the West has kept those stressing economic equality rights on the defensive. Even communist China has announced that 'iron rice bowl' guarantees are gone and workers must not only work but scurry to gain employment. At the same time protection against arbitrary confinement and rights of expression has been demonstrated to have wider appeal than some have thought, although perhaps still valued most by the middle classes.

See also: Common Law; Constitutional Courts; Constitutionalism; Human Rights, Anthropology of; Human Rights, History of; Human Rights: Political Aspects; Justice and Law; Justice: Philosophical Aspects; Justice: Political; Rights; Rights: Legal Aspects

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Binding Problem, Neural Basis of

For a large part of the twentieth century, the issue of how physical brain states represent mental objects was dominated by one idea, that of single units as elementary symbols of our mind. According to this idea, an individual's mental state is fully described by the ensemble of single units active in a given moment. This symbol system would be most peculiar in having only one composition rule, that of simultaneous activity, whereas all other known symbol systems have flexible means of building hierarchical structures. The mind, meeting place and source of all other symbol systems, surely must possess a mechanism for combining its semantic atoms into molecules and aggregates in a way richer than anything yet contrived on paper or in electronics. Identifying this mechanism is the binding problem.

1. The Binding Problem

One of the solid results of research on brain function is the localization of mental themes in the brain in a hierarchical manner down to the assignment of definite semantic meaning to individual neurons. It is, therefore, a broadly accepted view that neurons can be treated as elementary symbols with fairly fixed meaning. The assignment of meaning to neurons has been a very successful enterprise for decades, and it is probably a permissible extrapolation to apply this picture to every neuron in our cerebrum, if not in our whole nervous system. It has, furthermore, long been an uncontested view that the state of a neuron can be characterized by an activity variable, which in a not very precisely definable way corresponds to its current rate of firing (one speaks of 'rate coding'). Semantic meaning is routinely assigned to neurons by temporarily associating their rate of firing with sensory stimuli or motor responses.

A neuron is thus taken as an elementary symbol that is either active or dormant in a given mental state. It is elementary in the sense of having no internal structure in terms of subsymbols (although a neuron's semantic referent invariably is a composite entity). As a rule there seem to be groups of equisemantic neurons. To allow for this possibility, the term 'single unit' will be used instead of 'single neuron.' In spite of all the internal anatomical and physiological structure of single units, the mental symbols associated with them are taken to be elementary, i.e., having no internal degrees of freedom.

At issue here are the laws by which higher symbols are composed from single units. With rate coding there is only one composition rule: mere additive, unstructured combination of the active units' elementary meanings into one amorphous lump. This is a very poor composition rule, and a somewhat inadequate basis for cognitive and mental operations. A few examples may illustrate this inadequacy. Assume a first mental object (e.g., an imagined hand) to be represented by the set A of single units, and a second mental object (e.g., an apple) by set B (for simplicity let A and B have no units in common). Now assume there is reason to hold both mental objects simultaneously (as, for instance, when the hand is grasping the apple). The above composition rule states that the superset C = A ∪ B will be active. This, however, creates a problem in that C doesn't contain any information as to grouping of its elements in terms of its constituents A and B, and there now may be several ways to decompose C into part symbols. This ambiguity has
been termed the ‘superposition catastrophe.’ In a more concrete example, let a person perceive a blue letter A and a yellow letter B on a sheet of paper, and assume there are units to represent ‘A,’ ‘B,’ ‘blue’ and ‘yellow’ in the person’s brain. The simultaneous activity of all four units represents the situation incompletely, as a yellow A and a blue B would evoke the same situation. This type of ‘conjunction errors’ are actually committed by human subjects when not given enough time to inspect a situation (for review see Wolfe and Cave 1999). The experimental examples show that the binding of elements into groups can be a real problem for our brain if it is not given sufficient time.

If single units are the mind’s ‘bricks,’ what is the ‘mortar’ to erect its cognitive edifices—to group features into objects (such as in figure–ground separation), to attach attributes to referents (such as grammatical roles to the words of a sentence), to represent temporal or spatial arrangements of elements such as in a spoken sentence or in a visual scene, or to point out correspondences between structures found to be analogous to each other?

2. Binding by More Single Units

Single units can code for (fixed) combinations of other units, and in fact this is true for almost all units. In the above example, the colored letter ambiguity would be dispelled immediately if there were single units encoding blue As and yellow Bs. So why shouldn’t the cognitive architecture of the whole brain be based just on combination-coding units? A correct short answer to this question probably is that indeed it is to a very large degree, but that for the purposes of a small but vital subset of operations it cannot. The reason is that whatever a brain’s complement of combination-coding units, it is bound to run continuously into situations which call for new combinations and which would only be represented with dangerous ambiguities. Each individual ambiguity could be stopped by more combination-coding units, but those units happen not to be present (yet). Thus, vital flexibility in handling new situations will need a binding mechanism that transcends a code based entirely on single units.

Several serious obstacles stand in the way of achieving anything like completeness in terms of single-unit coding. The number of composite symbols that are required over a lifetime is too large to be covered ahead of time in any combinatorially complete way. To take just one example, there are an infinite variety of feature combinations through which physical objects can manifest themselves in our visual system, and which must be handled as composite mental entities. It is impossible to represent them one by one in terms of single units. Each one of them is new and unforeseeable, and a single unit to represent it would have to be manufactured on the spot. All that can be hoped for is that certain subpatterns are common to many situations, get represented in single units, and collectively reduce by large factors the combinatorial ambiguity the brain has to cope with, by representing a given mental object in terms of relatively few units.

