Week 7 – part 7: Helping Humans

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Neuronal Dynamics: Computational Neuroscience of Single Neurons

Week 7 – Optimizing Neuron Models For Coding and Decoding

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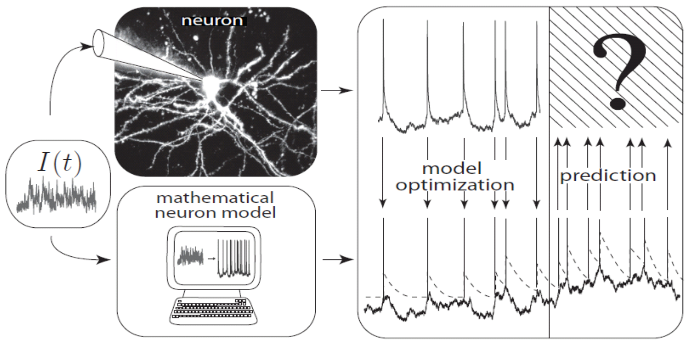
Week 7 – part 7: Helping Humans

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Neuronal Dynamics – Review: Models and Data

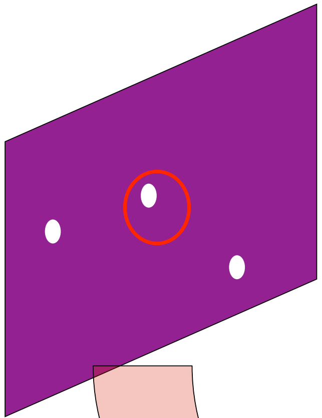


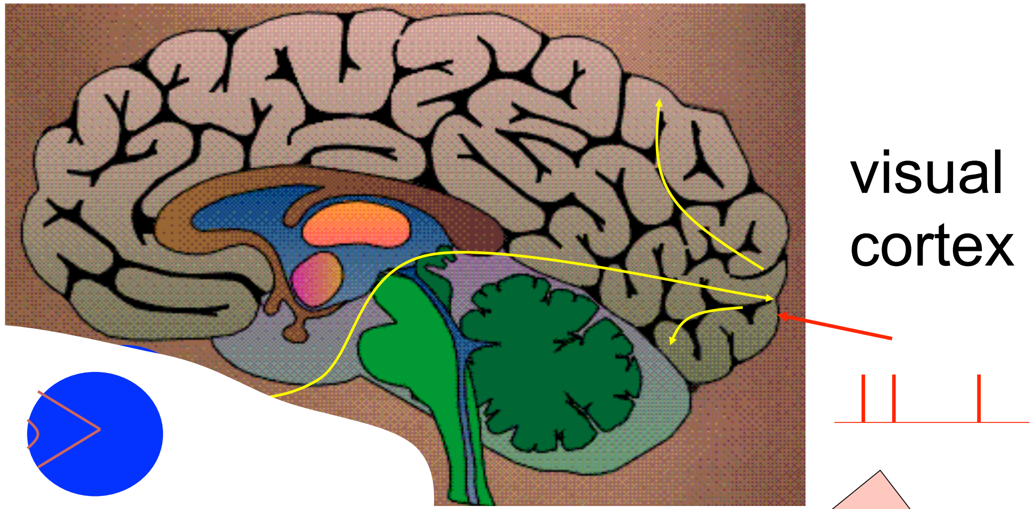
-Predict spike times
-Predict subthreshold voltage
-Easy to interpret (not a 'black box')
-Variety of phenomena
-Systematic: 'optimize' parameters

BUT so far limited to in vitro

Neuronal Dynamics – 7.7 Systems neuroscience, in vivo

Now: extracellular recordings





A) Predict spike times, given stimulus
B) ~~Predict subthreshold voltage~~
C) Easy to interpret (not a 'black box')
D) Flexible enough to account for a variety of phenomena
E) Systematic procedure to 'optimize' parameters

Model of 'Encoding'

