Neural Prediction Challenge

-Cognitive Science Project

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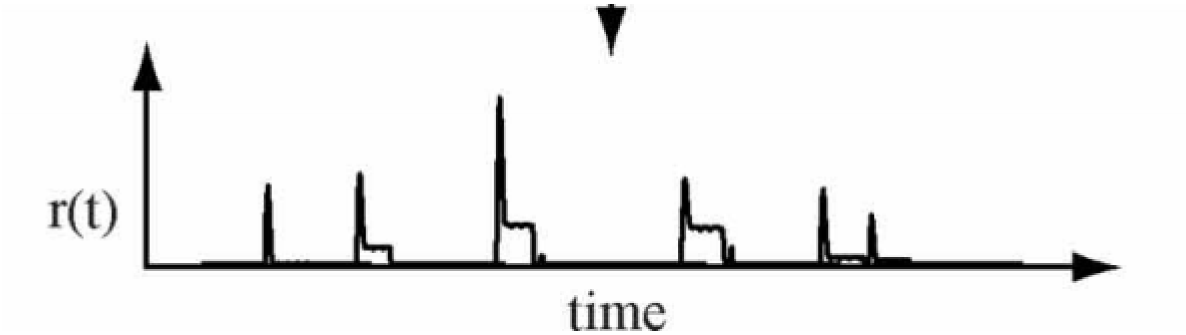
How do neurons work

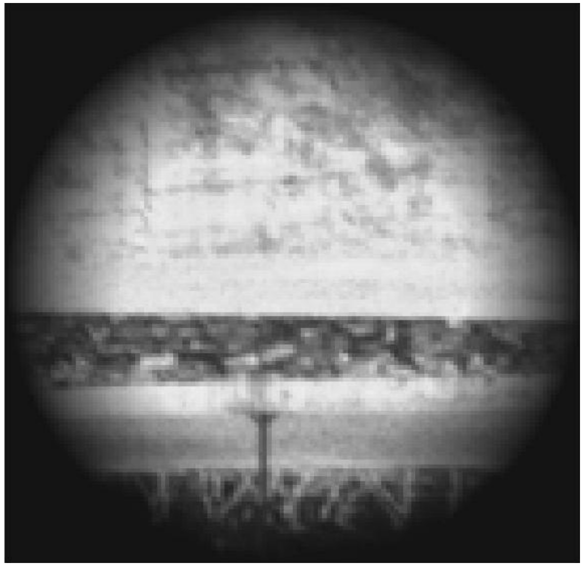
- Stimuli → Neurons respond (Excite/Inhibit)
- ‘Electrical Signals’ called Spikes
- Spikes encode information !! (Many Models)



Our Case…

- Stimuli → Video of Natural Images

- Response of 12 V1 neurons → #Spikes



Characteristics of Neurons

- Maximum fire rate (Need to discharge)
- Latency in response
- Concept of Receptive Field
  - Region of space where stimulus if present → alters neural activity
- Simple v/s Complex V1 neurons
  - Phase invariance: in complex

Our Data…

- A movie for each neuron
- Frames → Down sampled images (16x16)
- Each frame
  - Image spans twice the receptive field diameter
  - 16ms in duration
- Known: #Spikes/frame
- To build a model correlating stimulus and spike count.

So, how to do it ?

