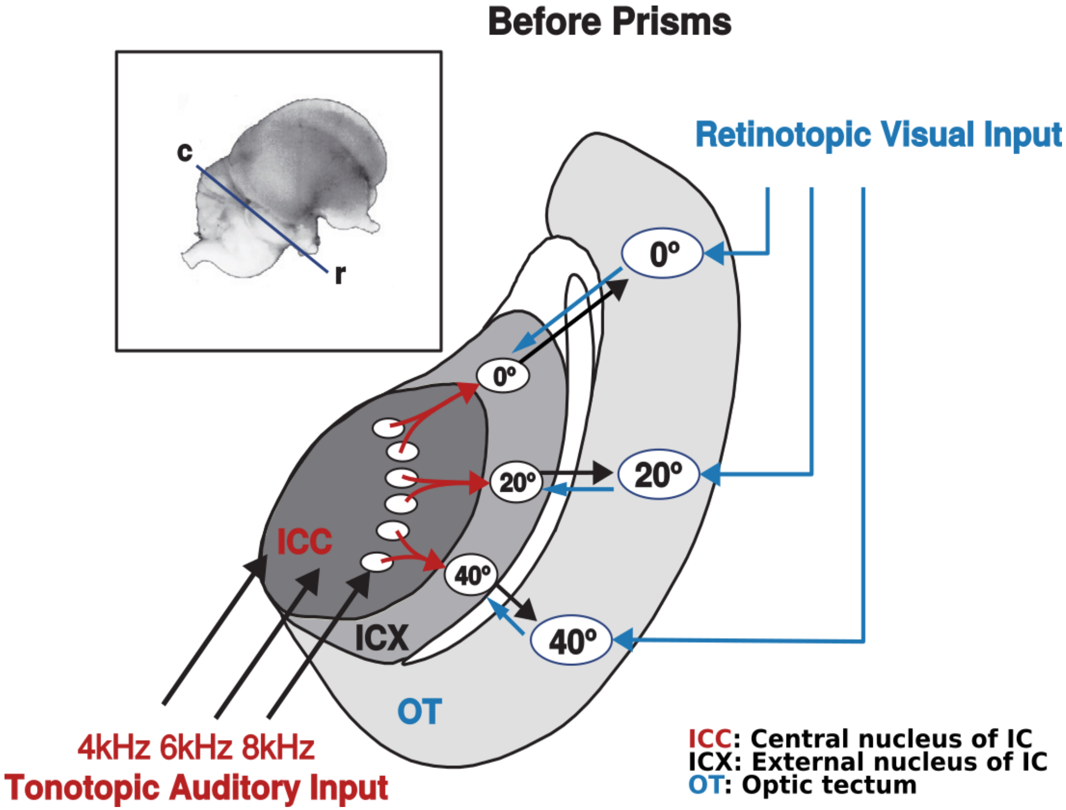
Computational Investigation of Visually Guided Learning of Spatially Aligned Auditory Maps in the Colliculus

Timo Oess, Marc O. Ernst, Heiko Neumann

Aligning Auditory Maps of Space

- Sensory receptor surface for auditory inputs is tonotopically organized.
- Spatial location of a sound source derived from computed binaural cues.
- Association between cues and spatial locations needs to be learned.

  ➜ Vision serves as a guidance signal



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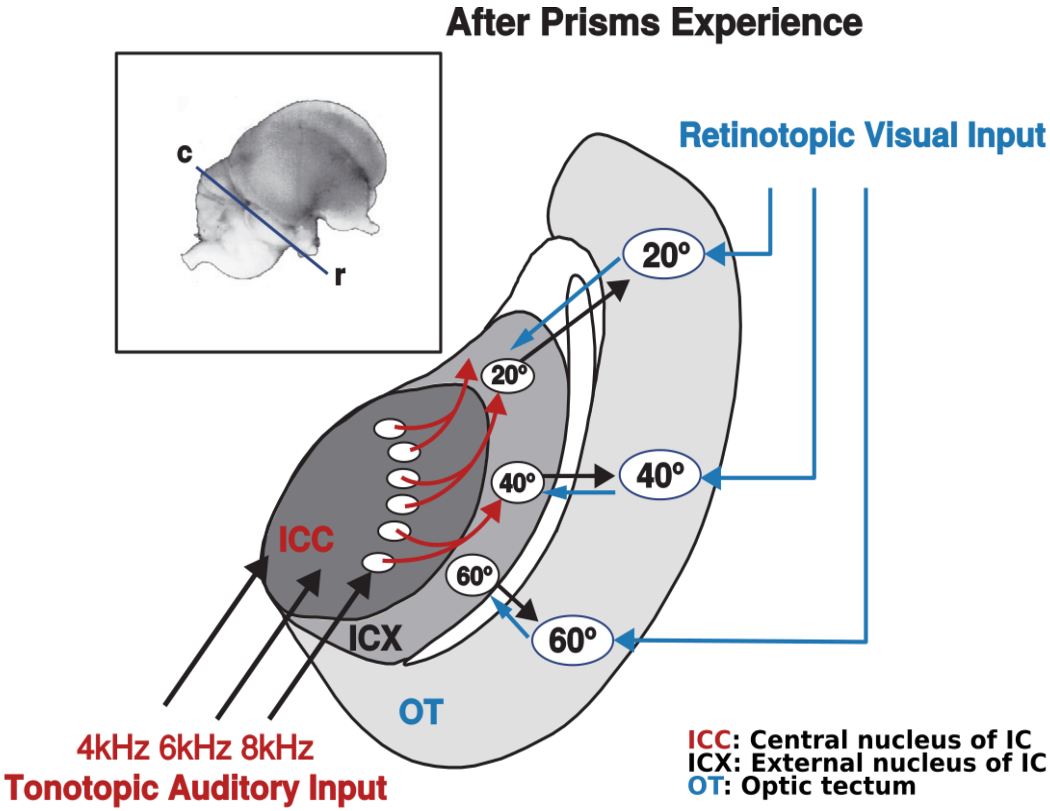

