The attentional routing circuit: Receptive field modulation through nonlinear dendritic interactions

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Overview

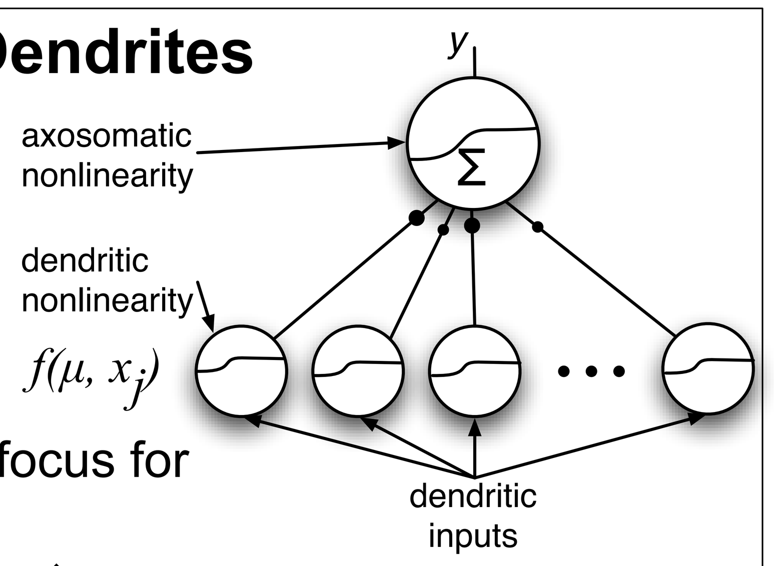
- Past focus of models is largely on determining an attentional target

  With this location selected, what are the neuronal mechanisms that cause attended information to be selectively routed and processed?

- ARC: Neurally detailed, scalable, functional model
- Spiking neuron implementation using a neuron model with nonlinear dendrites

Nonlinear Dendrites

- Allows neurons to compute two nonlinear functions [1]:
  - Dendritic and axosomatic

