Sequential Optimal Design of Neurophysiology Experiments

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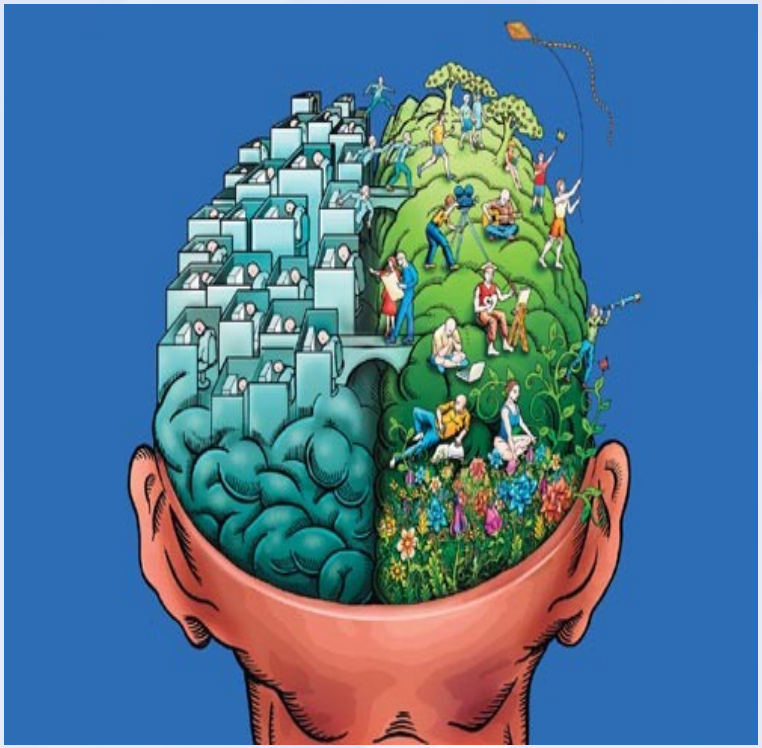
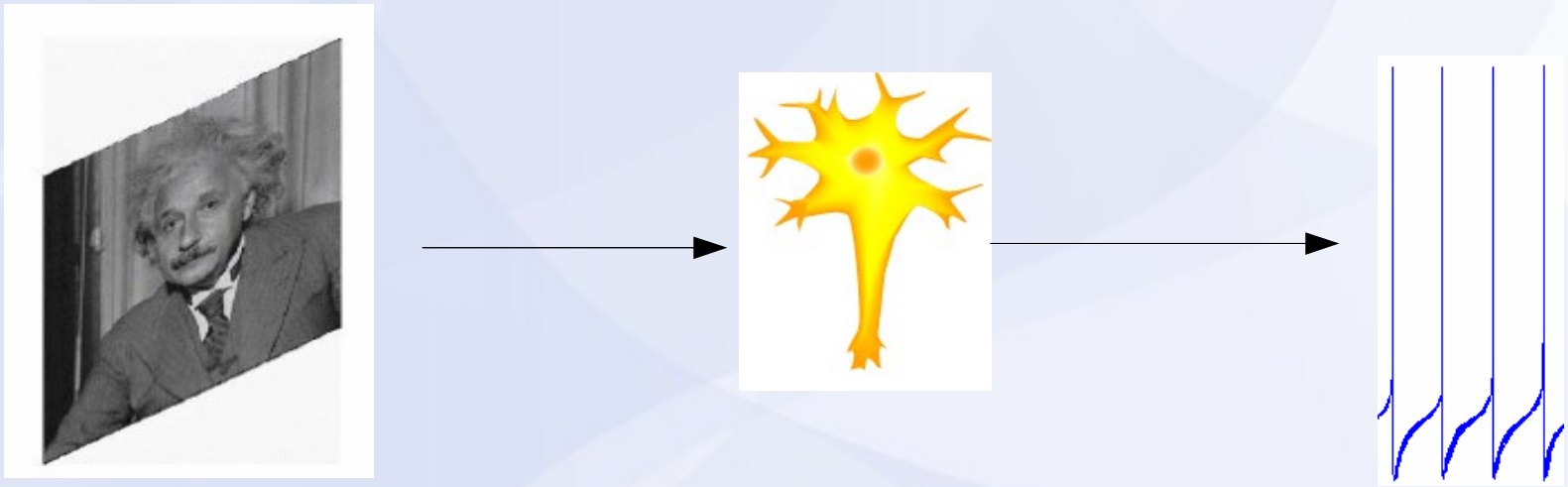
The Brain



Phineas Gage (1850's)

What happens when you poke?