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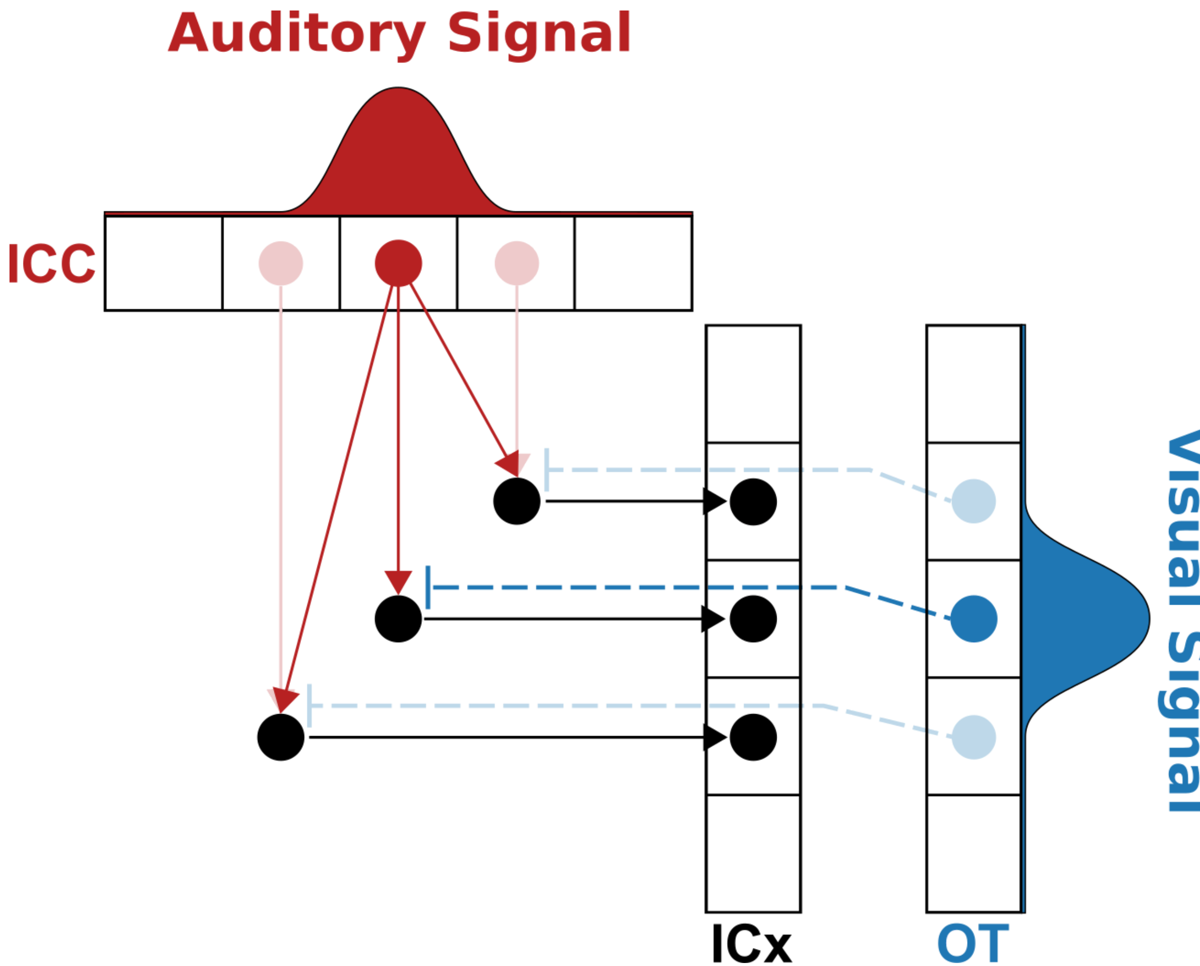
Model Implementation

- Conductance based neuron population:
- Randomly initiated connection creation.
- 3-Component-Learning-Rule *[Gerstner2018]*:



Gerstner et. al (2018) Frontiers in Neural Circuits
Oja, E (1989) International Journal of Neural Systems

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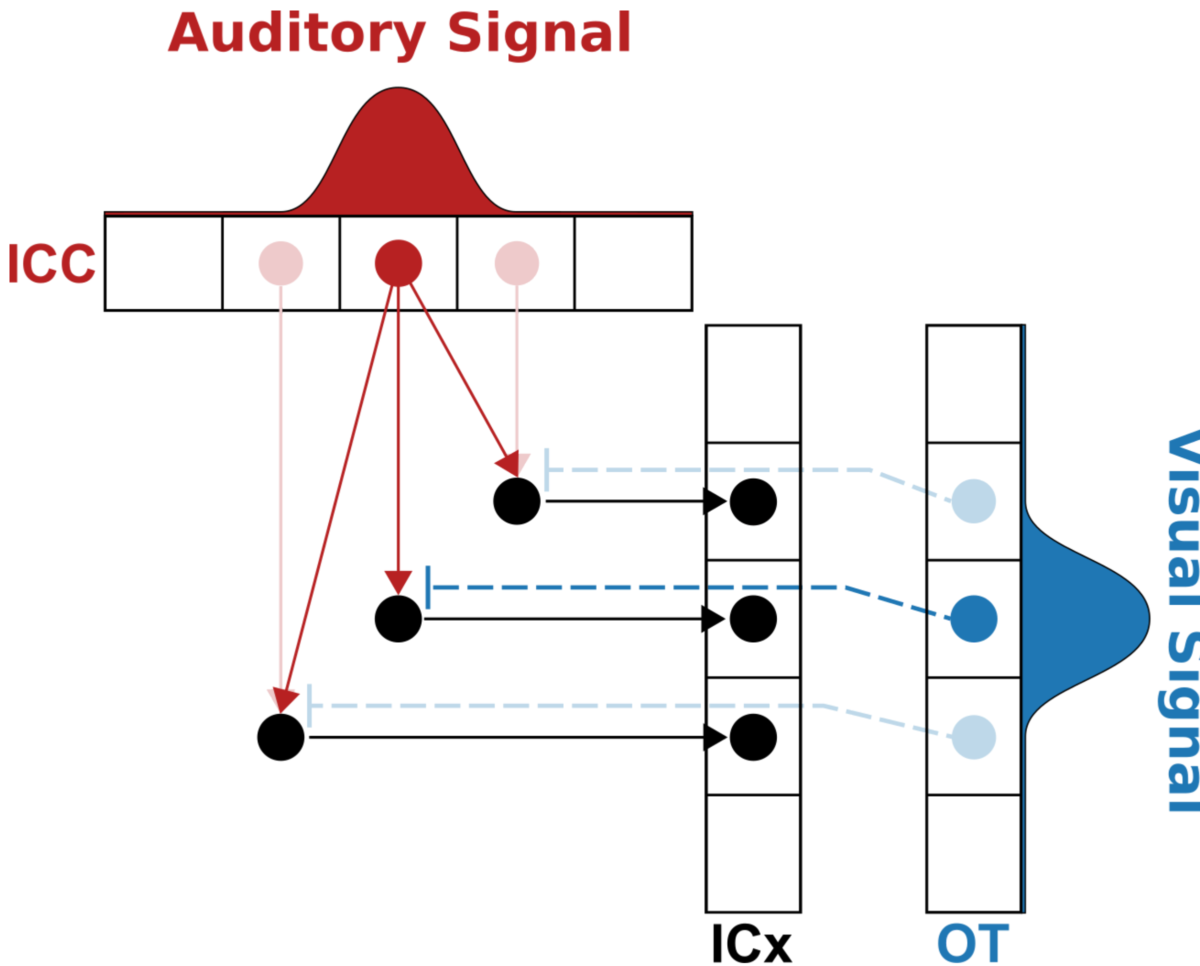

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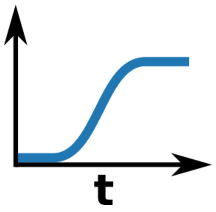

