

Networks in the Brain – Framing Talk

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Description

This document is part of an archival bundle of **Primary Materials from the 2016 CogNovo ColLaboratoire Workshop on Network Consciousness**. The workshop asked whether highly-connected networks—such as the Internet—could be said to be conscious, or could become conscious, approaching the topic through the lenses of embodied, situated, enactive, extended, and distributed cognition.

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Networks in the brain

Jack Fletcher

Why?

- The goal of this workshop is to explore the question:

Are networks becoming conscious?

Why?

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Are networks becoming **conscious**?

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In what ways is the brain a network?

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In what ways is the brain a network?

What are the properties of these networks?

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Are networks becoming conscious?

We know of one network which seems to contribute to consciousness.

In what ways is the brain a network?

What are the properties of these networks?

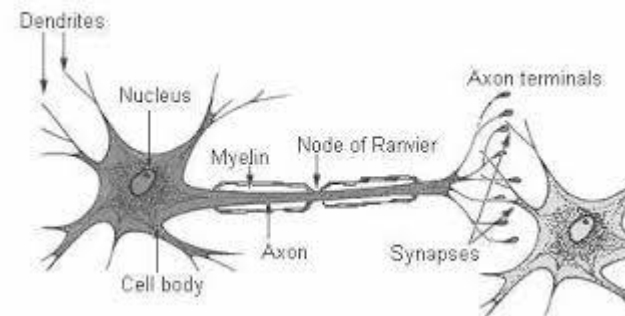
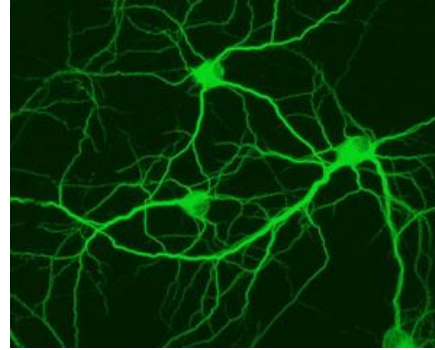
Are these properties necessary for consciousness?

Goal of this presentation

- Introduce the levels in which the brain can be seen as a network.
 - Neural networks
 - Cell assemblies
 - Functional + structural brain networks
 - Semantic networks
- Explain how the properties of the network structure can be exploited to understand cognition.
 - Centrality and the brain
 - Small worldness
- Speculate: **Should we see the same network properties in other possibly conscious networks?**

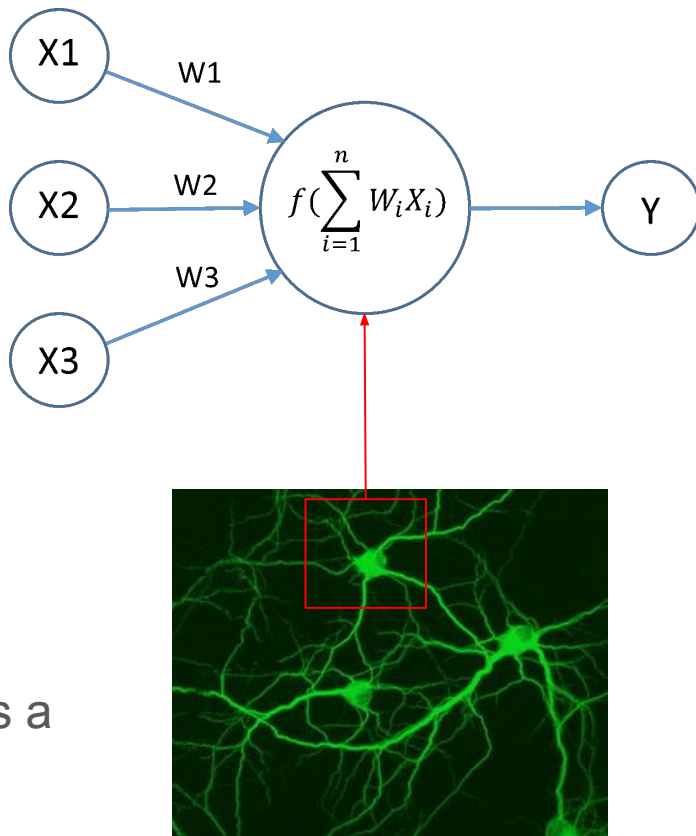
Level zero: Neural networks

- **Neurons are** thought to be the fundamental Information processing units of the brain.
- A neuron `stores' information in its electrical activity.
- It `talks' to other neurons with **synaptic connections** using electrical and chemical signals.
- There are 100,000,000,000 of them!!