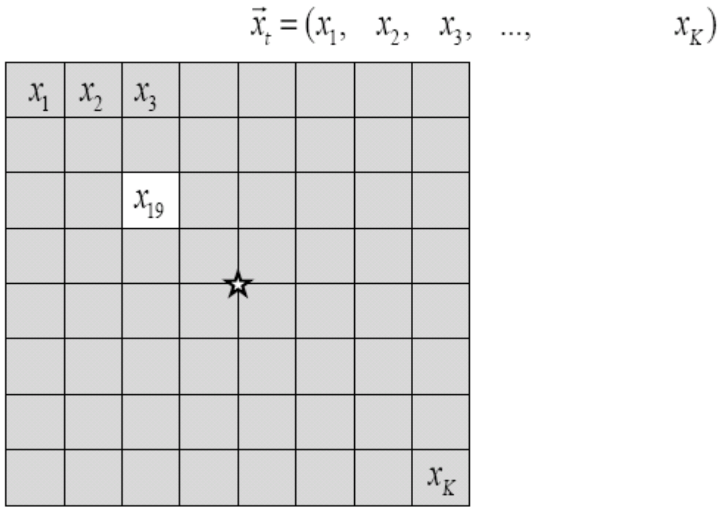
Neuronal Dynamics – 7.7 Estimation of receptive fields

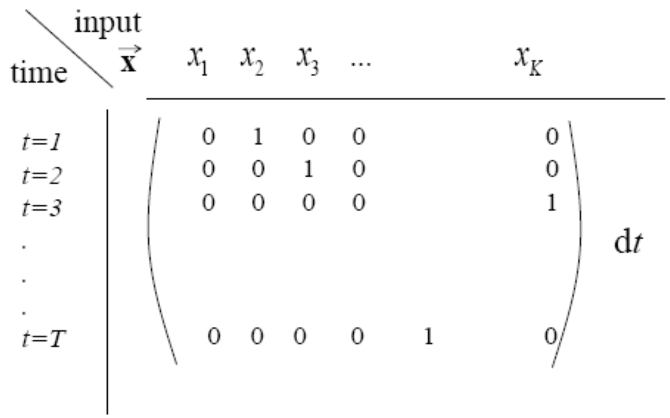
Estimation of spatial (and temporal) receptive fields

