

Senses" in the book *Analytical Philosophy* referred to as "the special introspectible character of the experiences [of perception]" (p. 250). This strategy relies on the appeal to the subjective, conscious "feel" of experiences—how the character of the experience of a smell is felt differently from that of the experience of seeing, for example. As Nelson Goodman and Austen Clark describe, one can look to the perceptual science of psychophysics to create "quality spaces" corresponding to the various sensory modalities. Psychophysicists do this by presenting subjects with perceptual stimuli and asking them to identify *just noticeable differences* in what they perceive. This, in turn, allows them to create *matching spans* of stimuli in which each stimulus matches its immediate neighbors, but the ends of the spans are easily discriminable. The quality spaces created by psychophysics have discontinuities that reflect the different modalities: all the colors of the spectrum can be connected together in the same matching span, as can all the pitches in a scale in another matching span; but these two spans are not themselves connected. This discontinuity lends empirical support to the philosophical intuition that the experience of colors is distinct from the experience of pitches, and that vision and audition are separate modalities.

Other accounts eschew the qualia-based approach in favor of a strategy of attempting to use the techniques of neurobiology to identify sensory organs. Instead of beginning with human phenomenology, this approach attempts to discover organs that transmit information to the nervous system, regardless of any conscious correlate to that organ's activity. This allows us to speak of sensory modalities in nonhuman animals, for example, without first answering the question of whether those animals have consciously perceived quality spaces. It also allows for the possibility of discovering putative human sensory modalities that are not conscious, a result that can be taken in two ways: For those that think that the goal of any explanation of sensory modalities is the explanation of our commonsense categories, any account of the senses that allows *unconscious senses* is clearly a nonstarter. For those that believe that the sciences can potentially lead to the revision—even radical revision—of commonsense

psychological categories, such neurobiologically inspired conceptions of the senses represent a potentially fruitful endeavor.

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See also Philosophical Approaches; Psychophysics; Detection; Qualia; Theoretical Approaches

Further Readings

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MODULARITY

Modularity implies self-contained, sometimes repeating, units. Modules can be large complex units (such as modules for homes containing large subparts) or small, more uniform units (such as the bricks in the wall of that home). In nature, **modular** patterns are visible everywhere, from the segmented bodies of colorful caterpillars to the individual toe pads of a dog's foot. Our distant fossil ancestors clearly were **modular** segmented creatures. We come from a long evolutionary history of animals that have **modular** body plans. Most of us can agree that the body has different organs, such as the kidney, stomach, heart and lungs, and that each of these organs can be subdivided into modules, such as the four chambers of the heart, but it has been more difficult to parse the brain into modules, particularly that part of the brain that may be most crucial to perception, namely, the cerebral cortex.

This entry explores whether the concept of a module is useful when considering the organization of the mind and brain. One of the initial

problems we face concerns the definition of a module. In engineering, a “modular design” implies a system that can be subdivided into smaller parts that can be created and operated independently. In psychology, this term has been variously used to suggest that the mind is made up of specialized mechanisms that evolved to deal with different senses or particular cognitive problems an organism might face. The idea of modular processing also has been used to describe components of basic aspects of perception, such as color and form vision, as well as higher order processes, such as short- and long-term memory. At the level of brain organization, “modular” has been applied to everything from major anatomical subparts, such as the olfactory bulbs concerned with the sense of smell, to specialized cortical areas that deal with complex object perception, to detailed anatomically or functionally defined features, such as cell layers or repeating columns of cells that appear to share common response properties.

Mapping the Mind: A Little History

The issue of whether one can link mental faculties to particular brain modules or locales has a long, detailed, and colorful history. It is beyond the purview of this entry to review this history, but several points are worth highlighting that relate to modern controversies concerning modular localization of function in the brain.

