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])?
Modelling Sensory Alignment in the Superior Colliculus

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

- 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

\[ u_n^{\text{aud}} = \frac{1}{||x^{\text{aud}} - w_n^{\text{aud}}||} \]
\[ y_n^{\text{aud}} = \frac{u_n^{\text{aud}} - \alpha^{\text{aud}}}{\beta^{\text{aud}} - \alpha^{\text{aud}}} \]

Normalised outputs

Additive combination

\[ y^{\text{ms}} = y^{\text{aud}} + y^{\text{link}} \]

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

Training and testing data (separate sets)
Selection: Random locations (uniform)
Whole area: 1675
Dense region: 825 (33%)
Total examples: 2500
Trained for 1000 epochs

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
Experiments: Multisensory

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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