Level zero: Neural networks

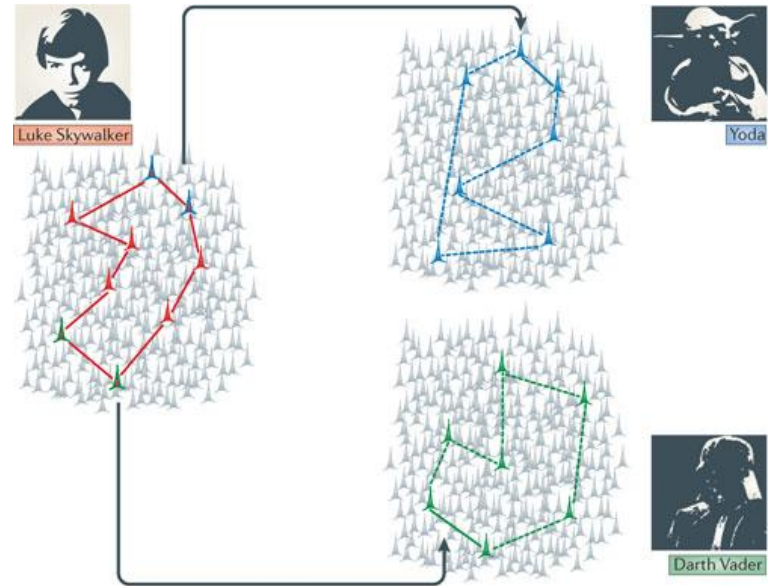
- We can abstract the function of a neuron.
- The value of a neuron is the weighted sum of the input neurons.
- Using networks of these neurons, one can do computations! (Turing Complete in certain cases)
- **Grandmother neuron:** a neuron represents a distinct concept, i.e your grandmother?!





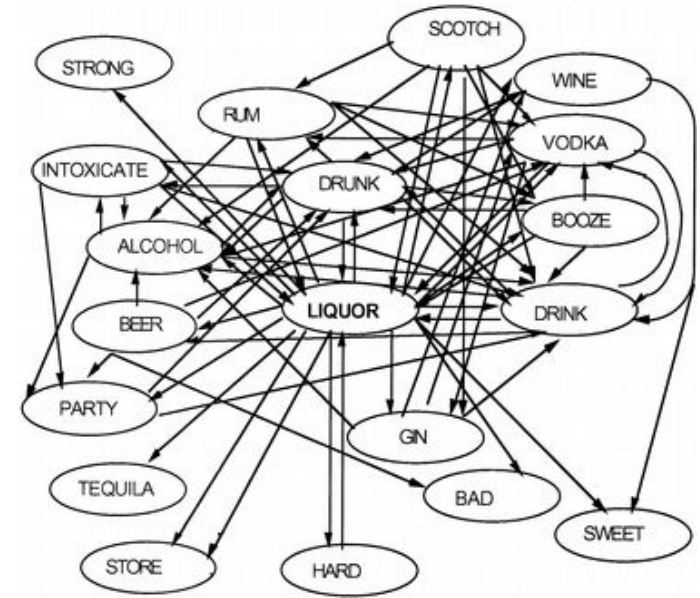
A level up: Cell assemblies (Hebb)

- A **cell assembly** is a collection of neurons with strong synaptic connections which represent a concept, percept or action.
- **Robust:** if one neuron is lost, the whole concept is not lost. **Efficient:** one neuron can be used in different assemblies
- Episodic memory, motor movements, and language through **Synfire chains**?
- Networks of assemblies can now be made!



← Sideways: Semantic networks

- A **semantic network** represents associations between concepts.
- Nodes represent concepts and edges represent semantic associations.
- They are arguably implemented in neural networks using cell assemblies!





