Decoding V1 Neuronal Activity using Particle Filtering with Volterra Kernels

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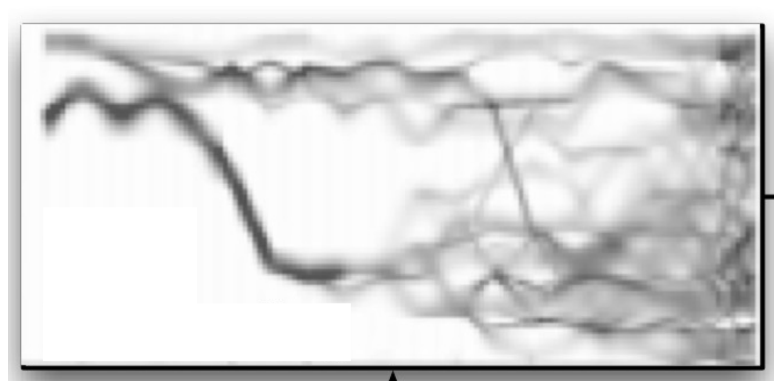
Motivation

Use Volterra Kernels to predict neuronal response at next time step from response history by predicting the scene variable.

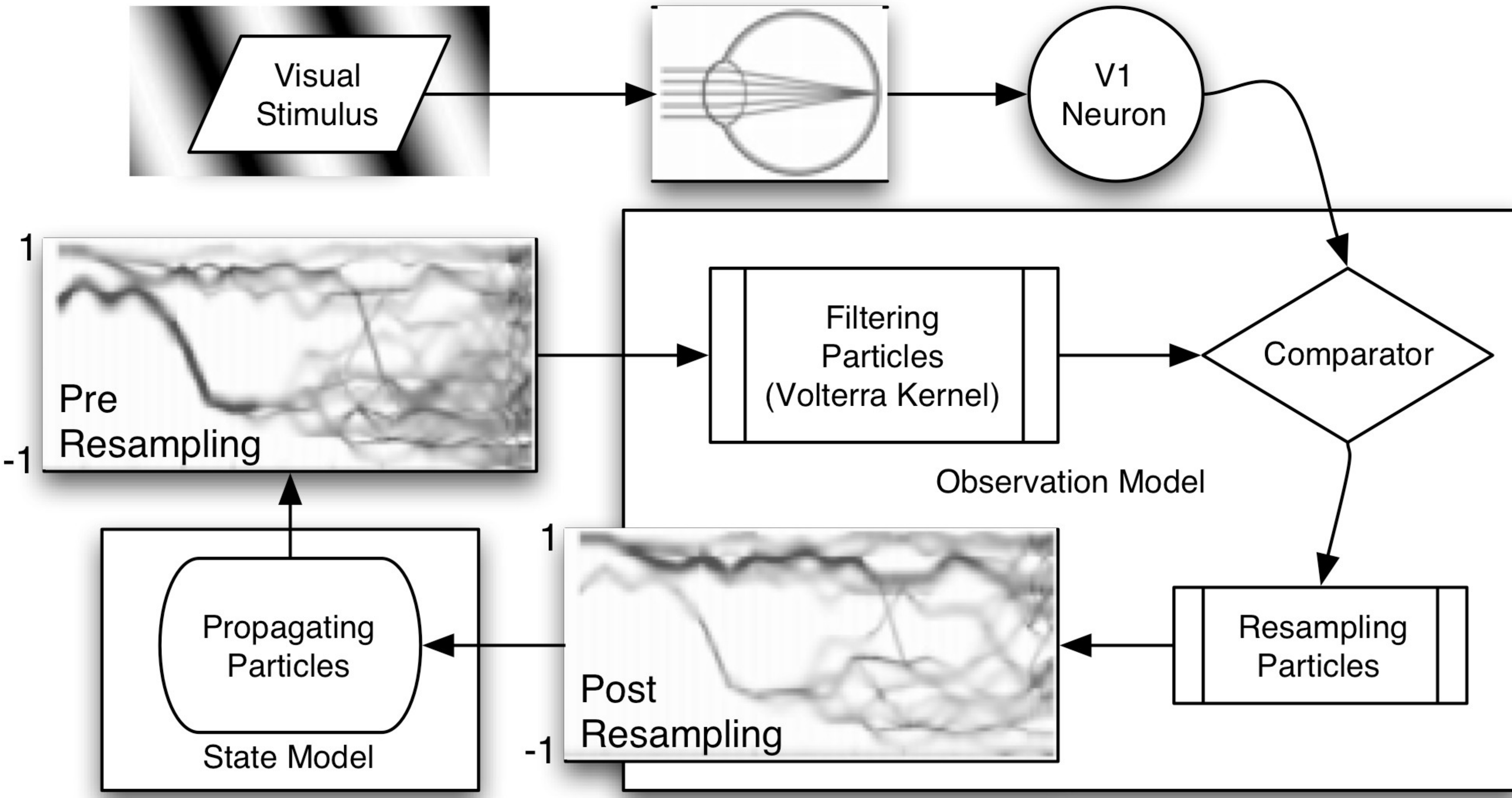
Hypothesis Particle

History of the scene variable as hypothesized from neuronal activity.



Filter particles to find the most likely.

Paradigm

