Inference by binary sampling as a model for V1 spiking responses

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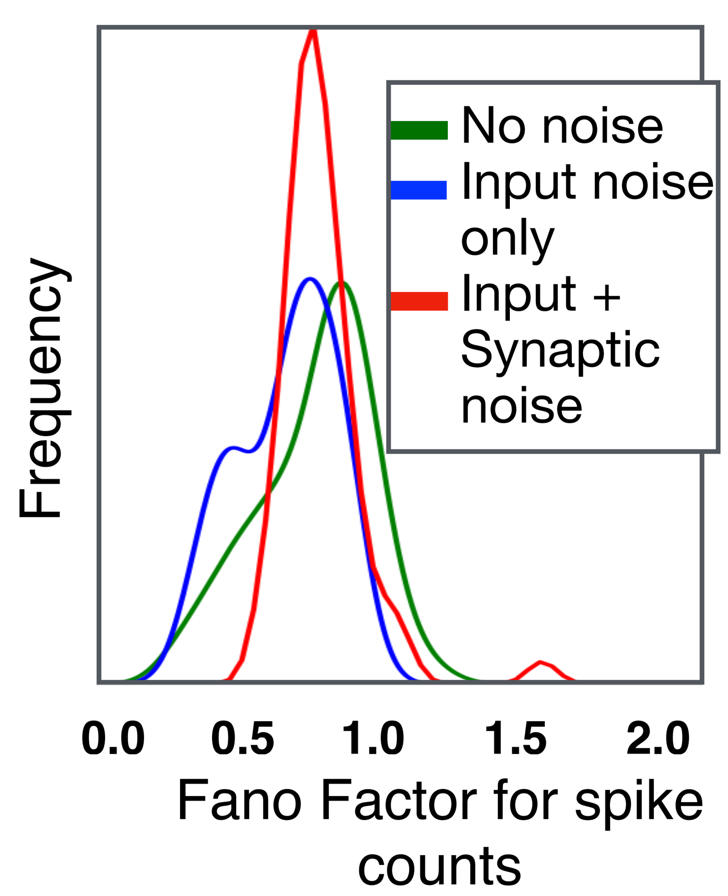
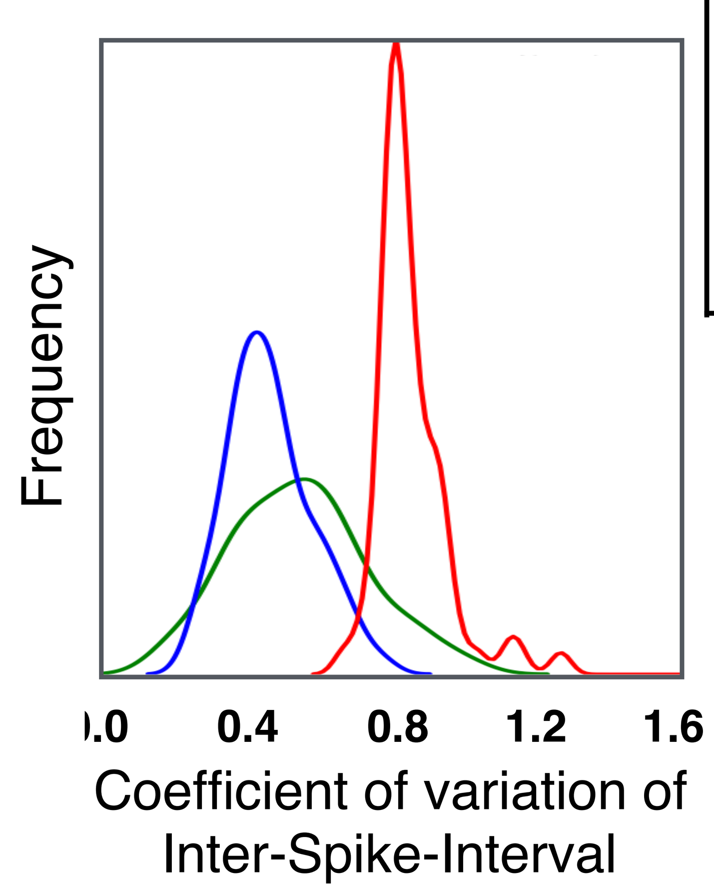
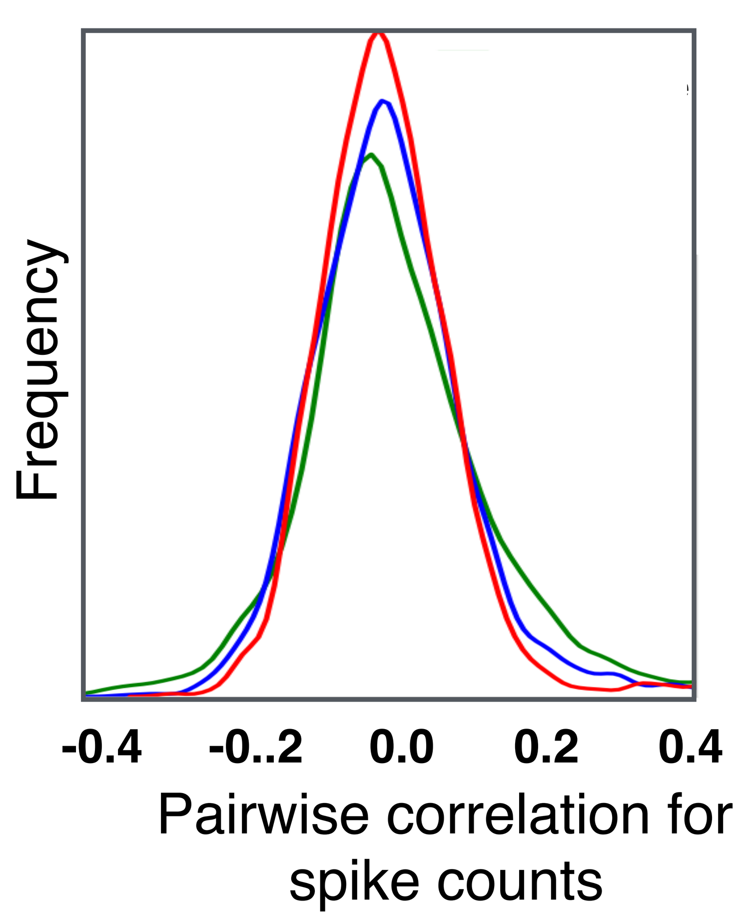
Introduction

