theory of consciousness* agrees and observes that the integration and modification of various modules is exactly what consciousness helps to facilitate. This rests on his argument that modules by themselves are too inflexible to deal with behavior and that they have to be knit and modified by his virtual central system (which also require consciousness) to coordinate actions which are in line with the organism's goals. Baars suggests that not only is there a need for integration to coordinate modules smoothly when they do not perform appropriately to serve the higher-order goals of the animal but that they are also needed to tune, or in more challenging situations, to rewire modules so that they perform up to the standard required. The latter case is similar to the concept of accommodation outlined many years earlier by Piaget (1950). Thus central systems could both coordinate the operations of modules and help to fashion new ones.

Prolonged Clash of Modular and Central Systems: Perception of the Vertical

Given what we know about modular and central systems, it would seem that we cannot rely on perceptual modules unconditionally. For if perception or at least a significant part of perception is mediated by relatively inflexible domain-specific modules, there is the likely chance of error. It is almost inevitable that at some time central and modular systems will arrive at very different conceptions of reality. With perception, we are informed by a system that is geared for the long haul of evolutionary or life history and is generally appropriate for the majority of situations. Perception is more suited to embody the "wisdom of the ages," providing rapid response, not requiring reasoning which is too time consuming and perhaps even more error prone. Yet such a modular system could give us wrong information.

Take the most often quoted example, the Muller-Lyer illusion, which is inevitably mentioned when discussing the modularity of perception. We are told that the two lines are of the same length and if need be, we can measure them with a ruler. The illusion persists, even after it is explained to us, arguing for inflexible perceptual mechanisms that constantly err despite "corrections." Few if any of these discrepancies cause distress in daily life. Such illusions are carefully contrived by researchers to establish some unexpected properties of our visual system but they do not occur with any regularity in nature and even if they did, it is not clear that we would notice them.

Some illusions do occur in normal life, however, and are more noticeable. These are the illusions of self-movement and the perception of one's bodily orientation in space. The illusions are the likely consequence of modular systems doing their job with characteristic inflexibility. Linear vection is a good example. We are familiar with the compelling yet illusory experience of our own movement, sensing that our stationary train is moving when it is only the movement of another train in the station. Such motion must start very slowly so that associated vestibular cues ordinarily accompanied by such movements would be too small to be sensed. Usually there are no untoward consequences because the perceptual illusion is short lived.

Some illusions of bodily position in space are not so fleeting. Consider illusions related to the classic rod and frame experiments (Witken, 1954) and studied more recently by Matin and colleagues (Matin & Li, 1992). The most dramatic example of such an illusion can be seen when stationed in a house that has been pitched so that normally vertical walls are inclined (see Figure 23.3). Our "modular" perceptual system uses visual cues in the environment to determine our own reference to upright in the environment and this continues even if we know that the house is pitched. The adherence to the wrong and in his case the local visual coordinate frame (the house) is so strong that our companions can appear as either shorter or taller than ourselves depending how they stand in relation to us and the internal room. This is the phenomenon of the alteration of perceived eye height (Matin & Li, 1992). We also notice that a freely rolling ball appears to move uphill, as does spilt water, appearing to defy gravity. Several of these examples have become well-known tourist attractions. The Mystery Spot in California's Santa Cruz Mountains is a particularly good example (Murphy, 1986). Here and in more controlled laboratory situations, it is evident that we have a visually based module (with shallow outputs) which tells us about the direction of the upright. These "mandatory" mechanisms cannot be shut down and continue to give us false information even though we are aware of the circumstances giving rise to the illusion. Under these circumstances, the perceptual module is so strong and ubiquitous that it cannot be ignored. Observers, including the proprietors of such establishments, not familiar with these phenomena of visual perception, explain the rather disparate array of phenomena as due to a "mysterious physical force" yet to be explained by physicists. For example, my tour guide in the Santa Cruz mountains assured us that the place was visited by America's top rocket scientists, Werner von Braun and Albert Einstein, and that neither could explain it.