A level up again: Functional and structural networks

- Generally on a much larger scale, each network node is made of millions of neurons!

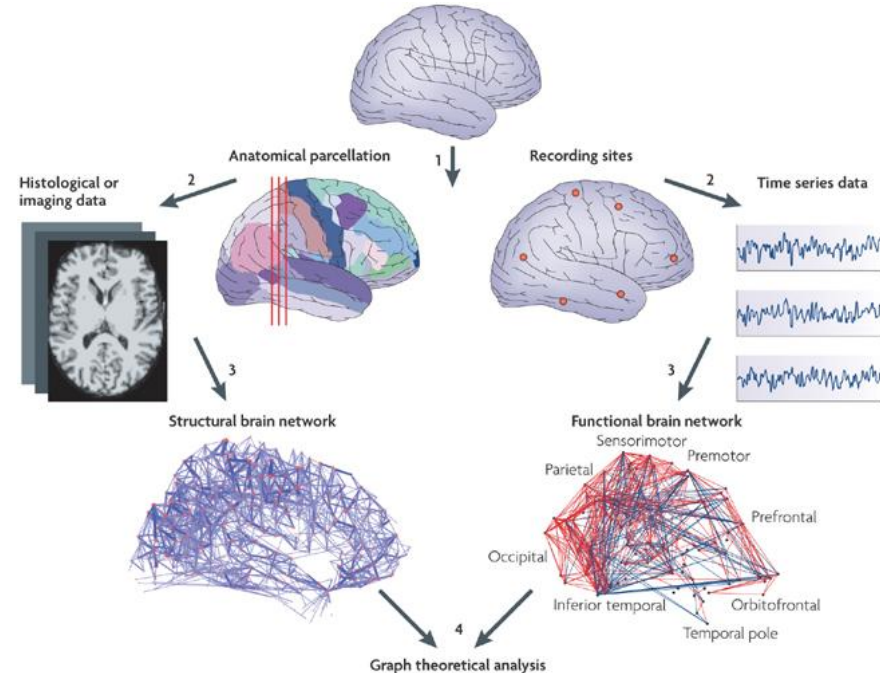
- **Structural brain network:**

A network is created by looking at the physical connections between areas of the brain.

- **Functional brain network**

A network is created using fMRI/EEG:

If two areas of the brain 'activate' together then an edge is drawn between the two



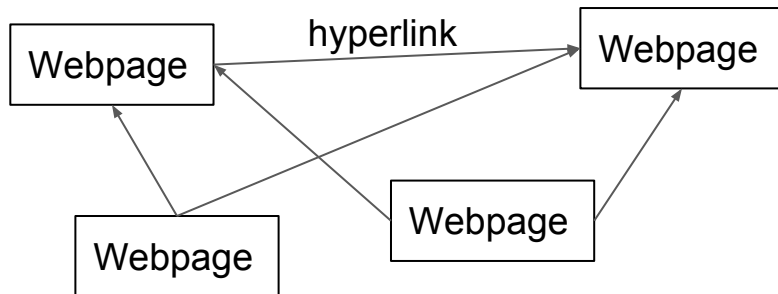
Recap

- We can see the brain as a network on multiple levels:
 1. Neural networks (traditional neuroscience/ AI)
 2. Cell assemblies (theoretical neuroscience)
 3. Semantic networks (psychology)
 4. Functional and structural networks (clinical neuroscience)
- Each network is useful for understanding different aspects of cognition!
- Each level is connected with a lower level, but how?!

Google, semantic networks and neurons!

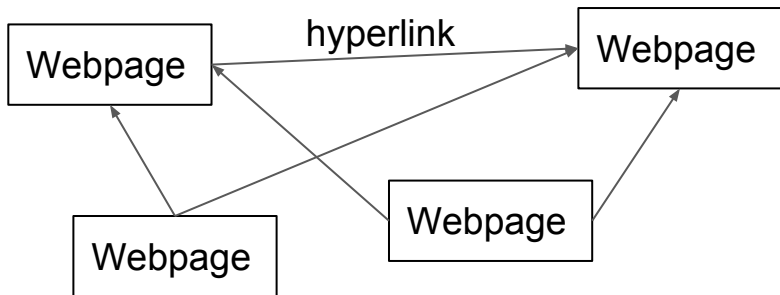
Google, semantic networks and neurons!