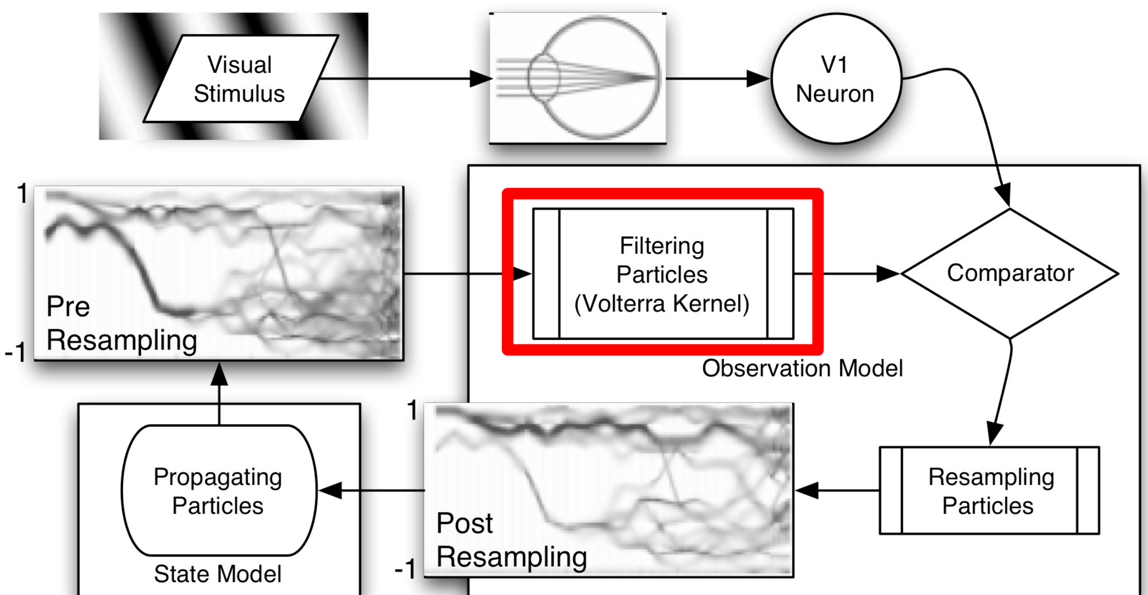


Visual
Stimulus
V1
Neuron
1
Pre
Resampling
-1
Filtering
Particles
(Volterra Kernel)
Comparator
Observation Model
1
Propagating
Particles
State Model
Post
Resampling
-1
Resampling
Particles

Particle Filtering

- Generate a prediction of the neuronal response by filtering the hypothesis with the Volterra Kernels

$$r(t) = h_0 + \sum_{\tau=1}^{L} h_1(\tau)\, x(t-\tau) + \sum_{\tau_1=1}^{L} \sum_{\tau_2=1}^{L} H_2(\tau_1, \tau_2)\, x(t-\tau_1)\, x(t-\tau_2)$$