$$u(t) = \sum k_k \, I_{K-k} + u_{rest}$$

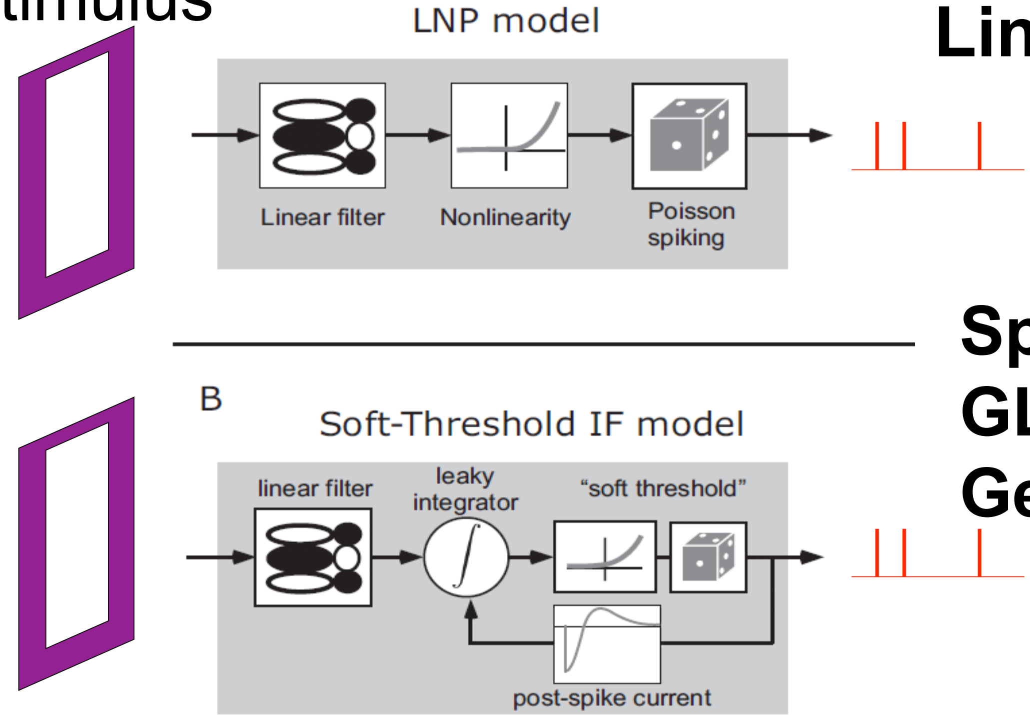
LNP

firing intensity $\rho(t) = f(u(t) - \vartheta(t))$





