NEURAL ATTRACTOR NETWORK CLASSIFICATION OF VISUAL FIELD DATA

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Abstract

Since many neuro-ophthalmological diseases and lesions, even subtle ones, may be recognized from perimetric examinations, the appropriate classification of visual field data is essential for diagnosis. However, adequate classification and interpretation of perimetric examination results is not a trivial task and requires well-trained personnel with long-term experience. Therefore, a computer-based classification system for visual field data is introduced that may act as a 'counsellor' to the diagnosing physician. The classification system consists of a neural attractor network that obtains input data from perimetric examination results. Due to an iterated relaxation process, which determines the states of the neurons dynamically, even 'noisy' perimetric output, e.g., early stages of a disease, may be classified correctly according to the predefined attractors (diseases) of the network.

Introduction

Since many neuro-ophthalmological diseases and lesions, even subtle ones, may be recognized from perimetric examinations, the appropriate classification of visual field data is essential for diagnosis. However, adequate classification and interpretation of perimetric examination results is a non-trivial task and requires well-trained personnel with long-term experience.

There has been recent interest in computer-based classification systems for visual field data using different approaches, e.g., feed-forward networks and Kohonen maps14,16. In this work presented here, we propose an alternative kind of neural network2,12, namely a Hopfield net14,16, for application in visual field data classification. It may be considered a 'counsellor' to, rather than a substitute for the diagnosing physician, providing an additional opinion in judging perimetric examination results.

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Methods

The classification system is based on a neural attractor network (Fig. 1a) consisting of \( N \) binary neurons. These neurons are assigned to the \( N \) stimulus locations of the stimulus grid used to examine the visual field. Therefore, the neurons obtain their input data from perimetric examination results. We define +1 as a scotoma and -1 as no scotoma at a particular test location within the visual field under examination.

The \( N \) neurons are fully connected with each other via synaptic couplings \( J_{ij} \).

The synaptic coupling strengths can be calculated directly out of the patterns to be stored as attractors of the network by means of, e.g., the Hebb rule or the Projection rule\(^{15,16}\). In general, these attractors may be numbers or image pixels. In the particular case of visual field data classification, the attractors are predefined idealized scotoma patterns (see e.g. Ref. 17) that are typical for specific diseases, e.g., hemianopic field defects, sectoral defects, central, paracentral and centrocecal scotomata, nerve fiber bundle defects, etc.

The following iterated relaxation process

\[
S_i(t+1) = \text{sgn}(\sum_j J_{ij} S_j(t)), \quad \text{with } \text{sgn}(\cdot) = \text{sign function}
\]

determines the states \( S_i(t) \) of the neurons dynamically. Therefore, even 'noisy' perimetric output (Fig. 1b), e.g., early stages of a disease, may be classified correctly (Fig. 1c) according to the predefined attractors of the network. 'Noisy' perimetric output means a scotoma pattern that differs from any attractor (idealized scotoma pattern) stored in the network.

A fix-point or attractor of the network dynamic is reached if the following condition is fulfilled for each neuron \( i \) of the network simultaneously:

\[
S_i(t+1) = S_i(t).
\]
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In the classification system presented here, we use two classification criteria:

1. Overlap parameter $q$ defined as $q = \sum |\sigma - \sigma'|$, with $\sigma$ being the idealized scotoma pattern derived from the perimetric examination and with $\sigma'$ being the ith idealized attractor (both normalized to unity). For better comparison, we calculate the overlap parameter and the Hamming distance for all predefined network attractors both, before and after the relaxation process described above. Table 1 shows a classification example of the visual field data depicted in Figures 1b and c. From the definition of the overlap parameter and the Hamming distance, it follows that the attractor with the largest overlap (closest to 1 or 100%) and the smallest Hamming distance (closest to 0) classifies the scotoma pattern under examination best (in this case a hemiopic visual field defect, DC=22). There is a theoretical limit $(\alpha_c)$ in the storage capacity $\alpha_c = \text{(number of classifiable attractors per total number of neurons) of a Hopfield attractor net for independent and randomly chosen attractors}^{[14]}: \alpha_c = 0.138$. However, in case the storage capacity of one neural attractor network is not sufficient for the classification task, each disease may be assigned with its own neural network, e.g., a classification system that is specialized only in scotoma patterns caused by glaucoma.

Table 1. Classification result sorted in descending order of probability: disease code (DC), overlap parameter and Hamming distance, before and after the relaxation process, respectively.

