# A Behavioral Model of Sensory Alignment in the Superficial and Deep Layers of the Superior Colliculus

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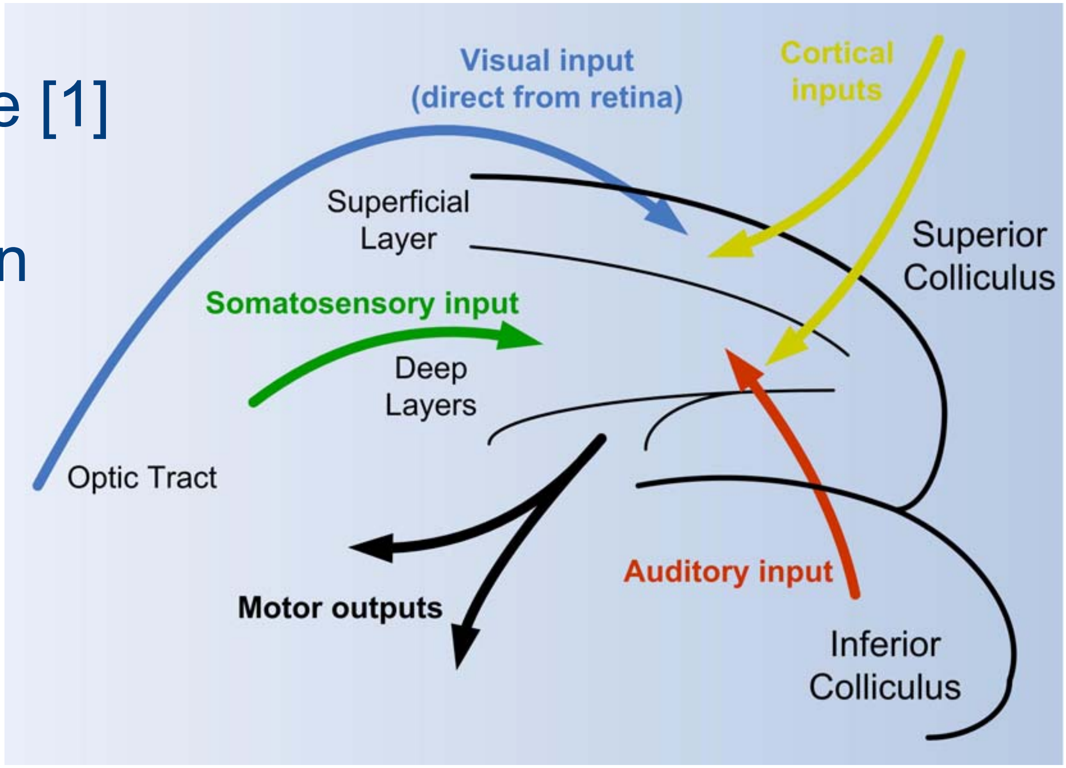
# Motivation

- Animals seamlessly fuse, process and act upon sensory information
  - Traditionally, sensory processing was thought to be done in isolation (unisensory)
  - It is now established that the senses are combined even during low-level processing [1-3] (multisensory)
  - Superior colliculus is key multisensory example
- What can we learn from this?
  - Can we construct models that can integrate different senses seamlessly?
  - Can we learn from how this is done to overcome limitations of computational paradigms (cf [4])?

# Superior Colliculus

- Laminated structure in the midbrain [2,5]
  - Combines visual, auditory and somatosensory stimuli
  - Sensory alignment of topographic maps (calibrated by vision [8])
- Forms a multisensory representation of space [1]
  - Causes gaze shift
- Multisensory integration
  - Enhancement and suppression [6]
  - Controlled by cortical feedback [2]



# Previous Models

- Physiologically motivated models focusing on saccades
  - Parallel pathways between SC and cerebellum [9]
  - Competitive combination of sensory and voluntary information [10]
  - Trajectory information encoded in outputs [12]
  - For antisaccades [11]
- Computationally motivated paradigms
  - Bayesian and perceptron models of enhancement and suppression [13]
- Grossberg et al [7] considered sensory alignment
  - Modelled output from burst and buildup neurons in the deep SC
  - Development of sensory alignment with visual and auditory inputs through associative learning