- Visual processing is often characterized as implementing **probabilistic inference.** [1]
- One candidate algorithm to do probabilistic inference, is '**neural sampling**'[2,5,7].
- We derive a **spiking neural network model using deterministic leaky integrate-and-fire (LIF) neurons** and **stochastic synapses** [11] whose responses represent **binary samples** from the **joint posterior in a linear model**[9] of the retinal input.

Near Poisson variability in LIF network with Input + Synaptic noise





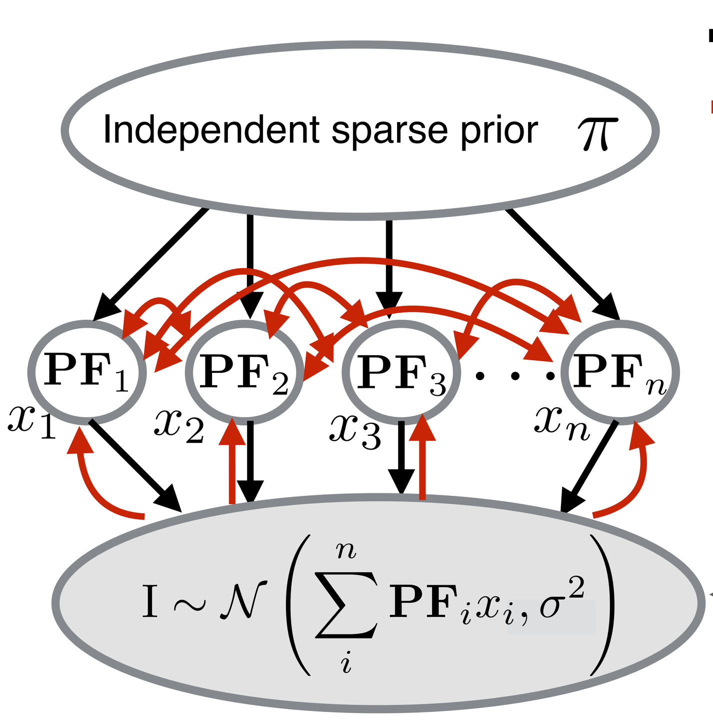


Bridging Marr's three levels[10]