- Problem: Stimulus

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  Black Box

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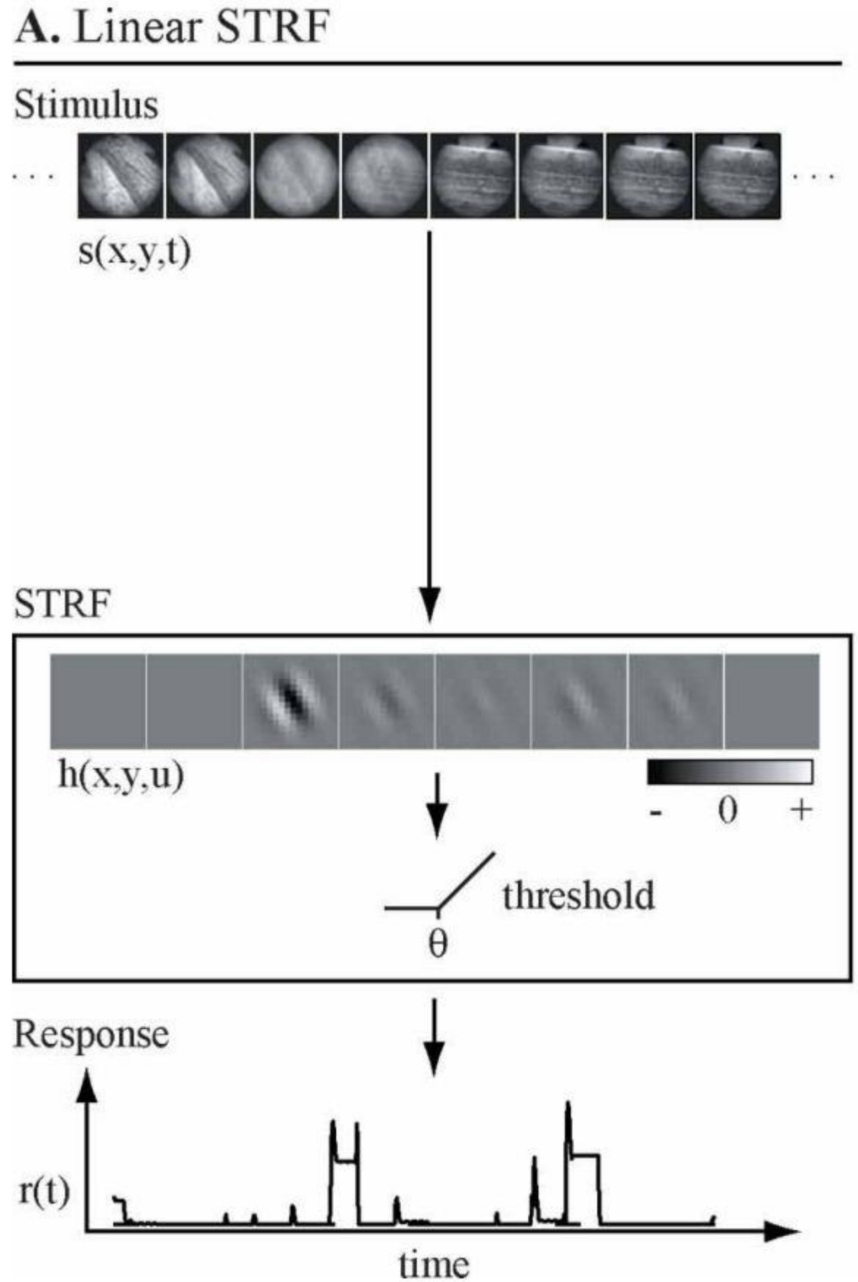
  Spike Rate