- Google have a problem:
 - A user searches a term, for example “The weather in Plymouth”
 - Lots of web pages contain this query (22,000,000)
 - How does Google decide what what webpage to display first (and second, third, fourth....)?
- The answer: exploit the network structure of html pages:



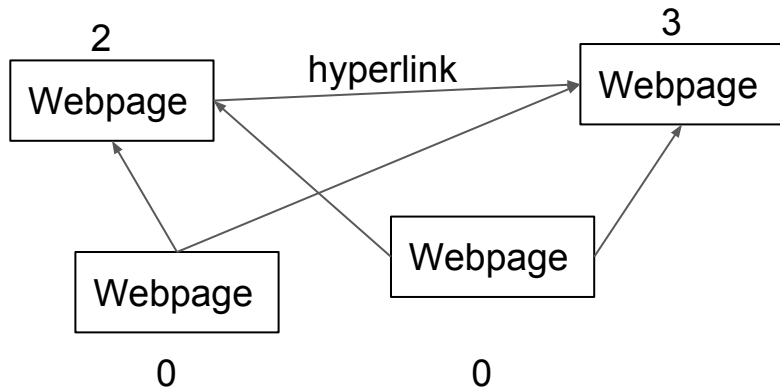
Google, semantic networks and neurons!

- We can see hyperlink a “vote of trust” i.e if bbc news links to your blog page it implies your web page is good in someway.
- In general, a method for “finding the most important node in a network” is called a **centrality measure**.



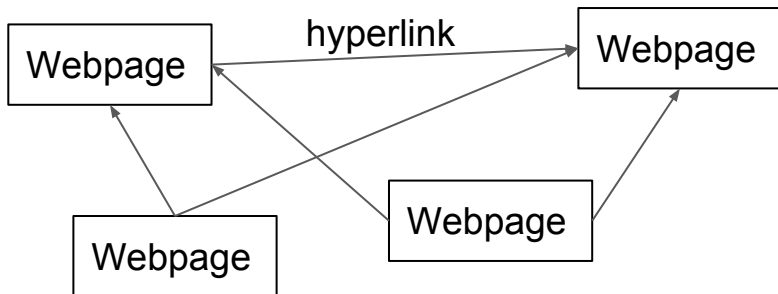
Google, semantic networks and neurons!

- A simple centrality measure is to count how many edges point to node. This is called **In-Degree centrality**.
- However, Google use a centrality measure called **PageRank**.



Google, semantic networks and neurons!

- **PageRank model:** You start on a webpage and randomly click on links. Every so often you jump to a random webpage and continue clicking links. You do this process forever. The amount of times you visit a web page is proportional to its PageRank!
- Google show webpages with high pagerank first!

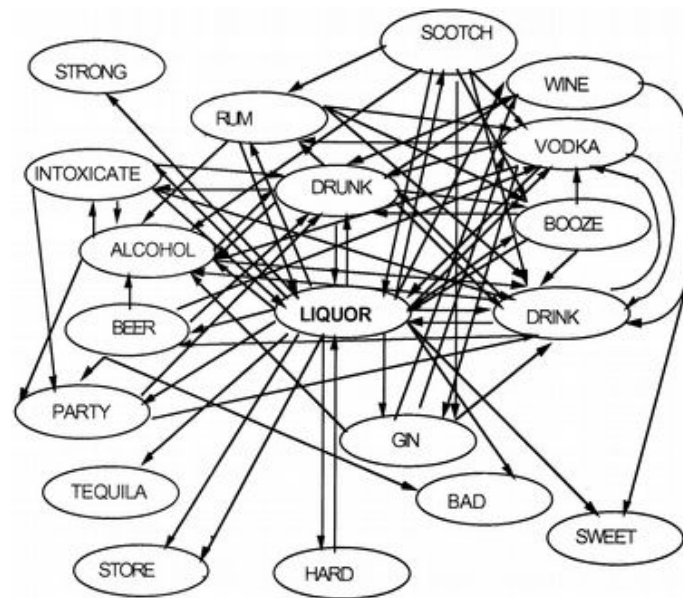


$$PR(p_i; t + 1) = \frac{1 - d}{N} + d \sum_{p_j \in M(p_i)} \frac{PR(p_j; t)}{L(p_j)}$$

Google, semantic networks and neurons!