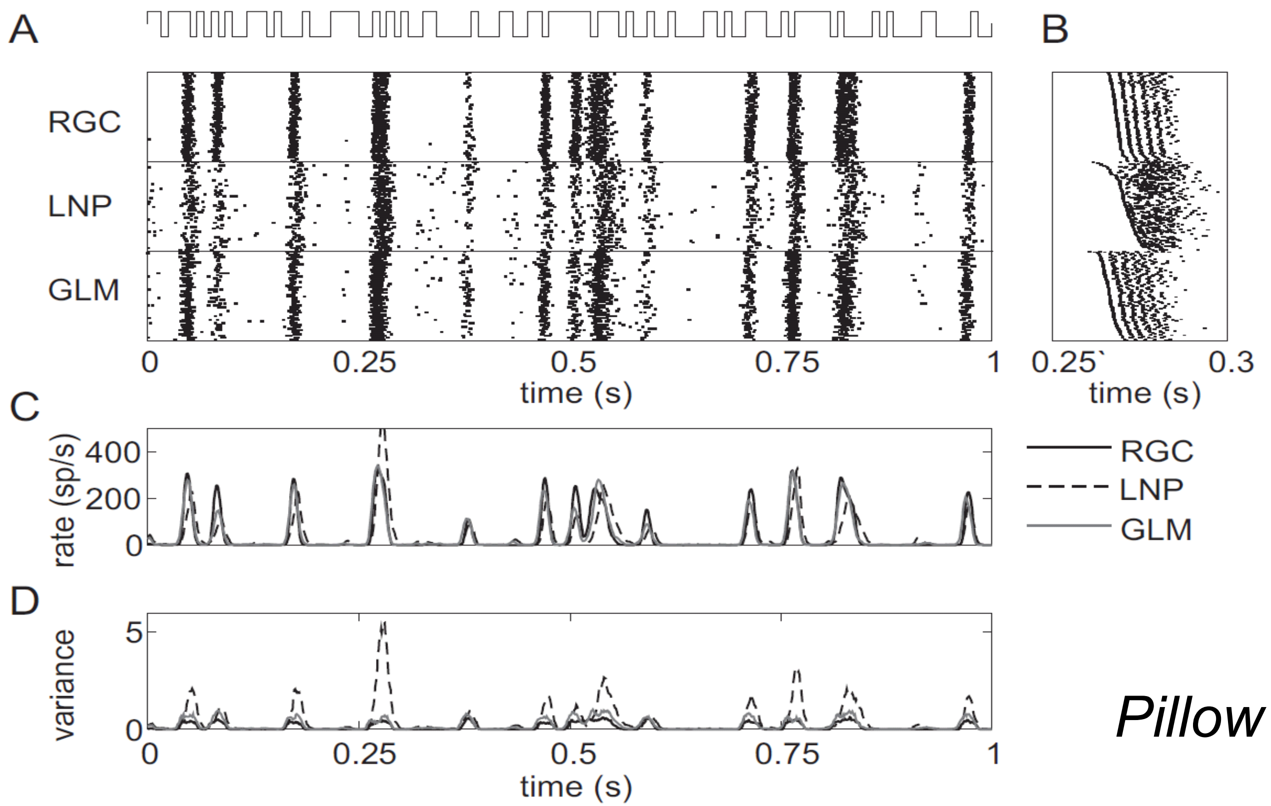
visual stimulus



LNP = Linear-Nonlinear-Poisson

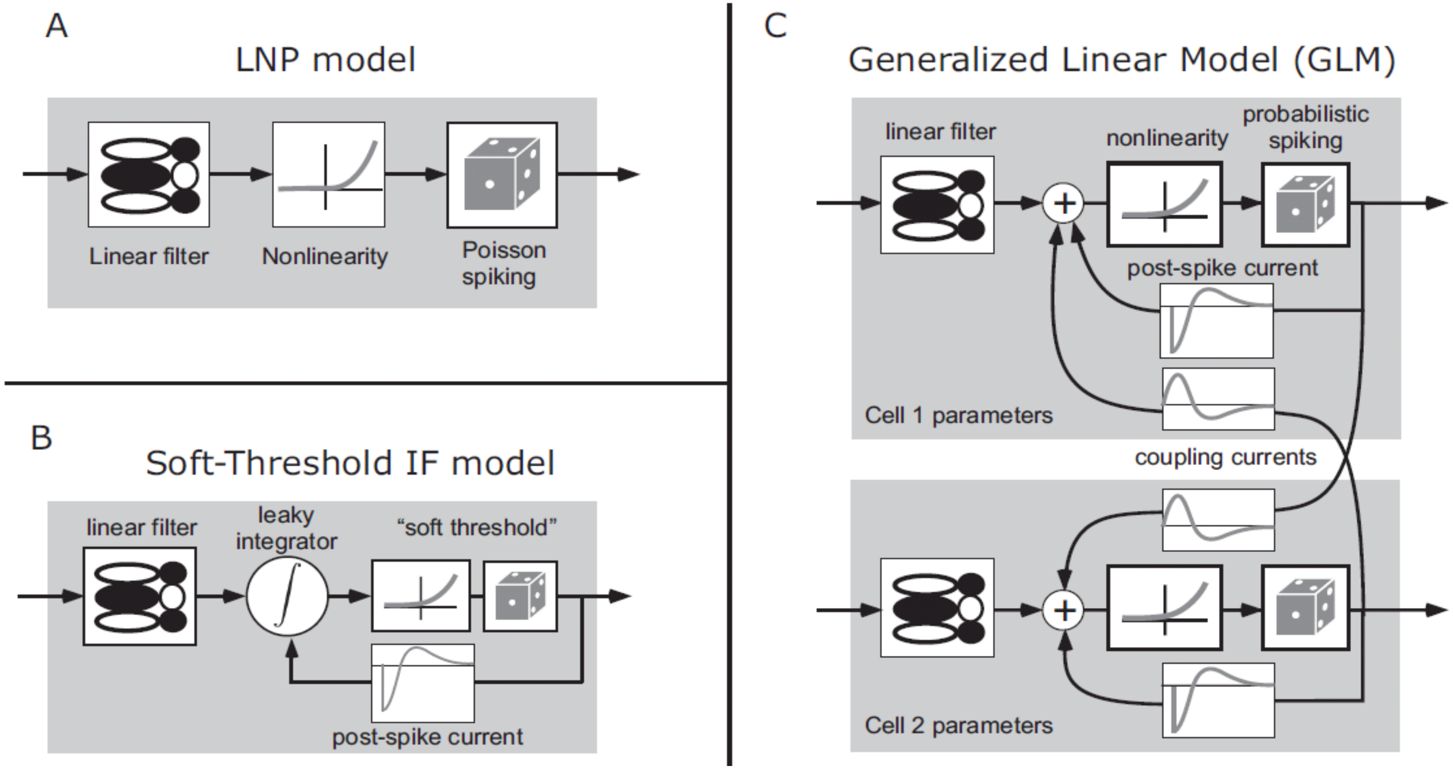
Special case of GLM= Generalized Linear Model

