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Storage capacity and criticality in a spiking network

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Several experimental results [1, 2, 3, 4, 5] concerning information coding, processing and memory in the brain, show that, combining spatial population coding with temporal coding into a dual code, provides signicant gains of information. Some evidence of independent rate and temporal coding also supports the idea that phase timing can code for an independent information, and population rate for another additional information.
However the mechanisms leading to such spatio-temporal coding in the brain and the possibility to use such dual coded patterns in an associative memory framework is not yet clear. Some attemps to include time and define dynamical patterns instead of static one has been done, such as sequence processing for Hopfiled-like models [6], or synfire chains spiking models [7].
In this work [8] we introduce a new paradigm: a nested coding where a population (spatial) distribution of active neurons is combined with phase-of-firing (temporal) label of active neurons, and we show that patterns coded in this way can be stored and retrieved in a associative memory framework.
Notably the learning of such patterns is not achieved with a manual design, but with a biologically plausible learning rule, composed of global inhibition term which play a crucial role, and a STDP-plasticity term, which gives a LTP only when presynaptic spike arrive few ms before post-synaptic spike.
We define an order parameter to measure the success of the cue-induced retrieval of such dynamical patterns, and measure the \information capacity", defined as the number of patterns encoded times the number of bits carried by each pattern, as a function of the learning parameters, network size, and fraction M=N of active neurons in each pattern.
Notably such capacity in dual coded patterns is higher of both the case of phase-coded alone patterns, and the case of Hopfield model with population (spatial) coding alone, while it is close than the maximum capacity found for sequence processing binary networks [6]. It's interesting that there seems to be a unique maximum information capacity for storing dynamical patterns, in which time has been introduced in two different ways in
two very different models, our spiking model with dual coded spatiotemporal patterns and STDP-plasticity, and sequence of binary patterns in a Hopfiled-like model with discrete time and binary Ising-like units.
Therefore, we introduce a new way to look at dynamical spiking patterns, based on a biological-motivated learning rule that enable the system to work as an associative memory, showing that the information capacity of such spiking patterns with nested phase and spatial coding is enhanced with respect to the population coding alone and the phase coding alone[8].
We then link togheter the memory function with another intriguing phenomena characterize cortical dynamics both in-vitro
and in-vivo: criticality and scale-free neuronal avalanches, characterized by power law distributions of bursts of spikes both in-vitro and in the resting spontaneous activity.
Near the phase transition between persistent replay and no-replay
regimes of the spontaneous dynamics[9], critical phenomena and neural avalanches are observed, with critical exponents close to the ones experimentally measured. Previous studies have separately addressed the topics of phase-coded memory storage and neuronal avalanches, and this is one of the few works which show how these ideas converge in a single cortical model. This work therefore helps to link the bridge between criticality and the need to have a reservoir of spatio-temporal metastable memories[9].

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