- What about PageRank on semantic networks?

Any guesses?

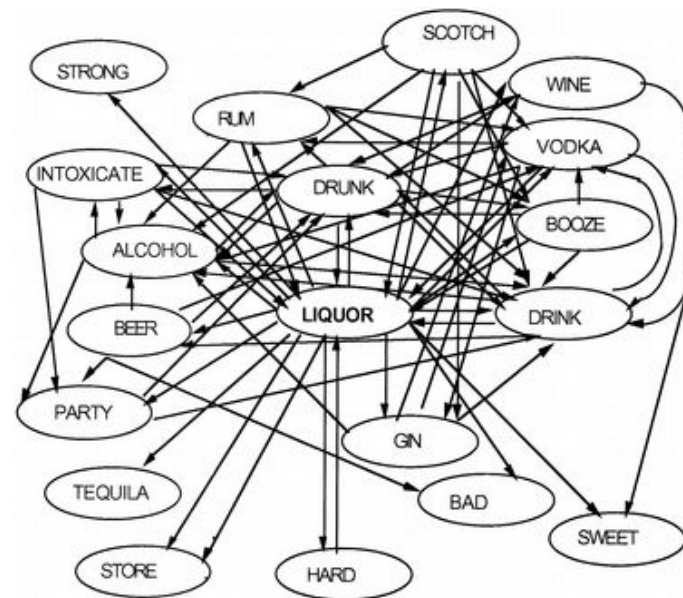


Google, semantic networks and neurons!

- What about PageRank on semantic networks?

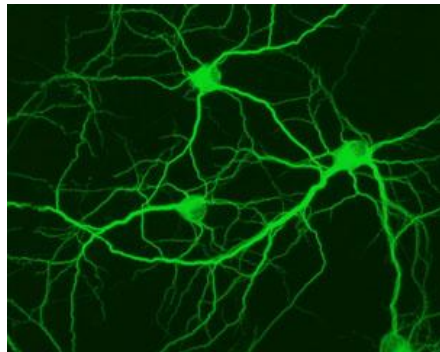
Any guesses?

- It is found that concepts with high PageRank are recalled more regularly by participants!
- That is, if I give you a query, i.e “think of word beginning with a”. You will recall the word with highest PageRank which begins with that letter!



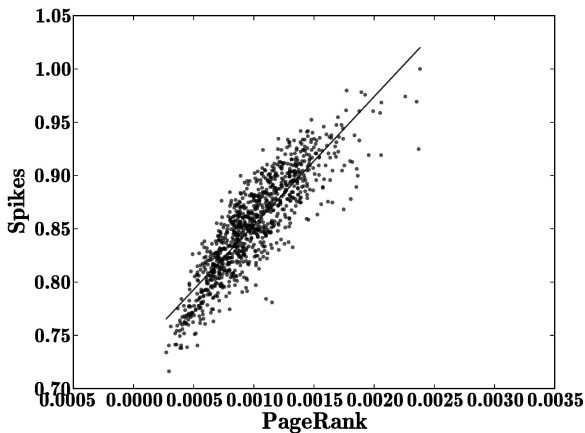
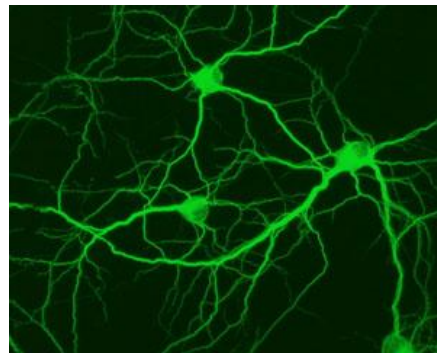
Google, semantic networks and neurons!

- What about PageRank on neural networks?
Any guesses?