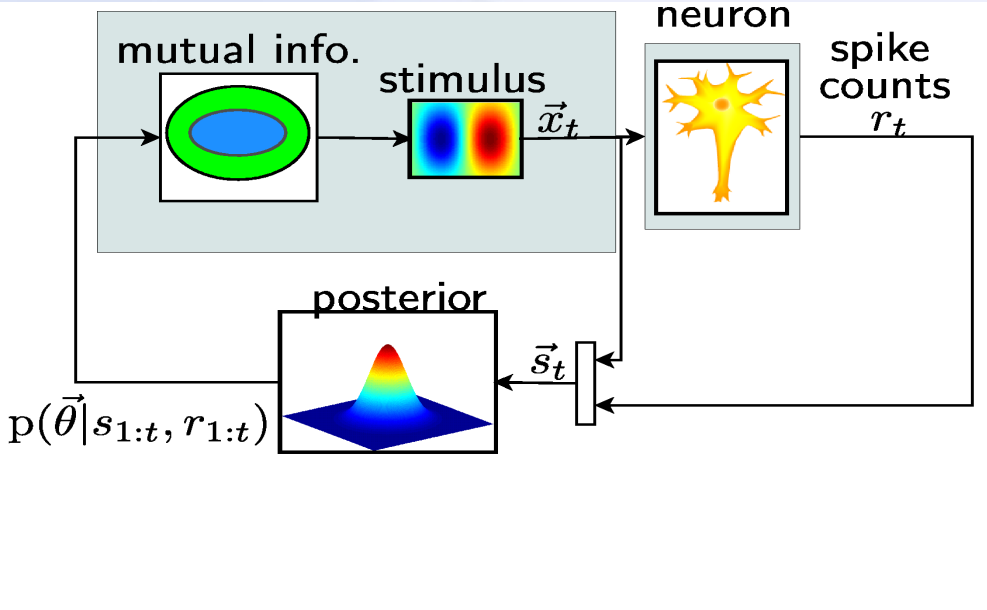
The neural code: $p(r_t|\vec{s}_t)$

$r_t = \text{response}$

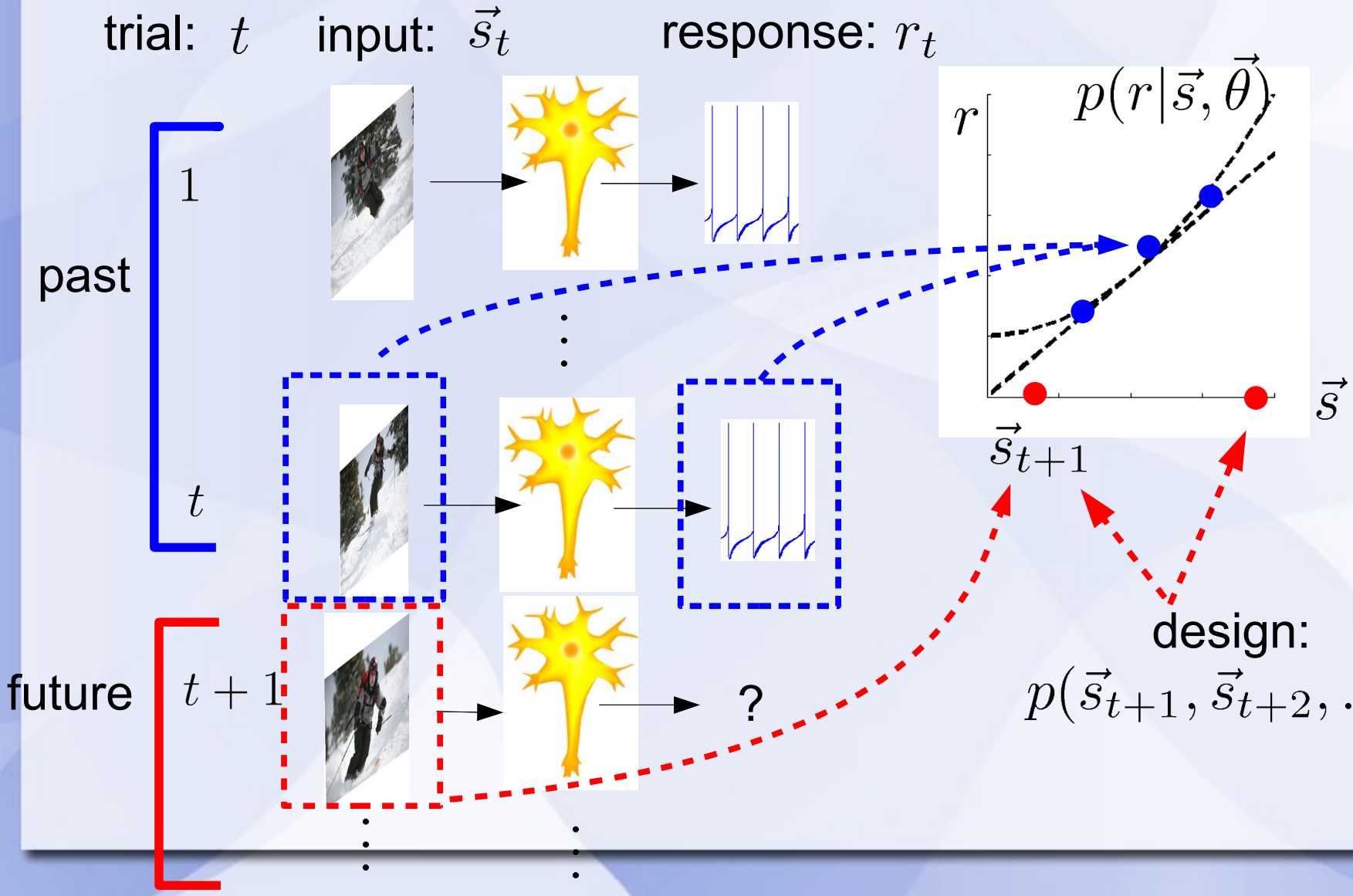
$\vec{s}_t = \text{stimulus}$

Sequential Optimal Experimental Design (SOE)

- same principle as the game twenty questions
- Optimal – choose the best questions
- Sequential – change the questions based on previous responses



Experimental Setup



Bayesian approach to SOE

$$p_{opt}(\vec{s}_{t+1}, \vec{s}_{t+2}, \ldots) =$$