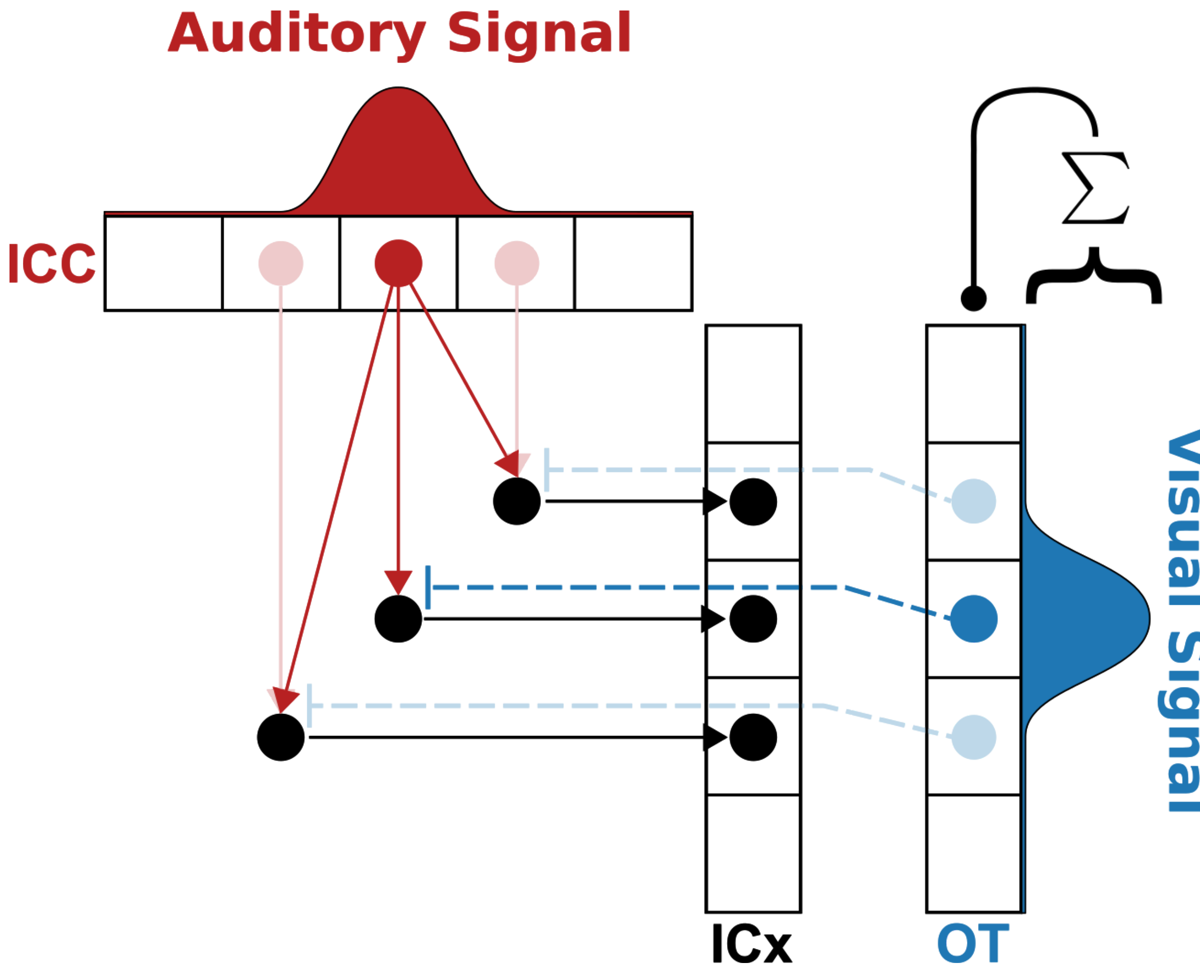

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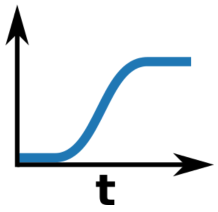

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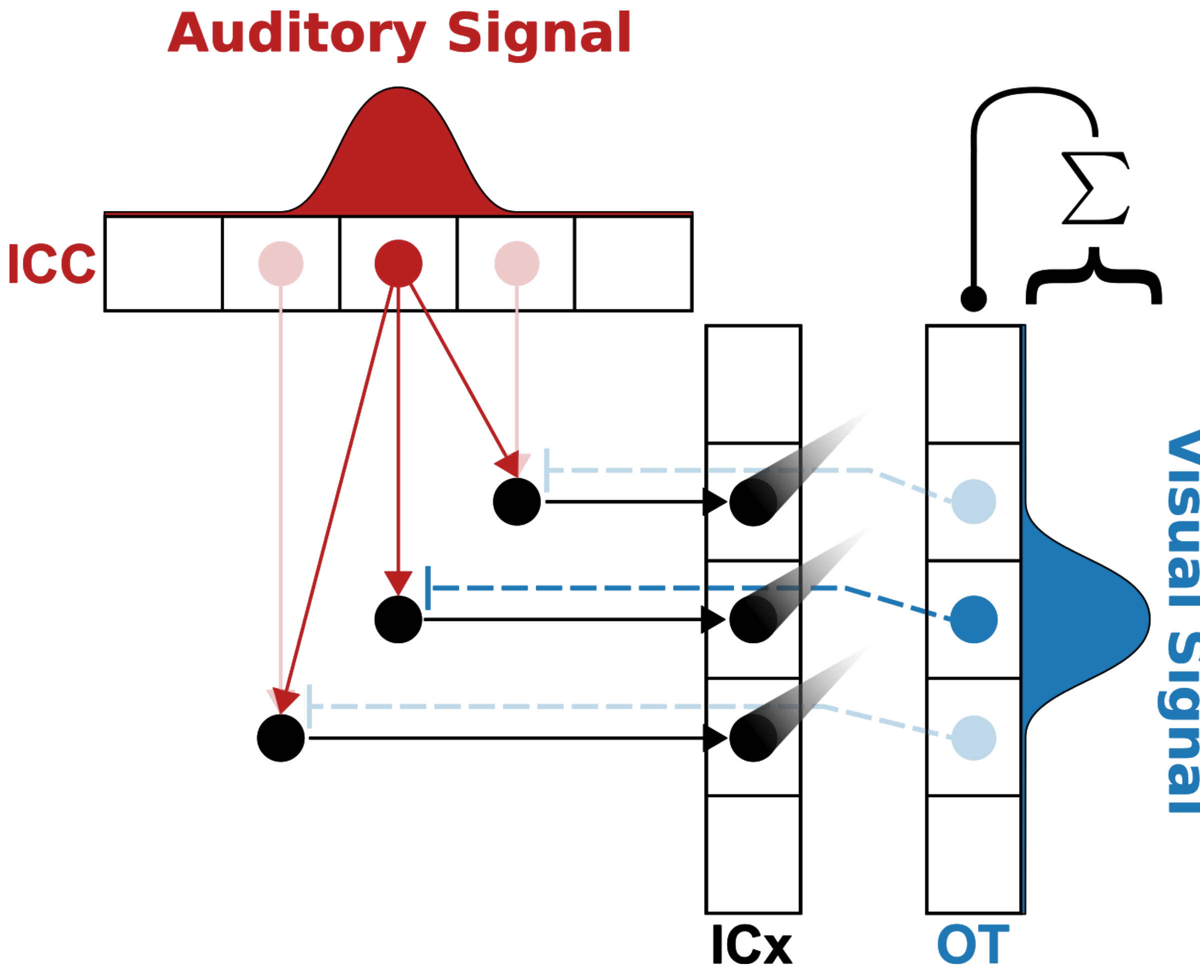

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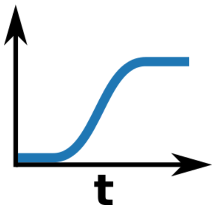