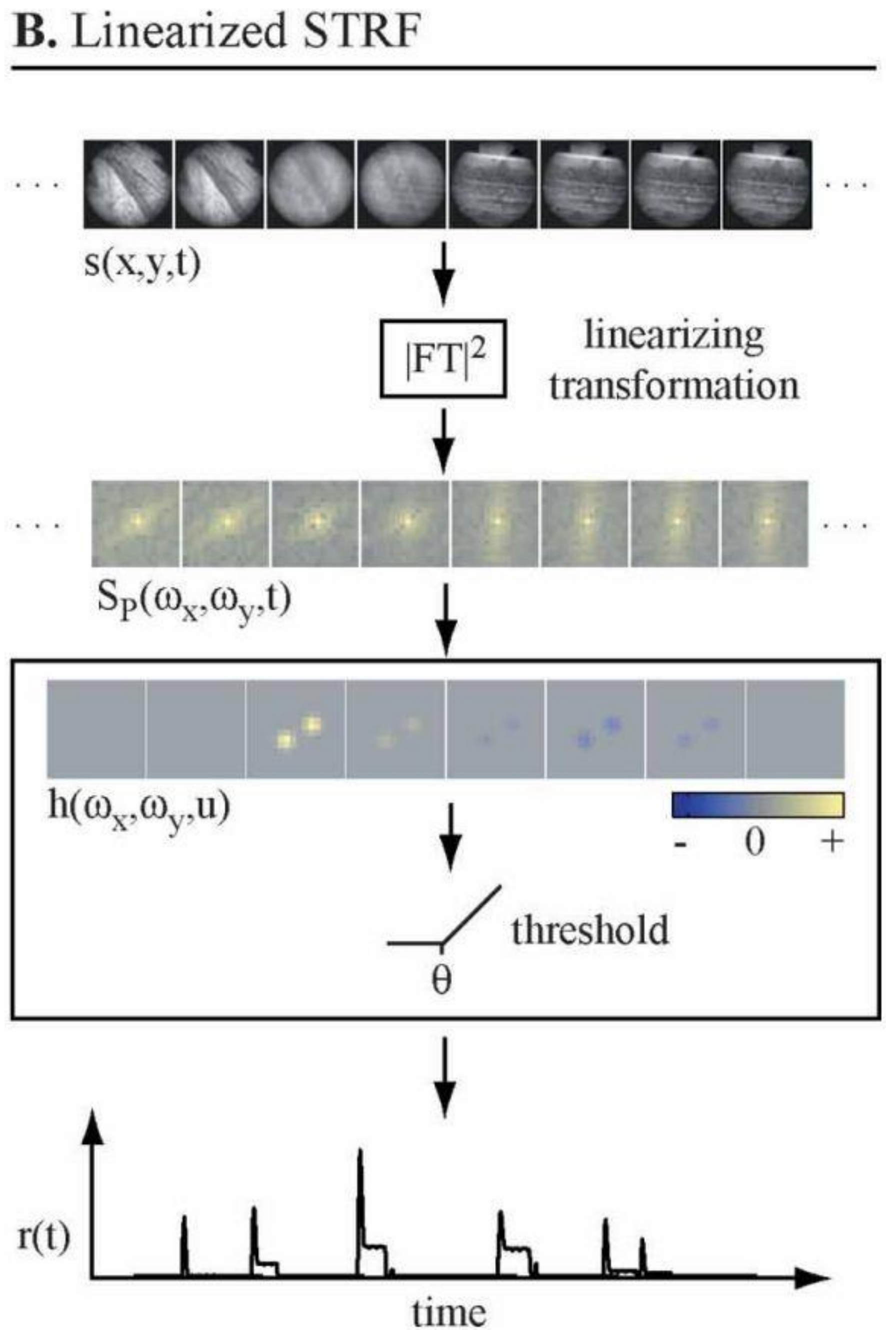
Concept of 'Filter'

Space and Time both !

Latency !



PHASE INVARIANCE..



The Math of Estimation..

$$r(t) = \left| \sum_{i=1}^{N} \sum_{u=0}^{U} h(x_i, u) s(x_i, t-u) - \theta + \varepsilon(t) \right|^{+}$$

$$S_u = \begin{bmatrix} s(1, 1-u) & s(2, 1-u) & \cdots & s(N, 1-u) \\ s(1, 2-u) & s(2, 2-u) & & s(N, 2-u) \\ \vdots & & \ddots & \vdots \\ s(1, T-u) & s(2, T-u) & \cdots & s(N, T-u) \end{bmatrix}$$

