CONSCIOUSNESS AND COGNITION 7, 196–201 (1998)
ARTICLE NO. CC980346

Commentary on "Cortical Activity and the Explanatory Gap" by John G. Taylor

Danko Nikolic

The University of Oklahoma, Department of Psychology, 455 W. Lindsey, Norman, Oklahoma 73019

Filling the Explanatory Gap or Jumping over It

The attempt to understand how the introspective phenomenal conscious experiences emerge from the brain's activity is probably the most thrilling question that science is facing today. Finding an answer to this question would, undoubtedly, have a revolutionary impact on science, philosophy, and technology. John Taylor has undertaken a pioneering step in attempting to determine the kind of neural network architectures that could provide these phenomenal experiences. The strategy he took was first to take the salient properties of the phenomenal conscious experiences and then to suggest the neural network criterion which is necessary to reproduce each property. Considering several different neural network architectures (or processing styles), he shows that recurrent neural networks that produce dynamical limit-cycle activity that persist after the stimulus vanishes are necessary in order to produce the properties of phenomenal conscious experiences.

Taylor's main conclusion is that the qualia of conscious experience corresponds to dynamical neural activity (e.g., bubbles) that is the longest in temporal duration. This dynamical activity is also at the highest level of the processing sequence. Both the neural architecture he proposes and the temporal properties of dynamical activity are well supported by neurophysiological evidence from cortical connectivity and MEG recordings. Thus, the conclusions that Taylor draws from his analysis are consistent with many other findings. They all suggest that the dynamical activity of the brain plays an important role in consciousness (Freeman, 1994; Newman, 1997; Nikolic, in press). Because Taylor attempted to answer one of the most difficult questions about consciousness, it should not be surprising that this pioneering work might be controversial. I will organize my concerns with Taylor's approach into four groups: (1) difficulties in dealing with phenomenal experiences, (2) assigned neural network criteria to phenomenal experiences, (3) tested neural network architectures, and (4) extent to which complex systems approach is used.

1. Difficulties in Dealing with Phenomenal Experiences

Introspection was for a long time almost taboo in cognitive science. After the recent "consciousness revolution," the problems with introspection still remain: It

Commentary on J. G. Taylor (1998). Cortical activity and the explanatory gap. *Consciousness and Cognition*, 7(2), 109–148.

1053-8100/98 $25.00

is difficult to obtain quantitative measures that could be appropriately tested, reproduced, or modeled. This methodological problem is especially serious for certain aspects of phenomenal experience. Thus, the temporal aspects of phenomenal experience, such as "no gap between different phenomenal experience activations," appear to be more objective than some other aspects like "grainlessness."

I believe that only a model that reproduces the whole process of introspection report could provide a complete explanation of our phenomenal experiences. In other words, we need to have one single neural network model that accomplishes all of the following steps: (1) sensory input, (2) corresponding neural activity, (3) phenomenological experience, and (4) report about the experience. This means that as long as we do not have a model that will say something like "Yes, my experience is grainless," we cannot claim that the model is consistent with this phenomenological experience. Unfortunately, such a model would first need to have a concept of grainlessness acquired in similar way we acquire it. Taylor, however, models the phenomenological experience on level 2 and assumes that it corresponds to our responses on level 4, and there is no sufficient proof that it does. The processes in levels 3 and 4 are still unknown.

2. *Assigned Neural Network Criteria to Phenomenal Experiences*

Today, we have limited understanding how some phenomenal experiences emerge from neural processes. An example is our perception of the subjective color palette and its relationship to the opponent processing cells in the cortex. However, it is difficult to test a hypothesis that a particular neural network architecture corresponds to a particular phenomenal experience if we do not know the underlying neural processes. Again, the problem is that we cannot test the criteria just by modeling it. Without testing the hypothesis, we remain at the level of analogy. As long as those hypotheses are not testable, people will disagree about the assigned criteria. To illustrate this problem, I will suggest different neural network criteria for the grainlessness of our phenomenal experiences.