Marr's Level 1

COMPUTATIONAL GOAL

Probabilistic Inference



$\mathbf{PF}_i$ = Projective Field/feature represented by neuron i

Marr's Level 2

ALGORITHM/ REPRESENTATION

MCMC Gibbs Sampling

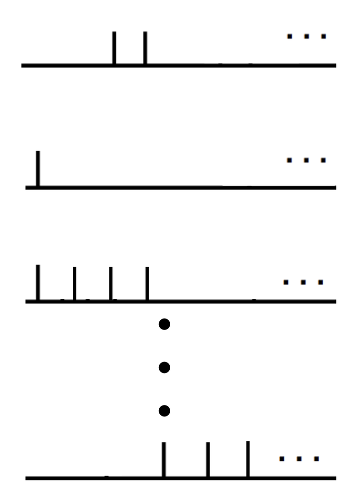
Gibbs sampling for binary x with sparse prior:

$$p\left(x_k = 1 | x_{\neg k}, \mathrm{I}\right) \propto exp\left(\frac{1}{\sigma^2}||\mathrm{I} - \mathbf{PF}^T\mathbf{x}||^2\right) \times \prod_i^n \pi^{x_i}\left(1 - \pi^{(1-x_i)}\right)$$

Binary samples of **x** can be interpreted as spikes

x_1	0	0	1	1	0
x_2	1	0	0	0	0
x_3	1	1	1	1	0
⋮					⋮
x_N	0	0	1	1	1

0 = no spike
1 = spike



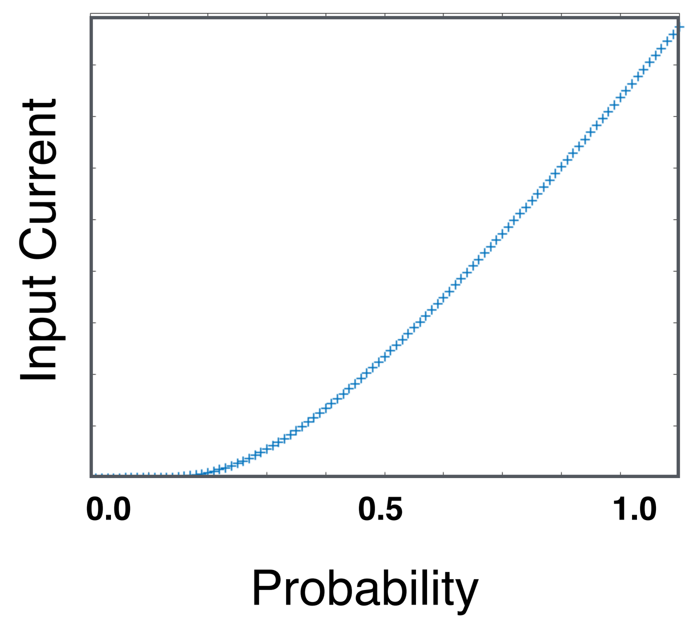
Marr's Level 3

IMPLEMENTATION

Network of leaky integrate and fire (LIF) neurons

I Vs **P** in LIF neuron for fixed input:

$$\mathbf{p} = \frac{\mathbf{1}}{\mathbf{\Delta t}} = \left[\tau \mathbf{ln}\left(\frac{\mathbf{I_{input\ current}}}{\mathbf{I_{input\ current}} + (\mathbf{V_{rest}} - \mathbf{V_{threshold}})}\right)\right]^{-1}$$



LIF equation(unitless):

$$\tau\frac{\mathbf{dV}}{\mathbf{dt}} = \mathbf{V} - \mathbf{V_{rest}} + \mathbf{I_{input\ current}}$$

$$\mathbf{I_{input\ current}} = \mathbf{I_{recurrent}} + \mathbf{I_{feedforward}}$$