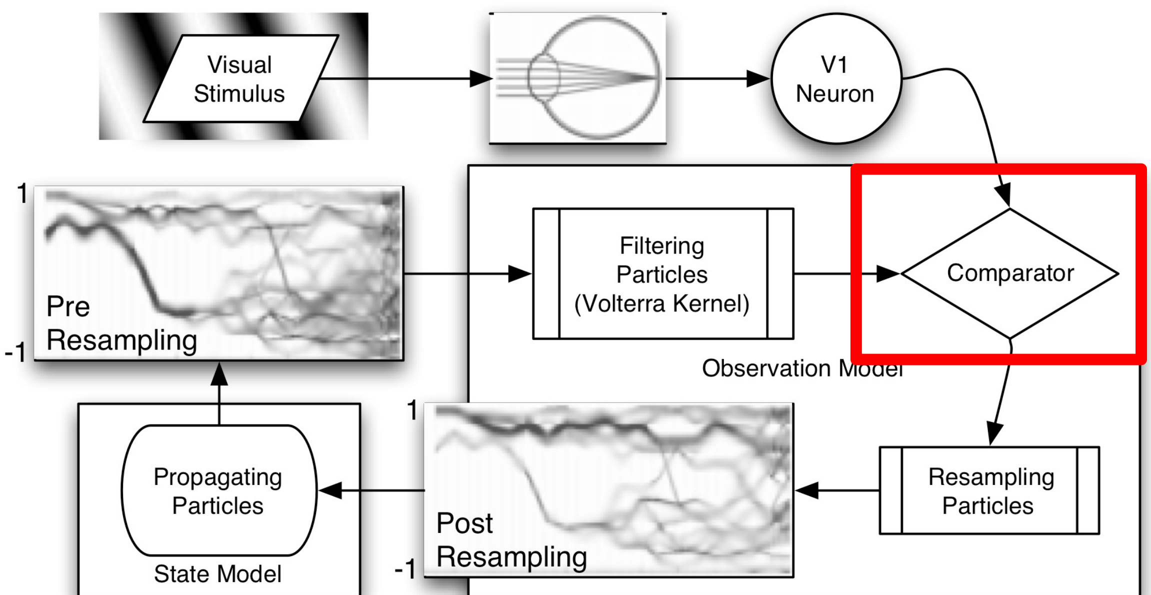


Kernel learned by:

$$H = (X'X)^{-1} X'R$$

Comparator

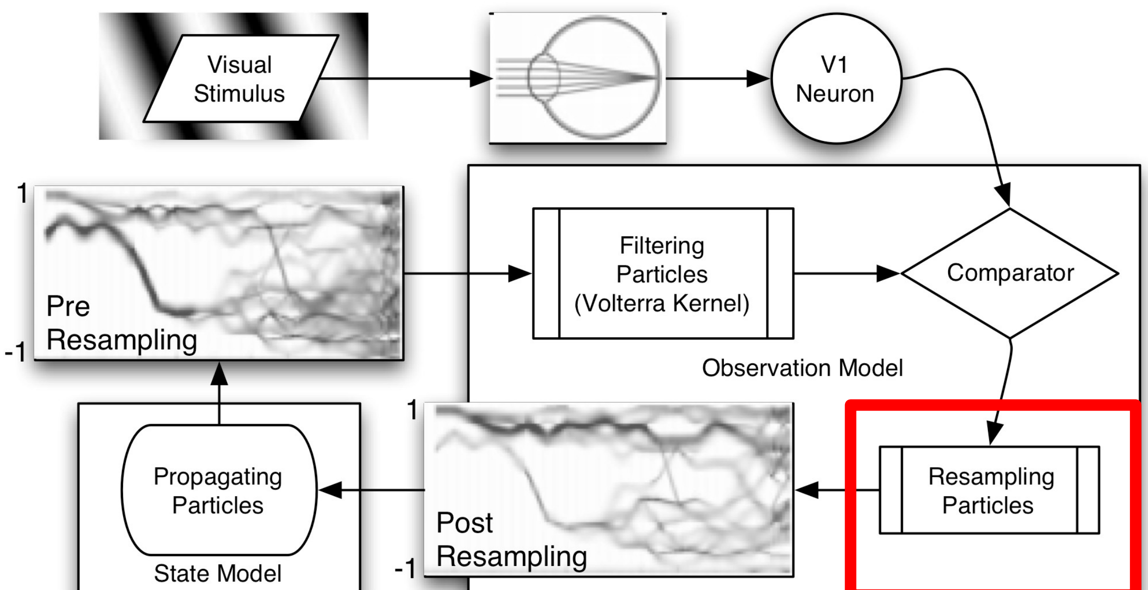
- For each hypothesis particle, compare neuronal response to predicted response to yield likelihood measure.
- Proportional to how close the particle's predicted response is to observed response.