# Modelling the SC

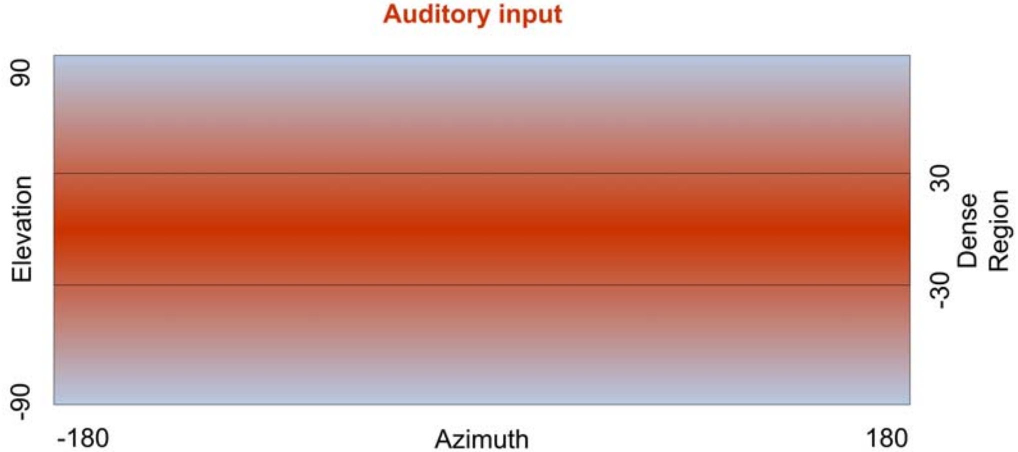
- Models so far:
  - Have focused on the deep SC layers and information encoded in the motor outputs
  - Grossberg et al [7] also considered sensory alignment
- Can we build a fuller model of the SC?
  - With superficial and deep layer topographic sensory maps?
  - Learning sensory alignment and multisensory integration?
  - What can we learn computationally from such a model?
- We present
  - A simple rate-coded model of the SC
  - Topographic maps to explore sensory alignment (SOMs [14])
  - Learning multisensory integration (Hebbian association [15])
  - Is such a simple model sufficient and capable?

# Approach

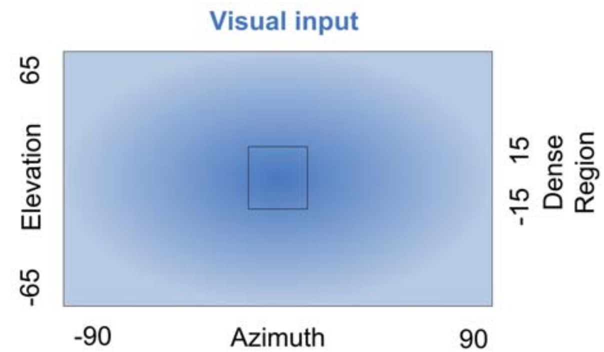
- Data representing a stimulus location in each modality
  - Gaussian activity patterns sampled at discrete points
  - Dense and non-dense regions of input (cf fovea)
- Topographic representations of visual and auditory space:
  - Kohonen's SOM [14]
  - Magnification factor to allow dense regions to occupy a greater proportion of the maps
- Sensory alignment
  - Association between visual and auditory map outputs achieved through Hebbian learning on multimodal training data
- Multisensory representation
  - Additive combination of auditory and (translated) visual map outputs

All experiments were carried out using Matlab (version 7.3.0.298) and the SOM Toolbox [19].