GLM for prediction of retinal ganglion ON cell activity

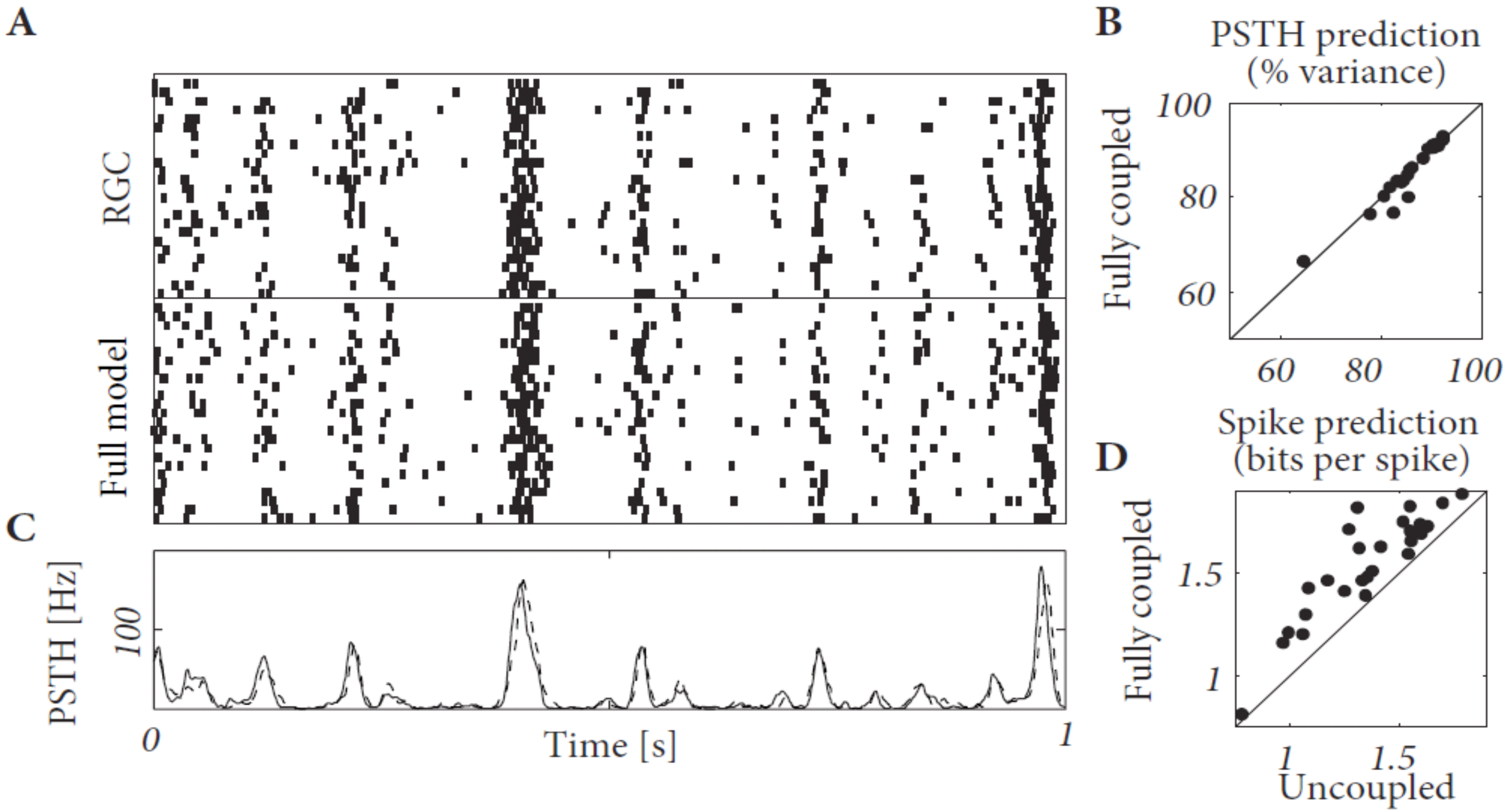


Pillow et al. 2008

Neuronal Dynamics – 7.7 GLM with lateral coupling

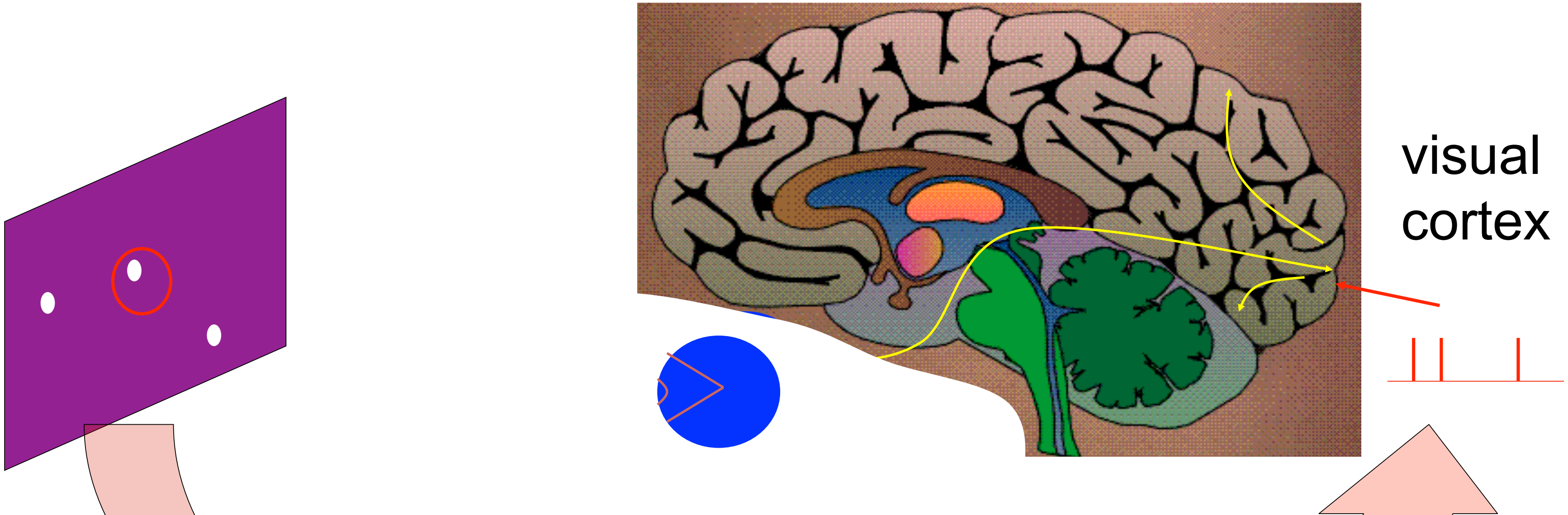


One cell in a Network of Ganglion cells



Pillow et al. 2008

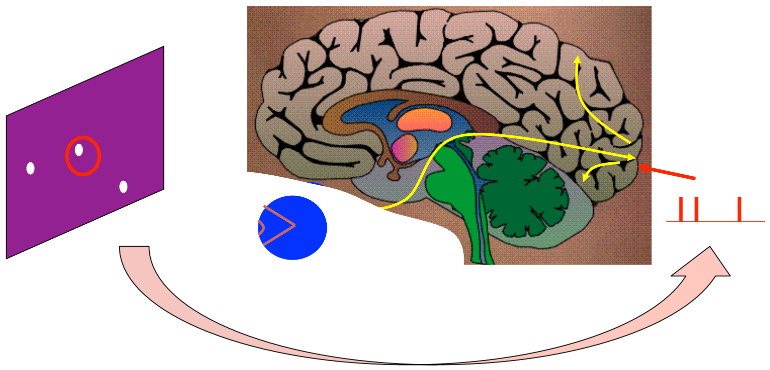
Neuronal Dynamics – 7.7 Model of ENCODING



A) Predict spike times, given stimulus
B) ~~Predict subthreshold voltage~~