Taylor assumes that grainlessness in our experiences requires a continuous sheet of neurons. Any discreteness would provide a coarse representation of the world. Otherwise, there would be gaps in our experiences. Which neurons would detect those gaps if there are no neurons in between? The grainlessness might, I believe, emerge from the inability of neurons to detect the gaps in discrete representations. For example, if a line consists of dots, but the dots are too small to be perceived separately, the feature detectors for line will fire and we will see a full line. Therefore, if we go far enough away from a stimulus then we cannot distinguish the difference, thus we see a smooth surface. Similarly, conscious experience might not require continuous sheets of neurons to produce grainlessness.

Because of these problems with phenomenal experiences, I believe that the goal of understanding the neural basis of consciousness can only be accomplished by including the modeling of the measurable experimental data. Many psychological experiments demonstrate measurable properties of conscious processes, for example, changes in response times or response accuracy. Another example of data that might help understand consciousness are the changes in measurable variables while the transfer from conscious to unconscious processing takes place during practice (Nikolic, in press). Thus, we should develop models that explain both the hard-core experimental data as well as their accompanying phenomenal experiences. Relying on phenomenal experiences alone does not provide sufficient information to test a model.

3. Tested Neural Network Architectures

The very goal of Taylor's paper was to determine which kind of neural processes produce phenomenal conscious experiences. For that reason, Taylor contrasts two different architectures: feedforward neural networks and recurrent neural networks. In addition, he distinguishes between the role of locally and globally recurrent networks. He, however, did not exhaust all the possible neural processes that could take place in the brain and might play an important role in consciousness. Two processes that seem to be of great importance are synchrony in neural firing and dynamical coupling.

Recently, it has been experimentally established that neurons often synchronize their action potentials (Singer, 1993; 1994). This phenomena has also received attention in theoretical work (Hummel & Holyoak, 1997; Shastri & Ajjanagadde, 1993). It seems, for example, that the brain could solve the so called ''binding problem'' by synchronizing the impulse activity of the neurons that belong to the same object (Damasio, 1989; Stryker, 1989). Synchrony in neural firing has also been shown to play an important role in learning by increasing the speed of synaptic changes (Markram, Lubke, Frotscher, & Sakmann, 1997). Neurons from different cortical areas also synchronize during execution of motor responses (Roelfsema, Engel, Konig, & Singer, 1997). Theoretically, it has been shown that synchrony in neural firing might explain analogy making (Hummel & Holyoak, 1997), inference making (Shastri & Ajjanagadde, 1993) and possibly the limited processing capacity of conscious processes (Nikolic, in press).

That synchrony in neural firing might underlie the consciousness has been proposed by several researchers (Crick & Koch, 1990). However, synchrony in neural firing is not equivalent to oscillations (Singer, 1993). Although these two are often correlated, synchrony in neural firing can exist without oscillations. In addition, synchrony in neural firing has different processing properties than oscillatory activity. For example, it might provide temporal overwriting of learned neural pathways (Nikolic, 1997). For those reasons, I believe that any model that attempts to account for the neural processes underlying consciousness should consider this phenomena seriously.

Recently, several researchers have suggested that the brain does not represent input from the environment in the same way computers do (Peschi, 1997). Instead, the brain couples with the environment (Freeman & Skarda, 1990; Maturana & Varela, 1980; von Stein, 1997). Through coupling, the dynamical systems in the brain attempt to produce the same dynamics as the one that occurs in the environment. When two dynamical systems are coupled they mutually exchange information about their states, which results in similarity of the dynamical activity of the two systems. Any perturbation in one of the systems causes the other to adjust its dynamics. The coupling hypothesis has important implications for the role of oscillations in the brain. Oscillations are not seen only as a form of short-term memory. There are additional implications for the role of oscillations for information processing in the brain. The purpose of these oscillations is to provide the brain with a prediction about the input in the near future. This prediction might, therefore, create expectations which could significantly decrease the need for the limited resources.