A Possible Lesson From Virtual Reality

In general, it is clear that perceptual errors occur in everyday life and one question is why we aren't more disturbed by them and more often. A goal of this chapter is to suggest that the answer must lie in the extreme richness of perception, its potential to get the most detailed information about a local scene so as to render anomalous information as spurious in relation to the wealth of consistent information available. We are not passive observers but can be informed by active interrogation of our environment, by the mobile movement of visual attention, the rotations of our eyes and, most important, the movement of our head to sample our vast environment from an infinity of vantage points (Gibson, 1966). So rich is our visual perception and so closely coupled is it with the outside world, that fully simulating it in all its range and detail is not possible Such is argued by Dennett (1991) who notes that few have ever been fooled or ever will be fooled by virtual reality (VR) displays, no matter how advanced they become. Dennett argues that for any VR simulation of a real-life situation, there would always be instances of sensory motor exploration that would reveal VR's illusory character, that the real world is usually such an

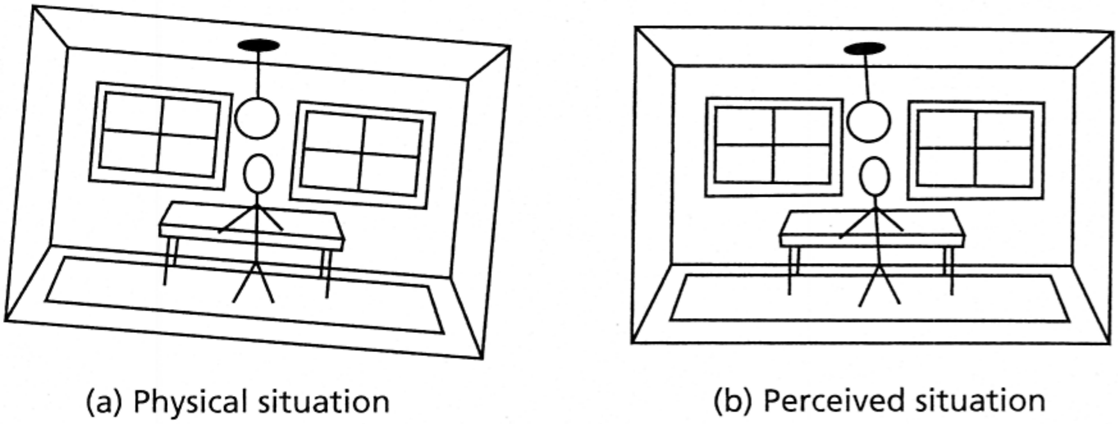

Figure 23.3. (a) Real tilted room that is part of a tilted house. (b) Cues from the room are very strong (as opposed to the sense of the gravitational vertical) and the observer perceives up in relation to the room, not gravity. (Adapted from Palmer, 1999.)

infinitely rich source of information that it could never be fully simulated. Added to these considerations is the difficulty in also providing simulated input to our vestibular apparatus, which provides almost unerring information as to changes in our orientation and positions in space. This does not take away the appeal of virtual reality displays, however, because we do not seek information regarding those aspects that would break the spell. We can attend to the game in a video arcade and the simulative experience provided is adequate for the occasion. Such interactive displays have been found to be very useful for the training and testing of commercial airline pilots. Yet, echoing Dennett, there is always the opportunity for the observer to see full well that this environment is indeed artificial. Furthermore, if the vestibular system inputs are inappropriate to the motion experienced, motion sickness is a frequent by-product (Reason, 1974).

Yet there exists at least one counter-example and possibly there are more, where a simulated environment is more than usually successful in creating an environment that is "perceptually" indistinguishable from reality. The example I have in mind is not the latest from high technology but is a more modest effort. It comes from the simulation of a very slowly moving ship moving in a harbor at nightfall. Here the participant is allowed to steer a very large ship, the size of an oil tanker, in a harbor, in a simulation at the Institute of Perception in Soesterberg, the Netherlands. Although the display is rather impoverished, simply a dim landscape portrayed panoramically in silhouette on distant walls, the simulated experience is fully convincing, exceeding higher-technology VR displays. The participant has the uncanny experience of being on a ship, steering it through the harbor. Linear vection, the sense of oneself and the boat moving through the harbor, is maintained, as are very slow rotational components of vection as the ship changes course slightly under one's command. From the point of view of perception, the simulation is completely convincing; there is no perceptual distinction between simulation and reality.