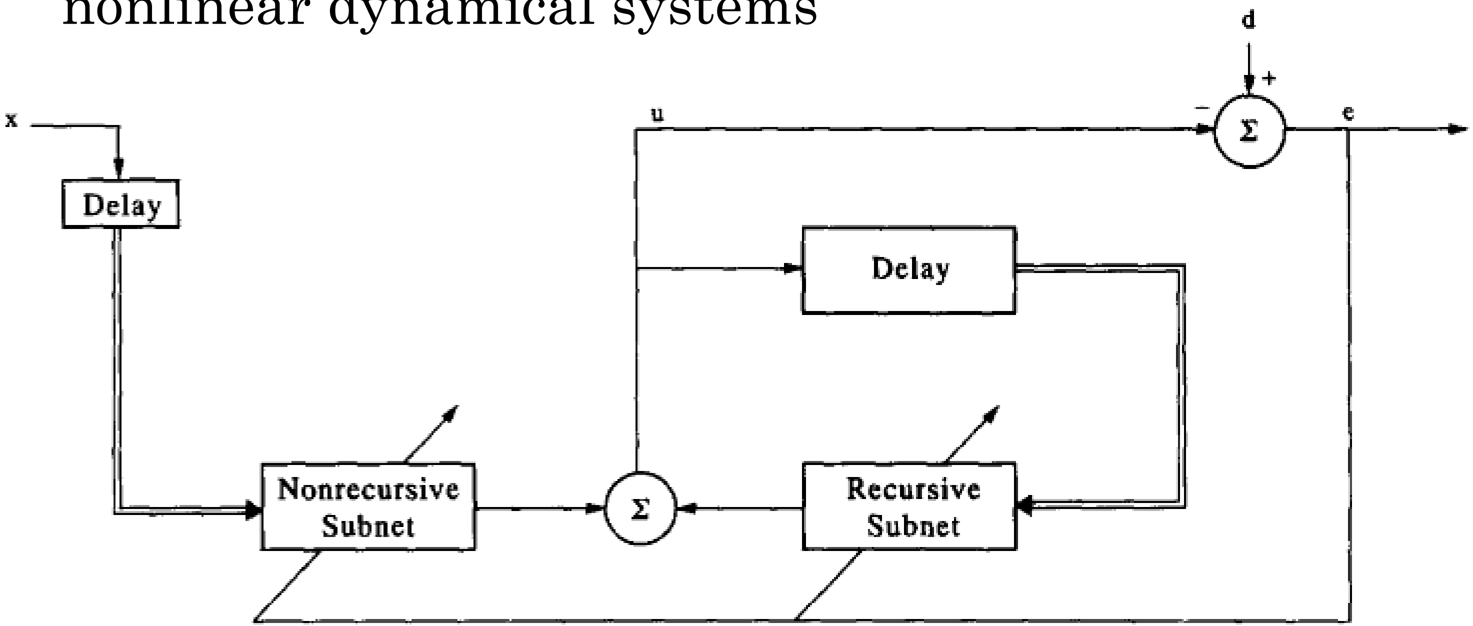
$$S = [S_0 \quad S_1 \quad \cdots \quad S_U]$$