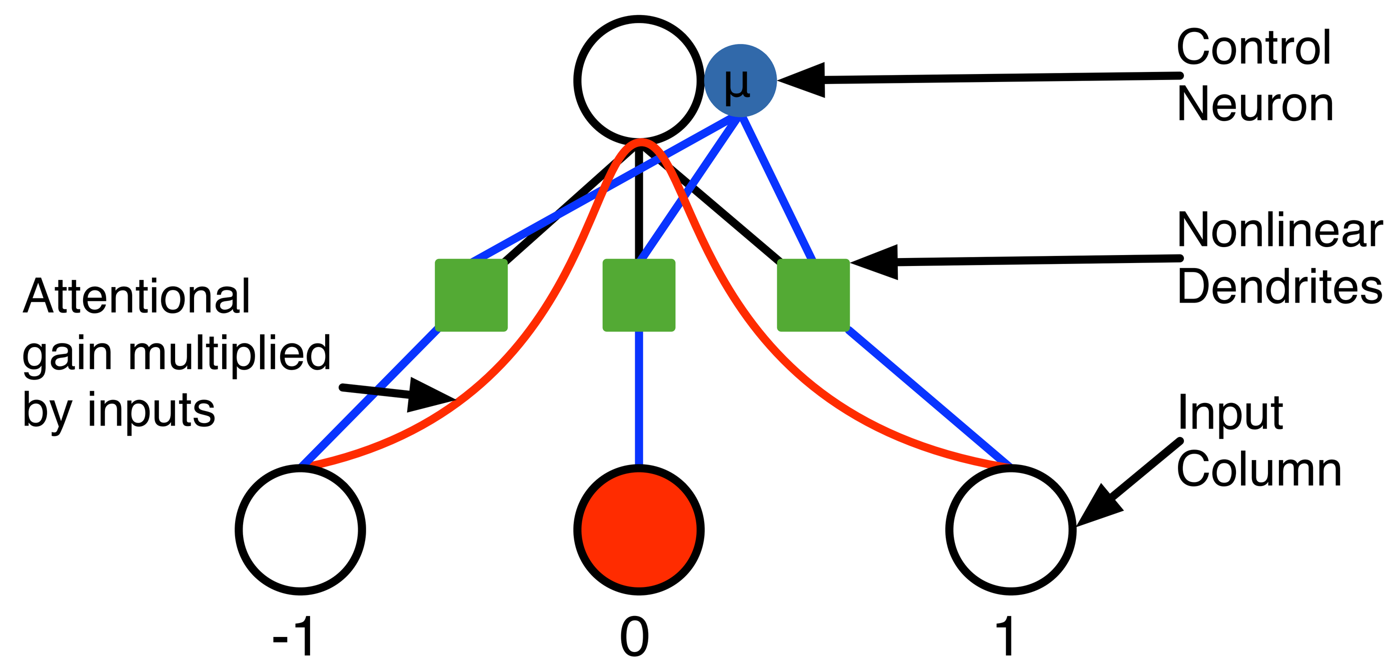


Attentional Routing Circuit:

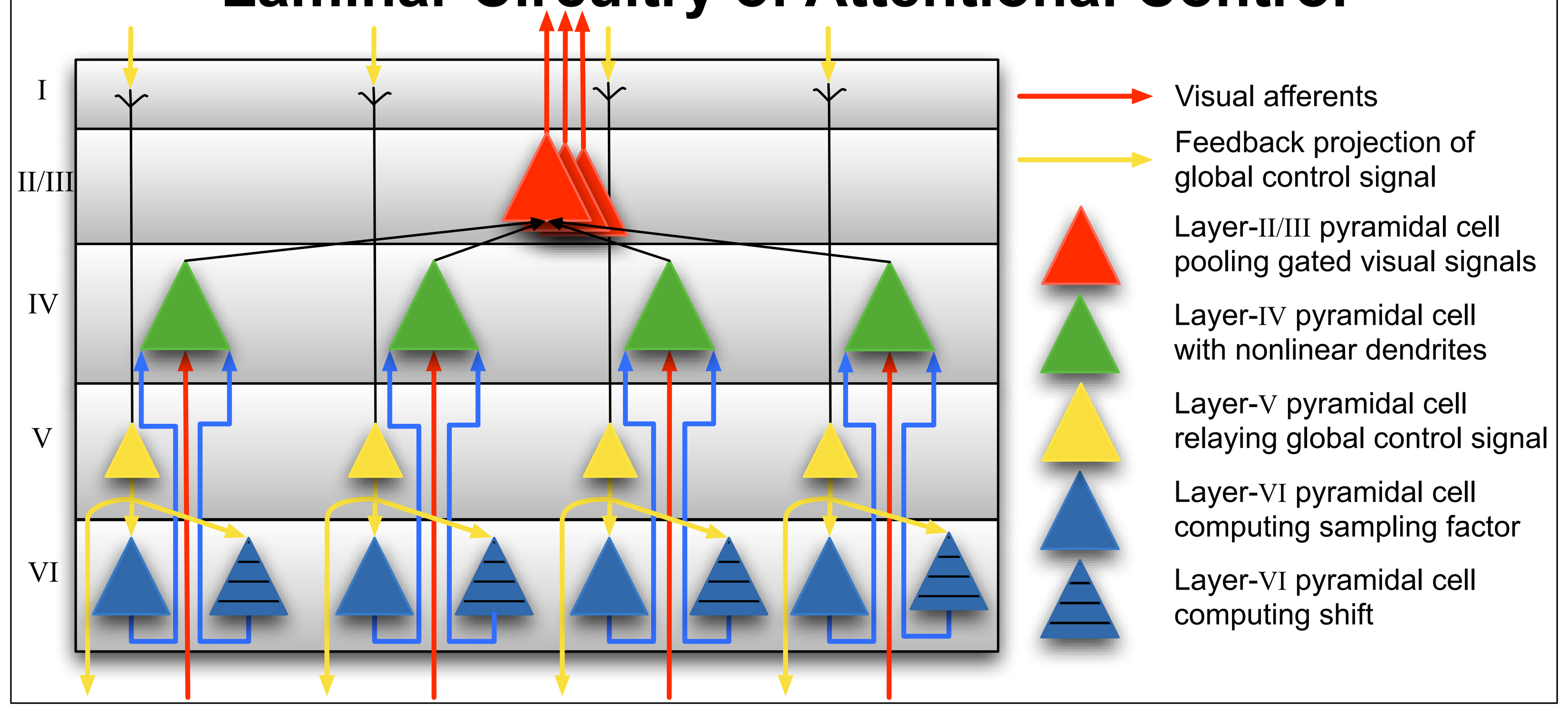
- Cortical control specifies attentional focus for each column (μ)

