Desirable Features of a Neocortically-Inspired Ab Initio Model of Associative Memory

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Outline



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- Unreliable Neurotransmitter Release, Reliable Network
- Preserves Topological Structure
- Preserves Temporal Structure
- Preserves Spectral Structure
- Associative
- Hierarchical
- Online



Introduction

Research Perspective:

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Topological relation of objects in real-world are preserved in their neural representation throughout the brain.

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Examples:

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Examples:

• Spiking Neuron:

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Examples:

• Spiking Neuron: Excitatory (cite?) and Inhibitory (cite?).

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Multisensory integration.

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Using characterization via "information-bearing signal", such similarity becomes more manageable to establish.

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Hierarchical

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Hierarchical

Simple memories encoded at lower levels can be combined to make more complex memories at higher levels. This is reminiscent of sequences of sequences.

Unrelable Neutorransmitter Release, Reliable Network Preserves Topological Structure Preserves Topological Structure Preserves Topological Structure Preserves Spectral Structure References Online

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There is some latency due to propagation time, refraction of membranes, etc.



There is some latency due to propagation time, refraction of membranes, etc. However, in general, environmental information encoded in neocortical structures are routed immediately to motor structures in a feedforward manner [46–51].

Conclusion

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Conclusion

We have attempted to integrate aforementioned features into our model.

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Figure: Basic Diagram of Signal Transduction Model (Layer 1). Each pair of populations sharing a border will have neurons connected to one another. Those that do not share a border will *not* have neurons that share a synapse.

- M. Volgushev, I. Kudryashov, M. Chistiakova, M. Mukovski, J. Niesmann, and U. T. Eysel, "Probability of transmitter release at neocortical synapses at different temperatures," *Journal* of *Neurophysiology*, vol. 92, no. 1, pp. 212–220, 2004. [Online]. Available: http://jn.physiology.org/content/92/1/212.abstract
- [2] J. von Neumann, "Probabilistic logics and the synthesis of reliable organisms from unreliable components (lectures delivered at caltech january 4- 15, 1952)," *Michael D. Godfrey version*, *Stanford*, 2010. [Online]. Available: http://www.mit.edu/~6.454/papers/pierce_1952.pdf
- [3] A. M. Duda and S. E. Levinson, "Complex networks of spiking neurons: Collective behavior characterization," *Proceedings of the Eighth International Conference on Complex Systems*, pp. 1627–1629, 2011. [Online]. Available: http://necsi.edu/events/iccs2011/papers/344.pdf
- [4] A. K. Engel, P. Fries, and W. Singer, "Dynamic predictions: oscillations and synchrony in top-down processing," *Nature Rev. Neurosci.*, vol. 2, pp. 704–716, 2001.
- [5] E. Salinas and T. J. Sejnowski, "Correlated neuronal activity and the flow of neural information," *Nature Rev. Neurosci.*, vol. 2, pp. 539–550, 2001.
- [6] P. Fries, "A mechanism for cognitive dynamics: neuronal communication through neuronal coherence," *Trends Cogn. Sci.*, vol. 9, pp. 474–480, 2005.
- [7] M. Abeles, "Role of the cortical neuron: integrator or coincidence detector?" Isr. J. Med. Sci., vol. 18, pp. 83–92, 1982.
- [8] P. König, A. K. Engle, and W. Singer, "Integrator or coincidence detector? the role of the cortical neuron revisited," *Trends Neurosci.*, vol. 19, pp. 130–137, 1996.
- [9] G. Buzsaki and A. Draguhn, "Neuronal oscillations in cortical networks," Science, vol. 304, pp. 1926–1929, 2004.

- [11] B. Haider and D. McCormick, "Rapid neocortical dynamics: cellular and network mechanisms," *Neuron*, vol. 62, pp. 171–189, 2009.
- [12] P. Lakatos, A. S. Shah, K. H. Knuth, I. Ulbert, G. Karmos, and C. E. Schroeder, "An oscillatory hierarchy controlling neuronal excitability and stimulus processing in the auditory cortex," *Journal of Neurophysiology*, vol. 94, no. 3, pp. 1904–1911, 2005. [Online]. Available: http://jn.physiology.org/content/94/3/1904.abstract
- [13] T. Moore, K. M. Armstrong, and M. Fallah, "Visuomotor origins of covert spatial attention," *Neuron*, vol. 40, pp. 671–683, 2003.
- [14] M. Siegel, T. H. Donner, R. Oostenveld, P. Fries, and A. K. Engel, "Neuronal synchronization along the dorsal visual pathway reflects the focus of spatial attention," *Neuron*, vol. 60, pp. 709–719, 2008.
- [15] G. Rizzolatti, L. Riggio, and B. M. Sheliga, "Space and selective attention," in Attention and Performance, pp. 231–265, 1994.
- [16] G. G. Gregoriou, S. J. Gotts, H. Zhou, and R. Desimone, "High-frequency, long-range coupling between prefrontal and visual cortex during attention," *Science*, vol. 324, no. 5931, pp. 1207–1210, 2009. [Online]. Available: http://www.sciencemag.org/content/324/5931/1207.abstract
- [17] J. Gross, F. Schmitz, I. Schnitzler, K. Kessler, K. Shapiro, B. Hommel, and A. Schnitzler, "Modulation of long-range neural synchrony reflects temporal limitations of visual attention in humans," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 101, no. 35, pp. 13 050–13 055, 2004. [Online]. Available: http://www.pnas.org/content/101/35/13050.abstract
- [18] J. F. Hipp, A. K. Engel, and M. Siegel, "Oscillatory synchronization in large-scale cortical networks predicts perception," *Neuron*, vol. 69, no. 2, pp. 387–396, 01 2011. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0896627310010755