Simulation details:

$\mathbf{LIF}\ \tau = 10ms$
$\mathbf{V_{threshold}} = -55mV$
$\mathbf{V_{rest}} = -70mV$
$\mathbf{Sampling\ time} = 5ms$

Feedforward and Recurrent Weights of LIF neuron derived from Gibbs sampling equations

Feedforward connection weight: $\mathrm{I}^T\mathbf{PF}_i$

Recurrent connection weight: $-\mathbf{PF}_i^T\mathbf{PF}_j$

***p*(neuron spikes now|Image, state of other neurons)**

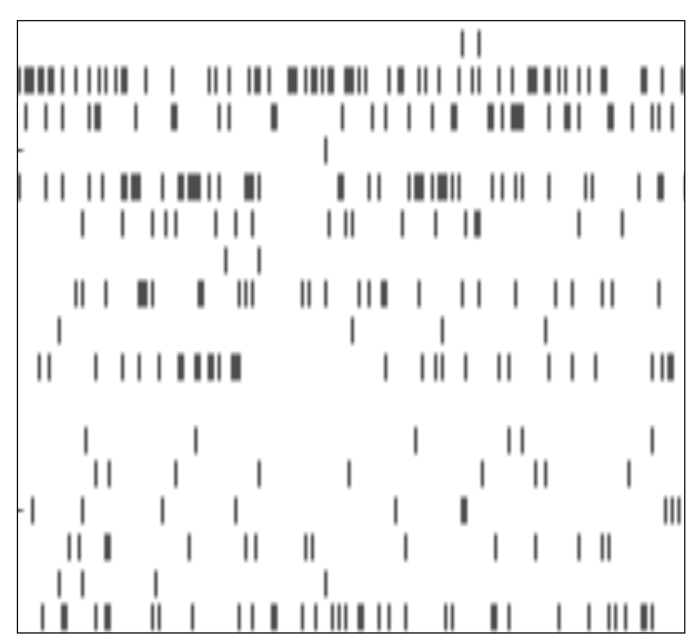
$\propto$ **Firing Rate**

Feedforward

Recurrent input from other neurons

Input Current

Example spike raster



Conclusion

Simulating the LIF network we find,

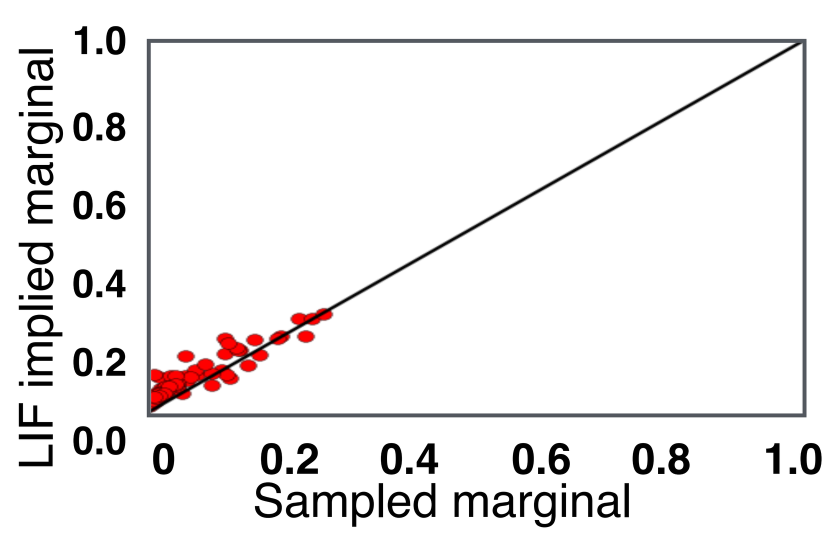
- agreement between posterior implied by LIF network spikes and Gibbs samples
- approximately contrast-invariant tuning curves
- near Poisson variability
- small noise correlations with mean of close to zero[6]
- negative causal influences between neurons of similar receptive fields[12]