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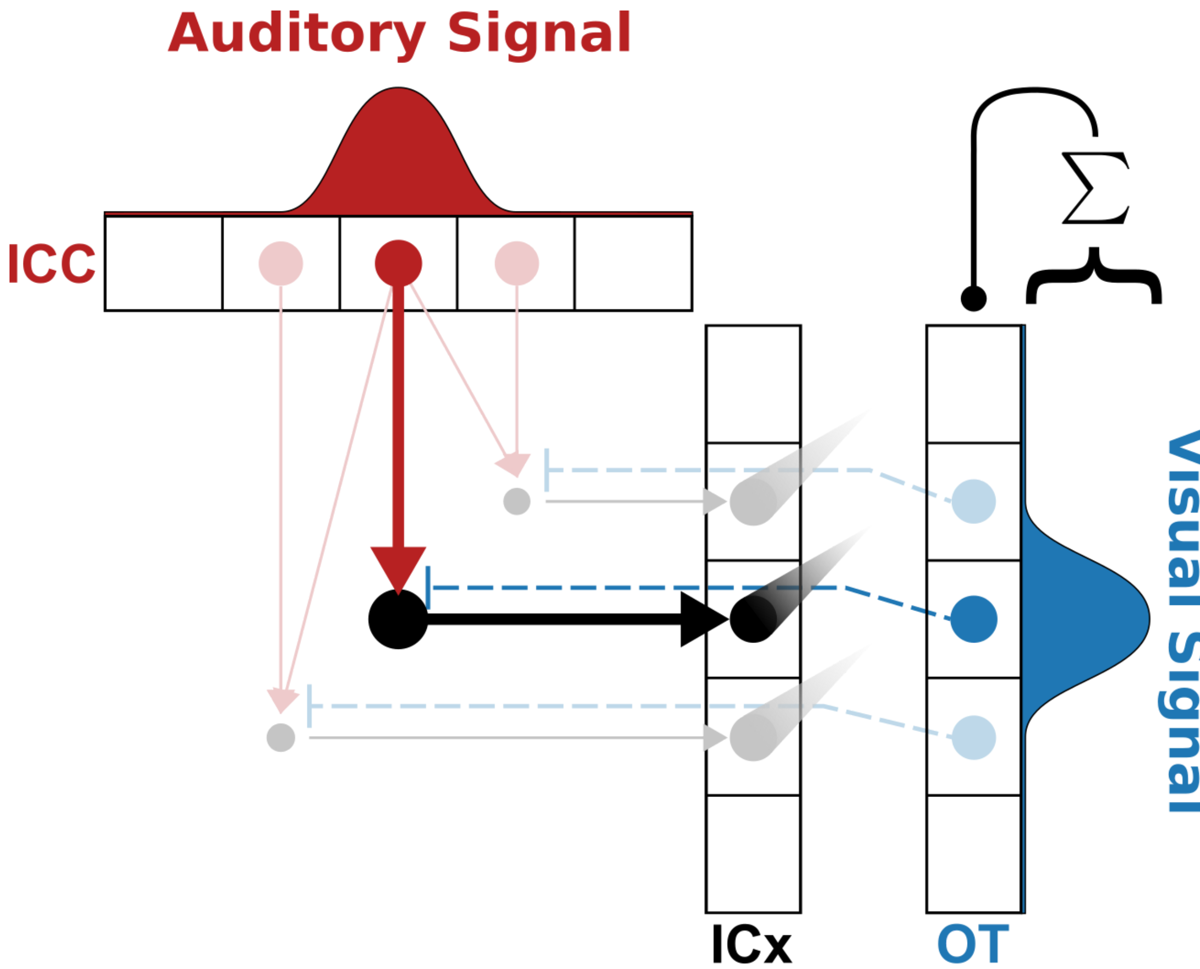

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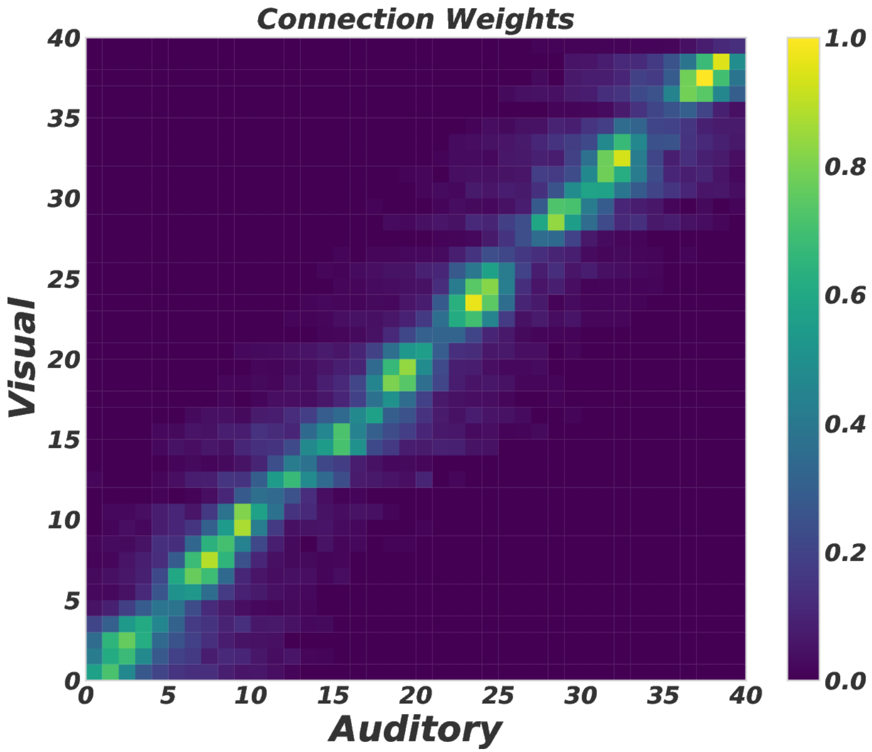
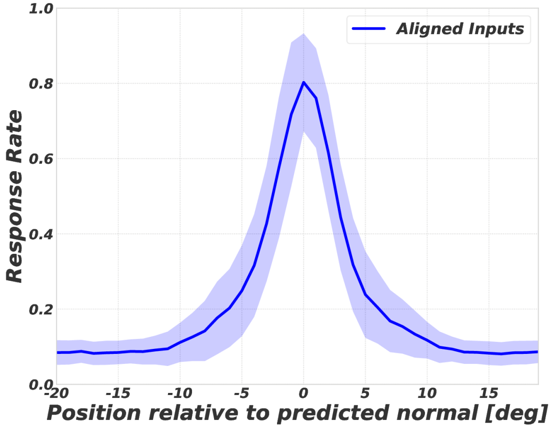
Results - Default Inputs

- Vision and audio inputs spatially aligned
- Temporal coincidence of stimuli
- Successful alignment of maps





