Commentary

A fuzzy limbic system

Robert L. Isaacson

Department of Psychology, State University of New York, Binghamton, NY 13902-6000 (USA)

(Received 3 August 1992)
( Accepted 11 August 1992)

Some years ago, while he was President of Harvard, James B. Conant pointed out that scientific theories are not overthrown by the accumulation of observations inconsistent with them, but are only abandoned by displacement by theories that encompass more data and explain known 'exceptions' to the general rules of the existing theory. In short, established concepts and theories disappear only when replaced by more useful and 'fruitful' ones. And so it is with the concept of the 'Limbic System'. As a conceptual term it will survive in the face of all criticisms until a more comprehensive, and fruitful, or useful theoretical scheme comes along and supplants it.

Is there really a limbic system? This is an unanswerable question. There is no external 'realness' about theories. Scientific reality, such as it is, changes with the times and with the ever-greater accumulation of information.

After discussing the various levels at which common objects, such as 'wood' and 'table' can be described ranging from everyday language to conceptualization at the level of molecules and the groupings of atoms, Conant goes on to say,

"...the question of the reality of many of the conceptual schemes of the scientist pose no more difficult problem than the question of the reality of the common sense concept of a table or the material we call wood. For scientists as for laymen, when they are not on their guard the degree of reality is largely a function of the degree of familiarity with the concept or conceptual scheme; this in turn is a function of the

fruitfulness of the idea over a considerable period of time." (Conant, pp. 35–36)

The reason that the 'limbic system' is so frequently used is that it has been a useful, even fruitful concept, over a period of many years. Most people understand it in a general way. Someday, it will likely be replaced by one or more concepts that are more fruitful and which 'fit in' with more adequate theories about other brain systems. But, until this occurs, the limbic system will remain with us.

In the quotation from Dr. Conant, it should be noted that he believes scientific reality can exist 'in degrees.' In the world of theory, things can be more or less real. The idea that concepts and ideas, simple or complex, can be more or less 'real,' foreshadows the approach taken by mathematicians and logicians, not to mention engineers and other scientists, that invokes the concepts of 'fuzzy sets' and 'fuzzy measures.' In this approach many concepts are seen to have a value that is not 1 or 0, true or false, but range anywhere between these extremes. Everyone has some degree of age, of health, and scientific concepts have some degree of 'reality.'

The mechanisms of the 'classic' (neo)cortical apparatus underlying vision, audition, and sensorimotor functions are still not well understood or conceptualized. The guiding principles of the structure–function interactions are obscure and await a comprehensive theoretical basis. Even the concept of a somatotopic pattern of organization for primary motor cortex in primates is in question with some researchers believing that a 'synergic' organization of this area to be more appropriate. The motor cortex is apparently not organized into individual control modules for movements of a selected muscle but rather organized into groups of...
more-or-less neighboring cells, the aggregate actions of all giving rise to particular actions, the exact nature and intensity of which depend on a host of external and internal factors. Further, cells in one aggregate may also be associated with other aggregated cells involved with different actions. In such a scheme a cell could properly be said to have some amount of association with one behavioral action and different amounts of association with different behavioral patterns. Because of the problems inherent in measuring the degree of association of cells with different motor actions, the precise amounts of these associations will never be known. This means that the estimates of a particular cell's associations with particular behaviors will never be firmly ascertained (that is, a 'crisp' number determined) but rather known in a vague and uncertain fashion, i.e., a 'fuzzy' estimate or measure. This is as it must be since the body and brain are enormously complex systems and must be simplified for even a cursory understanding. One approach to the simplification is to allow uncertainty to remain in the description of both laboratory and clinical observations and in the theories generated on their basis. Information must be lost, or even neglected, to create understandable theories. A mathematical approach under which such simplification cannot only be accepted but can be studied and used to develop new theories is the theory of fuzzy sets and measures, e.g., Klir and Folger\(^2\).

To recognize that even our best measures of neuroanatomy are 'fuzzy measures' is only to recognize the uncertainty of our knowledge. In the sensorimotor system this might involve the numbers and locations of targets for axons arising from pyramidal cells of the cortex.

We know that these targets are many in number and diffuse in location. They include other cells of the cortex, subcortical and brainstem areas, and spinal cord sites. But, the issues pertaining to the uniformity of the distributions of the projections of these cell processes is virtually unknown and the determination of the precise distribution of processes of any cell based on post-mortem examination of histological specimens only provides a partial glimpse of a cell's contact with other cells. As a consequence of such difficulties of measurements, the unescapable uncertainty of our most fundamental anatomical observations must be recognized. All have an inherent fuzziness in both measurement.

It is interesting to note that the modern founder of fuzzy set theory, LoFtī Zadeh, was concerned with the need in biology to develop a 'mathematics of fuzzy or cloudy quantities,' ones not describable in terms of the usual probability distributions but common to biological systems.

The theories and concepts in neuroanatomy, as in all sciences, are transitional in nature and, on top of that, have uncertain 'boundaries.' As noted above, the very measurements of the science generate numbers and observations that are themselves less than absolute and unchanging. They have various degrees of uncertainty, ones that cannot be described in terms of traditional probability distributions. Once again, this is no different from the conditions in other sciences.

What are the anatomical boundaries of what is commonly understood to be the limbic system? Such a question is without an answer, but the question of how much limbic-ness a given group of cells or some functional (although fuzzy) system may have meaning. Every portion of the brain could be described as having some degree of limbic-ness. Indeed, it might be said that every neuron has some degree of limbic quality. Beyond this, in the spirit of the fuzzy set approach, it is reasonable to say that every neuron has some degree of (neo)cortical-ness and some degree of every other functional system we may find it useful to attribute to the brain. By making this type of quantitative approach, we avoid the difficulties in trying to decide the precise limits (boundaries) of systems and do not have to worry about such questions as whether or not the frontal regions of the rat brain should be included in the limbic system or not. Based on the observations of Gaykema et al.\(^3\) concerning the close relationship of certain frontal cortical regions with the septal area, we may wish to say that some frontal cortical regions may have more limbic 'value' than we might have previously thought. But, increasing our evaluation of the limbic-ness of a cortical area does not necessarily diminish their (neo)-cortical values. The cells of this 'neocortical' domain can participate in many functional systems.

On the other side of the coin, the hippocampus seems to differ in several ways from other brain regions that have high 'limbic values.' It is a relatively silent area in the sense that, when electrically stimulated, it does not induce the autonomic changes found as a consequence of stimulation of the amygdala, the hypothalamus, or other areas high in limbic attributes. It also seems to have somewhat stronger, or at least more apparent, afferent pathways arising from transitional cortical areas than do some other portions of what we call the limbic system. I suggest that this only means that the hippocampus, and dentate gyrus in particular, may have a somewhat higher degree of corticality than do some other limbic areas.

I avoided confronting the issue of defining the attributes of the limbic system or limbic qualities. I believe that most neuroscientists with an interest in neuroanatomy and the history of brain research 'know' to some
degree about the limbic system and that there is a consensus about the basic components. The edges, the boundaries, of the system are indistinct and uncertain—perhaps somewhat more so than those of other brain systems. This is a condition that exists and it will persist until a better and more useful theory will be created. It is my belief that the better and more useful theory will be one that recognizes the need for dealing with the conceptual and the practical uncertainties inherent in the scientific enterprise. Indeed, I believe an approach that is capable of dealing effectively with the complexities and uncertainties of the brain is essential. We must remember that Ramón y Cajal believed that understanding the gray matter of the brain would take centuries. This might be an optimistic estimate.

REFERENCES