The reasons for success with this relatively modest simulation as opposed to obvious hi-tech failures elsewhere are of interest, particularly as they might be classified under reasons of omission: (a) there were no cues that the spatial information depicted was not that of a real as opposed to a simulated scene, and (b) there were no vestibular cues to contradict the perception of self-motion. Instead of attempting to provide the most detail as is so often done in the case of the most technically advanced virtual reality displays, the approach taken here was essentially the opposite, to provide only the minimum optical information to obtain the sense of vection in a stationary environment and to arrange it so that there is no conflict between visual and vestibular cues. Because the simulation was that of nightfall, we as observers were forced to rely on the information available from our visual system under low illumination where it is well known that sensitivity to high spatial and high temporal frequency information is markedly attenuated (van Nes, Koenderink, Nas, & Bouman, 1967). Because the simulation was that of a very large ship, it could only make the smallest changes of direction and course consistent with its tonnage and associated linear and angular momentum. This meant that all appropriate motions of the ship were in the very low temporal frequency range, just where our vestibular system is the least sensitive. This ensured that contradictory vestibular stimulation accompanying any possible course of action would be below or at near threshold levels and not readily perceptible.

All of this adds up to an interesting minimalist slogan, an apt handbook subtitle for any would-be Cartesian demon: *Supply only the minimal information and no more.* Of course, it is not terribly practical in the domain of virtual reality because the range of perceptual situations where there is such an opportunity for such deception is too limited. Yet, more generally, it is likely that this slogan would serve *any* liar or deceiver. One of the important rules of lying is to embellish only in areas where one is certain one's listener is ignorant and otherwise not to volunteer any additional information.

Given the fact that virtual reality's purpose is to deceive, its successes and failures might illuminate the question of knowledge and perception more generally. By understanding the reasons for virtual reality's success in limited situations we gain a different perspective on how perception might work in normal and abnormal circumstances. Our main thesis is that in ordinary perception (as opposed to contrived VR simulations), the potential of perception to "check up" on reality with fast dumb mechanisms is virtually endless. The special virtue of perception is not its infinite wisdom, but its access to near infinite data. By way of exception, this point is further supported by a special psychopathological case where perceptual errors are consequential, where they go unchecked and where psychopathology can be the unhappy result. We describe this next.

Cognition Trumped by Perception in Psychopathology?

Psychopathology is instructive because it offers some vivid examples of what might be taken as deception. Consider hallucinations, altered perceptual states which often accompany mental disorders. How do they stack up in terms of verisimilitude? Do they seem more or less "real" than a virtual reality display? Is a hallucination incorporated into our awareness as something "out there" or is it regarded as something separate, perhaps internal, reflecting some property of our mind or brain? We can identify some "technical" problems that need to be overcome before a hallucination might be considered as real. Much of it has to do with the rendering of the scene at what we might call mid-level vision (Nakayama et al., 1995; Nakayama, 1999), whether the hallucination can be appropriately interwoven into the scene. Obvious are two problems related to occlusion. First, does the hallucinated phantom occlude the background so that those surfaces behind the phantom are now invisible? Second, suppose the phantom steps behind an opaque object. Will its body be partially occluded as if it were a real person or real object? A similar set of questions could be asked of scene lighting. For example, does the hallucinated phantom cast a shadow on neighboring regions which is in accord with the position of the lighting sources in the scene? Are the shading and highlights on the phantom's face appropriate for the composition of the lighting in the scene? These are the classic problems of what is called scene rendering in the computer graphics world, that is, how to make a real object fit into the scene as if it was lit and arranged at different depths in relation to other objects. They apply equally well to the handiwork of any would-be Cartesian demon and no less to a hallucination.

Yet these considerations might be regarded as somewhat off the point for they are based on the assumption that hallucinations are centrally based, that altered perception is the consequence of a dysfunctional mental apparatus which actually constructs or interprets so that perception is different. This is a strongly top-down notion, one that is in accord with psycho-dynamic and cognitive explanations of mental disorders. But we have been pursuing a different question, asking how an altered perceptual experience, say through some kind of abnormality in Fodor's perceptual modules, might lead to mischievous and deleterious effects further along. Maher (1974, 1992) has been developing this point for a number of years; the basic idea being that some mental disorders might be traced to anomalous perceptual disorders. This is the reverse of the usual logic employed in psycho-dynamic or cognitive interpretations of psychopathology. Instead of attributing misperception and delusion to hidden urges or conflicts or to disordered thinking, Maher (1992) is suggesting an opposite causal route, hypothesizing that a primary event in the etiology of at least some forms of psychopathology could be an altered perceptual state and that psychopathology is its reasonable conclusion. He implies that a more or less normal mind, given the same circumstances, would find itself in a similar state. This could occur because perception has priority in the fixation of belief and that otherwise unopposed, perception trumps cognition. Recall that the distorted sense of the upright in a pitched house leads immediately to the false belief that there are mysterious forces afoot, contradicting our longstanding physical knowledge of the world. So too, says Maher, in the generation of psychopathological states. So compelling are some anomalous perceptual experiences that beliefs otherwise labeled as pathological are the plausible consequences.

