Connectionist value units: Some concerns

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(It’s a commentary on the target article by Dana H. Ballard, “Cortical connections and parallel processing: Structure and function”, in the same issue of the journal, pp. 67–120.

Ballard presents a reasonable and interesting case for the neural and computational plausibility of value unit networks. However, there are some difficulties.

The first point concerns connection weights that are stable in the long term. Are they innately determined or are they (partially) learned as a result of an individual's experience in the world? Some may well be innately determined. Suppose, however, that some weights are learned, and suppose for simplicity that the value units implementing some particular 2D space S each take weighted inputs from correspondingly positioned units in the implementations of some other 2D spaces. Assume that the pieces of input circuitry for different value units for S are similar to each other and all need to have their weights tuned in similar ways. Then, presumably, it must be that either (a) the system's experiences during development are such that all the similar circuits are exercised sufficiently, or (b) once a "good" setting of weights has been found for one of the circuits, it is transmitted to the other circuits, or (c) corresponding weights in different circuits are coupled in such a way that adjustment of a weight causes similar adjustment of weights coupled to it. Possibility (a) seems implausible, but how would (b) or (c) be achieved? (See also McClelland, 1985, 116.)

A major justification put forward for the work is the slowness of functioning of individual neural units. However, little serious attention seems to have been paid to what can happen in "local circuits" (Rakic 1975; Schmitt, Dev & Smith 1976; Shepherd 1983). Here, signal transmission can be fast, as it can be based on electrotonic conduction rather than spike transmission, and the signal may be a high-resolution graded potential rather than a low-resolution spike frequency (so that the rate of information transfer is further boosted). Also, signal processing in a small part of a neuron is probably significantly faster than input–output transformation effected by a whole neuron. These considerations are important because Ballard does explicitly countenance the possibility that a value unit is realized as a part of a neuron (see the end of Section 2.1 of the paper). In general, his assumptions concerning the distances and speeds involved in unit-to-unit communication and in individual-unit responses should be clarified.

The value-encoding/variable-encoding comparison needs further examination. First, Ballard's claim that variable encoding precludes parallel access to different values of a variable rests on an unfair comparison between a large set of value units and a single variable unit. But there might be several variable units simultaneously representing different values of a given variable. (However, such parallelism of values might compare unfavourably, in degree and ease of exploitation, with the value parallelism provided by value unit sets.) Second, there is a type of parallelism allowed by multiple variable units but more difficult to achieve by value units: namely, the use of a single value by several different processes. If, on the assumption of value encoding, those processes need to manipulate the activity level or some other characteristic of the relevant value unit (in an attempt, for instance, to examine the information structure of which that unit is currently a part) then there is a serious danger of interference. In the variable-encoding case, on the other hand, "copies" of the same value could be maintained in different variable units, with different processes using different copies. In sum, value encoding allows multiple-value parallelism but restricts single-value/multiple-process parallelism, but with variable encoding the situation is reversed. The latter sort of parallelism may be of importance in certain sorts of cognitive processing.

Ballard states in Section 7 that most single-cell electrophysiological recording data rule out variable units in cortex. This statement only makes sense if variable units are being assumed to be single, whole neurons - going against the impression conveyed in Section 2.1 that this is assumed merely for the purposes of explanation. Note in particular that a variable unit could take the form of a set of neurons where different patterns of activity over the set constitute different values or symbols (there being no necessary assumption that the neurons in the set can be viewed naturally as value units). Variable units of this form are the basis of the model described in Barnden (1985).

I am puzzled by Ballard's assumption in Section 6 that the variable connection weights are variable synaptic weights. There are other possibilities, for example, that a connection weight is (partly) a state of activity some neuron acting as a "way station" on the neural connection. The synaptic-weight assumption is somewhat at odds with Ballard's apparent desire to be flexible about the physiological nature of value units. Also, the assumption makes it difficult to see how information represented in the way Ballard suggests could be stored for short- term memory purposes. (It might be necessary, for instance, to store several different views of a scene at once.) For example, having connection weights as synaptic weights appears to preclude (for practical purposes) one particular way of doing short- term storage: namely, copying the activity levels and connection weights in a network into a special buffer zone.

The point about short-term storage is a part of a larger concern I have that connectionists should pay more attention to the problems of placing the rather specialized mechanisms they have strongly concentrated on so far in a more general computational setting. This will be necessary to make progress with the higher-level aspects of, say, problem solving and natural language understanding. There has been some recent connectionist work in these directions (indeed, Ballard & Hayes, 1984, is one example) but not as much as there could have been. In Barnden (1984) I show that there are significant, though perhaps surmountable, difficulties in extending traditional connectionism to cope with more general sorts of processing. Also, consideration of such an extension could serve to constrain or enrich connectionist accounts of the traditional tasks of pattern recognition, associative-memory retrieval, and so on. As a simple illustration, we just saw that considering short-term memory can influence one's thinking about the nature of connection weights.