Illusory Conjunction and the sSoTS Model
Research Aims & Placement Objectives:

- Adapt sSoTS model to incorporate Feature Binding and Grouping
- Analyse the performance of the adapted model in the context of behavioural data from the Illusory Conjunction literature
- Do results provide insight into the question:
  - How is grouping and binding implemented in the visual system and what are its effects?
COMPLEXITY OF VISUAL STIMULI

Dimensions: Shape, Colour, Orientation
Features: Circle, Red, 45°
A BRIEF EXAMPLE

• Digits: 0 – 9

• Letters: T S N O X

• Colours: PINK, YELLOW, GREEN, BLUE, BROWN

• Treisman (1982)
Treisman & Schmidt (1982)

- Stimuli presented for 200 - 100ms (mean 120ms)
- Instructed not to guess but to report “only what they were fairly confident they had seen”

<table>
<thead>
<tr>
<th></th>
<th>Mean number reported per trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Item</td>
<td>0.52</td>
</tr>
<tr>
<td>Illusory Conjunction</td>
<td>0.39</td>
</tr>
</tbody>
</table>

- Conjunction errors significantly exceeded errors which combined one correct feature with one not present in the display
- Prinzmetal et al 1999; Gillbert & Humphreys, 2010

Conclusions:
- When attention is loaded subjects make conjunction errors in dimensions that include colour, shape, size and solidity
Treisman & Gelade (1980):

- Features processed in parallel, early and automatically
  - Behavioural & Physiological evidence
    - (Shepard, 1964; Garner, 1974; De Valois et al, 1975)

- Attention required to combine features correctly to form objects
  - Focal attention applied serially to stimulus locations
  - Features present at the same location are combined to form objects
    - Visual Search data: Feature vs Conjunction search (Treisman et al, 1977)

- Conjunction of features conjoined randomly unless:
  - Attended to
  - Top-down:
    - Contextual information
    - Past experience

- Biologically plausible, spiking-level neural network model of visual attention
- Attentional selection operates through biased competition

Mavritsaki et al (2011)

- Links single-cell to psychological data for visual attention
- Constrained by visual search data
  - Simulates:
    - Physiological studies of single-cell activity
    - Whole system behaviour in visual search
    - Break-down in performance following neural lesioning
    - Data from brain imaging
**Mavritsaki et al (2006)**

- **Stimulus Input**: Provided at 150Hz to corresponding pools
- **Feature Maps**: Record presence of features in the visual field (regions V2 - V4)
- **Noise**: Simulating input from other brain areas follows Poisson distribution, $\lambda = 3$ Hz

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**sSoTS: ARCHITECTURE**

- **Feature Maps**: Record presence of features in the visual field (regions V2 - V4)
- **Inhibitory & non-specific pools**: Ratio between inhibitory and excitatory neurons 20-80 same for all layers, derived from populations in the brain. (Rolls & Deco, 2002)
- **Location Map**: Activation relative to saliency of stimuli (Pulvinar (Shipp, 2004))

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**Stimulus**:

- **Stimulus Input**: Provided at 150Hz to corresponding pools
- **Feature Maps**: Record presence of features in the visual field (regions V2 - V4)
Deco & Rolls (2005)

Integrate & Fire Neurons

Synaptic Currents:
- NMDA, AMPA, GABA

Frequency Adaptation mechanism
- Based on Ca\(^{2+}\) sensitive K\(^+\) current
- Inhibits activation as Ca\(^{2+}\) concentration increases

Spiking-level neurons complex and computationally expensive
- Mean Field Approximation allows modelling of large numbers of integrate and fire neurons
- Deco & Rolls (2005); Brunel & Wang (2001)
Spiking-level neurons complex and computationally expensive

Mean Field Approximation:

- Deco & Rolls (2005); Brunel & Wang (2001)
- Allows modelling of large numbers of integrate and fire neurons
- Grouped into populations who share statistical similarity
- Activity of group represented by distribution of neural spikes
  - Assumption = Network stays in stationary state

\[
\begin{align*}
\tau_x \frac{dV(t)}{dt} &= -V(t) + \mu_x + \sigma_x \sqrt{\tau_x} \eta(t) \\
\tau_{Ca} \frac{d[Ca^{2+}]}{dt} &= -[Ca^{2+}]_x + a \tau_{Ca} v_x
\end{align*}
\]
Feature Binding:

- Features processed in separate cortical areas

- Features across differing dimensions are bound if they inhabit the same spatial location within the visual stimulus
  - Binding: Association between location and corresponding features
  - Tales et al (2002); Gillebert & Humphreys (2010)

- High levels of noise may lead to incorrect binding of features to location
  - Reduced stimulus exposure leads to impoverished input signal
  - Errors in feature binding may produce greater incidents
**Perceptual Grouping:**

- Duncan (1995)
  - Elements with shared feature can be selected or rejected as a group

- => increased activation selected group

- Increased activation in grouped items may lead to binding errors, which in turn may result in increased Illusory Conjunction error
GROUPING IMPLEMENTATION

Activation of pool within feature map breaches Grouping threshold

Is there another pool within the same feature map that has breached the Grouping threshold?

No

Yes

Increase excitatory connections in both directions between flagged pools

Feature Map

Grouping Threshold = 4Hz

Background sSoTS Adaptation Study Results Discussion
Activation of pool within feature map breaches Binding threshold

Is the same position in the location map already bound

No

Does another pool exist associated with the same position yet in a different feature dimension that has also breached the binding threshold

Yes

Increase feedback location map to corresponding pools

Binding Threshold = 4Hz
**Study**

- **Simulation**
  - Simulation:
    - Stimulus Onset
    - Stimulus Removed
    - Time (ms):
      - 0
      - 100
      - 300 / 350 / 400 (Baseline 2000)
      - 2000

- **Stimuli**
  - Different (dif):
    - HA
  - Same Colour (sc):
    - HA
  - Same Shape (ss):
    - HH

- **100 trials per condition**
An item was identified in either position 3 or 4 in all trials, for all displays and for both models.

- An item is said to be identified when the contrast between its activation and that of its distractors reaches a 60% threshold.
  - Attention Index: Luce (1959, 1977)

**BASELINE: SUCCESS RATE**

- Different (dif)
- Same Colour (sc)
- Same Shape (ss)
Features conjoined in identified items

- **Grouping & Binding: OFF**
  - Correct Features Conjoined: 93%
  - Illusory Conjunction: 1%

- **Grouping & Binding: ON**
  - Correct Features Conjoined: 96%
  - Illusory Conjunction: 1%

Grouping & Binding lead to an increase in correctly identified items across all conditions and a single increase in Illusory Conjunction errors in the same colour condition.
- Grouping & Binding Model is quicker to identify items.
- Both models identify items slower when there is no similarity between objects displayed.
**BASELINE: AVERAGE ACTIVATION**

- **Average activation across entire trial**
  - Charts display average activation for ‘different’ condition, **blue** map

- **OFF**
  - [Graph showing average activation for OFF condition]
  - **Peak = 2.5Hz**

- **ON**
  - [Graph showing average activation for ON condition]
  - **Peak = 5Hz**

**Characteristics common to all maps:**

- Increase in peak activation
- Exaggerated function:
  - steeper rate of increase and decline in activation
- Activation similar until approx. 400ms
- Activation returns to similar levels by approx. 950ms
BASELINE: SPIKE RATE

- Spike rate in first 1000ms
  - for ‘Same Shape’ condition, trial 75, H Map

- OFF
  - 0 - 300ms: Both models show similar activity
  - 275ms: Pool 3 bound to Green Map
  - 300ms: Grouping initiated between pool 3 and 4
  - 450ms: Pool 4 bound to Blue Map

- ON
  - Thresholds Breached 275-300ms
**BASELINE: SPIKE RATE**

- Spike rate in first 1000ms
  - for ‘Same Shape’ condition, trial 75, **Location** Map

**OFF**

- 0-400ms: Models show similar activity

**ON**

- 500–600ms: Effects of grouping in H map between position 3 and 4 present
- 650-850ms: Binding causes increased activation in position 4
  - Effect also present in trial in which grouping is not active
  - Binding effect effects accumulative, therefore less immediate

- Binding active for position 4 BH
  - 450ms
- Binding active for position 3 GH
  - 300ms
- Grouping active in H map
  - 300ms
Summary:

- G & B Model matches baseline success rates and RTs
  - G & B Model displays consistently quicker RTs for all displays
    - Activity in all maps *accelerates at a greater rate* in the G & B model during periods where binding is likely to be active
    - *Binding is initiated before* any acceleration in activity rate is displayed
    - Grouping and Binding leads to *increased activity within bound and grouped pools*, which corresponds to the period of accelerated activity in average activation plots
    - ➞ Faster RTs result from an acceleration in activation caused by G & B