To be fully convincing, abnormal perception should be such that it cannot be easily contradicted by other sorts of experience. As such, more undifferentiated perceptual experiences having less detail are perhaps more suitable. This is the lesson learned from the ship simulation at nightfall where visual detail is missing, yet given the circumstances, it is not considered as anomalous. Private perceptual experiences, less able to be disconfirmed by others, are most likely to be effective. Such is indeed the case in Maher's argument; he cites subjective perceptual feeling states as the prime examples, where persons have abnormally increased or decreased feelings of familiarity with a scene or person. Others might sense a feeling of foreboding about a scene, etc. Thus, Maher suggests that a schizophrenic patient might know that a particular person is familiar but there would be such a feeling state associated with that person that is so anomalous that unusual thoughts might be the unhappy results, so unusual as to lead to some kind of psychiatric diagnosis.

This line of thinking has received much greater attention of late, defining a new subspecialty combining cognitive neuropsychology and psychiatry (Stone & Young, 1997), and also providing novel explanations for otherwise puzzling and bizarre symptoms. For example, consider the now well-publicized but rare Capgras syndrome, where patients have a very specific delusion. They are sure that a very close relative has been replaced by an imposter. Because such patients were often diagnosed as mentally ill, psychodynamic explanations were initially proffered, thus the patient's beliefs were attributed to ambivalent feelings for a spouse or close family member, etc. This sort of explanation, however, became less plausible as the number of such cases increased and even more telling was the fact that Capgras patients were found to have damage in right ventral occipital temporal cortical regions, close to regions having to do with face recognition. As such, a more satisfying explanation was required, one that accounted for the specific delusion in relation to putative face recognition machinery.

Ellis and Young's (1990) new psychiatric theory is based on recent findings suggesting a dual nature of face perception, the idea that face recognition mechanisms have two distinct and separable outputs. For example, prosopagnosics who lack the ability to recognize faces overtly still are able to make differential emotional responses to faces that are different as measured by various physiological measures (DeHaan, Young, & Newcomb,1987; Tranel & Damasio, 1985). This suggests that there are at least two ways in which face recognition can occur: first is an overt route leading to identification, calling forth explicit memories about the person; second is a covert route, an unconscious identification process activating implicit knowledge of the individual, including vaguer yet powerful emotional states. Ellis and Young (1990) draw upon this dual theory to explain the Capgras syndrome. In this syndrome, opposite to what is found in prosopagnosia, they assume that overt face recognition is normal, but covert is not. When confronting strange faces, Capgras patients would not be different than normals. Recognition would be lacking when seeing such faces and also lacking would be any feelings of familiarity. When confronted with very close associates and loved ones, however, there would be a large discrepancy; patients would recognize the faces of others and have all sorts of memory associations, but there would be no feeling of familiarity. Such a strong discrepancy is then hypothesized to call for a set of cognitive readjustments, "beliefs." The patient resolves the matter with what would otherwise seem like an unlikely conclusion, that these people are imposters!

The specificity of the clinical phenomenon in relation to face perception is supported by recent observations by Hirstein and Ramachandran (1997). Persons who are regarded as imposters when seen face-to-face are less likely to be regarded as such when speaking to them over the telephone. In sum, the Capgras syndrome is in accord with Maher's original hypothesis, that the origin of some types of psychopathology is disordered perception and not the other way around.