Particle Resampling

- Resample (with replacement) the posterior distribution based on this likelihood.
- Particles predicting a response similar to the observed neural response will have higher likelihoods will repeat with high probability.

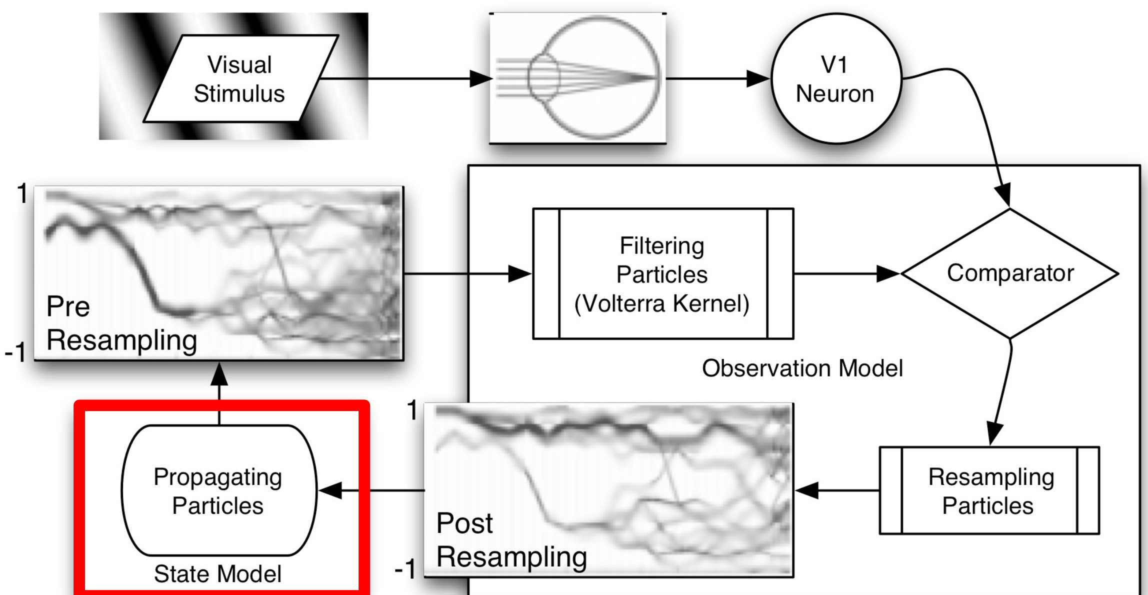
$$p(\hat{x}_t | y_1, y_2, \ldots, y_t) \propto p(y_t | \hat{x}_t)\, p(\hat{x}_t | y_1, y_2, \ldots, y_{t-1})$$



