MSTd-like response properties emerge from evolving STDP and homeostatic parameters in a Spiking Neural Network (SNN) model

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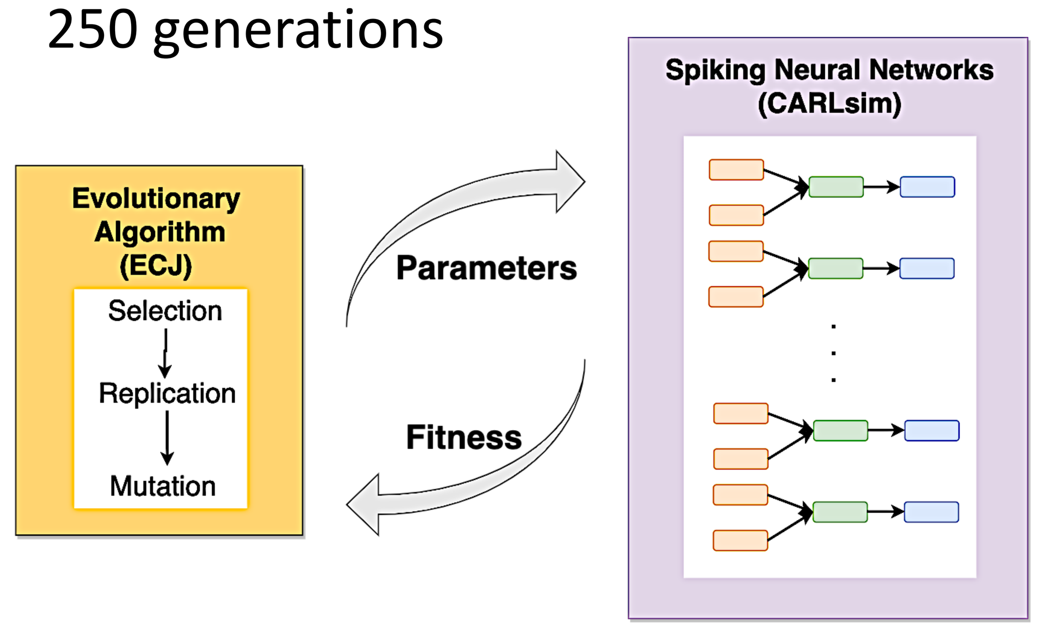
Introduction

- The dorsal part of the Medial Superior Temporal (MSTd) area plays a key role in visual motion processing.
- A previous study showed that 3D translation and rotation selectivity of MSTd emerged from applying non-Negative Matrix Factorization (NMF), a dimensionality reduction method, to MT activity patterns [1].
- Hypothesized that spike-timing dependent plasticity and homeostatic synaptic scaling (STDP-H) performs a similar function as NMF.
- Implemented a model of macaque MT and MSTd, with STDP-H in a neuroevolutionary paradigm [2].