# Input Representation




Interval: 5°
Dimension: 37 x 73 (2701)
Non-dense: λ=0.5, σ=10
Dense: λ=1, σ=5

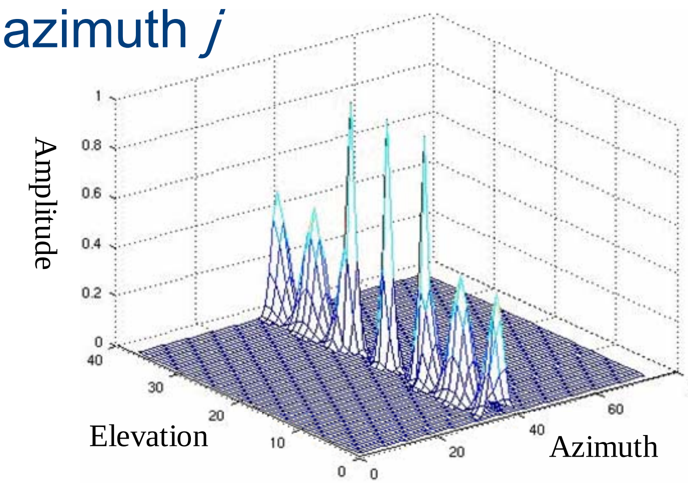



Interval: 5°
Dimension: 27 x 37 (999)
Non-dense: λ=0.5, σ=10
Dense: λ=1, σ=5

- Gaussian input *x* at elevation *i* and azimuth *j*

$$x_{ij} = \lambda e^{-\left(\frac{i^2 - j^2}{\sigma^2}\right)}$$

- Dense regions have greater amplitude and smaller bandwidth

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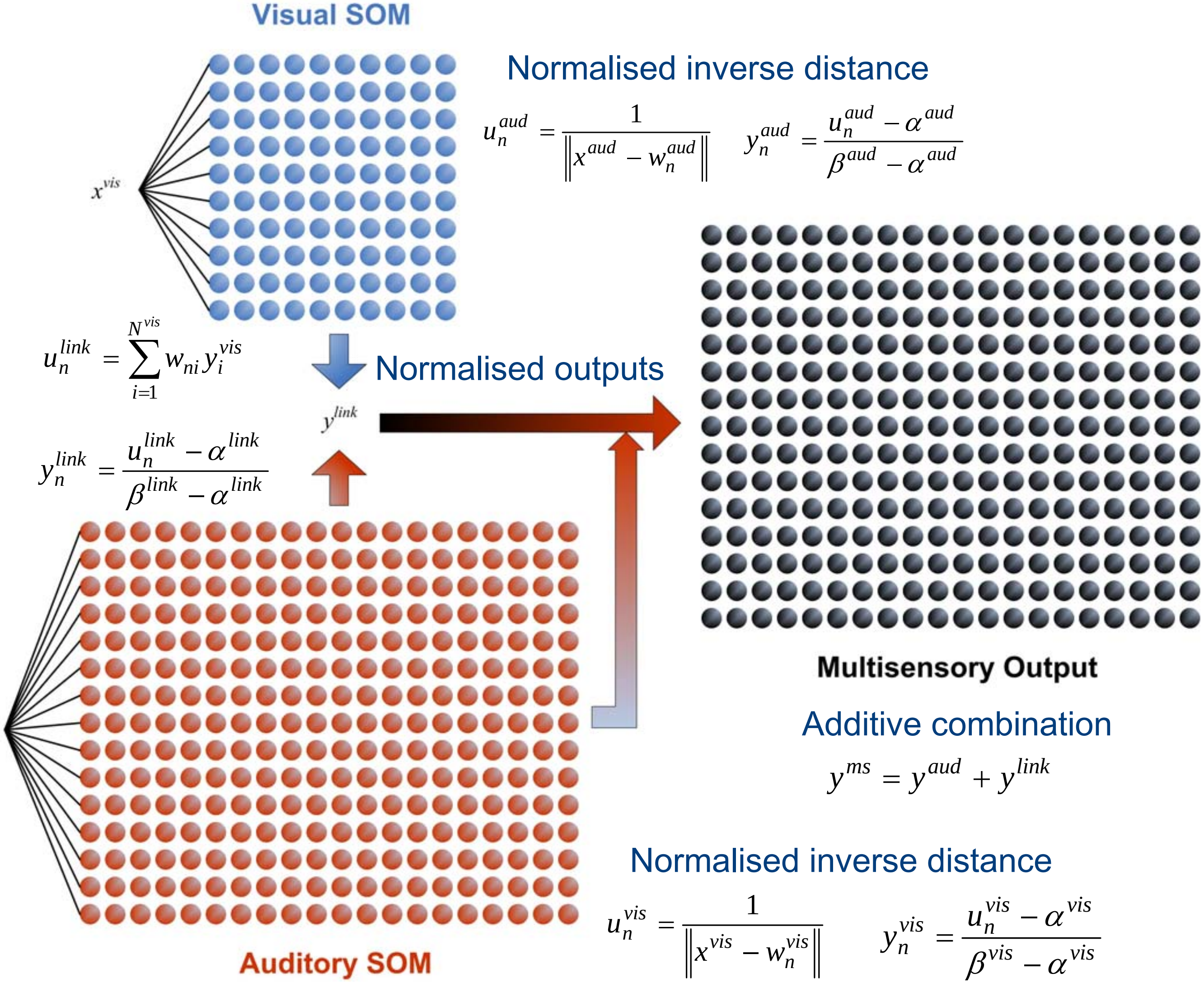
# Model

Map size: 10 x 10
Learning rate: Inverse
Value: Initial 0.5
Neighbourhood: Gaussian
Radius: Initial 10, final 1