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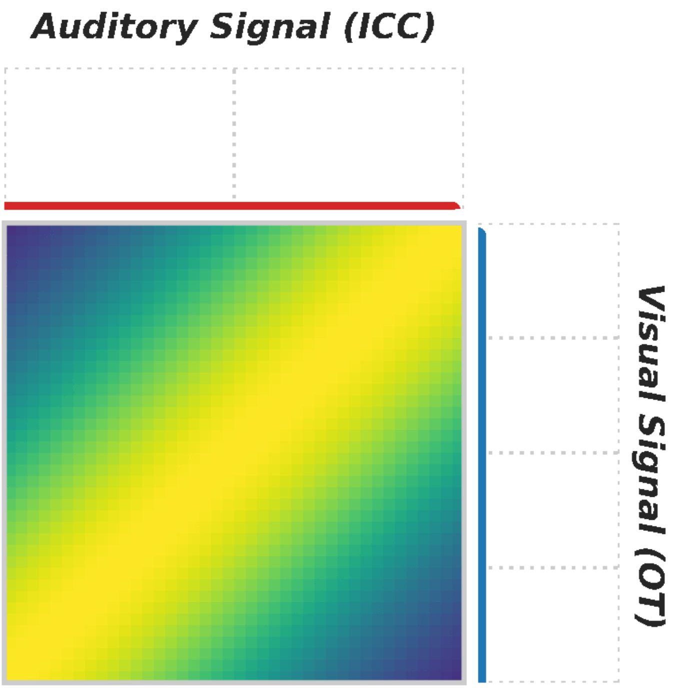
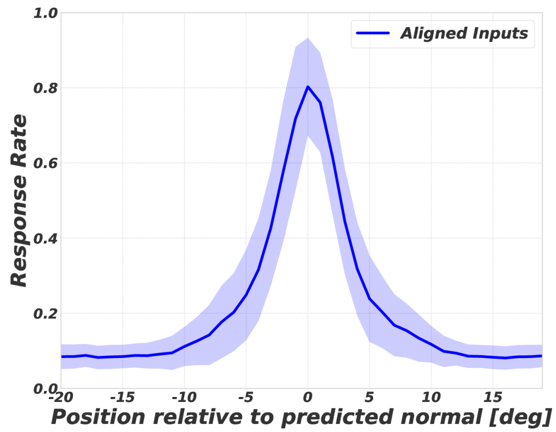
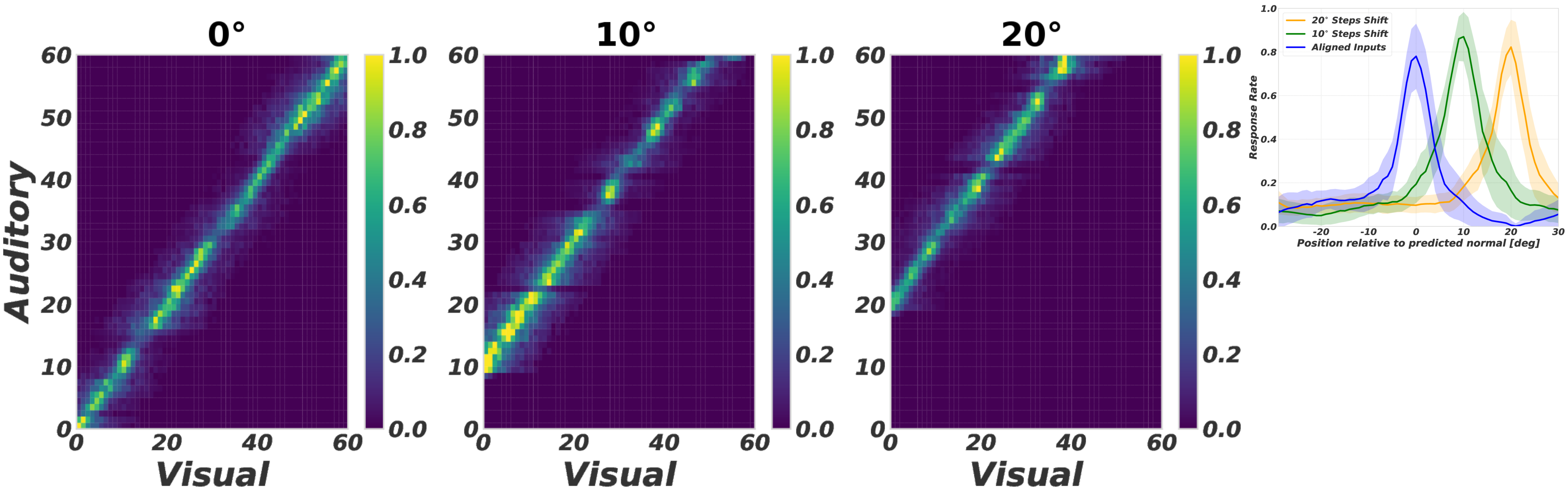




Results - Prismatic Shift during rearing

- Visual input is prismatically shifted with different offsets (Rearing barn owls with a prismatic shift *[Knudsen1989]*)
- Auditory map alignment shifts according to visual shift (0°, 10°, 20°)



Knudsen, E. I. and Knudsen, P. F. (1989) Journal of Neuroscience

Results - Prismatic Shift in Adult Owls

- “Incremental training increases the plasticity of the auditory space map in adult barn owls” *[Linkenhoker2002]*
- Single large prismatic (visual) shift does **not** induce a shift but unlearning. Shift of auditory map possible with incremental steps.

Single large shift

Incremental shifts

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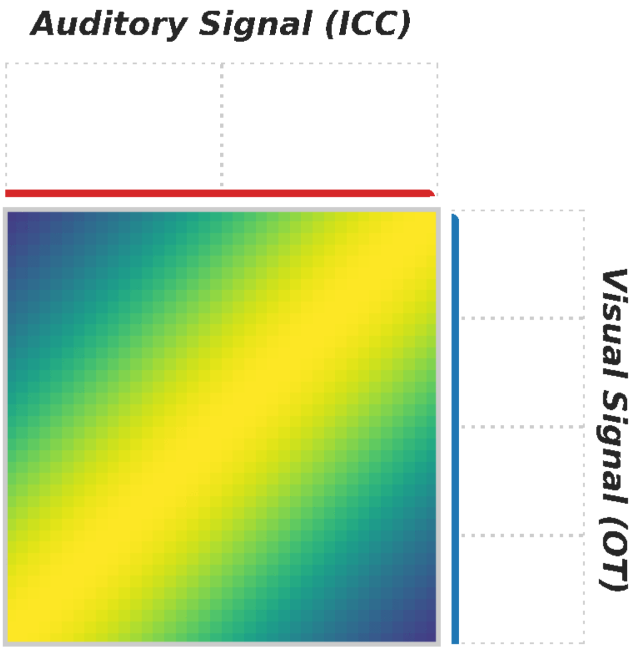

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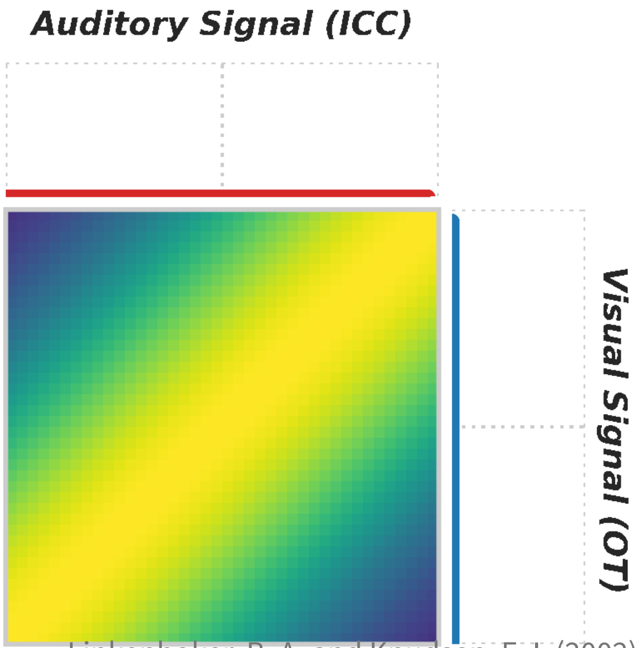