Synchrony in neural firing and coupling are two relevant and well-established phenomena that need to be considered in any attempt to understand the neural basis of consciousness. Neural mechanisms that have certain theoretical and experimental support should not be neglected. If those mechanisms are not considered, some arguments should be provided why they are not important for a particular model.

4. *Extent to Which Complex Systems Approach Is Used*

Dynamical system theory is considered a part of a more general discipline called "complex systems science." Complex system science develops and provides tools necessary to deal with the complexity of the brain. In addition to dynamical systems, complex systems science has found many other phenomena that are or might be relevant for the brain research. Since this discipline is quite young, we can hope that additional complex system phenomena will be found in the future that will further help us understand the brain and the mind. However, I will mention several relevant issues concerning complex systems that Taylor did not mention but seem to be important for understanding the neural basis of consciousness.

The neural network systems that Taylor describes produce limit cycle temporal dynamics. However, there are many sources of evidence that the dynamical activity in the brain is more complex than limit cycle. Electrophysiological recordings on both scalp electrodes (cortical areas) and in subcortical areas (Basar, Basar-Eroglu, & Rosche, 1988; Freeman, 1994; Roelsfema et al., 1997) have found that the brain does not observe limit cycle behavior but low dimensional chaos. On the behavioral level, it has also been found that the simplest repetitive behavior, which appears to be a limit cycle, is actually chaotic (Mitra, RIley, & Turvey, 1997; Mitra, Amazeen, & Turvey, in press). The 1/f noise in human behavior (Gilden, 1995) indicates that probably some other more complex processes occur in the brain.

There is also evidence indicating that chaos is not undesirable noise in the brain but a part of the processing mechanisms that the brain utilizes. For example, Freeman (1994) concludes that a different attractor represents each stimulus category. Those attractors must be chaotic because limit cycle attractors cannot be distinguished one from another. It has been also shown that in some cases information processing is enhanced in a noisy environment (Collins & Imhoff, 1996).

Emergence is a very general complex system property. It pertains to the fact that often the parts of a system would interact in such a way that they would produce a new, unpredictable behavior that was not engineered by the designer of the system. The behavior emerges from the elements of the system. In the case of the brain, we have neurons and their basic processing mechanisms as the elements of the system and the psychological behavior, including phenomenal experience, as the emergent phenomena. Many psychological phenomena, therefore, emerge from a complex interaction of the elements. The problem, however, is that often we do not know to what degree the phenomena emerge from a complex interaction of some other processes and to what degree they rely on separate modules for this phenomena. The problem becomes more difficult as the number of levels of the hierarchy of complexity increase. Phenomenal experience is probably situated very high on this hierarchy. Feedforward and recurrent neural networks, on the other hand, are somewhere at the bottom of the hierarchy. In between those two extremes there seem to be several additional levels. The organization and the specialization of brain areas are at least one step higher on the level of complexity than the basic feedforward and recurrent neural network architectures. A relevant example of the brain organization is the processing distinction between dorsal and ventral pathways in the cortex (Goodale & Milner, 1992). Many experimentally observed psychological phenomena are a step lower on the complexity hierarchy than the phenomenal experiences. It is, therefore, difficult to bridge the gap between the two extreme ends without having appropriate understanding about the intermediate levels.

Conclusions

In order to obtain a satisfactory explanation of how our conscious experience emerges from the processes within the brain, we must acquire more knowledge about many still unknown processes. Such an understanding would result in a model that actually is conscious and that does have experiences similar to ours. In order to accomplish this, we need to understand many levels of complexity in the brain between the extreme levels of the hierarchy of complexity. In addition, the higher levels in the hierarchy of brain's complexity must be tested with measurable behavioral data. Phenomenal experiences alone are not sufficient for testing such models. Therefore, much more research must be conducted and much more experimental facts from both neuroscience and psychology must be taken into account before we can fill the explanatory gap. Only then can we build a firm bridge over it. It seems, therefore, that we will have to fill the explanatory gap step by step instead of quickly jumping over it. Taylor's work is, nevertheless, one step toward this goal.