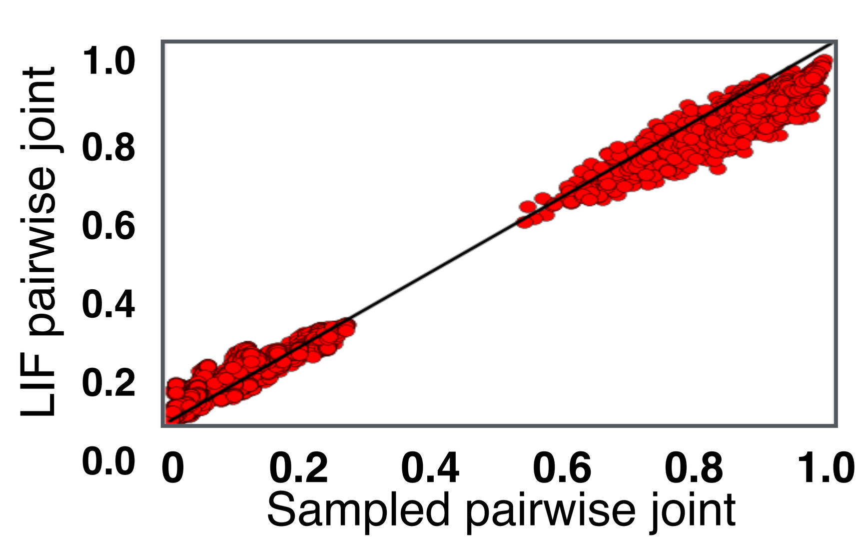
Models / Properties	Hoyer and Hyvärinen. NIPS 2003	Buesing, Lars, et al.PLoS COMP BIO 2011 [4]	Bornschein et al PLoS COMP BIO 2013 [3]	Petrovici et al 2015 [8]	Gibbs Sampling in LIF neurons (Our Work)
V1 Model	✓		✓		✓
MCMC Sampling	✓	✓		✓	✓
Binary Hidden States		✓	✓	✓	✓
Deterministic LIF neurons				✓	✓

References

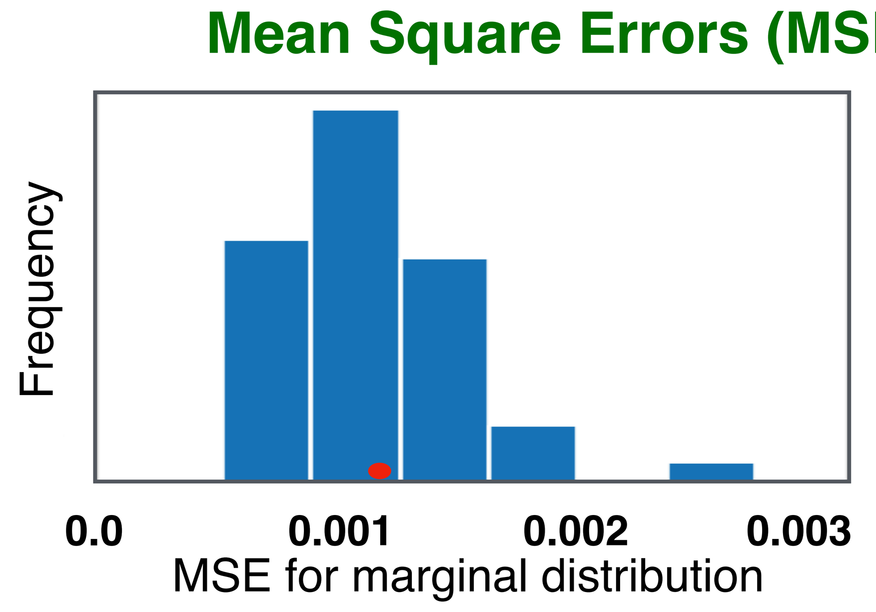
[1] Fiser, József, et al. (2010) [2] Hoyer, Patrik O., and Aapo Hyvärinen. NIPS. (2003) [3] Bornschein, Jörg et al PLoS CB 9.6 (2013) [4] Buesing, Lars, et al. PLoS CB(2011) [5] Orbán, Gergő, et al. Neuron (2016) [6] Ecker, Alexander S., et al. Science (2010) [7] Haefner,et al Neuron (2016) [8] Petrovici, Mihai A., et al. BMC neuroscience (2015) [9] Olshausen, and Field Vision research(1997) [10] David Marr, Vision.(1982) [11] Aitchison,et al. arXiv preprint (2015) [12] Chettih et al Nature (2019)