C) Easy to interpret (not a ‘black box’)
D) Flexible enough to account for a variety of phenomena
E) Systematic procedure to ‘optimize’ parameters

Model of ‘Encoding’

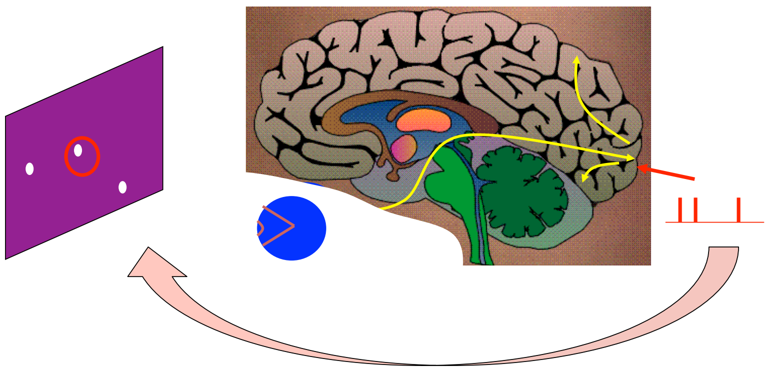
Neuronal Dynamics – 7.7 ENCODING and Decoding



Model of ‘Encoding’

Generalized Linear Model (GLM)

- flexible model
- systematic optimization of parameters



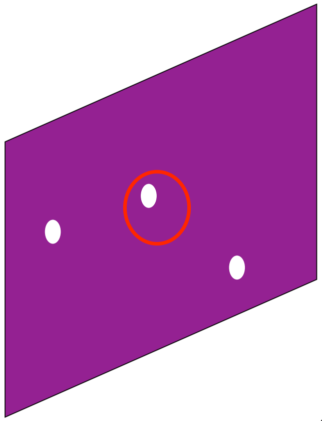
Model of ‘Decoding’