<table>
<thead>
<tr>
<th>Overlap</th>
<th>Hamming</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>before</td>
</tr>
<tr>
<td></td>
<td>before</td>
</tr>
<tr>
<td>22</td>
<td>92.34%</td>
</tr>
<tr>
<td>14</td>
<td>43.03%</td>
</tr>
<tr>
<td>12</td>
<td>40.00%</td>
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<tr>
<td>21</td>
<td>36.72%</td>
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<tr>
<td>19</td>
<td>43.03%</td>
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<tr>
<td>17</td>
<td>39.28%</td>
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<tr>
<td>8</td>
<td>35.36%</td>
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<tr>
<td>5</td>
<td>28.81%</td>
</tr>
<tr>
<td>21</td>
<td>21.61%</td>
</tr>
<tr>
<td>12</td>
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<tr>
<td>4</td>
<td>10.48%</td>
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<tr>
<td>18</td>
<td>15.71%</td>
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<tr>
<td>6</td>
<td>8.89%</td>
</tr>
<tr>
<td>9</td>
<td>7.52%</td>
</tr>
<tr>
<td>15</td>
<td>11.11%</td>
</tr>
<tr>
<td>16</td>
<td>11.11%</td>
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<tr>
<td>10</td>
<td>8.89%</td>
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Results

Preliminary test results of the classification system on real visual field data derived from perimetric examinations have come up with a classification success of over 80%. This success rate may be significantly improved in future versions of the classification system (see Discussion and Outlook).

Discussion and Outlook

Advantages of the classification system presented here are that the classification of visual field data is computationally fast, and no neural learning process (e.g., back propagation) is required to determine the synaptic coupling strengths. Furthermore, the assignment of a confidence level to the diagnosis by means of the overlap parameter and the Hamming distance makes the system a real 'counsellor' rather than just a 'yes/no' machine. Finally, the classification system may be readily applied to arbitrary stimulus grids for static perimetry (e.g., 30° or 90° visual fields), since only the idealized scotoma patterns (network attractors) have to be adjusted accordingly.

In our study, we used the Tübingen Automated Perimeter stimulus grid for a 30° visual field. Its 191 test locations allow for a high spatial resolution of position, shape and extent of scotomas (compared to only 60–70 test locations of conventional automated threshold perimetry).

Future developments of the attractor network classification system should take into account relative scotomas as well as binocular visual field data for the diagnosis of binocular scotomas. Furthermore, more research is needed on the detailed specification of the network attractor sets (idealized scotoma patterns) to allow for more precise and specific classifications.

Since we are at the start of a new era of computer-based classification systems in medical sciences, the choice of the appropriate neural network type should not be too restricted. Rather, combinations of different neural network types should also be taken into account.

References

ESTIMATING CATARACT BY MEANS OF RESOLUTION PERIMETRY

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Abstract

Cataracts and other optical faults spoil retinal imagery in both central and peripheral vision. In the case of resolution perimetry, thresholds are raised in inverse relation to their native levels. This property allows the application of regression techniques to calculate an index that summarizes the effects of optical faults over a large solid angle. It is also possible to estimate peripheral vision 'behind blur'. Both techniques are applicable in eyes with concurrent focal visual field defects from non-optical causes. Major provisions are spatial uniformity of optical faults and sparing of subsets of test locations from non-optical influences. The proposed blur index appeared to provide a useful summary indicator of optical faults in deliberately blurred normals and in patients tested before and after cataract surgery. Predictions of neuroretinal function were good for artificial blur, but only modest for cataracts, presumably because of frequent deviations from spatial uniformity. Severe blur obscuring detail that cannot be restored analytically in fields containing focal defects poses another dilemma.

Introduction

Cataract is usually an easily recognized cause of visual loss, but it is often difficult to decide whether any concurrent retinal or neural disorders may also influence function. A large number of studies has explored the capacity of various central vision tests to aid diagnosis and predict the effects of cataract surgery1. For maximum utility, tests need to be sensitive to either optical or neuroretinal faults, but not to both. Interferometric tests appear to come closest to meeting these demands, but suffer other disadvantages2. An alternative approach is to involve peripheral vision. Granted, there is currently no visual field test that is completely immune to either type of fault, but advantage can be taken of the different spatial distributions of fault effects: optical factors may be assumed to display symmetry about the optical axis, whereas neuroretinal disorders (except macular degenerations) do not.

We studied high-pass resolution perimetry (HRP), a well-documented five-minute

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