Hebbian linkage: 100 (visual) to 300 (auditory)
Learning rate: Constant
Value: 0.1

Map size: 20 x 15
Learning rate: Inverse
Value: Initial 0.5
Neighbourhood: Gaussian
Radius: Initial 20, final 1




Normalised inverse distance

$$u_n^{aud} = \frac{1}{\left\| x^{aud} - w_n^{aud} \right\|} \qquad y_n^{aud} = \frac{u_n^{aud} - \alpha^{aud}}{\beta^{aud} - \alpha^{aud}}$$

$$u_n^{link} = \sum_{i=1}^{N^{vis}} w_{ni} y_i^{vis}$$

$$y_n^{link} = \frac{u_n^{link} - \alpha^{link}}{\beta^{link} - \alpha^{link}}$$

Additive combination

$$y^{ms} = y^{aud} + y^{link}$$

Normalised inverse distance

$$u_n^{vis} = \frac{1}{\left\| x^{vis} - w_n^{vis} \right\|} \qquad y_n^{vis} = \frac{u_n^{vis} - \alpha^{vis}}{\beta^{vis} - \alpha^{vis}}$$

Matlab source and experimental data files for this work can be found at http://www.cs.surrey.ac.uk/BIMA/People/M.Casey/software.html.

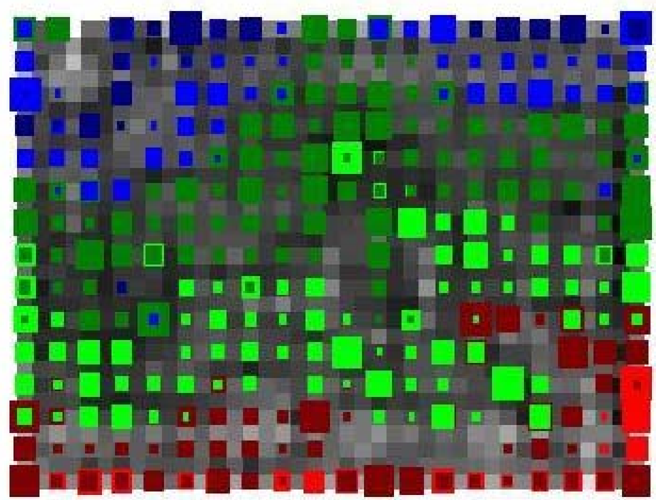
# Evaluation

- Unisensory training
  - To train the SOMs to establish topographic representations
  - Independent co-ordinate systems for auditory and visual spaces
  - Evaluate organisation of stimuli and proportion of map associated with dense regions
- Co-ordinate alignment
  - To train the Hebbian linkages between the visual and auditory (larger) spaces
  - Evaluate the ability of the links to translate coincident visual to auditory stimuli
- Multisensory integration
  - To combine the auditory and (translated) visual representations into a multisensory representation
  - Evaluate the strength of unisensory, multisensory (coincident and non-coincident) stimuli and compare with multisensory enhancement and suppression

# Experiments: Unisensory

Auditory SOM

[-90, 90],[-65, -30]
[-90, 90],[-29.9, -15]
[-90, 90],[-14.9, 0]
[-90, 90],[0.1, 15.9]
[-90, 90],[16, 30.9]
[-90, 90], [31, 65]

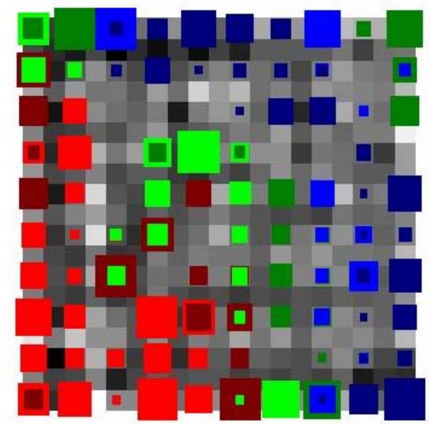


Training and testing data (separate sets)

| | |
|---|---|
| Selection: | Random locations (uniform) |
| Whole area: | 1675 |
| Dense region: | 825 (33%) |
| Total examples: | 2500 |

Trained for 1000 epochs

Visual SOM



[-180, 180],[-90, -65]
[-180, 180],[-64.9, -30]
[-180, 180],[-29.9, -1]
[-180, 180],[-0.9, 29]
[-180, 180],[30, 64.9]
[-180, 180],[65, 90]