- [19] A. Bruns, R. Eckhorn, H. Jokeit, and A. Ebner, "Amplitude envelope correlation detects coupling among incoherent brain signals," *NeuroReport*, vol. 11, no. 7, 2000. [Online]. Available: http://journals.lww.com/neuroreport/Fulltext/2000/05150/ Amplitude_envelope_correlation_detects_coupling.28.aspx
- [20] D. A. Leopold, Y. Murayama, and N. K. Logothetis, "Very slow activity fluctuations in monkey visual cortex: Implications for functional brain imaging," *Cerebral Cortex*, vol. 13, no. 4, pp. 422–433, 2003. [Online]. Available: http://cercor.oxfordjournals.org/content/13/4/422.abstract
- [21] M. H. J. Munk, P. R. Roelfsema, P. König, A. K. Engel, and W. Singer, "Role of reticular activation in the modulation of intracortical synchronization," *Science*, vol. 272, no. 5259, pp. 271–274, 1996. [Online]. Available: http://www.sciencemag.org/content/272/5259/271.abstract
- [22] F. P. de Lange, O. Jensen, M. Bauer, and I. Toni, "Interactions between posterior gamma and frontal alpha/beta oscillations during imagined actions." *Front Hum Neurosci*, vol. 2, p. 7, 2008.
- [23] T. H. Donner, M. Siegel, P. Fries, and A. K. Engel, "Buildup of choice-predictive activity in human motor cortex during perceptual decision making," *Current biology : CB*, vol. 19, no. 18, pp. 1581–1585, 09 2009. [Online]. Available: http://linkinghub.elsevier.com/retrieve/pii/S0960982209015437
- [24] A. Mazaheri, S. Coffey-Corina, G. R. Mangun, E. M. Bekker, A. S. Berry, and B. A. Corbett, "Functional disconnection of frontal cortex and visual cortex in attention-deficit/hyperactivity disorder." *Biol Psychiatry*, vol. 67, no. 7, Apr 2010.
- [25] A. Mazaheri, I. L. Nieuwenhuis, H. van Dijk, and O. Jensen, "Prestimulus alpha and mu activity predicts failure to inhibit motor responses," *Human Brain Mapping*, vol. 30, no. 6, pp. 1791–1800, 2009. [Online]. Available: http://dx.doi.org/10.1002/hbm.20763 (2) > 2

- [26] T. Inouye, Die Sehstörungen bei Schussverletzungen der kortikalen Sehsphäre: nach Beobachtungen an Verwundeten der letzten japanischen Kriege. W. Engelmann, 1909. [Online]. Available: http://books.google.com/books?id=02QJGQAACAAJ
- [27] T. Inouye, Visual disturbances following gunshot wounds of the cortical visual area: based on observations of the wounded in the recent Japanese wars. Oxford University Press, 2000. [Online]. Available: http://books.google.com/books?id=P2RzHAAACAAJ
- [28] G. Holmes, "Disturbances of vision by cerebral lesions." The British journal of ophthalmology, vol. 2, no. 7, 07 1918. [Online]. Available: http://ukpmc.ac.uk/abstract/MED/18167806
- [29] M. Glickstein and D. Whitteridge, "Tatsuji inouye and the mapping of the visual fields on the human cerebral cortex," *Trends in Neurosciences*, vol. 10, no. 9, pp. 350 – 353, 1987. [Online]. Available: http://www.sciencedirect.com/science/article/pii/016622368790066X
- [30] C. J. Kros, "physiology of mammalian cochlear hair cells," in The Cochlea (Dallos, P., Popper, A.N., and Fay, R. R., eds.), pp. 318–385, 1996.
- [31] M. C. Liberman, "The cochlear frequency map for the cat: Labeling auditory-nerve fibers of known characteristic frequency," *The Journal of the Acoustical Society of America*, vol. 72, no. 5, pp. 1441–1449, 1982. [Online]. Available: http://link.aip.org/link/?JAS/72/1441/1
- [32] B. C. J. Moore, An Introduction to the Psychology of Hearing. Academic Press, 1997.
- [33] A. L. Hodgkin and A. Huxley, "A quantitative description of membrane current and its application to conduction and excitation in nerve," J. Physiol., vol. 117, pp. 500–544, 1952.
- [34] E. M. Izhikevich, "Which model to use for cortical spiking neurons?" IEEE Trans. on Neur. Nets, vol. 15, no. 5, pp. 1063–1070, 2004.