$$f(\mu_i, x_j) = e^{\frac{-(\mu_i - x_j)^2}{2\sigma_a^2}} \times \hat{x_j}$$

- Dendrites compute routing function $f(\mu,x)$

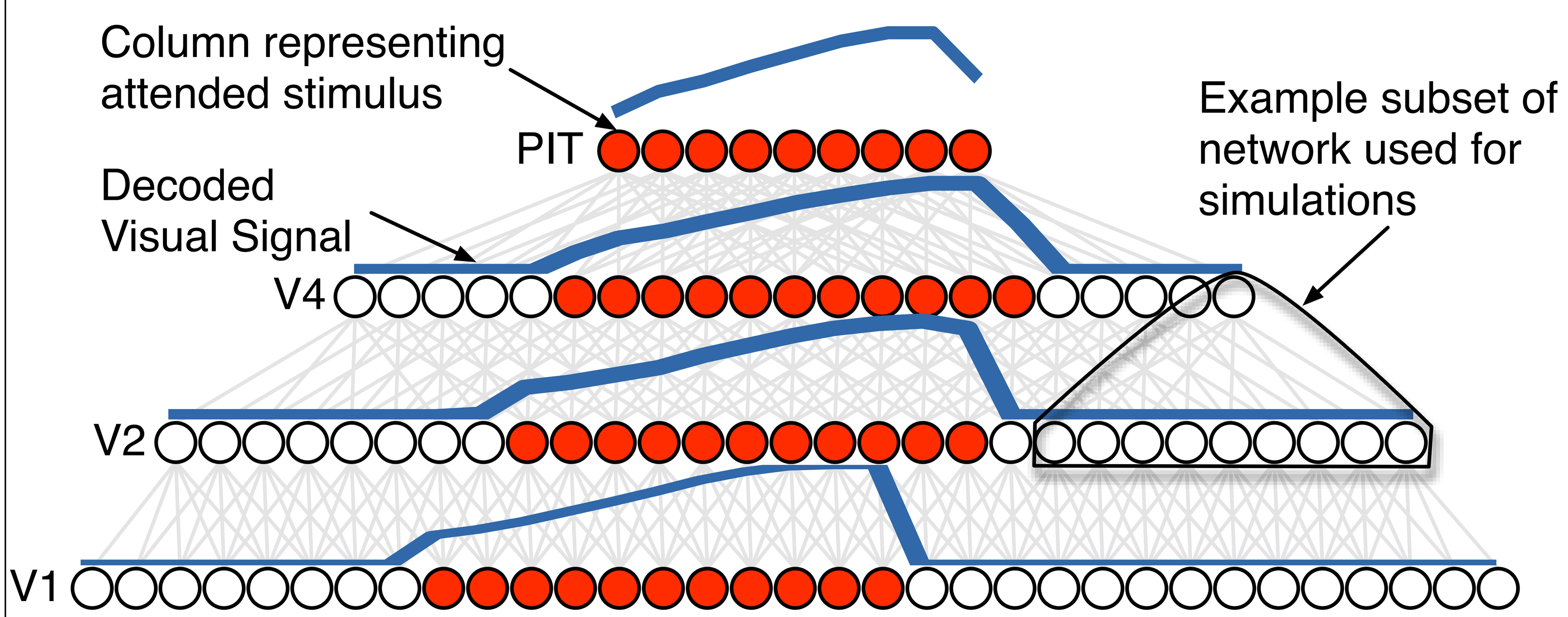


Laminar Circuitry of Attentional Control