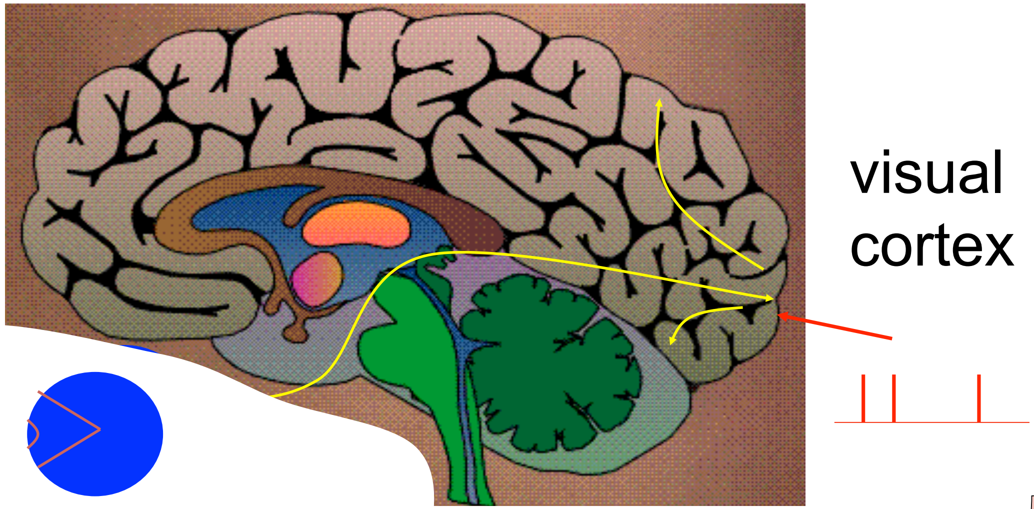
The same GLM works!

- flexible model
- systematic optimization of parameters

Neuronal Dynamics – 7.7 Model of DECODING

Predict stimulus!

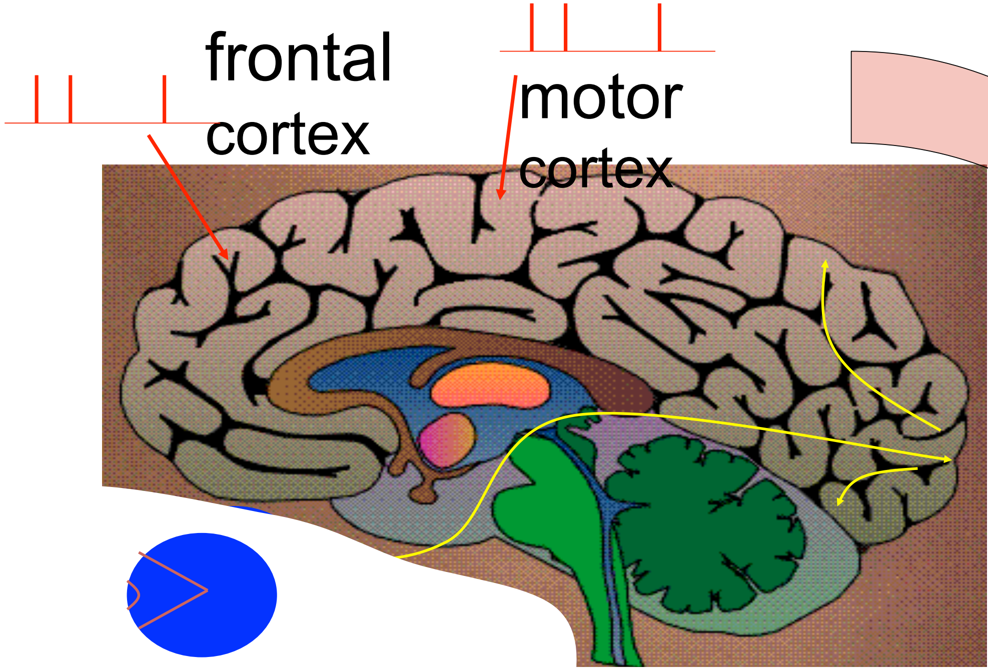




Model of 'Decoding':

predict stimulus, given spike times

Application: Neuroprosthetics



Many groups world wide work on this problem!