$$\arg\max_{p(\vec{s}_{t+1}, \vec{s}_{t+2}, \ldots)} EU\left(p(\vec{s}_{t+1}, \vec{s}_{t+2}, \ldots), \{r_{t+1}, r_{t+2}, \ldots\}, \vec{\theta}, \ldots\right)$$

Utility functions

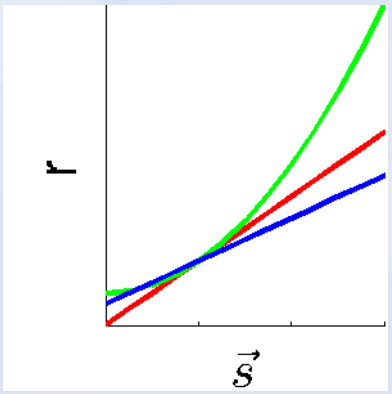
- Mutual information between input and response (Machens 2005)
- Maximize the firing rate (O'Connor 05)
- M.S.E of predicted response (Schein 05)
- Entropy of the conditional response (Mackay 92)

Mutual Information

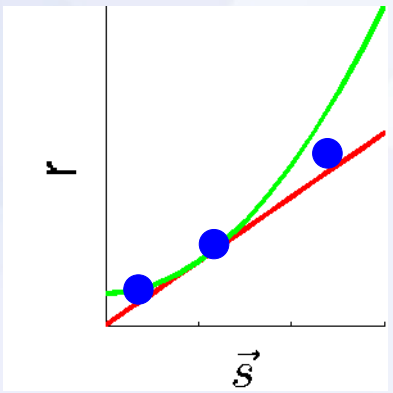
Before

After

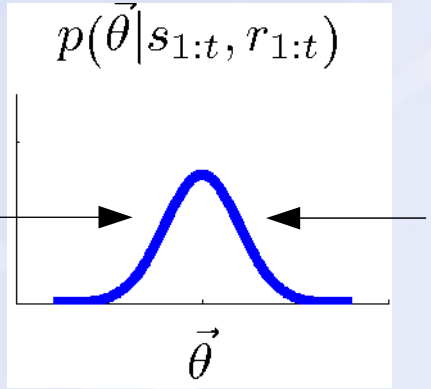
Models:

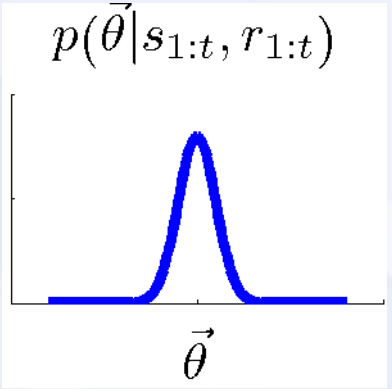


Collect Data



Uncertainty:





1. Update high dimensional posteriors
2. High dimensional expectation
3. High dimensional optimization inputs

Outline: Algorithm

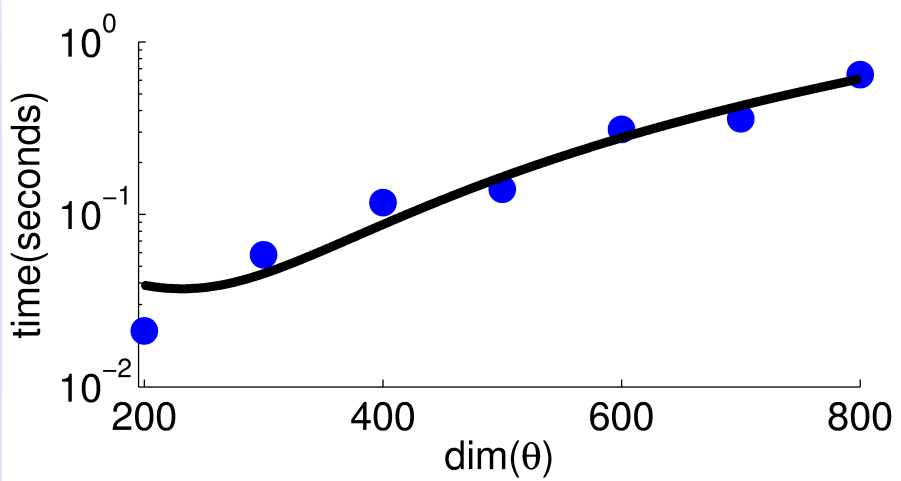
1. Model Responses using a 1-d Generalized Linear Model

2. Recursively approximate Posterior as Gaussian
   - Asymptotically posterior is Gaussian [Paninski 05]
   - Update using stochastic gradient ascent [Fabian 78, Sharia07]

3. Solve the optimization
   - Finite Horizon $\{\vec{s}_{t+1}, \vec{s}_{t+2}, \ldots, \vec{s}_{t+b}\}$
   - Infinite Horizon $\lim_{b \to \infty} \{\vec{s}_{t+1}, \vec{s}_{t+2}, \ldots, \vec{s}_{t+b}\}$

Summary

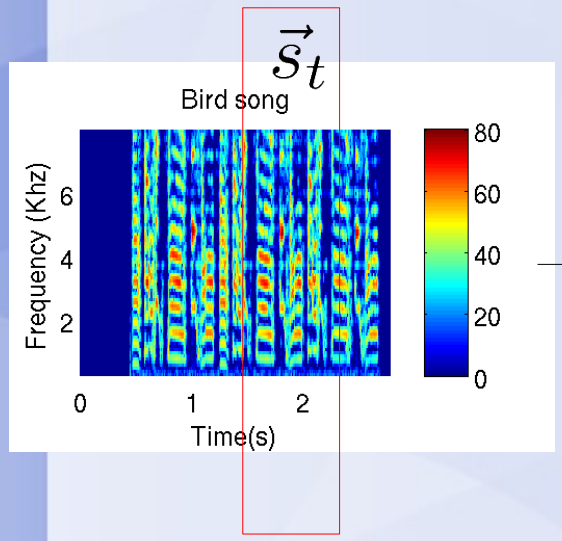
1. An efficient algorithm whose running time scales as: $O(d^2)$