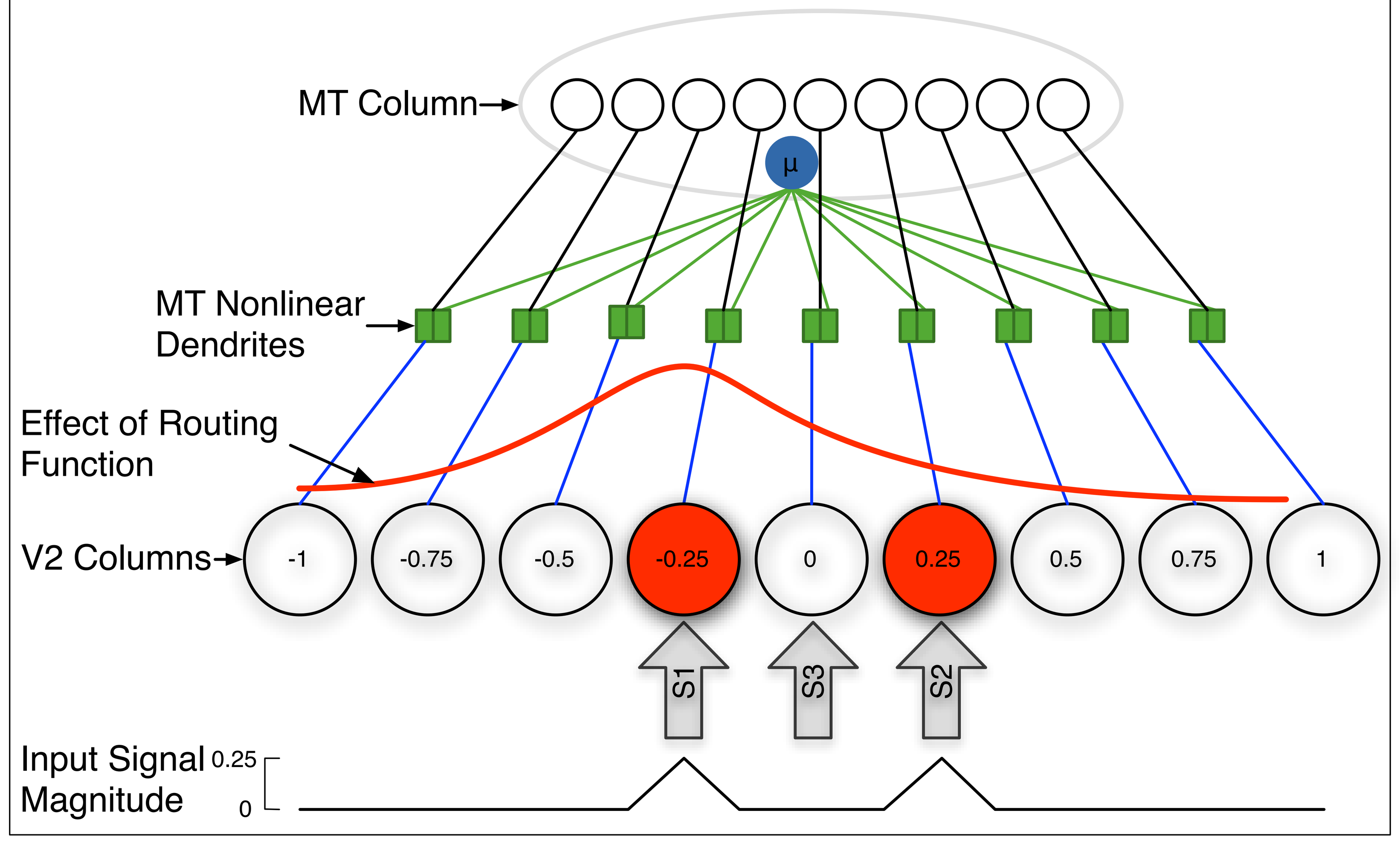
Model Architecture

- Columnar and retinotopic organization for ventral stream areas V1, V2, V4, and posterior IT (PIT)
- Same control computations performed by all columns in all levels