Particle Propagation

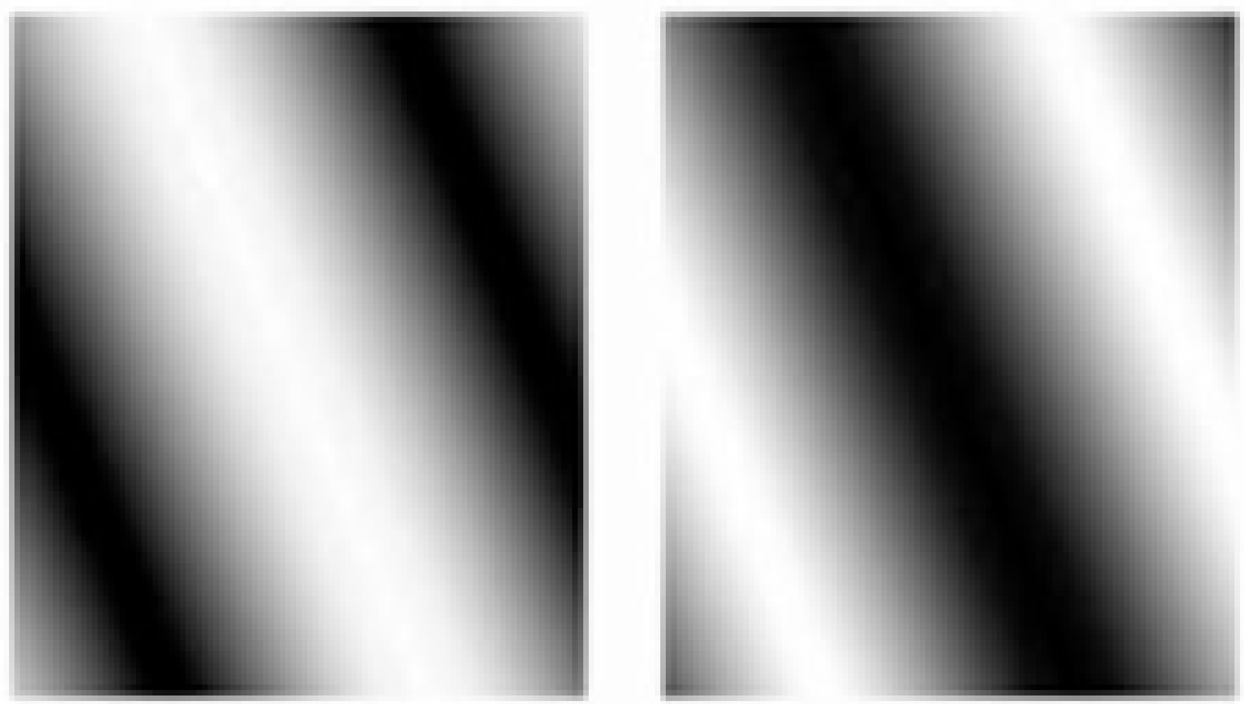
- Combine likelihood with prior on how scene variable tends to vary

$$p(\hat{x}_{t+1}|y_{1,}y_{2,..},y_t)=\int p(\hat{x}_{t+1}|\hat{x}_t)\,p(\hat{x}_t|y_{1,}y_{2,..},y_t)\,dx_t$$