$$h = \frac{1}{T} C_{ss}^{-1} S^T r.$$

$$r = |Sh - \theta + \varepsilon|^{+}.$$

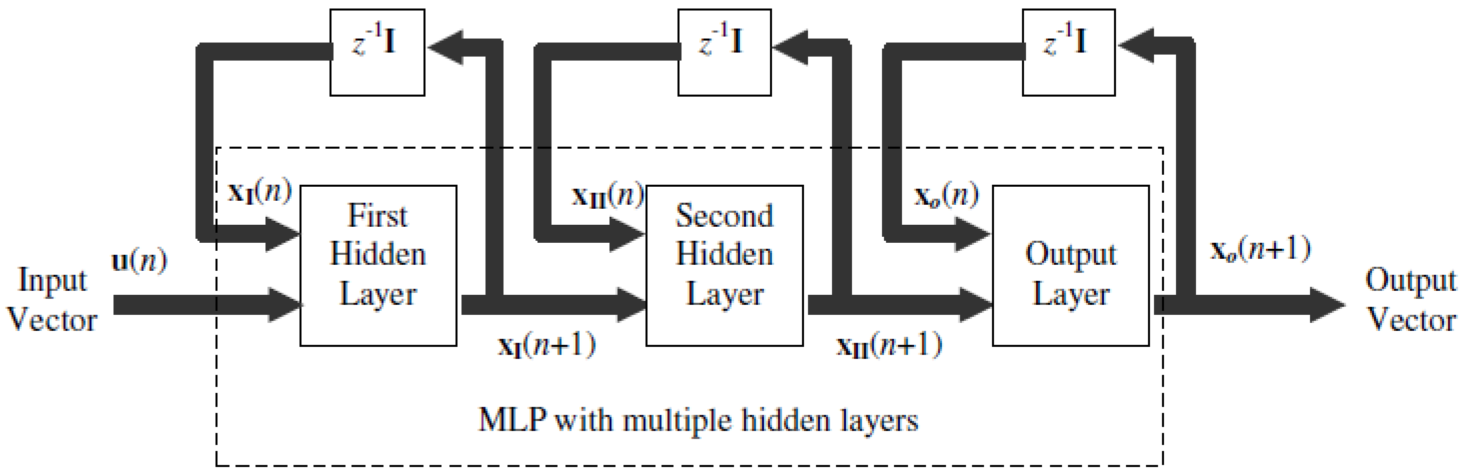
Second Approach: Machine Learning

- Recursive neural networks
  - Composed of feed forward and feed back subnets.
  - Were initially designed for the purpose of controlling nonlinear dynamical systems



Source: Hush et al. *The Recursive Neural Network and its Application in Control Theory*. Computers Elect. Engng. Vol. 19, No. 4, pp. 333-341, 1993

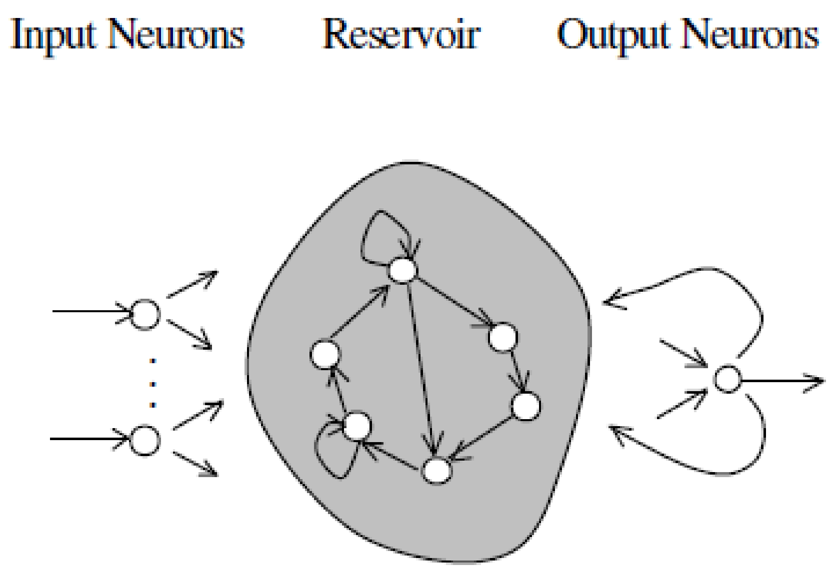
An exemplary recursive multi-layer perceptron:



$$
\begin{aligned}
\mathrm{x}_I(n+1) &= \varphi_I(\mathrm{w}_I \cdot \begin{bmatrix} \mathrm{x}_I(n) \\ u(n) \end{bmatrix} \\
\mathrm{x}_{II}(n+1) &= \varphi_{II}(\mathrm{w}_{II} \cdot \begin{bmatrix} \mathrm{x}_{II}(n) \\ \mathrm{x}_I(n) \end{bmatrix} \\
\mathrm{x}_o(n+1) &= \varphi_o(\mathrm{w}_o \cdot \begin{bmatrix} \mathrm{x}_o(n) \\ \mathrm{x}_{II}(n) \end{bmatrix}
\end{aligned}
$$

Echo State Networks

- Dynamic neural networks
- The hidden layer of ESN consists of a single large reservoir with neurons connected to each other randomly.



Using RNNs

- RNNs have been used for inverse modeling purposes
- Can handle time series data because of the presence of feed back and delay mechanisms
- May need to down sample data even further to keep network size manageable.

References

- Predicting neural responses during natural vision, S. David, J.Gallant, Computation in neural systems 2005
- Wikipedia article on neural coding (http://en.wikipedia.org/wiki/Neural_coding)
- Theunissen et al., Estimating spatial temporal receptive field of auditory and visual neurons from their responses to natural stimuli .Network: Comp Neural Systems 12:289–316.
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- Le Yang, Yanbo Xue. *Development of A New Recurrent Neural Network Toolbox (RNN-Tool)* (http://soma.mcmaster.ca/~yxue/papers/RMLP_ESN_Report_Yang_Xue.pdf)