- G & B model *identifies a greater number of items* correctly in all conditions and leads to an *additional illusory conjunction* error in the SC condition

- When the period of exposure is reduced we expect the increased noise present in the system to lead to a greater proportion of incorrectly bound features, resulting in an increase in illusory conjunctions
Stimuli presented for 250ms

- Similar proportion of illusory features produced by both models
- Small increase in proportion of illusory conjunctions produced by G&B model
IC CONDITIONS

- G & B model is consistently **slower** across all conditions

- Models display the same pattern of reaction times across conditions
  - Slowest Response = Different
  - Fastest Response = Same Shape
IC CONDITIONS

- Grouping and Binding did not lead to a consistent increase in Illusory Conjunctions

- Increases in Illusory Conjunctions were not at a level consistent with experimental evidence

Number of Illusory conjunctions produced in each display condition (60% contrast threshold)

<table>
<thead>
<tr>
<th>G&amp;B</th>
<th>Display</th>
<th>Dif</th>
<th>SC</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>On</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
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</table>

- What factors in the G&B model lead to additional Illusory Conjunctions
Is the stimulus being presented for too long?
- This may explain why all models show a far greater proportion of correct responses

Is the stimulus being presented for too short a period?
- Values for both illusory and correct responses are very low, by increasing the presentation period clearer trends may emerge

Presentation periods:
- 200ms
  - further reductions lead to difficulty breaching 60% contrast threshold
- 250ms
  - Period used in initial shortened exposure trials
- 300ms
  - further increases lead to levels of performance similar to full 2000ms presentation
**Proportion of Illusory Conjunctions**

- The proportion of illusory conjunctions is low for both models.
- G & B consistently produces a marginally greater proportion of ICs in all conditions.

**Proportion of Illusory Features Identified**

- The proportion of illusory features increases as the presentation period decreases.
- Similar proportion of illusory features reported by both models.
Is the self excitation (coupling) value set too high?

- By reducing coupling the influence of external inputs to the pool is increased and fluctuations in these inputs has a more immediate effect.

- Therefore bound or grouped pools have a greater and more immediate impact on one another.

Values tested:
- Low: \( w_{\text{plus}} = 2.2 \)
  - lower values resulted a negligible number of items identified
- Moderate: \( w_{\text{plus}} = 2.3 \)
- High: \( w_{\text{plus}} = 2.4 \)
  - value used in all previous simulations
Proportion of Illusory Conjunctions

- Proportion of ICs low across all conditions for both models
- G & B model produces greater proportion of illusory conjunction errors in all conditions

Proportion of Illusory Features

- Proportion of illusory errors greatest when moderate coupling implemented
Is the feedback from the location map too strong?
- Binding increases feedback, therefore if feedback is already high pools that are bound will gain little advantage

Values tested:
- Low: $wi_4 = 0.15$
  - lower values resulted a negligible number of items identified
- Moderate: $wi_4 = 0.20$
- High: $wi_4 = 0.25$
  - value used in all previous simulations
- **G&B models reported more illusory conjunctions and illusory features**

- **The proportion of illusory features and conjunctions remains low across all conditions**

- **Higher proportions of illusory features and illusory conjunctions are identified in the moderate feedback condition**

- **Both models display a similar trend when feedback is adjusted**
Having run all possible combinations of the parameters discussed, the following model produced the highest proportion of ICs:

- Presentation Period: 250ms
- Coupling: Moderate
- Feedback: High

- Proportion of Illusory Conjunctions remains at a similar level
- Model performance does not match behavioural data
Contrast Map across first 1000ms ('Different' condition, trial 50)

OFF

ON

Blue A Identified in Position 4
Contrast Map across first 1000ms (‘Different’ condition, trial 50)

OFF

ON

Time Lock Applied
Low levels of Illusory Conjunction error, may be due to method of analysis
- Time locked analysis may prove a more appropriate measure of model performance

Reported perception of features not present in the stimulus is commonly used as a baseline for analysis of illusory conjunction error
- Informs judgement of significance of 2-3% illusory conjunction error produced by G&B model

Feature – location association strongly coded within system from an early stage
- Leads to few positions not receiving direct input breaching G & B thresholds
- By increasing feedback from non-specific feature pools input signal can be blurred across locations
- In conditions of high noise, number of cases in which incorrect features are bound should increase, leading to a corresponding increase in illusory conjunctions