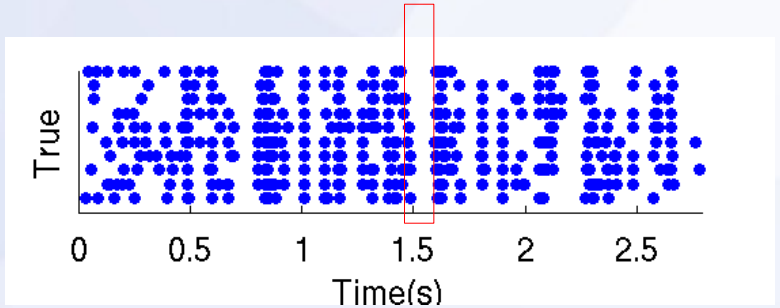


2. Algorithm is asymptotically optimal and the benefit of an adaptive design increases linearly with the dimensionality
3. General algorithm for GLMs.

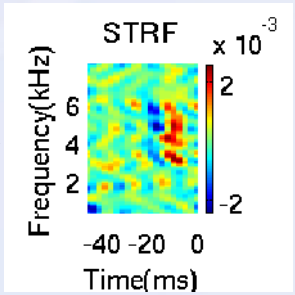
Auditory Experiments:

Experiment



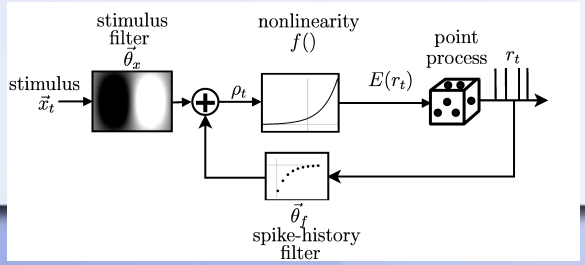


Linear Model:

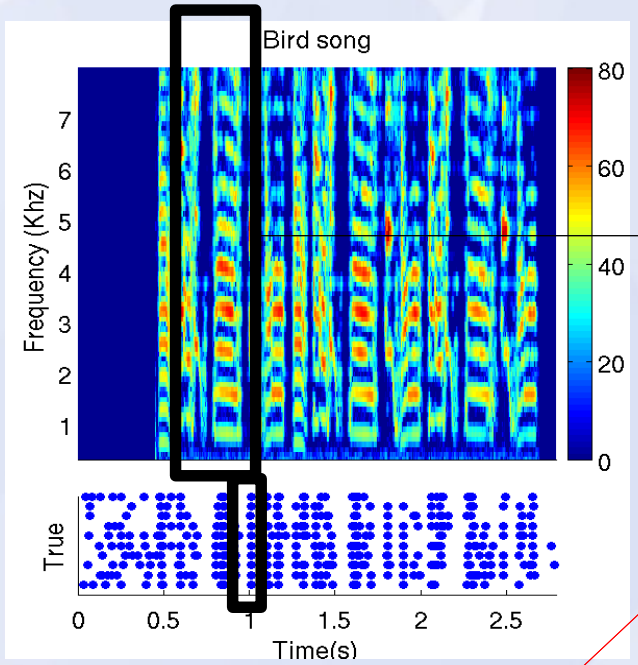


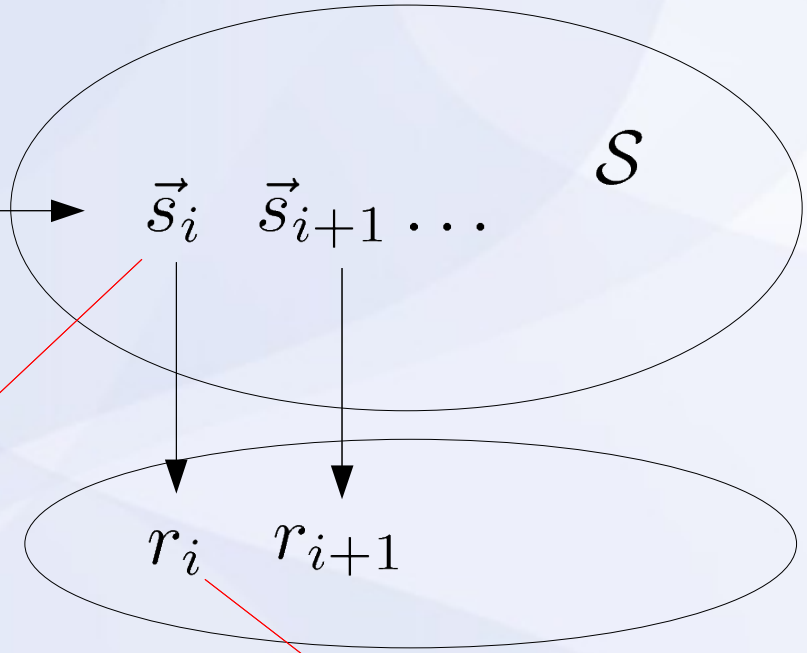
$$E(r_t)$$

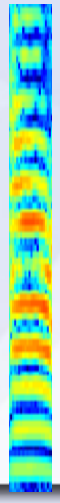
GLM:

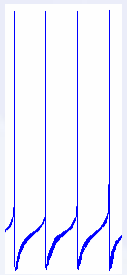


Validation with real data

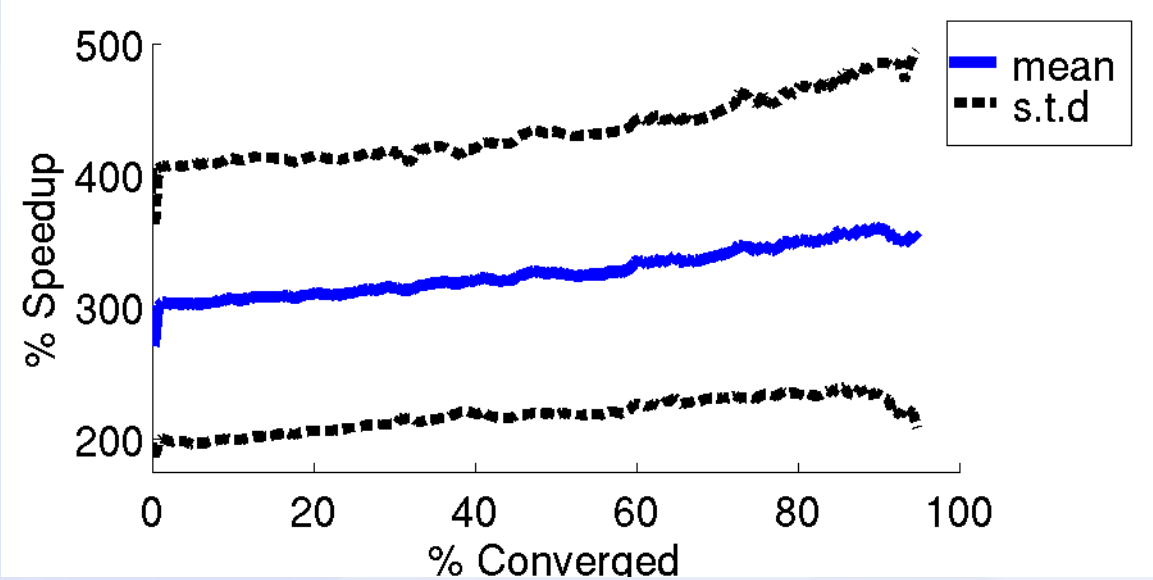






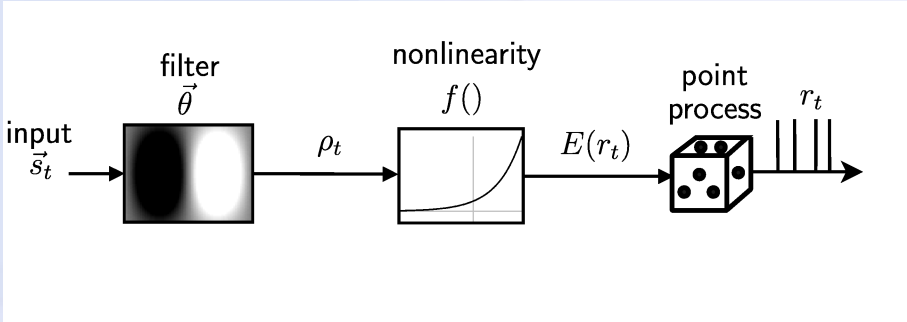


Speedup due to SOE



Conclusion:

- SOE → Speedup
- Speedup → Investigate more complicated models.



Acknowledgments

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