REFERENCES

Basar, E., Basar-Eroglu, C., & Roschke, J. (1988). Do coherent patterns of the strange attractor EEG reflect deterministic sensory-cognitive states of the brain? In Markus M., Muller S., and Nicolis G. (Eds.), *From chemical to biological organization.* Berlin, Heidelberg, New York: Springer.

Collins, J. J., & Imhoff, T. T. (1966). Noise-enhanced tactile sensation. *Nature,* **383,** 770.

Crick, F., & Koch, C. (1990). Towards a neurobiological theory of consciousness. *Seminars in the Neurosciences,* **2,** 263–275.

Damasio, A. R. (1989). The brain binds entities and events by mutiregional activation from convergence zones. *Neural Computation,* **1,** 123–132.

Freeman, W. J. (1994). Neural networks and chaos. *Journal of Theoretical Biology,* **171,** 13–18.

Freeman, W. J., & Skarda, C. A. (1990). Chaotic dynamics versus representationalism. *Behavioral and Brain Sciences,* **13,** 167–168.

Gilden, D. L. (1995). 1/f noise in human cognition. *Science,* **267** (March 24), 1837–1839.

Goodale, M. A., & Milner, D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences,* **15,** 20–25.

Hummel, J. E., & Holyoak, K. J. (1997). Distributed representations of structure: A theory of analogical access and mapping. *Psychological Review,* **104,** 427–466.

Markram, H., Lubke, J., Frotscher, M., & Sakmann, B. (1997). Regulation of synaptic efficacy by coincidence of postsynaptic APs and EPSPs. *Science,* **275,** 213–215.

Maturana, H. R., & Varela, F. J. (1980). *Autopoiesis and Cognition. The Realization of the Living.* Dordrecht, Boston, London: Reidel.

Mitra, S., Riley, M. A., & Turvey, M. T. (1997). Chaos in human rhythmic movement. *Journal of Motor Behavior,* **29,** 195–198.

Mitra, S., Amazeen, P. G., & Turvey, M. T. (in press). Intermediate motor learning as decreasing active (dynamical) degrees of freedom. *Human Movement Science.*

Newman, J. (1997). Putting the puzzle together, Part I: Towards a general theory of the neural correlates of consciousness. *Journal of Consciousness Studies,* **4**(1), 47–66.

Nikolic, D. (in press). A dual processing theory of brain and mind: Where is the limited processing capacity coming from? *InterJournal of Complex Systems.*

Peschl, M. F. (1997). The representational relation between environmental structures and neural systems: Autonomy and environmental dependency in neural knowledge representation. *Nonlinear Dynamics, Psychology, and Life Sciences,* **1,** 99–121.

Roelfsema, P. R., Engel, A. K., Koenig, P., & Singer, W. (1997). Visuomotor integration is associated with zero time-lag synchronization among cortical areas. *Nature* **385,** 157–161.

Roeschke, J., & Basar, E. (1989). Correlation dimensions in various parts of cat and human brain in different states. In E. Basar & T. H. Bullock (Eds.), *Brain dynamics. Progress and perspectives* (pp. 131–148). Springer Series in Brain Dynamics 2. Berlin, Heidelberg, New York: Springer.

Shastri, L., & Ajjanagadde, V. (1993). From simple associations to systematic reasoning: A connectionist representation of rules, variables and dynamic bindings using temporal synchrony. *Behavioral and Brain Sciences,* **16,** 417–494.

Singer, W. (1993). Synchronization of cortical activity and its putative role in information processing and learning. *Annual Review in Physiology,* **55,** 349–74.

Singer, W. (1994). The organization of sensory motor representations in the neocortex: A hypothesis based on temporal coding. In C. Umilta & M. Moscovitch (Eds.), *Attention and performance 15: Conscious and nonconscious information processing* (pp. 77–107). Attention and performance series. Cambridge, MA: MIT Press.

von Stein, A. (in press). Does the brain represent the world? Evidence against the mapping assumption. *Evolution and Cognition.*

Stryker, M. P. (1989). Is grandmother an oscillation? *Nature,* **338,** 297–298.