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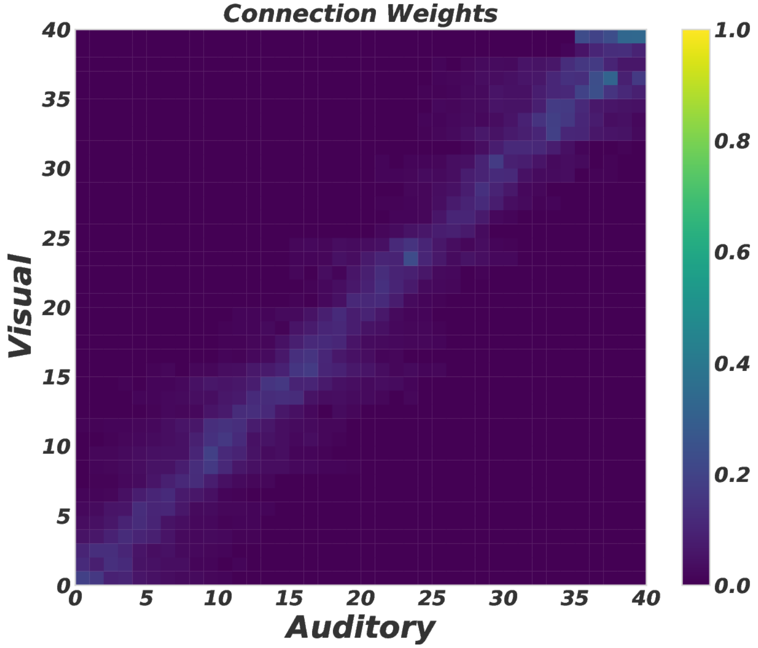

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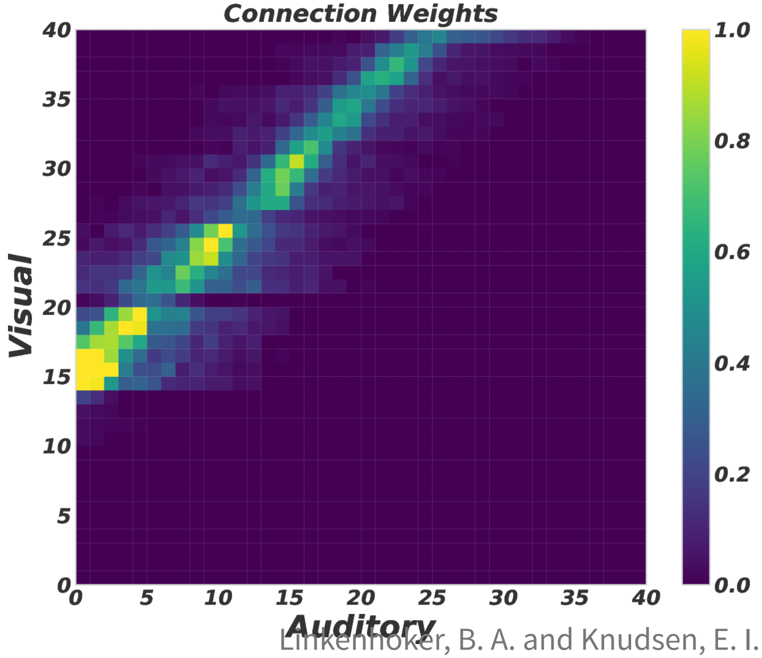

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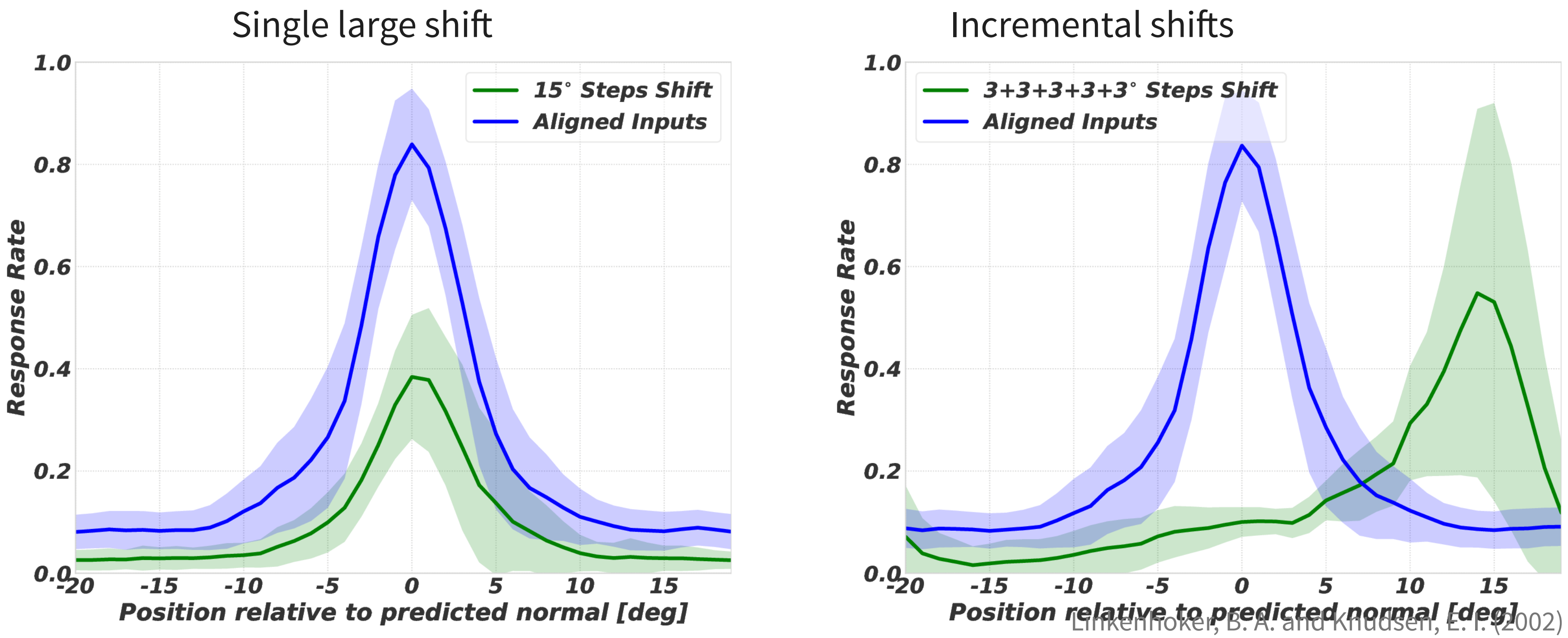

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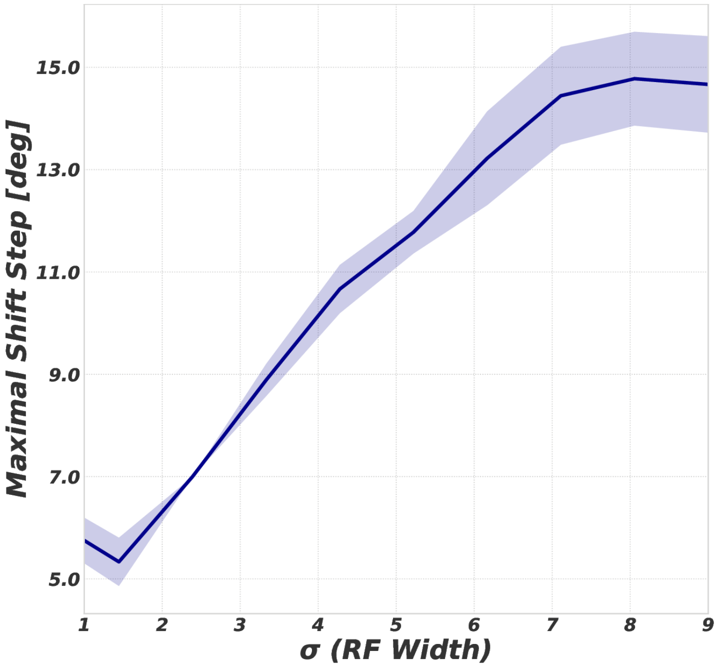
Results - Model Prediction

Ability to shift the alignment of the auditory map correlates with the receptive field size of the auditory map neurons.