Methods

Neuro-evolutionary paradigm

- Each generation: 15 individual networks
- 250 generations



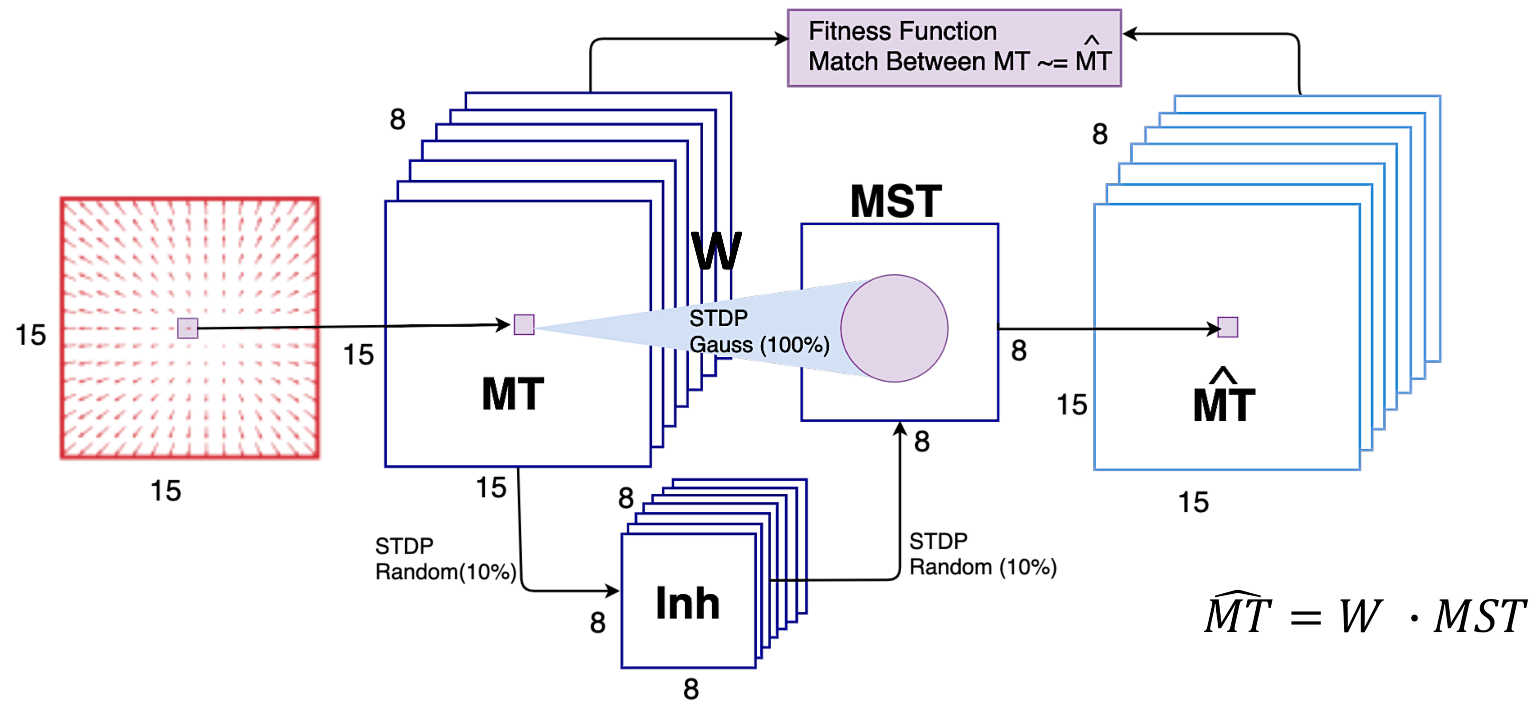
Objective function

$$y = \frac{1}{S}\sum_{i=1}^{S} corr(R_{MT_{(i)}}, (W \cdot R_{MST_{(i)}})) - L$$

(1) S: number of stimuli, $R_{(i)}$: group response to one stimulus
(2) S: number of MT neurons, $R_{(i)}$: response of one neuron to all stimuli

Network architecture

- 6000 flow fields (15x15 pixels): viewing conditions during locomotion (including translation and rotation)
- Randomly draw 400 for training, and 100 for testing
- MT: 1800 neurons, each tuned to 1 speed and 1 of 8 directions
- MST: 64 neurons



$$\widehat{MT} = W \cdot MST$$

STDP-H [3]

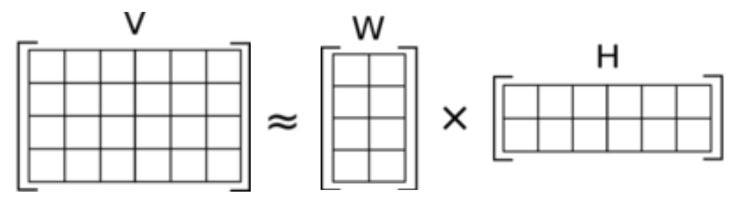
$$W_{LTP}(t) = A_{+}exp(-t/\tau_{+}) \text{ for t} > 0$$

$$W_{LTD}(t) = -A_{-}exp(t/\tau_{-}) \text{ for t} < 0$$

$$\frac{dw_{i,j}}{dt} = \left[\alpha \cdot w_{i,j}\left(1 - \frac{\bar{R}}{R_{\text{target}}}\right) + \beta\left(LTP_{i,j} + LTD_{i,j}\right)\right] \cdot K$$

$$K = \frac{\bar{R}}{T \cdot \left(1 + \left|1 - \bar{R}/R_{target}\right| \cdot \gamma\right)}$$