Historically, Francis Gall is closely associated with localization of function in the brain. Gall, born at the end of the 1700s, promoted the idea that the mind is located in the brain and that the mind is modular. He is best known for establishing a system known as phrenology. Phrenologists believed that specific brain modules reflected specific mental traits and that their relative development in the brain deformed the overlying bone, allowing physicians to evaluate the prominence of different faculties by measuring the bumps on the head. This system remained quite popular through the 19th century. When Gall originally argued for brain/mind modules, he was roundly criticized for his heretical views that ran counter to both religious doctrine and scientific proposals about the function of the mind and brain. Although scientists

today find little support for Gall’s proposed modular subdivisions of mind, most scientists agree that regions of the brain are specialized for different tasks. Yet, in spite of a large number of studies trying to define the limits of brain and mind modules, there is still no general agreement on their number or exact boundaries.

One can also cite many historical examples of the opposite view, namely, that mind/brain modules do not exist. The work of Karl Lashley represents the clearest historical example arguing against the existence of mind/brain modules. Lashley, born a century after Gall in the late 1800s, used cortical lesions and measured behavior in rats to examine for the locus of memory in the brain. Although Lashley did believe that there were specialized regions of the brain concerned with primary sensation, his conclusion was that the cerebral cortex was equipotential for complex functions, such as memory and learning. In his view, the rats’ memory deficits following cortical lesions simply got worse when lesions were larger, regardless of where the lesions were placed. Lashley’s conclusion was that no brain modules for learning or memory existed and that these functions were based on widely distributed cortical networks. Modern neuroscience recognizes that the brain retains some amount of plasticity well into adulthood and that some functions, such as perceptual learning, can occur in a distributed manner throughout sensory areas.

Modularity in Development and Evolution

Although debate persists about functional modules in mind/brain, current evolutionary and developmental studies strongly support the idea that there are anatomical and physiological modules in the brain. A few examples will suffice to make the point. As previously described, modularity of the body plan appears obvious. Following on the lead of early work in insects, numerous studies in vertebrates have provided evidence that specific sequences of genes control the development of different brain parts. For example, in the vertebrate hindbrain, a set of genes known as the Hox genes are expressed in a sequential fashion during development and their expression matches the development of boundaries of hindbrain compartments

(modules). **Hox genes** are part of an important family of developmental regulator **genes** that exist in all studied animal phyla and are arranged in clusters in the genome. The forebrain (part of which develops into the cerebral cortex), however, is structurally more cryptic than the hindbrain. Nevertheless, developmental and genetic studies have revealed subdivisions that appear to mark what will later become major areas of the forebrain. The problem with these studies is that they only define large areas of the forebrain and do not neatly subdivide the cerebral cortex into modules that match boundaries of accepted functional areas. Moreover, during development, migrating cells and growing axons (nerve cell processes) freely cross these proposed forebrain developmental boundaries, making it difficult to determine if a true compartmental or **modular** boundary exists in this part of the brain. Therefore, although most scientists agree that **genes** regulate the subdivisions of major brain parts, genetically subdividing the cerebral cortex (where complex perceptual and cognitive tasks are accomplished) is problematic.

Current Controversies

As in the case of genetics previously described, most investigators currently agree on many larger brain subdivisions. For example, investigators have known for many years that the cortex contains maps of sensory surfaces. Using microelectrodes, anatomical tools, and lesions, investigators have defined the boundaries of primary cortical areas that map the body surface in the somatosensory cortex in the parietal lobe, the visual world in the primary visual cortex in the occipital lobe, and the frequency of tones in the primary auditory cortex in the temporal lobe. These primary sensory cortical areas exist in all studied mammals. For the olfactory sense, specific areas of the forebrain contain odor maps. Thus, there is general agreement that the cortex can be divided up into large sensory maps or modules. In primates, the importance of these maps to perception is particularly obvious for the primary visual cortex, where a localized lesion causes a blind area (a scotoma) in the corresponding part of the visual world. General consensus also exists that mammals have

an orderly cortical map (motor map) devoted to the control of discrete sets of muscles in the frontal lobe.

