Discussion

Discreteness and Relevance: A Reply to Roman Poznanski

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First, a clarification. Poznanski says that I conclude that: “encoding and decoding spike trains must be discrete at some level.” There are two possible interpretations to his characterization: (1) the process of encoding and decoding must be discrete; and (2) our characterization of the process must be discrete. I hope it is evident that I don’t claim that the *process in neural systems* is discrete, but rather that a complete *characterization of* the process can be discrete; these of course are significantly different claims. Only the second is endorsed by my paper and it is deducible from the claim Poznanski labels ‘ii)’, i.e., that the: “continuous nature of neurons is not relevant to the information they process”. So, I will take this to be the claim that Poznanski finds problematic.

Now, as surprising as my contention may initially seem, in some ways it shouldn’t be surprising at all. We know for a fact that such claims are true of *some* physical systems. Consider a typical digital computer. The processes in such machines are indeed continuous (to a similar extent that processes in neural systems are). That is, transistors that make up integrated circuits are, in fact, continuous physical devices. Their transfer function traces out a (nonlinear, continuous) S-shaped curve, which is why they are used as both switches and amplifiers. Of course, we treat them *as if* they are only ever in one of two possible states. In fact, they have been engineered such that the noise they typically encounter won’t interfere with our ability to treat them this way (the noise due to high heat levels remains an ever-present challenge for those ensuring we *can* treat these systems in this way). So, it is clear that in the case of these physical systems, the continuous nature of their components, or the processes in them, is irrelevant for characterizing their information processing. This demonstrates, at a minimum, that continuity of underlying processes doesn’t guarantee the need for a continuous theoretical characterization.

My central claim in Eliasmith (2001) is that the same is true for neural systems, and I provide a good reason — noise. That is, given the presence of noise, we are guaranteed that a digital description of the system will capture all of the information processing properties of the system. The trouble comes, says Poznanski, once we realize that certain nonlinear dynamical behaviors (e.g., chaos) are essential for the sophisticated behavior of neural systems. While I agree that chaos and other such kinds of behavior are likely important for understanding neural systems, I disagree that it is a problem. Citing Freeman (2000), Poznanski notes that “most

Minds and Machines **12:** 437–438, 2002.

nonlinear dynamical systems that are chaotic will degenerate into quasi-periodic and point attractors from which they cannot recover when the chaotic processes are discretized." However, in that same paper, Freeman also realizes that his analysis depends on the system being *noise free*. When noise is introduced, according to Freeman, these problems with the discretization are subdued. Therefore, a combination of discretization *and* noise (just what I was proposing in the paper) permits a good characterization of these processes.

Furthermore, there has been work done on discrete chaotic attractors that shows such attractors have all the standardly useful properties (e.g., rapid divergence, fractal attractors, etc.) of continuous attractors (Waelbroeck, 1995; Waelbroeck and Zertuche, 1998). Of course, this is only true up to a limit (i.e., depending on the step size of the discretization). My argument in Eliasmith (2001) helps establish the precise nature of this limit for cognitive/neural systems. As a result, we should conclude that continuity does *not* provide any special kind of computational advantage (e.g., chaos) relevant to our understanding of these systems.

Poznanski concludes that noise "should not be seen as crucial for information representation" given the fact that certain neural structures (e.g., gap-junctions, distributed representations, etc.) "increase the signal-to-noise ratio ... [since] single neurons in networks play a role in the reduction of noise." However, the implicit conditional is simply false (i.e., if neurons help reduce noise then noise is not crucial for information representation). Eliasmith and Anderson (in press) contains an extended analysis of the *close* relation between noise reduction and representation in neural systems. In fact, the examples presented by Poznanski help *establish* my point. The purpose behind increasing signal-to-noise is precisely to increase the precision of the representation that single neurons provide. This means that the precision of the representation in both single neurons and populations *is* limited (although to different degrees), which means that we can use discrete characterizations of those representations. After all, the difference between continuous and discrete systems is that the former has *no* limitation on precision. In the paper, I cite evidence that the precision of many neural systems is limited to about 3 bits per spike.

In conclusion, then, all of the concerns voiced by Poznanski in his reply fail to offer a serious challenge to the idea that continuity is irrelevant to a good understanding of cognitive systems.

References

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