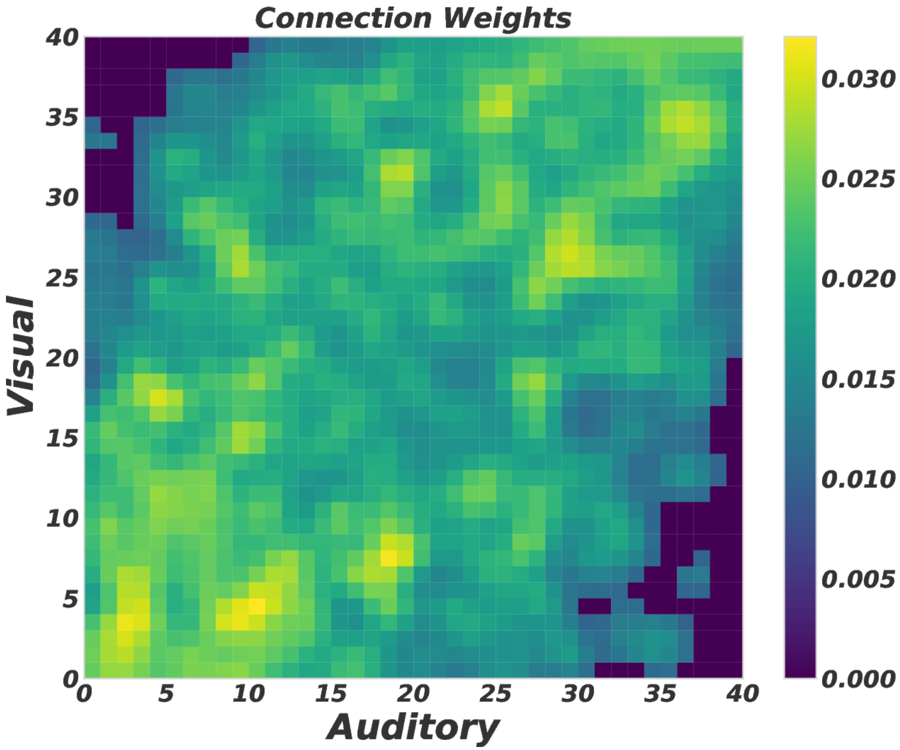
- Receptive field size large at learning onset
- Gradually shrinks until adult state is reached

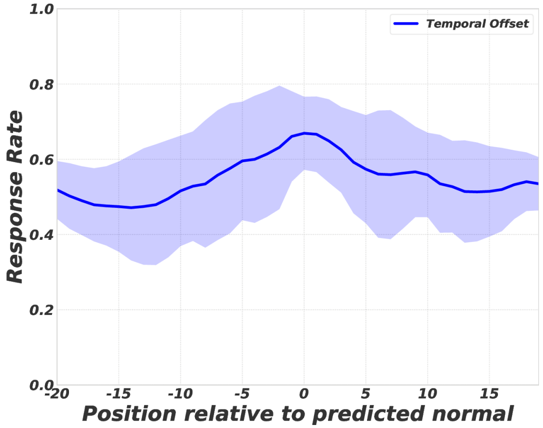
➜ Hypothesis: Relearning is only possible if shifted visual stimulus is still within receptive field of auditory neuron

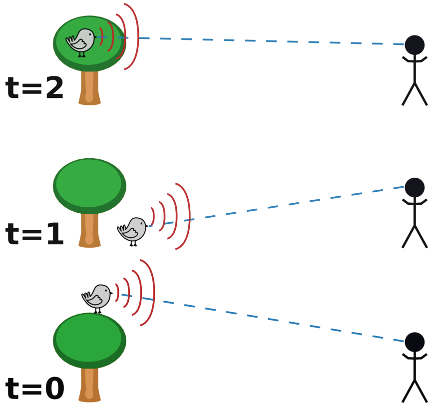


Results - Temporally Shifted Inputs (1/3)

- Visual and auditory inputs are temporally shifted
- Stimulus locations are randomly chosen from a uniform distribution
  ➜ **Low** autocorrelation of stimulus locations

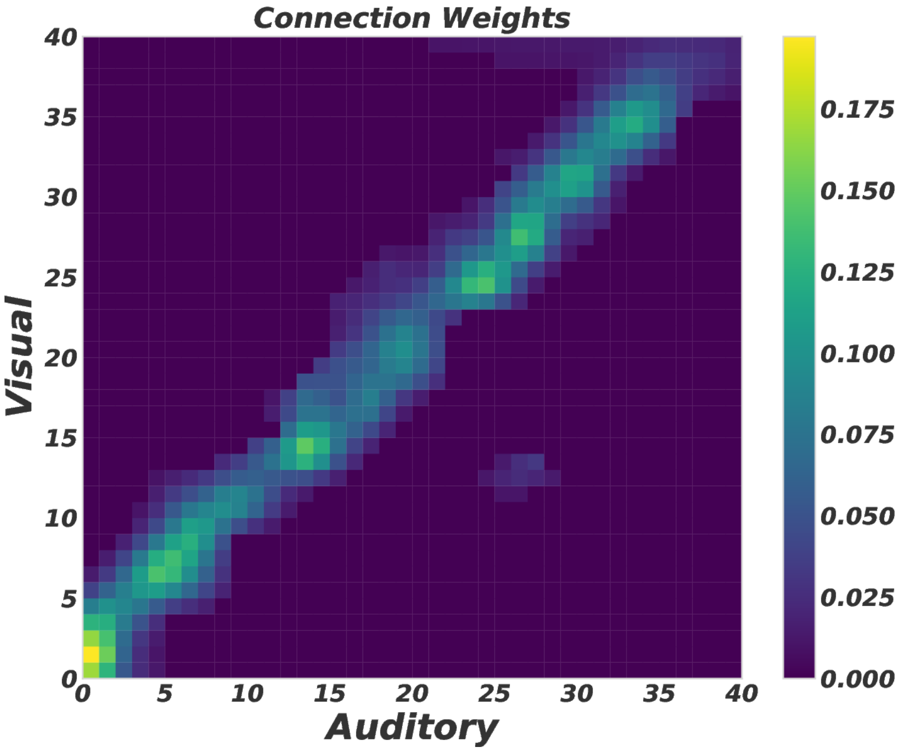


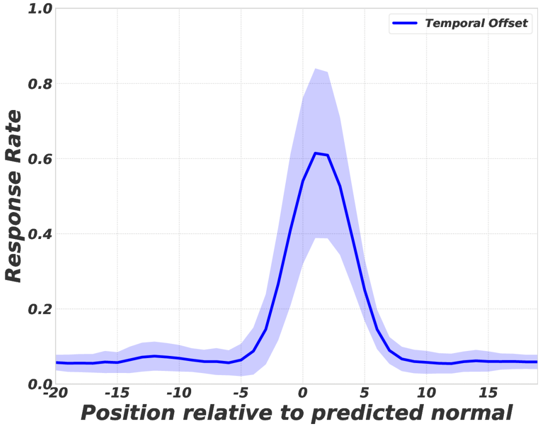


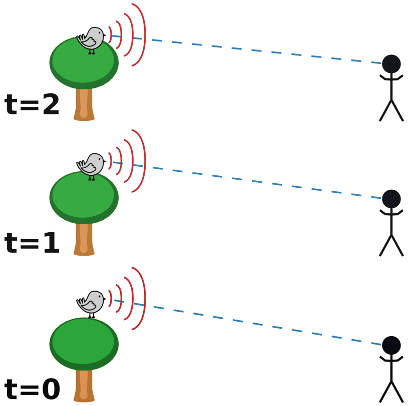


Results - Temporally Shifted Inputs (2/3)