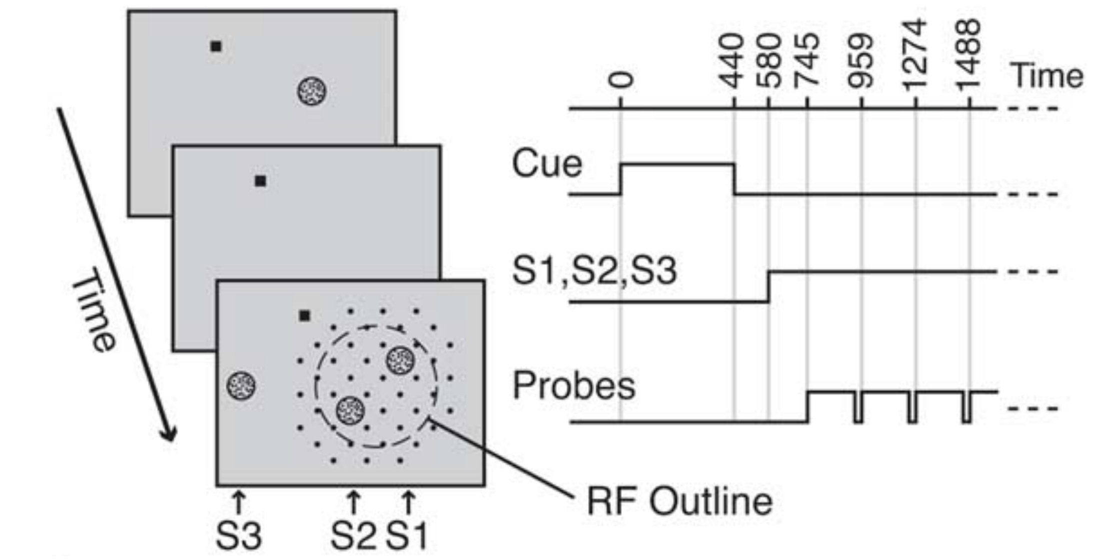
Model Details

- Spiking implementation using Neural Engineering Framework [2]
- MT column model:
  - 450 Layer-IV spiking pyramidal cells each with 25 nonlinear dendritic subunits
  - 50 Layer-VI control neurons (blue)
- Spiking activity recorded from 100 Layer II/III cells with attention directed to 3 targets (S1, S2, S3)
- **Only two free model parameters (σ_a and fan-in)**