Training and testing data (separate sets)

| | |
|---|---|
| Selection: | Random locations (uniform) |
| Whole area: | 810 |
| Dense region: | 90 (10%) |
| Total examples: | 900 |

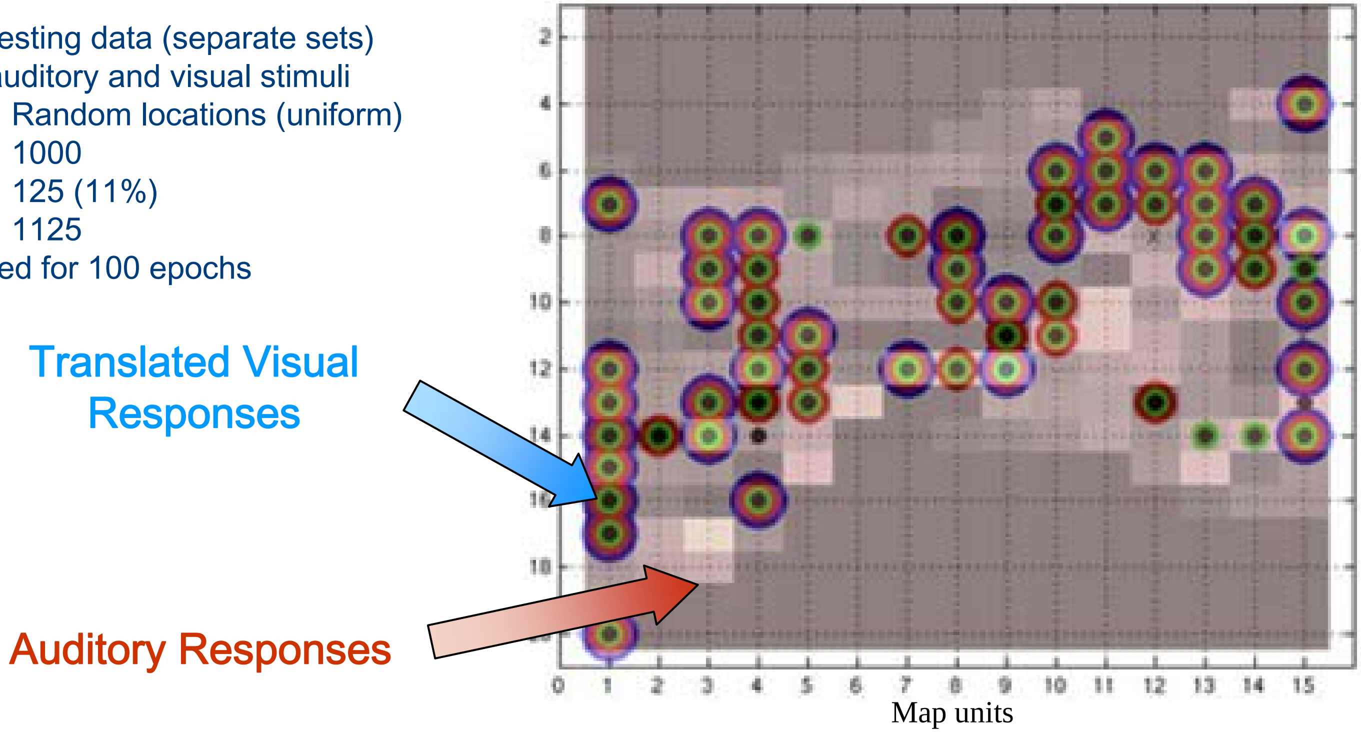
Trained for 1000 epochs

- U-matrix visualization overlaid with test best matching units
- Preservation the spatial relationships of their inputs (mostly)
- Auditory dense region covers 55% of the map (vs. 33% of the inputs)
- Visual dense region covers 26% of the map (vs. 1% input of the inputs)
- Greater representation of dense regions

# Experiments: Alignment

Training and testing data (separate sets)
Coincident auditory and visual stimuli

Selection: Random locations (uniform)
Whole area: 1000
Dense region: 125 (11%)
Total examples: 1125
Trained for 100 epochs




- Blue circles direct translation from visual to auditory output (27%)
- Red circles translation within a radius of 1 unit (62%)
- Green circles translation within a radius of 2 units (71%)
- Approximate alignment of visual to auditory representations