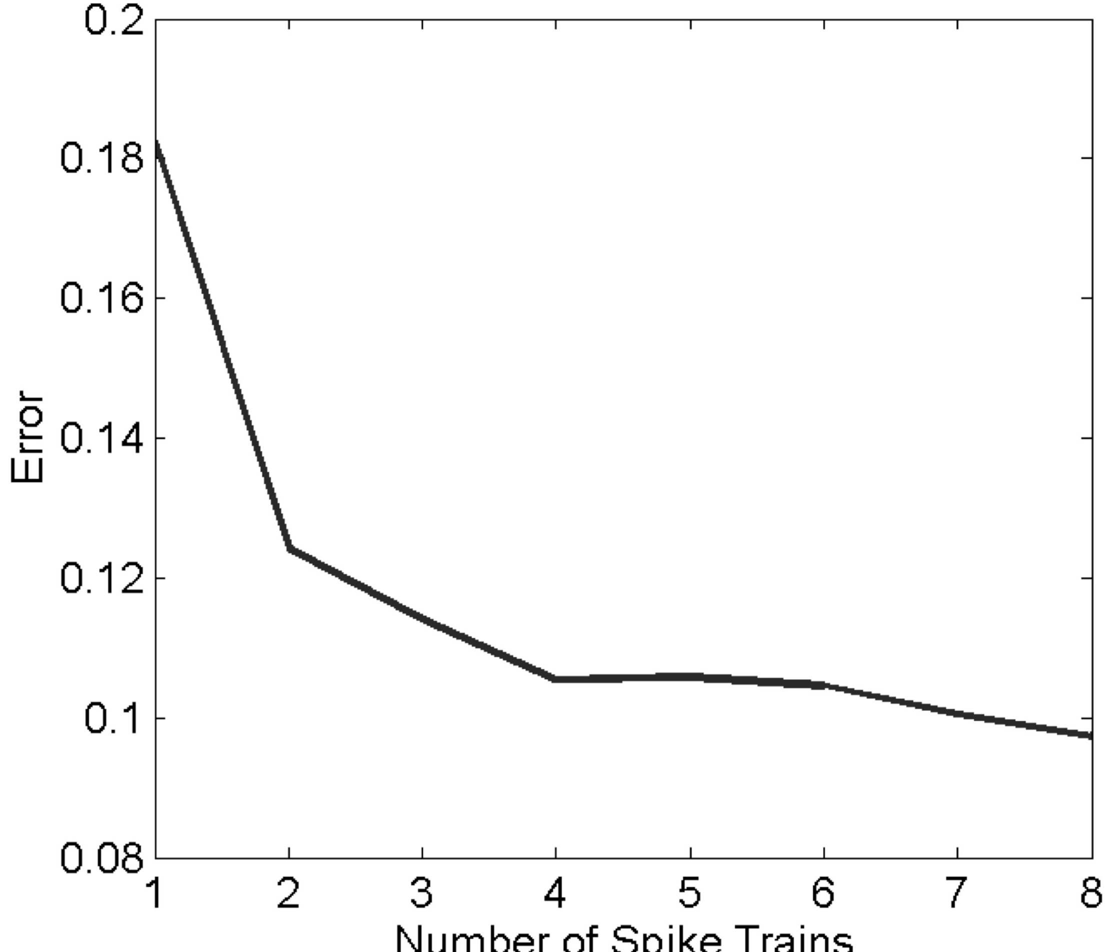
Experiment

- Used phase of sine-wave grating as scene variable.



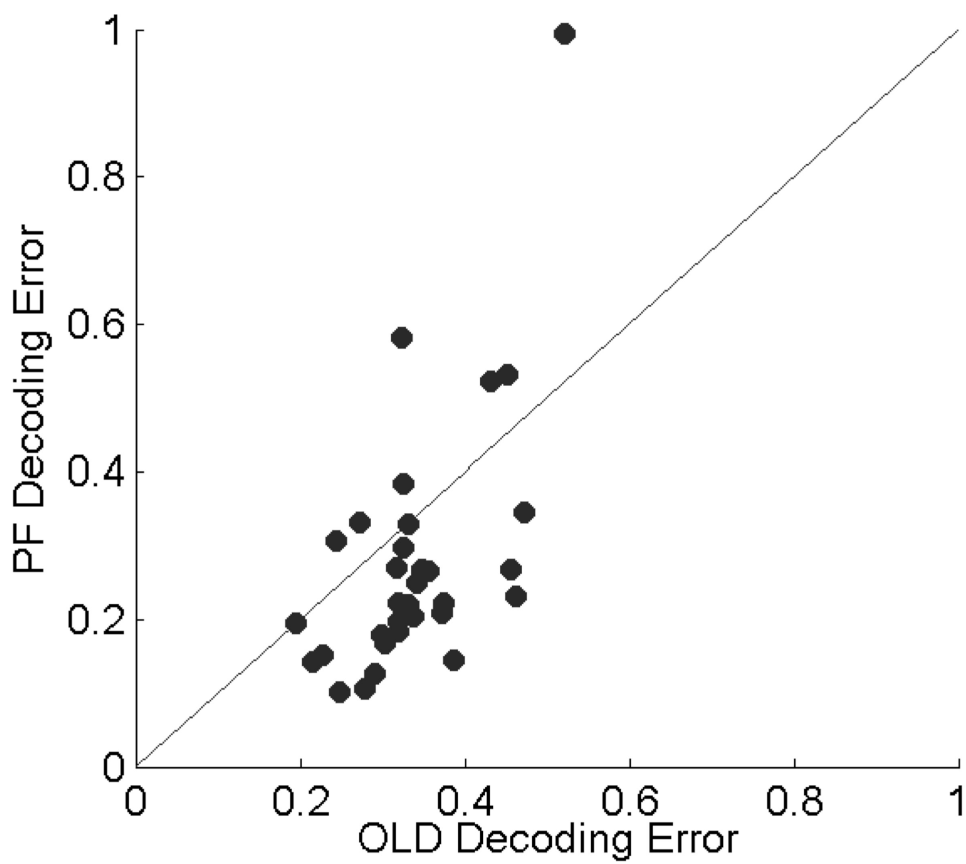
Results

- Sampling from 10 independent neurons is sufficient to reconstruct scene variable with 90% accuracy



Results

- General improvement over optimal linear decoding (OLD).
- OLD keeps only one hypothesis at a given time step.



Conclusions

- Nonlinearities are significant when modeling neurons – using second order Volterra Kernels improves decoding accuracy.
- Particle filtering allows an efficient approximation of relevant areas of the hypothesis space, while tracking several very different hypotheses.
- Keeping a prior on how the scene variables tends to change allows pruning of the hypothesis space.