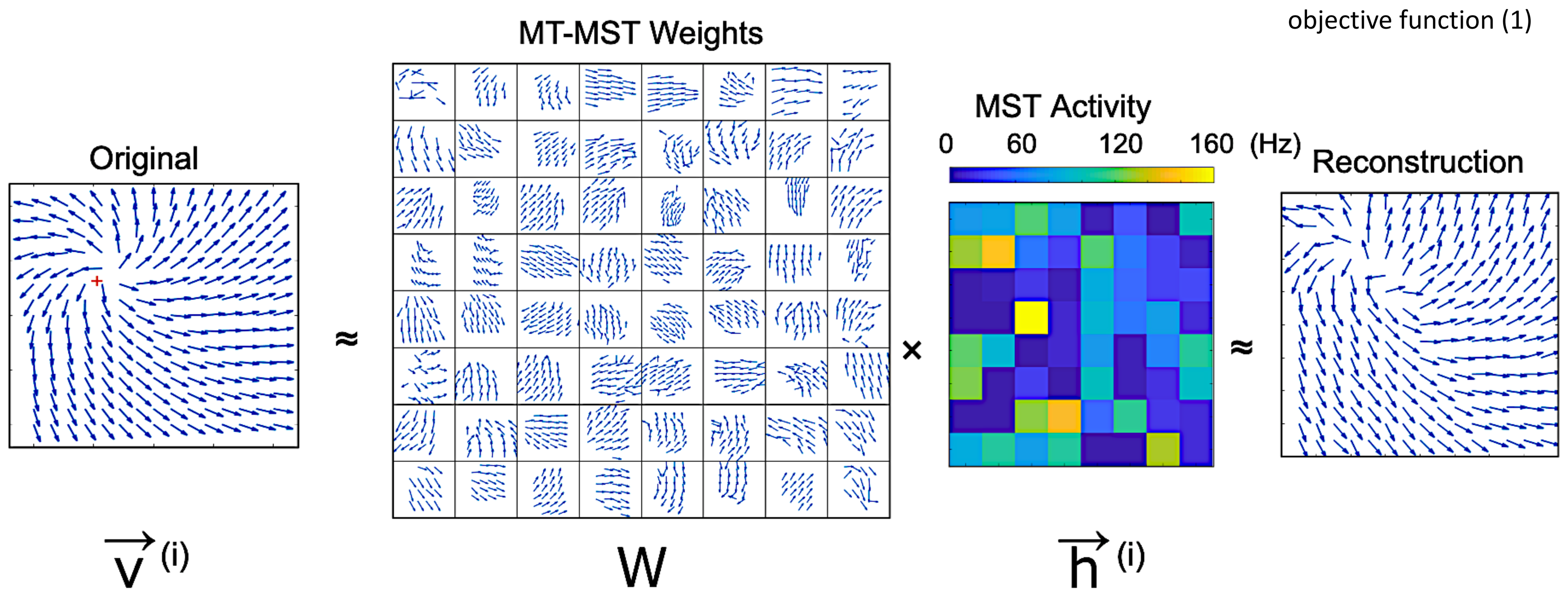
NMF



Results

Stimulus Reconstruction

objective function (1)



Encoding of perceptual variables

objective function (1)

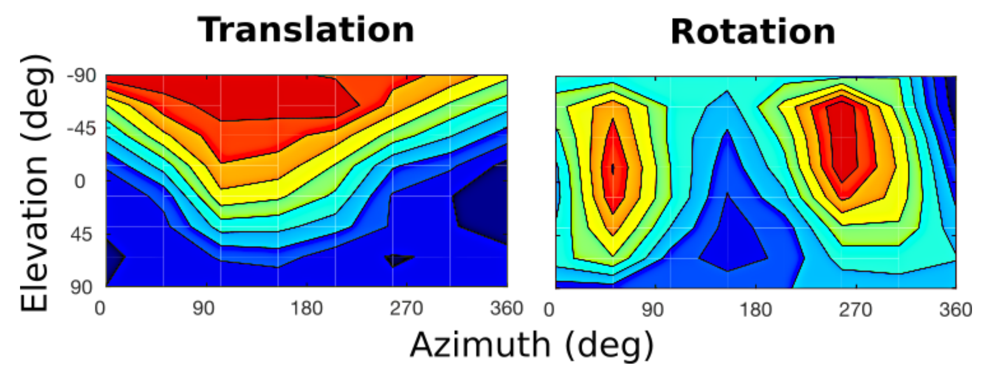
- Error between prediction and ground truth

	FOE (x,y)	Eye Velocity (ω_x, ω_z)
Macaque Monkey [4]	(3.62° ± 6.78°, 3.87° ± 4.96°)	(1.39° ± 3.69°, 1.38° ± 3.02°)
SNN Model	(2.26° ± 2.30°, 3.11° ± 2.91°)	(2.55° ± 2.18°, 3.26° ± 2.75°)

