EMERGENT NEURAL CODING IN NEURAL MICROCIRCUIT MODELS

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ABSTRACT

A key challenge for neural modeling is to explain how a continuous stream of multi-modal input from a rapidly changing environment can be processed by stereotypical recurrent circuits of integrate-and-fire neurons in real-time. We propose a new computational model for real-time computing on time-varying input that provides an alternative to paradigms based on Turing machines or attractor neural networks. It does not require a task-dependent construction of neural circuits. Instead it is based on principles of high dimensional dynamical systems in combination with statistical learning theory, and can be implemented on generic evolved or found recurrent circuitry. It is shown that the inherent transient dynamics of the high-dimensional dynamical system formed by a sufficiently large and heterogeneous neural circuit may serve as universal analog fading memory. Readout neurons can learn to extract in real-time from the current state of such circuit information about current and past inputs that may be needed for diverse tasks. Stable internal states are not required for giving a stable output, since transient internal states can be transformed by readout neurons into stable target outputs due to the high dimensionality of the dynamical system. Furthermore we show that even linear readout neurons are usually able to extract the relevant information if the circuit is sufficiently large and complex, since such circuits tend to play a similar role as high dimensional nonlinear kernels in machine learning (support vector machines).

This approach towards modeling computations in neural microcircuits can be applied to complex real-time processing tasks in speech recognition and robotics, and we will present a few examples of such applications. This approach does not require any a priori assumptions about the neural code in which information is processed by a neural circuit. Rather, one sees that particular neural codes *emerge* from particular circuit architectures and circuit inputs in the sense that most of the information contained in the current circuit dynamics can be captured by just looking at particular variables, i.e. neural codes.

Software for using generic neural microcircuit models for real-time information processing is available from www.lsm.tugraz.at, see [3]. The basic ideas of this approach are already online available ([1], [2]). But the talk will focus on more recent work that has not yet been published.

Keywords: neural microcircuit, real-time computing, neural coding.

References

[1] Maass, W., Natschlaeger, T., and Markram, H. (2002) Real-time computing without stable states: A new framework for neural computation based on perturbations. *Neural Computation*, 14(11): 2531-2560. See # 130 on http://www.igi.tugraz.at/maass/publications.html.

[2] Maass, W., Natschlaeger, T., and Markram, H. (2003) Computational Models for Generic Cortical Microcircuits. In: *Computational Neuroscience: A Comprehensive Approach* (J. Feng, Ed.), CRC-Press, to appear. See # 149 on http://www.igi.tugraz.at/maass/publications.html.

[3] Natschlaeger, T., Markram, H., and Maass, W. (2003) Computer models and analysis tools for neural microcircuits. In: *Neuroscience Databases. A Practical Guide* (R. Koetter, Ed.), chapter 9, pp. 123-138, Kluwer Academic Publishers (Boston). See # 144 on http://www.igi.tugraz.at/maass/publications.html.