Introduction to Neural Networks
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Lecture 1

Goal

Understand the functioning of the brain as a computational device. Brain & behavior. Relation to connectionist, neuromorphic, computational neuroscience research, and cognitive science.

Relation to Cognitive Science

The interdisciplinary study of the acquisition, storage, retrieval and utilization of knowledge.

For many of these problems, we don't know how to solve them in principle. For others, we have solutions, but they don't resemble how a biological system might solve it.

Given a broad approximation of neural function and connectivity, what kinds of problems can large interconnected systems of model neurons solve? What are the limitations? What are the strengths?

Understanding the relation between brain and behavior requires

A multidisciplinary point of view.

Multiple levels of explanation.

Multidisciplinary point of view

Three primary areas or discplines influence current neural network research:

Neuroscience, computational neuroscience

Understand the basic building blocks or "hardware" of the nervous system
these are: nerve cells or neurons, and their connections, the synapses

Our emphasis is on: Large scale neural networks. Requires great simplification in the model of the neuron...in order to compute and theorize about what large numbers of them can do.

Compare with Neuroscience I, II, III. Emphasizes the biology. Here we emphasize "brain-style"" computation. Often wrong in detail, but driven by a curiousity about how the complex processes off
perception, and memory might work using "brain-style" computation..

What can these large scale neural systems do? That is, what can they compute? And how?

Computational theory, mathematics

Statistical inference, engineering (communication theory), statistical physics and computer science.

Provides the tools and analogs to abstract and formalize for analysis and simulation.

One of the characteristics of this course is to try to relate the neural models to statistical methods of inference and regression..

What should these large scale neural systems compute? What are the ways in which information is represented?

Psychology, cognitive science and ethology

Understand what subsystems are supposed to do as a functioning organism in the environment.

Psychology &;Computational theory =>

The brain is NOT a general purpose computer.

Multiple levels of explanation.

A useful set of distinctions to bear in mind were drawn by David Marr.

Functional or rational or computational level

Psychology/Cognitive Science/Ethology tells us what is actually solved by nervous/brain systems.

Algorithmic

Mathematics of computation tells us what is computable and how

Implementation or hardware

Neuroscience tells us the adequacies and inadequacies of our modeling assumptions

Functionalities supported by neural network computing provide a useful way of categorizing models, as can be seen in the Syllabus organization:

1. Learning input/ouput mappings from examples (Regression)
multi-layer networks

2. Self-organization of data into meaningful classes (e.g PCA, clustering, ART))

3. Associative memory
e.g. Hopfield net, local minima are useful.

4. Optimization or constraint satisfaction (e.g. Hopfield net, Boltzmann machine). local minima problem

Overview of the Brain

Before we look at models of neurons and their interactions, let us get an overview of the brain and nervous sytem.

OVERHEAD of levels of organization, scales.

(10,000 A to a micron)

OVERHEAD of brain
basic structures
neocortex, thalamus, etc.

The human brain is::
volume - 1.4 liters
Cortex 2 mm - "cortico-centric" neuroscience
volume 0.32 liters
Cortex
1.6 x 10^10 neurons, with about 4000 synapses/neuron
about 6x10^13 connections.

Some reference numbers taken or inferred from those published by:

Cherniak, J. of Cog. Neurosc., 1990, vol 2., pp 58-68

Area of cortex 1.60E+05 mm^2
Thickness of cortex 2.00E+00 mm
Volume of cortex = 3.20E+05 mm^3 3.20E-01 liters
Cortex synapse density 4.00E+03 synapse/neuron
Cortex connectivity 2.00E+08 synapses/mm^3
connectivity/neuron 5.00E+00 mm
connection length/mm^3 2.50E+04 mm
neuron density in cortex 5.00E+04 neurons/mm^3

Total brain volume 1.40E+00 liters

Total neurons in cortex 1.60E+10
Total visual neurons 8.00E+09
Total visual connection lengths 4.00E+09 mm 4.00E+07 m 24873.7374 miles of connections

Casual inspection shows that the brain has gross structure, what is not apparent immediately is that structures are do not consist of randomly connected nerve cells. For example, the neocortex has 6 more or less distinguishable layers, there is a microorganization (1 to 2 mm) into vertical columns.

OVERHEAD of layers

And a medium level organization into multiple functional groupings.

OVERHEAD of visual areas

References

Kandel, E. R., Schwartz, J. H. & Jessell, T. M. (1995). Essentials of Neural Science and Behavior. Norwalk, Connecticut: Appleton & Lang.

Zeki, S. (1993). A Vision of the Brain. Oxford: Blackwell Scientific Publications.

Links

The Whole Brain Atlas has a very impressive collection of labelled MRI scans of the human brain. http://www.med.harvard.edu/AANLIB/home.html

Notes on getting started with *Mathematica*

- **Numerical Calculations.** You can do arithmetic. For example, type 5+7 as shown in the cell below, and then hit the "enter" key. Try other operations, 5^3, 4*3 (note that 4 3, where a space separates the digits is also interpreted as multiplication). Note that if you try division, e.g. 2/3, you get the exact answer back. To get a decimal approximation, type N[2/3].

```
5+7
```

```
12
```

```
N[2/3]
```

```
0.666667
```

You can go back and select an expression by clicking on the brackets on the far right. These brackets are features of the Macintosh interface and serve to organize text and calculations into a Notebook with outlining features. You can group or ungroup cells for text, graphs, and expressions in various ways to present your calculations. Explore these options under Cell in the menu. You can see the possible cell types under the **Style** menu.

- **Built-in functions.** *Mathematica* has a very large library of built-in functions. They all begin with an uppercase letter. You can get information about a function, e.g. for the exponential of a function, or for plotting graphs:

```
?Exp
```

```
Exp[z] is the exponential function.
```



```
?Plot
```

```
Plot[f, {x, xmin, xmax}] generates a plot of f as a
   function of x from xmin to xmax. Plot[{f1, f2, ...},
   {x, xmin, xmax}] plots several functions fi.
```

If you type two question marks before a function, **??Plot**, you'll get more information. Try it. What does the **Random** function do?