- Visual and auditory inputs are temporally shifted
- Stimulus locations are randomly chosen from a Wiener process
  ➜ **High** autocorrelation of stimulus locations





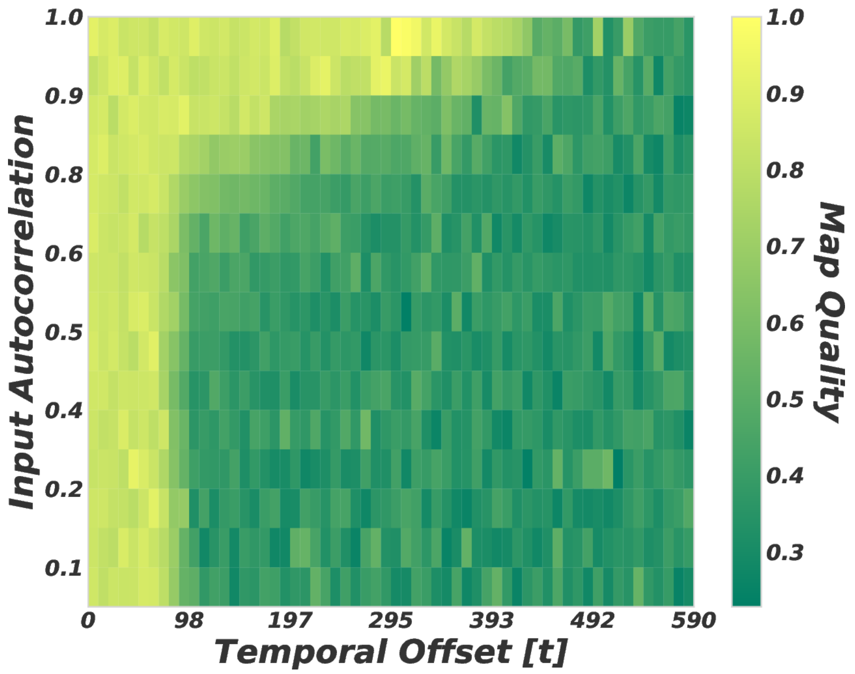


Results - Temporally Shifted Inputs (3/3)

Quality of map alignment depends on spatio-temporal correlation of inputs.

- Temporal coincidence is crucial for stimuli with low autocorrelation of stimulus locations
- Highly autocorrelated stimulus locations lead to successful map alignment even for large temporal offsets

➜ Learning depends on the spatial autocorrelation of the inputs

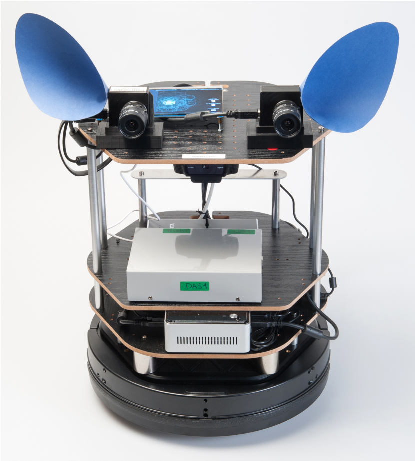


Conclusion

- Ability of shifting auditory map in adult animals depends on the receptive field size of auditory neurons.
  - Large Receptive Fields ➜ Large shifts are possible
  - Small Receptive Fields ➜ Small, gradual shifts are need

- Spatial autocorrelation of inputs
  - Temporal offset between stimuli effects learning
  - Map alignment is still possible for highly autocorrelated inputs

- Model allows flexible and stable map formation
  - Suitable for real-world application in mobile robots



Thank you

Model Implementation - Equations

- Conductance based neuron population of ICx:

  $\tau \dot{r}_j = -\alpha \cdot r_j + (\beta - r_j) \cdot \sum_{j=0}^{N} w_{ji} \cdot s_i^A$

- Randomly initiated connection creation.
- 3-Component-Learning-Rule *[Gerstner2018]*:

  $\Delta w_{ji} = \eta \cdot ((post_j(t) \cdot pre_i(t) \cdot fb_j(t) - stab_j(t))$

  with:

  $post_j(t) = \bar{r}_j(t)$

  $pre_i(t) = s_i^A$ (auditory input)

  - **Temporal Trace:**

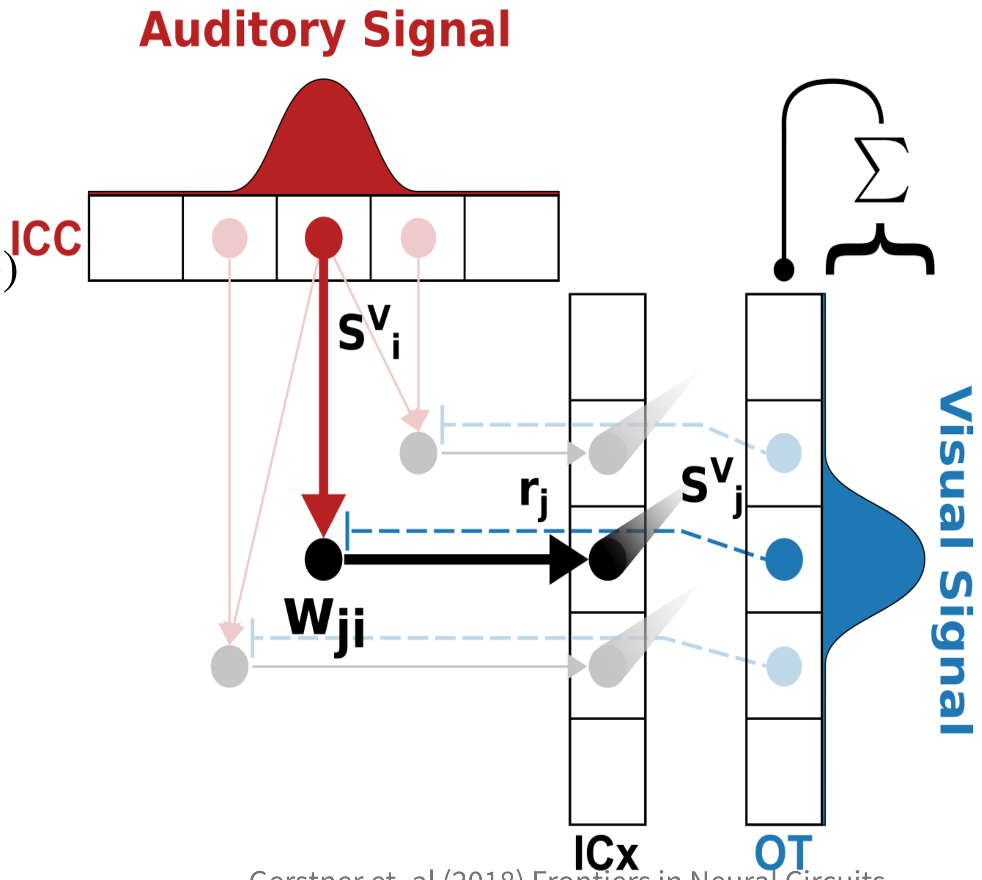
    $\bar{r}_j(t + \delta t) = (1 - \lambda) \cdot \bar{r}_j(t) + \lambda \cdot r_j(t)$

  - **Eligibility** (Controlled by Vision):

    $fb_j(t) = \hat{s}_j^V(t) \cdot E(t)$

  - **Stabilizer** (leads to *[Oja1989]*):

    $stab_j(t) = \bar{r}_j^2 \cdot w_{ji}$



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