However, controversy continues concerning boundaries of other cortical areas or modules. The problem is that the cellular architecture of the cortex is surprisingly similar over its entire extent. The cortex consists of ~2 to 4 millimeter (mm) thick layered sheets of cells. Some investigators have argued that the subdivisions or modules of the cortex inherit their regional differences from another area of the brain called the thalamus. The argument here is that cortical modules are defined developmentally by thalamic modules or nuclei. The thalamus has many groups of cells (nuclei) whose architectural boundaries are easy to identify in microscopic tissue sections. These thalamic cell groups communicate with discrete regions of the cortex via long processes called axons. Redirecting developing axons carrying visual information into the part of the cortex that is normally devoted to hearing has allowed animals to "see" without the visual cortex, suggesting that thalamic modules specify cortical areas. However, research also shows that differential gene expression patterns persist in the cortex in genetically manipulated mice that never develop thalamic connections to the cortex, indicating that some architectural modularity is intrinsic to the cortex. How these developmentally defined genetic cortical gradients relate to adult cortical modules is unclear. The other problem is that outside of the primary sensory cortical areas (and a few other regions) there is no general consensus concerning **modular** boundaries in the adult cortex. Although Korbinian Brodmann, more than a century ago, proposed a map of 52 cortical areas based on cell staining differences, there is still little agreement on the majority of these areas despite massive numbers of anatomical, physiological, and clinical studies.

In addition to controversy over larger regions or areas of the cortex, there is also debate about modules defined on a smaller scale. One could argue that layers define modules because they show distinct cellular connections. There also appear to be anatomically definable modules within layers. For example, in the somatosensory cortex of rodents, the whiskers on the face are represented by discrete

clusters of cells called *barrels*, so named because of their shape in cell-stained sections. In the visual cortex of some primates, including humans, axons coming from the thalamus define radial columns of cells that respond preferentially to input from either the left or right eye (ocular dominance columns). Whether these anatomical markers contribute to function remains a controversial issue.

Staining the primary visual cortex for the relative levels of the mitochondrial enzyme cytochrome oxidase shows a distinct pattern of dark dots in the primary visual cortex and dark and light stripes in the secondary visual cortex of monkeys; these dots and stripes have been argued by some investigators to represent functional modules within the primary and secondary visual cortex. Specifically, it has been argued that cells marked by dark and light staining for cytochrome oxidase in the primary visual cortex are specialized for the processing of color and edges, respectively, and that cells that live in these modules, in turn, send their information to cells located in cytochrome oxidase dark and light stripes in the second visual area. The cells within these modules in the second visual area, in turn, put together information about color and form in more complex ways. This information is then transmitted to higher visual areas that contain modules for still more multifaceted processing of object features. Finally, the signals are sent to the inferotemporal cortex where, some have argued, modules exist for particular types of objects, such as faces, houses, or body parts. It also has been proposed that a second hierarchy of visual areas exists concerned with visual space or active vision involving visual motion. Active vision can be considered vision that allows us to guide our body in space or form our hands into the right shape to pick up a cup on the table in front of us. As with the object vision hierarchy (the “what is it” pathway), it has been argued that visual areas related to space (the “where is it” pathway) contain modules that analyze different aspects of motion and space at each hierarchical level. To sum, the broad proposal here is that the two different hierarchies, the different areas within each hierarchy, and the different modules within areas are all specialized to process different pieces of information necessary for the final, goal-directed behavior.

Similar pathways and hierarchies of areas devoted to “what” and “where” processing have also been

proposed for the auditory and somatosensory systems as well. **Modular** hierarchies have even been proposed for frontal cortical areas concerned with decisions about objects and locations.

These proposals remain the subject of active research. One problem with many of these proposals lies in defining anatomical boundaries for the modules and areas within the hierarchies. For most of the cortex, no structural markers that consistently define such areas or modules within areas exist.

Linking Functional and Structural Modules

If we accept, for the moment, the existence of structural brain modules, even if they are hard to define, then we are faced with the larger issue of linking brain modules to mind modules. Although many more experimental tools are available now for linking brain to mind than at the time of Gall, no clear model of this link exists. Some of the more successful efforts to link mind and brain modules have involved electrophysiological recordings in animals trained to perform certain behavioral tasks that specifically engage certain brain areas. For example, it is possible to study the activities of individual cells in the inferotemporal cortex while the animal performs face identification or face discrimination. By relating the activities of individual cells to the decisions made by the animal, it is possible to infer associations between specific brain areas and specific behaviors or cognitive functions.