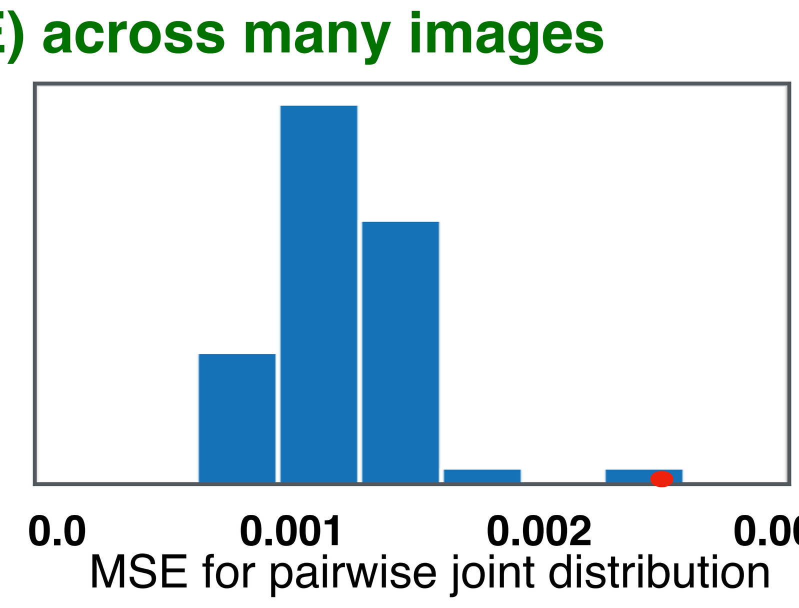
Good agreement between posterior implied by LIF network spikes and Gibbs samples for an example image



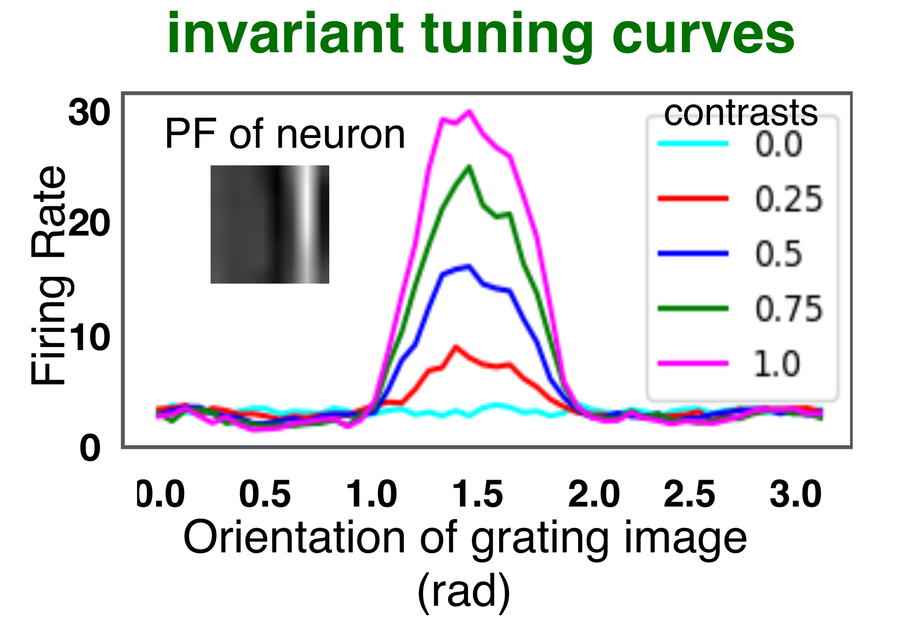


Mean Square Errors (MSE) across many images





Approximately contrast-invariant tuning curves



Negative causal influence between neurons of similar RFs