Model of 'Decoding'

Predict intended arm movement, given Spike Times

Application: Neuroprosthetics

Decode the intended arm movement

Hand velocity

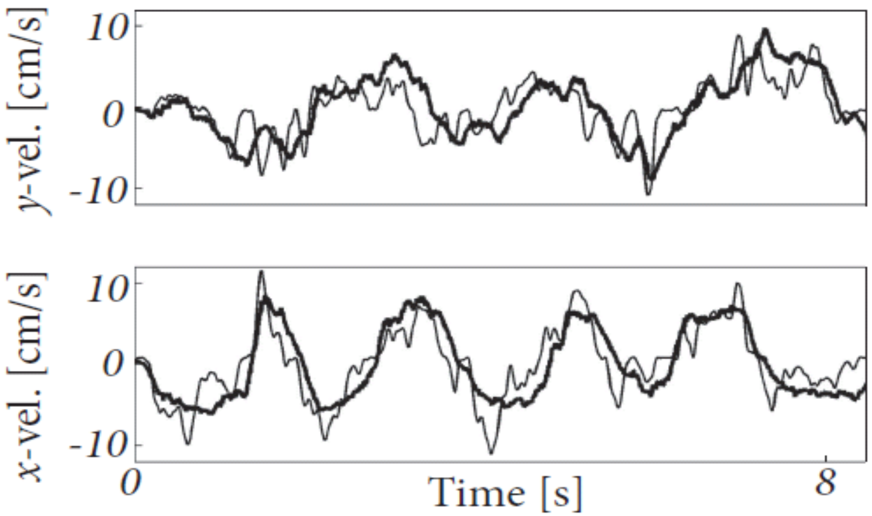


Fig. 11.12: Decoding had velocity from spiking activity in area MI of cortex. The real hand velocity (thin black line) is compared to the decoded velocity (thick black line) for the $x-$ (top) and the $y-$components (bottom). Modified from Truccolo et al. (2005).

Mathematical models for neuroscience

↓

help humans

The end

Neuronal Dynamics week 7– Suggested Reading/selected references

Reading: W. Gerstner, W.M. Kistler, R. Naud and L. Paninski,
Neuronal Dynamics: from single neurons to networks and models of cognition. Ch. 6,10,11: Cambridge, 2014

Nonlinear and adaptive IF

Fourcaud-Trocme, N., Hansel, D., van Vreeswijk, C., and Brunel, N. (2003). How spike …. *J. Neuroscience*, 23:11628-11640.
Badel, L., et al. (2008a). Extracting nonlinear integrate-and-fire, *Biol. Cybernetics*, 99:361-370.
Brette, R. and Gerstner, W. (2005). Adaptive exponential integrate-and-fire *J. Neurophysiol*., 94:3637- 3642.
Izhikevich, E. M. (2003). Simple model of spiking neurons. IEEE Trans Neural Netw, 14:1569-1572.
Gerstner, W. (2008). Spike-response model. *Scholarpedia*, 3(12):1343.

Optimization methods for neuron models, max likelihood, and GLM

-Brillinger, D. R. (1988). Maximum likelihood analysis of spike trains of interacting nerve cells. *Biol. Cybern*., 59:189-200.
-Truccolo, et al. (2005). A point process framework for relating neural spiking activity to spiking history, neural ensemble, and extrinsic covariate effects. Journal of Neurophysiology, 93:1074-1089.
- Paninski, L. (2004). Maximum likelihood estimation of … *Network: Computation in Neural Systems*, 15:243-262.
- Paninski, L., Pillow, J., and Lewi, J. (2007). Statistical models for neural encoding, decoding, and optimal stimulus design. In Cisek, P., et al. , *Comput. Neuroscience: Theoretical Insights into Brain Function*. Elsevier Science.

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Encoding and Decoding

Rieke, F., Warland, D., de Ruyter van Steveninck, R., and Bialek, W. (1997). Spikes - Exploring the neural code. MIT Press,
Keat, J., Reinagel, P., Reid, R., and Meister, M. (2001). Predicting every spike … *Neuron*, 30:803-817.
Mensi, S., et al. (2012). Parameter extraction and classication …. *J. Neurophys.,*107:1756-1775.
Pozzorini, C., Naud, R., Mensi, S., and Gerstner, W. (2013). Temporal whitening by . *Nat. Neuroscience,*
Georgopoulos, A. P., Schwartz, A.,Kettner, R. E. (1986). Neuronal population coding of movement direction. *Science*, 233:1416-1419.
Donoghue, J. (2002). Connecting cortex to machines: recent advances in brain interfaces. Nat. Neurosci., 5:1085-1088.