Representing composite entities (like ‘my grandmother’) by single units is problematic in itself. It is as if a mathematician wanted to replace all composite expressions by single-letter symbols. We can operate with composite objects (especially when they appear for the first time) only with reference to their parts (and their relations) with which we have had previous experience. Consequently, those parts (and relations) have to be explicitly represented themselves! If, for instance, all colored letters were, for the sake of avoiding ambiguity, represented by colored-letter coding cells (blue-A etc.), anything that I have learned in the past about green As would not be available for blue As and I would have to learn it anew. If, on the other hand, all part-representing units were visible along with the units representing the whole (blue, yellow, A, B along with blue-A and yellow-B), the potential confusion would be even bigger than without the combination-coding units. Each client (that is, group of units) would have to learn to pay exclusive attention to the appropriate symbol level, by disconnecting from units on all levels that would cause confusion. For this and other reasons, installing a new unit is a complicated business that is warranted only for representing frequently recurring symbols. Finally, a brain based entirely on single units could not represent explicitly the hierarchical structure of complex symbols and would consequently not be able to discover structural relations between mental entities.

In summary, a nervous system based entirely on a flat symbol system composed of single units would be totally inflexible and uncreative and would not be able to deal with novel situations.

3. Temporal Binding

According to this idea sets of units express mutual binding by synchronizing their signals. In the above example, the units ‘blue’ and ‘A’ would express their binding by firing in synchrony, or the two sets of units A and B would avoid the superposition catastrophe by firing with strong positive signal correlations within each set and zero or negative correlation between them. This idea as such does not go beyond the generally accepted fundamental principle, stated above, that the composition rule for unit symbols is simultaneous activity; it extends it, however, down to the millisecond time scale, and it requires the processing of whole signal sequences if complex binding structures are to be expressed. Temporal signal structure is induced by the presence and structure of connections between units, with strong excitatory links generating positive correlations. Temporal signal
structure is interpreted by structured circuits in that the correlation structure of a set of signals may or may not fit the internal connectivity of a circuit upon which it impinges (two units with mutual excitation are easily excited by correlated signals, for instance, but would respond less readily if they inhibited each other).

Random connectivity structures would neither produce clear-cut signal structures nor could they selectively respond to structured signals. Appropriate connectivity patterns can be formed by network self-organization on the basis of (possibly rapid and reversible) synaptic plasticity: an initially random circuit would create correlation patterns, which would act back on the circuit by strengthening or weakening connections in a feed-forward fashion (strong correlations leading to strong connections, for instance), rapidly converging to an attractor state in which signal correlation and circuit structure are optimally reinforcing each other.

The binding problem and its solution by signal synchrony was first discussed as a fundamental issue of brain function by Von der Malsburg (1981) (although the idea of synchrony coding has been briefly mentioned in several earlier references), and the same reference has proposed network self-organization as its basis. Temporal binding has been applied successfully to a range of problems of brain function, as reviewed in Von der Malsburg (1999). Among these are logical reasoning, figure-ground segregation in the visual, auditory and olfactory modalities, and invariant object recognition. Experimental evidence for temporal signal structure relevant for binding and its occurrence under appropriate circumstances is reviewed in Gray 1999 and in Singer 1999. Main objections to the temporal binding hypothesis, reviewed in Shadlen and Movshon 1999, concern still insufficient experimental evidence and doubts about the ability of cortical tissue to process temporal signal structure on an interestingly fast timescale.

A strong limitation on temporal binding is the low bandwidth of neural signals. According to optimistic estimates, the temporal resolution with which correlations are evaluated in the cerebral cortex is one millisecond. This leaves little space for many time slices to be kept separate in typical processing times of 100 milliseconds. Are there other, more efficient means of binding? One possibility that will have to be explored in the future is based on multicellular units: the neurons in a unit may all code for the same elementary symbol but they may differ in their connectivity to other units. By proper control of a unit’s internal activity distribution it may be made to dynamically change its connection pattern and thus express selective binding to other units. This will require highly specific connectivity patterns. Before these are installed, temporal binding and rapid reversible synaptic plasticity will have to act as the ‘fire brigade’ suppressing binding ambiguities as they emerge.

Once the neural community will start to build up momentum and methodology to fully utilize the strengths of a neural-based symbol system with full binding capability, the remaining deep riddles of our cognitive apparatus may be ready for assault.

See also: Neural Synchrony as a Binding Mechanism; Object Recognition: Theories; Perceptual Organization; Visual Perception, Neural Basis of

Bibliography


C. von der Malsburg

Binet, Alfred (1857–1911)

1. A Brief Biography

Alfred Binet was born in the French town of Nice on July 11, 1857. According to his daughter Madeleine (Avanzini 1974), Alfred was a bright child who succeeded so well in school that his mother decided to send him away to the capital when he was barely twelve years old, in order that he might study at one of the best schools in France. Upon graduation from high school, he completed a law degree in 1877, but then decided to pursue studies in medicine and biology. Under the supervision of Balbiani, who was later to become his father-in-law, he started writing a dissertation on ‘The sub-intestinal nervous system of insects.’ At the same time he wrote plays for the theater. He finally managed to combine his different areas of interest in one discipline, psychology. To simplify, one can distinguish three phases in his career as a psychologist, although his publications prove that the stages were overlapping rather than strictly separate (Delay 1958): psychopathology, experimental psychology, and child psychology.

French psychology in the second half of the nineteenth century was focused mainly on psychopath-