Can self-organisation generate the discontinuities in the somatosensory map?

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Summary

The primary somatosensory cortex contains a topographic map of the body surface, with two notable discontinuities — the representation of the face is next to that of the hands, and that of the feet is next to the genitals.

Farah (1998) has suggested that these discontinuities are due to the mechanisms of self-organisation which underlie cortical map development. The typical position of the foetus in the womb means that these two pairs of body parts will often touch and hence their representations will be simultaneously co-active, even though they are distal in terms of the body surface.

We use the Kohonen self-organising map algorithm to provide an existence proof of the plausibility of Farah’s hypotheses. We then use the model to test the viability of other possible causes of the known map structure and to explore the limitations of self-organisation for explaining the features of the somatosensory map.

The model shows that a) the Kohonen algorithm requires high frequencies of co-activation to introduce a discontinuity into the map. b) that high frequency of separate activation of the critical patterns alone is not sufficient to generate the selective discontinuity. c) the consistency of near-optimal map formation, and in particular the medial-lateral ordering, cannot be reliably generated by a simple Kohonen algorithm.

1. The Somatosensory map contains major discontinuities

Kohonen's self-organising feature map algorithm provides a standard way of generating a topographic map by tuning a physical array of units to some set of inputs. A fishnet plot shows the units positions in the input space according to their maximal response. Immediately adjacent units are joined by a line.

2. Farah’s hypothesis - self-organisation by co-activation

Martha Farah (1998) suggests that these discontinuities can be explained by the mechanism of map development and by foetal position. In the womb the foetal posture is such that the hands and face are likely to touch, and hence become simultaneously active; likewise the feet and the genitals.

Activity-dependent self-organisational processes are known to underlie the development of many cortical topographic maps (e.g. in the visual system; Sengpiel & Kind, 2002).

The combination of these two factors, Farah suggests, is sufficient to explain the discontinuities in the somatosensory map.

3. Kohonen’s self-organising map algorithm

Kohonen’s self-organising map algorithm provides a standard way of generating a topographic map by tuning a physical array of units to some set of inputs. Our first step was to confirm that we had the Kohonen algorithm working. A conscience mechanism (Desieno, 1988) which finesse map formation was introduced to ensure a more even spread of the unit tunings throughout the input space.

The plot (right) shows a typical distribution of the units which respond maximally to the inputs in the 12th (green) and 6th (red) rows.

4. Coactivation during self-organisation creates discontinuities

Co-presentation of patterns leads to their co-localisation in the map, but only at high-frequencies (left). A typical distribution of the maximally responding units for the inputs in rows 6 and 12 when the map demonstrates co-localisation is shown (right).

5. Stimulus preponderance does not create discontinuities

The two factors can interact so that a higher frequency of pattern presentation reduces the minimum probability of co-presentation required to generate co-localisation (near right).

Typical arrangement of maximally responding units to the critical inputs shown (far right).

6. Predictions and problems

Our model provides an existence proof of the plausibility of Farah’s hypothesis. However it also shows the limitations of self-organisation processes, as instantiated by the Kohonen algorithm, in the case of the somatosensory map.

The model omits major details of the biology of map formation — for example it is known that there is pre-cortical sensory map formation (with the grouping of face and hand and feet and genital afferents beginning early in the spinal cord).

The Kohonen algorithm doesn’t produce acceptable consistent maps without the conscience mechanism, nor does it contain any mechanism for producing a consistent orientation of the resulting map.

The consistency of formation in somatosensory cortex, and in particular the consistent orientation of the map (medial-lateral), cannot be reliably generated by a simple Kohonen algorithm.

Increased preponderance drives representations apart (see section 5). Our initial speculation was that the location of the discontinuities may be linked to the fact that they are positioned between the four areas which command the largest representational area. This fact however, by the logic of the Kohonon algorithm, would actually appear to mitigate against co-localisation.

The model lays the foundation for further investigations. Potential topics include the reorganisation of the map following the loss of inputs (i.e. limb amputation), the coordination between multiple maps, and the investigation of the role of the timing of plasticity in producing consistent developmental outcomes. (Including the critical discontinuities which have been the subject of this initial investigation).

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Farah (1998) has suggested that these discontinuities are due to the mechanisms of self-organisation which underlie cortical map development. The typical position of the foetus in the womb means that these two pairs of body parts will often touch and hence their representations will be simultaneously co-active, even though they are distal in terms of the body surface.

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The model shows that a) the Kohonen algorithm requires high frequencies of co-activation to introduce a discontinuity into the map. b) that high frequency of separate activation of the critical patterns alone is not sufficient to generate the selective discontinuity. c) the consistency of near-optimal map formation, and in particular the medial-lateral ordering, cannot be reliably generated by a simple Kohonen algorithm.

1. The Somatosensory map contains major discontinuities

Primary somatosensory cortex contains a topographic map of the body surface.

Generally adjacent body parts are represented by adjacent cortical areas.

Two major discontinuities interrupt the cortical map - the face and the hand representations and the feet and genital representations are adjacent.

2. Farah’s hypothesis - self-organisation by co-activation

Martha Farah (1998) suggests that these discontinuities can be explained by the mechanism of map development and by foetal position. In the womb the foetal posture is such that the hands and face are likely to touch, and hence become simultaneously active; likewise the feet and the genitals.

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The combination of these two factors, Farah suggests, is sufficient to explain the discontinuities in the somatosensory map.

3. Kohonen’s self-organising map algorithm

Kohonen’s self-organising feature map algorithm provides a standard way of generating a topographic map by tuning a physical array of units to some set of inputs. A fishnet plot for basic algorithm with (far left) and without (far right) conscience mechanism.

Our first step was to confirm that we had the Kohonen algorithm working. A conscience mechanism (Desieno, 1988) which finesse map formation was introduced to ensure a more even spread of the unit tunings throughout the input space.

The plot (right) shows a typical distribution of the units which respond maximally to the inputs in the 12th (green) and 6th (red) rows.

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Co-presentation of patterns leads to their co-localisation in the map, but only at high-frequencies (left). A typical distribution of the maximally responding units for the inputs in rows 6 and 12 when the map demonstrates co-localisation is shown (right).

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