- [36] G.-q. Bi and M.-m. Poo, "Synaptic modifications in cultured hippocampal neurons: Dependence on spike timing, synaptic strength, and postsynaptic cell type," *The Journal of Neuroscience*, vol. 18, no. 24, pp. 10464–10472, 1998. [Online]. Available: http://www.jneurosci.org/content/18/24/10464.abstract
- [37] P. J. Sjöstrõm, G. G. Turrigiano, and S. B. Nelson, "Rate, timing, and cooperativity jointly determine cortical synaptic plasticity," *Neuron*, vol. 32, no. 6, pp. 1149 – 1164, 2001. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0896627301005426
- [38] X.-J. Wang, "Neurophysiological and computational principles of cortical rhythms in cognition," *Physiological Reviews*, vol. 90, no. 3, pp. 1195–1268, 2010. [Online]. Available: http://physrev.physiology.org/content/90/3/1195.abstract
- [39] T. J. Buschman and E. K. Miller, "Top-down versus bottom-up control of attention in the prefrontal and posterior parietal cortices," *Science*, vol. 315, no. 5820, pp. 1860–1862, 2007. [Online]. Available: http://www.sciencemag.org/content/315/5820/1860.abstract
- [40] M. Siegel, K. P. Körding, and P. König, "Integrating top-down and bottom-up sensory processing by somato-dendritic interactions," *Journal of Computational Neuroscience*, vol. 8, pp. 161–173, 2000. [Online]. Available: http://dx.doi.org/10.1023/A:1008973215925
- [41] A. von Stein, C. Chiang, and P. König, "Top-down processing mediated by interareal synchronization," *Proceedings of the National Academy of Sciences*, vol. 97, no. 26, pp. 14748–14753, 2000. [Online]. Available: http://www.pnas.org/content/97/26/14748.abstract

- [43] S. R. Jones, D. L. Pritchett, M. A. Sikora, S. M. Stufflebeam, M. Hamalainen, and C. I. Moore, "Quantitative analysis and biophysically realistic neural modeling of the meg mu rhythm: rhythmogenesis and modulation of sensory-evoked responses." *J Neurophysiol*, vol. 102, no. 6, pp. 3554–3572, Dec 2009.
- [44] A. K. Roopun, F. E. N. Lebeau, J. Ramell, M. O. Cunningham, R. D. Traub, and M. A. Whittington, "Cholinergic neuromodulation controls directed temporal communication in neocortex in vitro." *Front Neural Circuits*, vol. 4, p. 8, 2010.
- [45] C. Kayser and N. K. Logothetis, "Directed interactions between auditory and superior temporal cortices and their role in sensory integration." *Front Integr Neurosci*, vol. 3, p. 7, 2009.
- [46] P. W. Glimcher, "The neurobiology of visual-saccadic decision making." Annu Rev Neurosci, vol. 26, pp. 133–179, 2003.
- [47] J. I. Gold and M. N. Shadlen, "The Neural Basis of Decision Making," Annual Review of Neuroscience, vol. 30, no. 1, pp. 535–574, July 2007. [Online]. Available: http://dx.doi.org/10.1146/annurev.neuro.29.051605.113038
- [48] H. R. Heekeren, S. Marrett, and L. G. Ungerleider, "The neural systems that mediate human perceptual decision making," *Nat Rev Neurosci*, vol. 9, no. 6, pp. 467–479, 06 2008. [Online]. Available: http://dx.doi.org/10.1038/nrn2374
- [49] R. Romo and E. Salinas, "Flutter discrimination: neural codes, perception, memory and decision making," *Nat Rev Neurosci*, vol. 4, no. 3, pp. 203–218, 03 2003. [Online]. Available: http://dx.doi.org/10.1038/nrn1058
- [50] J. Schall, "Neural basis of deciding, choosing and acting." Nat Rev Neurosci, vol. 2, no. 1, 01 2001. [Online]. Available: http://ukpmc.ac.uk/abstract/MED/11253357
- [51] M. Siegel, A. K. Engel, and T. H. Donner, "Cortical network dynamics of perceptual decision-making in the human brain." Front Hum Neurosci, vol. 5, p. 21, 2011.