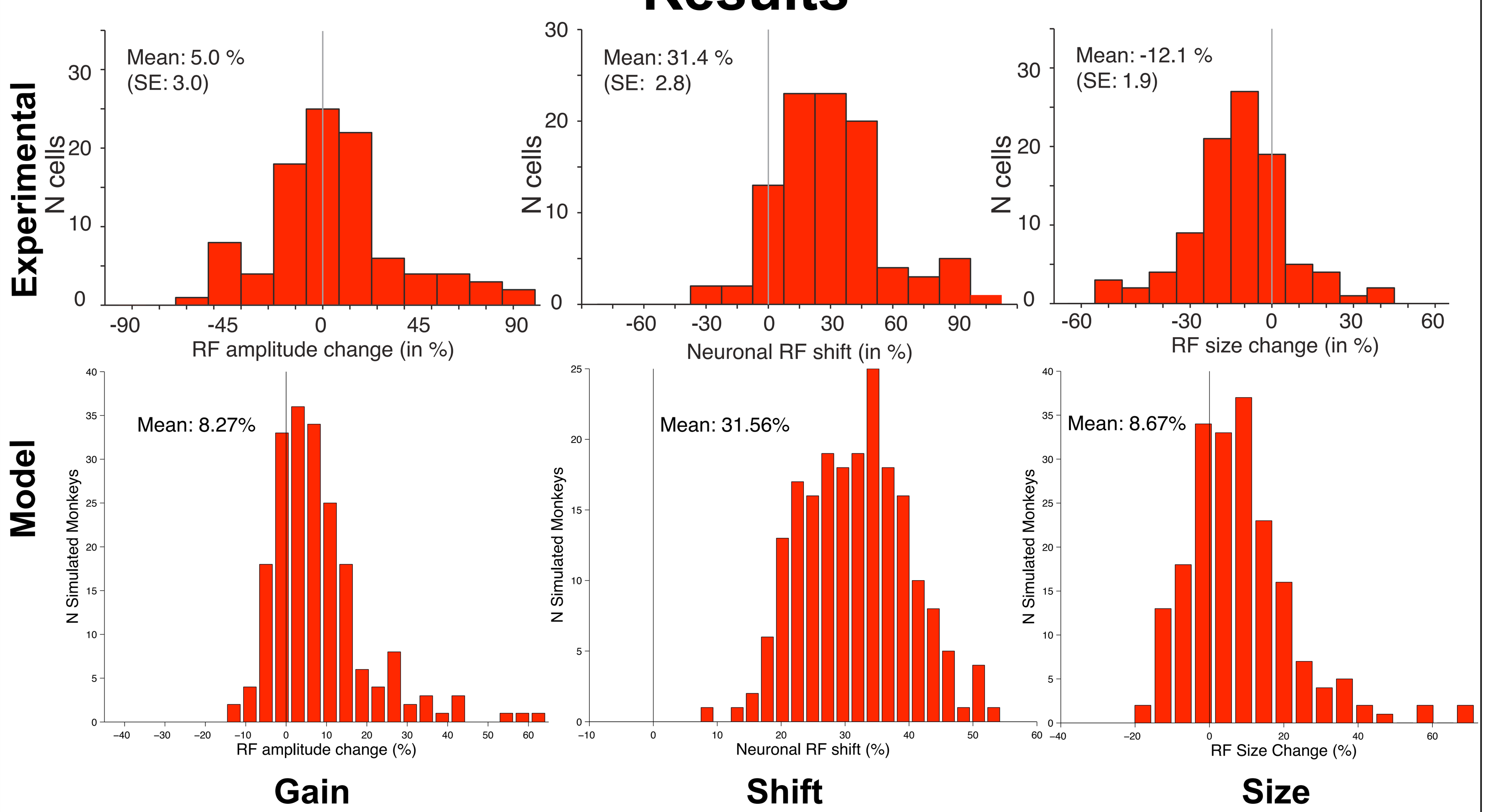


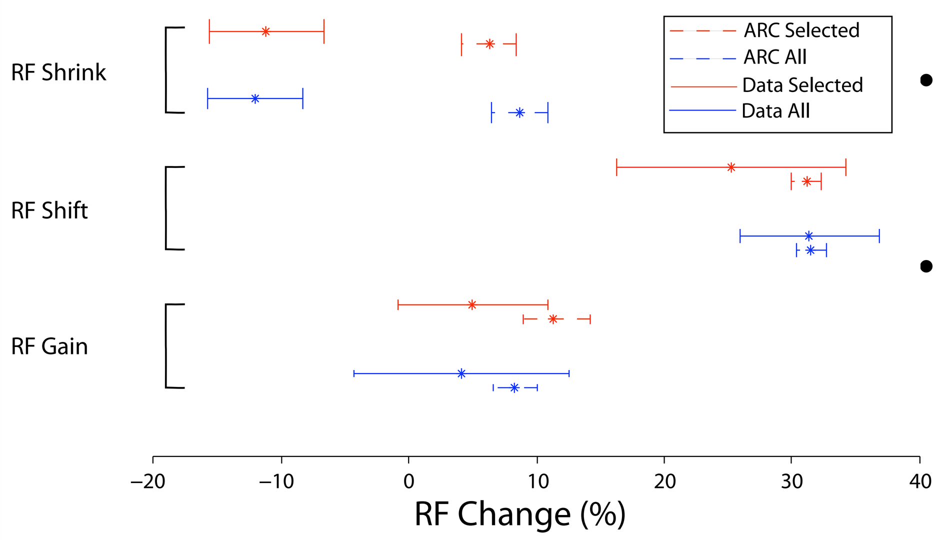
Simulations of Womelsdorf et al. (2008) [3]

- Recorded from MT neurons, compared attend-in and attend-out cases



Results





- Quantitively consistent for gain and shift, without fitting parameters to match data
- >30% of simulated monkeys exhibited RF shrink

Conclusions

- Our model suggests that RF shrink may be less common than suggested by the data, as RF expansion is predicted on average
- Model and experiment data are consistent for RF shift and gain changes
- Cells driven by visual and attentional inputs in layer IV may have nonlinear dendrites
- New methods for computing population-level functions with non-linear dendrites were employed

[1] Polsky et al. (2004) – Nat Neuro 7(6)
[2] Eliasmith and Anderson (2003) – Neural Engineering – MIT press
[3] Womelsdorf et al. (2008) – J. Neurosci 28(36)