One limitation of this approach is that so far it has only been possible to study one simple function at a time by recording the activities of cells in one or two different brain areas simultaneously. Therefore, our understanding of how these specialized brain areas and modules work together to facilitate complex perceptions remains sketchy. For example, the visual, auditory, somatosensory, and olfactory signals that arrive at the cortex during a fine dining event result in a holistic culinary experience, yet, very little is known about how information from the different senses come together in the brain to give rise to this coherent experience. Some argue that in order to understand this process, we must solve the so-called binding problem (i.e., figure out how the different modules exchange and integrate the results of the information processed within each). However, whether information from the different modules needs to be actively

integrated together in one brain region or through one brain process itself remains an important and outstanding question. The gap in our knowledge about how the different brain modules work together can be attributed in part to the "modularization" of neuroscience itself and to how we conceptualize mental processes.

Even if we can agree on definitions of mind modules and have some idea how they become linked, we still have no clear idea how such mind modules relate to the genetic underpinnings that determine the form of the brain itself. What role, for example, does experience play in determining modules of the mind? It is obvious that the brain is plastic and we learn to attach meaning to perceptual experiences. A person who learns to speak Chinese and not English has limited ability to discriminate between certain English phonemes, a limitation brought about by experience and not genetics. Some investigators have even argued that modules proposed for facial recognition are actually modules designed for discriminating between complex objects that are most commonly encountered in the animal's ecosystem. To wit, an ornithologist may have more cells in this region devoted to discriminating between bird species, while an auto mechanic may have a profusion of cells that code for different models and makes of cars. Clearly, such mind modules must be at least modified, if not defined, by experience. Yet, it is equally clear that mammalian brains are quite similar, and that many mammals can perform very complex perceptual judgments within hours of birth. Wild horses must recognize their mothers and move with the herd within hours of birth. This requires they make enormously complex judgments about forms and motion so they stay with their mother and distinguish her from other moving objects, avoid bumping into others while in motion, or falling over rocks. Clearly, basic modular architecture for complex perception can develop without experience yet must remain flexible enough to allow new information to be stored continuously and later recalled.

Future Directions

Support exists for both brain and mind modules. Brain areas, including the cortex, are not uniform structurally or functionally. Subdivisions can be

recognized using a variety of tools, from genetics to functional imaging. Primary sensory and motor areas are the clearest, best studied, and best accepted examples of such modular regional specialization. However, even these subdivisions cannot be considered modules in rigid engineering terms, where modular parts have rigid boundaries and can operate independently. Definitions of brain modules or areas devoted to the representation of more complex cognitive/perceptual properties continue to remain controversial. Much of this controversy stems from our still primitive understanding of the language of the brain. How complex properties are coded by individual or groups of nerve cells still has not been resolved. Appropriately linking mind modules to brain modules will require a better understanding of the neural language. The ability to record from many neurons at once combined with increasing computer power should aid in this endeavor. Additionally, increasing our knowledge of the architectural boundaries defined by genes, protein expression, and connections in a variety of species can guide us as to where to look for functional brain modules. Finally, sophisticated neural models can be used to test the adequacies of hypothesized mind/brain modules.

Knowledge of the functional and structural modularity of the brain has allowed neuroscientists to study each part of the brain in great detail without worrying too much about the complex relationship that one part may bear to other parts of the brain. Analogous relationship between modules also reduces the overall complexity of the problem because results obtained for one module can be extrapolated to others with reasonable integrity. This reductionist approach has yielded valuable details about brain function, but at the same time it has overly "modularized" neuroscience itself. Eventually, conceptual models may need to be developed to explain how the modules functionally cohere into a whole.

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See also Auditory Processing: Central; Cutaneous Perception; Neural Representation/Coding; Physiological Approach; Visual Processing: Extrastriate Cortex