Other syndromes as strange and dramatic as the Capgras syndrome have been documented and suggest a similar explanation. Ramachandran (1995) has called attention to a class of parietal cortical damaged patients who are not normally regarded as psychopathological because of obvious brain damage, but who also demonstrate that false perception can lead to even more preposterous false beliefs. Parietal patients can have striking perceptual anomalies; particularly well documented are disorders of body image. For example, right hemispheric parietal patients can insist that the left half of their body is alien, that it belongs to someone else. More pertinent for our topic, parietal patients can be paralyzed say on the contralesional side and because of some peculiarity of such damage, they lack the awareness that they are paralyzed (Ramachandran, 1995). Called anosognosia in the clinical literature, such patients insist that their paralyzed limbs are normal even after aggressive questioning by a physician. Thus patients will repeatedly insist that they can use their paralyzed limbs and so strong is their belief that they do not make any effort to fabricate credible explanations as to why the outcome of using their so-called paralyzed arm is so unsuccessful. Such patients will offer obviously incorrect accounts of why the outcome of a neurologist's challenge is to be explained. Patients, for example, will claim that others have three hands, that they are touching their nose at the same time their arm is immobile, etc. If we regard the body image as including the perceived ability to move as a given state of affairs revealed by perception, then the abandonment of common sense and logical thinking becomes comprehensible. If the body image is the consequence of a perceptual module and its outputs are simply given, no questioning is possible. So compelling is perception here that all logic and knowledge pales in its wake.

Conclusions: Fast Dumb Mechanisms in World Rich in Information

At the beginning of this chapter we asked how potentially contradictory information, from perception and from other higher-level sources, might be reconciled. In the last several sections we have described very rare and unusual situations where errors in perception are consequential, where the organism's ability to select coherent true information from other sources is either unavailable or unexpected and where false beliefs are a possible outcome. In the tilted mystery house, the perception of the upright is dominated by vision, not gravity, and this leads to persistent error. In turn, this can lead to the belief that there are mysterious physical forces. In the ship simulation, there are no other perceptual clues and if persons were temporarily blindfolded and taken to this spot, they could be fooled. In some forms of psychopathology, there are strong feelings, of familiarity or of body competence, which are so strong as to trigger very bizarre thoughts or to violate logical thinking.

Yet, these are very peculiar circumstances where other sources of contradictory information are not available, and where mistaken perception, unchecked by normal perception, can lead to mistaken thoughts. It should be obvious, however, that everyday life is very different. The richness and redundancy of information supplied by the ambient visual array is almost limitless for ordinary terrestrial environments (Gibson, 1966). As such, any small amount of inconsistent misinformation is tiny in comparison to the wealth of coherent information available. Also critical is the fact that perception is highly selective. The organism can determine what is perceived. Much of this is simply physical. Moving to different places affords very different visual vantage points. Shifts of gaze are also critical. We can't see an object in much detail if our eyes are not fixated on it. Most important and becoming deservedly appreciated of late is the role of visual attention. Studied extensively in the past but not in its fullest form, visual attention is now seen as a prerequisite for vision. Thus if we don't attend to an object in a scene, we simply do not see it. This is the phenomenon of inattentional blindness which has become well documented in the past few years (Joseph, Chun, & Nakayama, 1997; Mack & Rock, 1998; Rensink, O'Regan, & O'Regan, 1997; Simons & Levin, 1998). Thus misinformation, along with all other information not of interest to the organism, can be safely ignored. As such, perceptual modules, dumb as they are, are not a significant source of error. This suggests that our worried question, the issue of reconciling perception and cognition, is not a troublesome one. Perception, by being so closely coupled to the environment, is, in aggregate, correct and even when it is wrong, it rarely matters.

Postscript: Broader Lessons From the Study of Perception's Modularity?

Having considered perception as an assemblage of modules which work surprisingly well to keep us informed about our environment, I speculate as to whether this understanding might help to understand other mental functions. If we agree with Fodor's thesis, it would seem that there are no obvious riches in attempting to use perception's modularity for understanding broader questions of cognition. The very modularity of perception, particularly its encapsulation, protects it from central systems, allowing perception to be studied with such evident success (witness the treasures in this book). Detailed and satisfying answers are forthcoming but the accumulated knowledge may generalize less and less. Perhaps this is the price to be paid in the study of perceptual modules. This would support Fodor's gloomy prognosis, dashing hopes for a greater and more extended cognitive science.