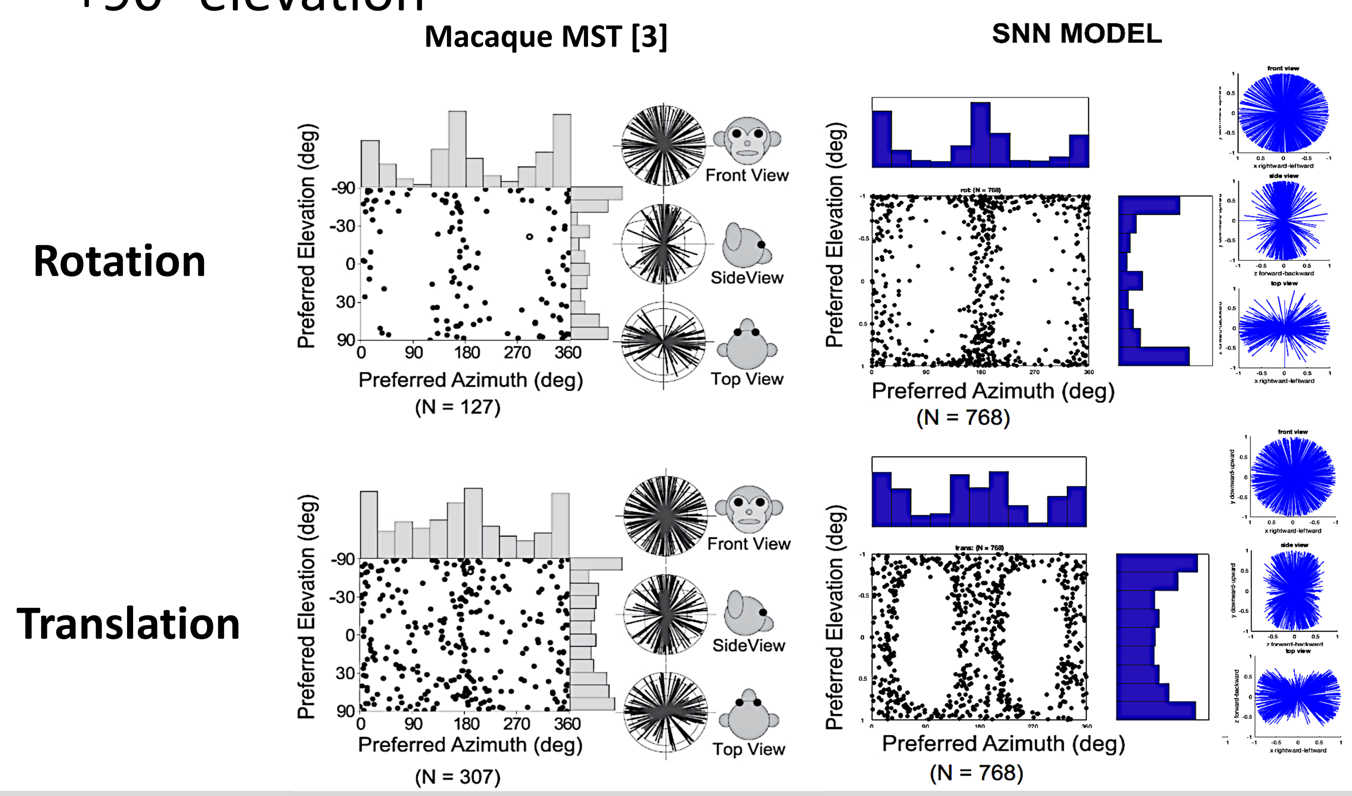
3D Direction Preferences for Trans. and Rot, from [3]

objective function (1)

