Evolving model parameters for generating a biologically plausible neural network.

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PhD Students' Short Talks 14/3/2013
Introduction

many biological concepts can be thought of as

networks

network models have been developed to aid understanding of how these networks develop and operate.
Neural networks
Caenorhabditis elegans

Nematode worm

Model organism with

306 neurons
2345 synaptic connections

Human brain

10^{11} neurons
10^{14} synaptic connections
Network Models

We attempt to create networks with properties similar to that of the *C. elegans* neural network.

To do that we use **network models**.

A network model is an algorithm that produces a network from a given input.

```
randomNetwork :: Int -> Double -> ([Node], [Edge])
randomNetwork 5 1.75
```
Global topological measurements

Measurements that we take from each node.
We then take the average from across the network.
Average Degree

the average number of edges that a node in the network has
or
the total number of edges, divided by the number of nodes
Average Path Length

the average shortest path length between two nodes

calculate the total length of all the shortest paths in the network, and then divide it by the number of paths

1+1+2+3+1+1 +2+1+1+1+2 =16 /11 =1.45
Average Cluster Coefficient

A measure of how many of a node's neighbours are connected together

\[ \frac{\text{number of connections between neighbours}}{\text{number of possible connections between neighbours}} \]

0/3

1/3

3/3
Erdős-Rényi model

nodes connected together randomly

one parameter: probability to have an edge between two nodes

average degree and path length close to \textit{C. elegans}

clustering coefficient much too low
Watts-Strogatz model

start with a regular network, then add randomness

Ring Lattice  \rightarrow \text{rewire edges} \rightarrow \text{Watt-Strogatz}
Watts-Strogatz model

two parameters: number of edges, probability to rewire an edge

average degree and path length close to *C. elegans*

and clustering coefficient close to target
Structured Node model (SN model)

nodes have a structure

creation of new nodes and edges based on structure
Structured Node model (SN model)

pick an existing node

mutate its structure to form a new node

add node to network, adding edges to other nodes based on a distance measure

repeat until you have the desired number of nodes
Structured Node model (SN model)

complex model

many parameters

found networks with values close to those of the targets
Structured Node model (SN model)

creating networks from the SN model is more difficult
many parameters means multi-objective optimisation

used a genetic algorithm to find a suitable set of parameters
Multi-Objective Optimisation

Want to get the generated network to match as closely as possible the empirical network on 3 measurements:

- **Average degree**
- **Average path length**
- **Average clustering coefficient**

Distance from target value:

- **Least optimal** (∞)
- **Most optimal** (0)

The diagram shows the relationships and distances between the target values and the generated network across the three measurements.
Paerto Front

The set of solutions which are not irrefutably worse than any others

Distance from target value

Distance from target value

average degree

average path length

average clustering coefficient
Fitness Function

For each solution the fitness needs to be calculated.

The SN model needs to be run with the parameters from the solution.

For large networks this could take up to an hour or more.

For large populations and many generations this would take a long time to run.
Fitness Function

Run the SN model in parallel

Solutions needing to be evaluated

Dispatcher

Evaluated solutions

fitness = ?

bwlf16

bwlf17

bwlf18

bwlf19

bwlf20

bwlf21

Solutions

fitness = 1.2
Global topological measurements

For each network model we created 10 networks.

We took measurements for each of the networks, and then averaged them.
Global topological measurements

<table>
<thead>
<tr>
<th>Network</th>
<th>Average Degree</th>
<th>Average Path Length</th>
<th>Average Clustering Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. Elegans</td>
<td>7.66</td>
<td>2.46</td>
<td>0.284</td>
</tr>
<tr>
<td>Erdos-Renyi</td>
<td>7.56±0.15</td>
<td>2.41±0.02</td>
<td>0.05±0.00</td>
</tr>
<tr>
<td>Watts-Strogatz</td>
<td>8</td>
<td>2.78±0.01</td>
<td>0.29±0.01</td>
</tr>
<tr>
<td>Structured Nodes</td>
<td>6.43±0.41</td>
<td>3.73±0.12</td>
<td>0.36±0.03</td>
</tr>
</tbody>
</table>

Watts-Strogatz is a very good match to *C. elegans*

SN model is in second place
Distribution of topological measurements

Tells us more than just the global averages, but are harder to analyse as they provide multidimensional data.
Degree distribution

ER & WS models not like *C. elegans*

SN model similar to *C. elegans*
Path Length distribution

ER & WS model like \textit{C. elegans}

SN model not like \textit{C. elegans}
Cluster Coefficient distribution

ER model not like *C. elegans*

WS model like *C. elegans*

SN model more like to *C. elegans*
Outgoing edge heatmaps show how nodes are connected to other nodes based on their degree.
Outgoing edge heatmaps

There are many nodes of degree 7 connected to nodes of degree 13 & 14.

Nodes of degree 32 have very few incoming nodes, but those are all from nodes with smaller degrees.
Outgoing edge heatmaps
## Distributions of measurements

<table>
<thead>
<tr>
<th>network</th>
<th>avg. degree</th>
<th>avg. path length</th>
<th>avg. clustering coefficient</th>
<th>similar to degree distribution</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Yes</td>
</tr>
</tbody>
</table>

The SN model is the best fit of the distribution, depending on the measurements considered.
Random Recurrent Neural Networks

simple model of a neural network
Random Recurrent Neural Networks

simple model of a neural network
Adding an Influence

Three different methods of adding an influence were used:

- All Neurons
- Most Outgoing Synapses
- Least Outgoing Synapses
Observing the Dynamics

Average firing rate

Influence is applied

Time

graph showing the dynamics of average firing rate over time, with a step where the influence is applied, leading to a decrease in firing rate.
Regular Dynamics

Regular

Not Regular
# Exploring the dynamics

<table>
<thead>
<tr>
<th>network</th>
<th>% regular all nodes</th>
<th>% regular most connected nodes</th>
<th>% regular least connected nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. Elegans</td>
<td>100</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>Erdos-Renyi</td>
<td>94</td>
<td>67</td>
<td>54</td>
</tr>
<tr>
<td>Watts-Strogatz</td>
<td>75</td>
<td>27</td>
<td>29</td>
</tr>
<tr>
<td>Structured Nodes</td>
<td>82</td>
<td>52</td>
<td>40</td>
</tr>
</tbody>
</table>

*C. elegans* has by far the most regular dynamics!
Conclusions

The WS model, though widely used, fails to model any distributions of measurements.

The SN model closely matches the distributions of measurements

None of the examined models come close to matching the regularity of the dynamics shown by the *C. elegans* network.

Future models may need to draw inspiration from neural development.
Thanks for listening,

any questions?

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