It is very likely, however, that Fodor's pessimism is too pervasive, resting so heavily on a strict division of the mind into distinct categories, modular and central systems. Although this division has been clarifying, idealizing two extremes, we have already mentioned the existence of transitional cases. For example, studies of visual word recognition indicate the existence of modular systems which are not genetically specified. Yet, these show strong formal similarities with so-called inborn systems. We also mentioned putative modules for higher-level psychological functions. In recent developments in the "theory of mind," it is suggested that a "theory of mind module" develops from more primitive modules, those having to do with eye gaze detection, the detection of animacy, shared attention, etc. (Baron-Cohen, 1997). Although less firmly established, they indicate the fruitfulness of dividing up what would otherwise be too large a terrain. These examples suggest that a variety of mental processes could be described at least in part as modular, that there may be no clear dividing line between modular and non-modular.

I suggest we abandon Fodor's strong views yet retain his property list characterizing modular systems. From this we inherit a useful, open-ended set of distinctions. For a given psychological process, we can determine the degree to which it satisfies various modular criteria. Then by looking over a variety of processes we may see illustrative patterns. So far, we have suggested that genetic specificity is not essential in defining a module, citing the perception of written language. Other properties might also be diminished or absent. As just one example, consider the degree to which a module's operation is obligatory or mandatory. For the bulk of this chapter, we considered perceptual modules as obligatory. Yet, there is the likelihood that all modules are not always obligatory. Earlier stages in the perception of writing and in the learning of a second language in adulthood are transitional examples. Proficiency for the beginner would be limited and as a consequence, the operations of a putative module would become mandatory only at a later time. The opposite might also be the case. Modularity might decrease or be overshadowed over time. Perceptual modules ensure that we see the world as it is. As such, when we look at a scene, we can't help but see it as three-dimensional. There is no choice. Yet, if we were to learn to draw, this would be a great handicap, witness children's drawings. It takes training to see 3-D scenes as 2-D and to render the shapes of objects on a flat surface. This suggests that as expertise develops, the mandatory seeing of 3-D might be superseded by seeing in 2-D.

What determines whether one system will become modular or will be overshadowed by another? Clearly experience and practice must be of importance. But structural considerations are also likely to be relevant. One obvious constraint is the brain itself. The existence of modules seems inevitable if we realize that a given neuron in the brain can connect on average with only 10,000 other neurons at most. Given the 100,000,000,000 neurons in the brain, we can see that some form of nesting of neural connections is required, that neurons can connect widely only by being parts of larger assemblies that can connect to other assemblies over longer distances. This suggests that modules can emerge most easily over regions of high interconnectivity, say over cortical columns or adjacent sets of columns.

As such, it seems reasonable to suppose that modules formed by long-distance connections in the brain would be much harder to establish. Consider an audio-visual speech recognition mechanism that is suggested by the advantages of lip reading and the McGurk effect. The latter is demonstrated by the altered hearing of speech with changes in facial motion (McGurk & MacDonald, 1976). Because brain regions specialized for the processing of faces and speech sounds are not adjacent, such a presumed mechanism presents an interesting challenge. Is acoustic visual speech processing a module? Little is known on the topic but Green, Kuhl, Meltzoff, and Stevens (1991) suggest that such a process is at least domain specific. The McGurk effect is as strong for voices and faces of differing sexes as it is for conditions where the sex of the voice and face is the same. If it is a module, by what anatomical route is the coordination of such a module accomplished, and is there a characteristic way that other multi-modal modules in general can emerge?

By answering these questions and others motivated by questions of modularity, I suggest that we can obtain much more systematic knowledge, not only about perception, but for a wider range of topics where the presumption of modularity might also be informed by a closer examination of perception's modularity. Perception has long been held up as an example for understanding other mental processes. Its methodologies have been appropriated (Green & Swets, 1966) and broader theoretical concepts (Marr, 1982) have gained wide currency in cognitive sciences. Yet, in all of these endeavors, it has been easy to ignore the specific findings of perception, to regard them as too detailed and technical and not relevant for the understanding of higher-order processes. Yet closer attention to the field of perception might offer more than has been previously appreciated. Perception may furnish the best and most extensive set of examples regarding the nature of, the development of, and the interaction of modules. As such, the degree to which other systems can be understood as modular or partially modular may be informed by progress here. In short, the specific contents derived from the study of perception, not just its methods, may be more useful than has been generally apparent.

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