region of kindled slices in the presence of blockers of excitatory amino acid receptors with the aim to re-  lease endogenous Zn$^{2+}$ onto the granule cells. In  one of three experiments, we successfully repro- duced the effects of perfused Zn$^{2+}$ on sIPSCs, pre- sumably through the release of Zn$^{2+}$ from sprouted mossy fibers. Repetitive stimuli delivered to the same  location in control slices had no effect on sIPSCs (n = 6). In slices, Zn$^{2+}$ release experiments are difficult  to control because even low-frequency stimuli used  to test evoked responses can inadvertently release the bulk of Zn$^{2+}$ from the mossy fibers. In the ab- sence of any exogenous Zn$^{2+}$ added to the ACSF, the lost Zn$^{2+}$ cannot be replenished (C. J. Frederick- son, personal communication).


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**TECHNICAL COMMENTS**

**Analog Computational Power**

Response: Peter Shor (1) and Richard Y.  Kain (2) recently commented on my report “Computation Beyond the Turing Limit” (3). Shor questions the nature of the advice  used in analog computation, or equivalently,  the real weights in the neural networks model. He suggests that they must either be  programmed, or be random, or be physical  constants, and notes problems in all these  cases.

First, by definition, the constants are not  necessarily programmable, because they are  general, not only computable, real numbers.  Second, the constants are inherently dif- ferent from random numbers. Rather, they  compose the real characteristics of a system.  To exemplify this, consider the logistic map

$$x_{n+1} = ax_n(1 - x_n)$$

(4) (the state of the system at time n is  represented by $x_n$). Here a minute change in  the constant $a$ may result in a qualitative  change in the motion, such as period dou-bling or a transition from periodic to cha-otic motion. Independent of this, let me  illuminate random processes. Computer sci- entists often model a random process as a  coin that has a success probability (to fall  on “heads”) of $1/2$. Probabilistic Turing  machines that use a coin with (exactly) $1/2$  success probability compute the class BPP (which, as Shor says, is believed to be no  stronger than what deterministic Turing  machines compute efficiently). However, I  have shown (5) that if the success proba- bility of the coin is a real number, the  resulting class is again super-Turing! The  networks in this case compute the class  BPP/log, which is included in P/poly. The  exact probability of the coin is not known  to the Turing machine (nor the underlying  process) that utilizes it and can only be  approximated by a chain of flips; yet, it still  adds power to the classical model.

Third, the weights in neural network  models can be thought of as modeling the  physical characteristics of a specific system.  Shor’s comment that the current measure- ments of physical constants are poor is cru- cial if one wants to build a general analog  computer directly from the description; the  design of such a computer is an open prob- lem. However, this problem is immaterial  for the mathematical modeling of an analog  computation of nature.

In a natural analog computation process,  one starts from initial conditions that con- stitute the (finitely describable) input, and  the system evolves according to the specific  equations of motion to its final position,  which constitutes the output. The evolu- tion is controlled by the exact equations of  motion with the exact physical constants.  The analog physical system “solves” the  equations of motion exactly. For example,  planetary motion is used to measure time  with very high precision although we know  the gravitational constant $G$ only to two  digits. The planets, of course, revolve ac- cording to the exact value of $G$, irrespective  of its measurement by humans.

Although the networks are defined with  unbounded precision, up to the $q$th step of  the computation, only the first $O(q)$ bits in  both weights and activation values of the  neurons (and the first $log q$ bits that de- scribe the stochastic process) influence the  result (6). This property of neural networks  is identical to that of chaotic systems, sug- gesting that neural networks are indeed  natural models of analog physical dynamics.

In his comment, Kain does not mention  the importance of constraints in computa- tion as established by Karp (7) and others.  The imposition of constraints is one of the  main developments that revolutionized the  classical theory of computation from dis- crete mathematics into the modern com- plexity theory of realistic machines. Readers  interested in pursuing some of the issues  raised by Kain (for example, the difference  between oracle and advice machines, as  well as complexity) are referred to (8) for  their precise description. To summarize,  both under resource constraints (complexi- ty) and in their absence (computability),  my model exceeds the Turing power, and  thus may be referred to as a “super-Turing”  one.

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**REFERENCES**


2. R. Y. Kain, ibid., p. 92.


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