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# Experiments: Multisensory

Coincident | Non-coincident

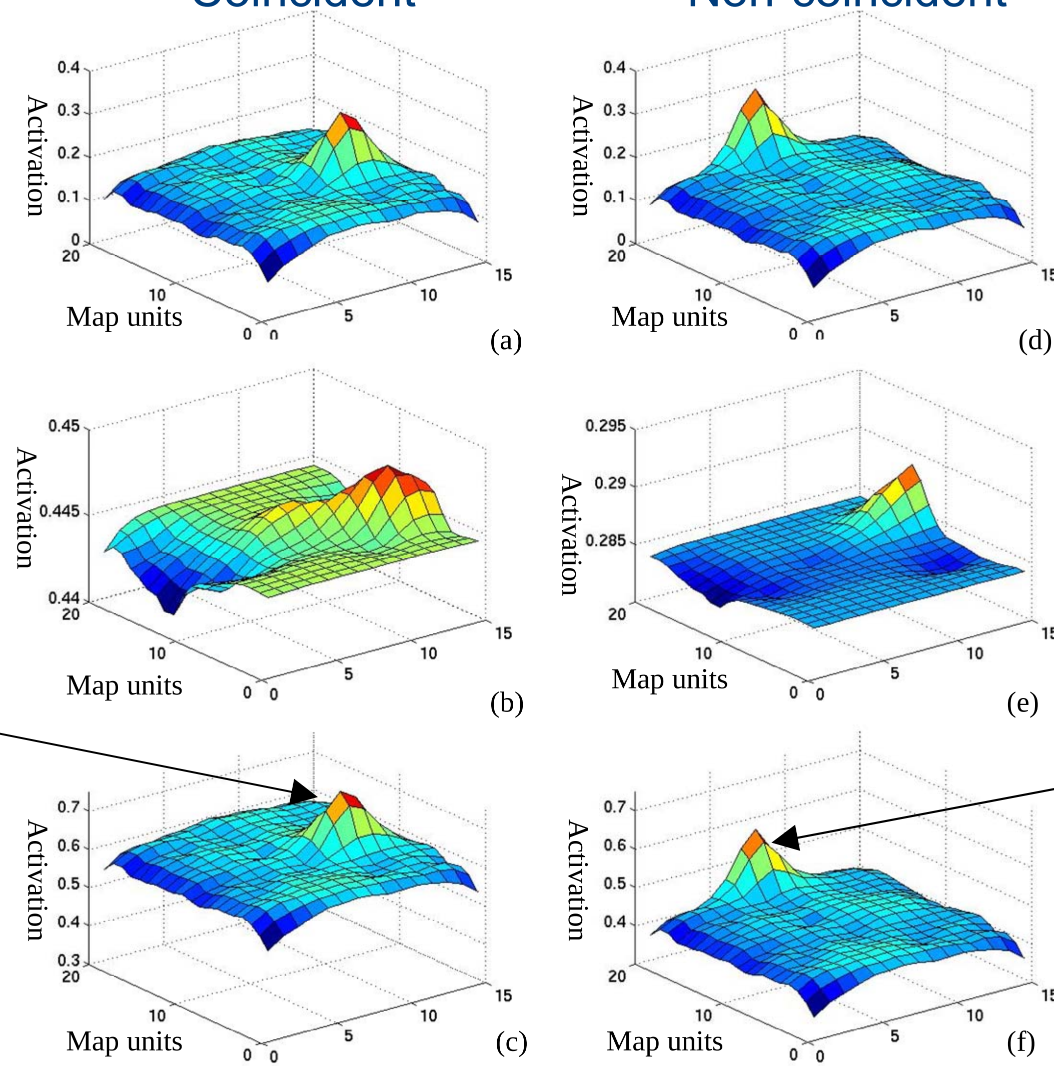
Auditory

Translated Visual

Multisensory

0.74 response: enhancement

0.57 response




# Conclusions

- Contributions:
  - Alignment: translating co-ordinate spaces
  - Integration: learnt by association
  - Simple multisensory enhancement [20]
  - Fuller model of the SC comparable to biology
  - Model sufficient for abstract inputs and low resolution
- Limitations:
  - Simplistic combination (additive) vs. physiological (logarithmic) [6]
  - No suppression (consider multiple single-modal stimuli)
  - No cortical feedback (implicit through association)
- Future work
  - Model cortical feedback explicitly
  - Build a larger scale model and use pre-processed images and sounds as input: repeat physiological experiments (pulse-coding?)
- Incrementally increase scale and complexity of models and embed them in real environments (for example robots)

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# Thank you

# Questions?

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