- Example 3D direction tuning for an MSTd neuron in SNN

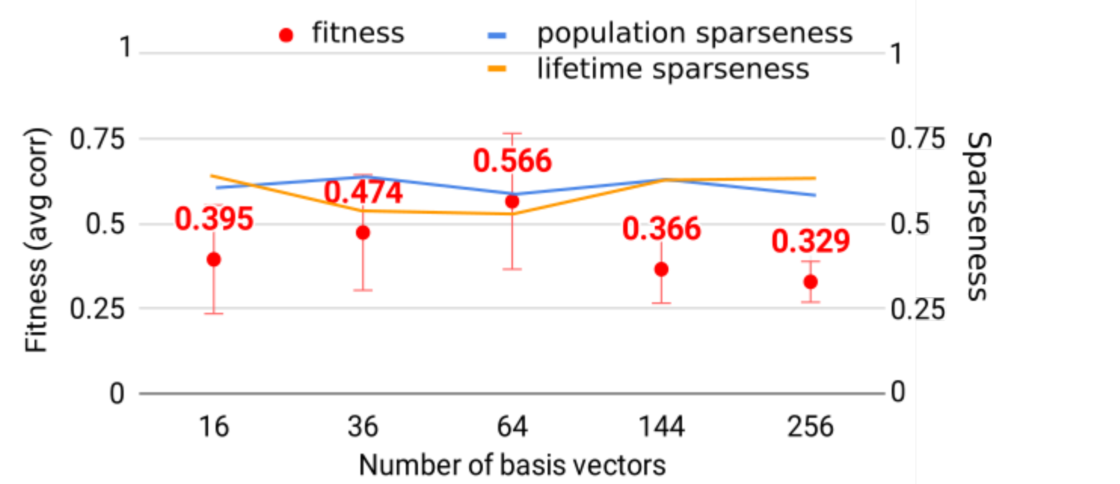


- Tightly clustered around 0 and 180° azimuth, -90° and +90° elevation



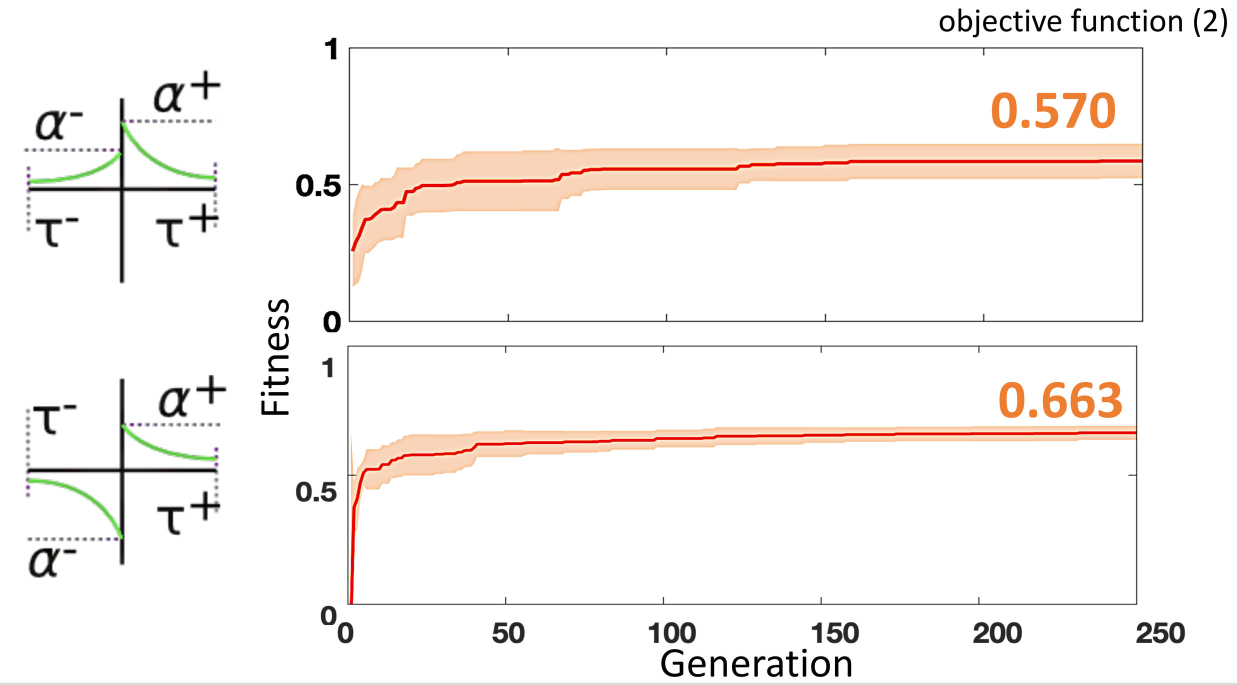
Number of basis vectors

objective function (1)



Different STDP curves (64BV)

objective function (2)



Conclusions

- MSTd has a sparse, reduced representation of the motion fields.
  - Population code was sparse in all cases, neither dense or local.
- STDP, together with homeostatic scaling may be performing dimensionality on inputs from area MT and other inputs to MSTd.
- STDP-H may be performing similar functions on other areas of the nervous system.

References

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