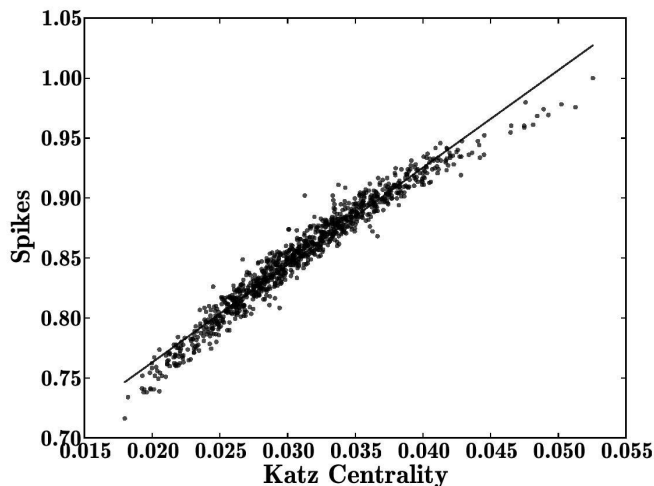
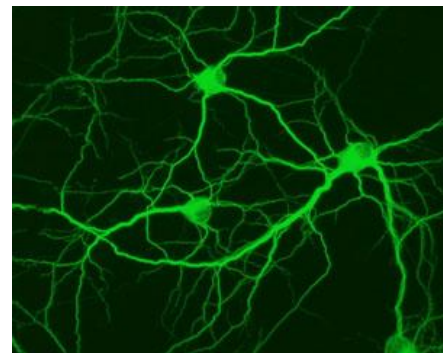
Google, semantic networks and neurons!

- What about PageRank on neural networks?
Any guesses?
- I find that neurons with high PageRank are more Active! (0.87 correlation)



Google, semantic networks and neurons!

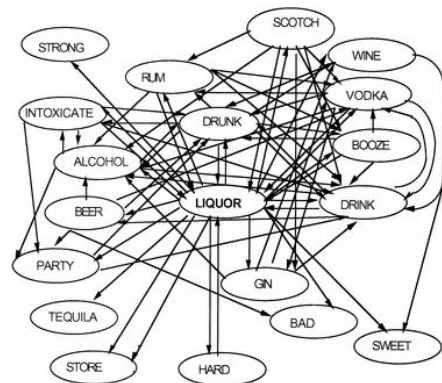
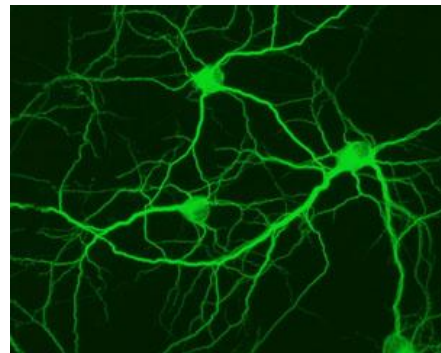
- However, I find that another centrality measure called **Katz Centrality** outperforms PageRank. (0.98 correlation)



Google, semantic networks and neurons!

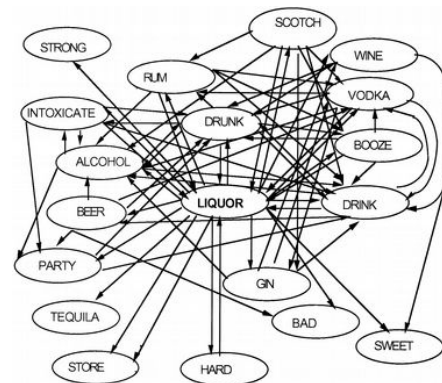
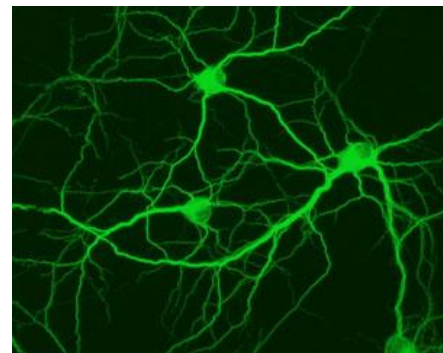
- Why are words with high PageRank recalled more regularly in semantic networks?

Any guesses?



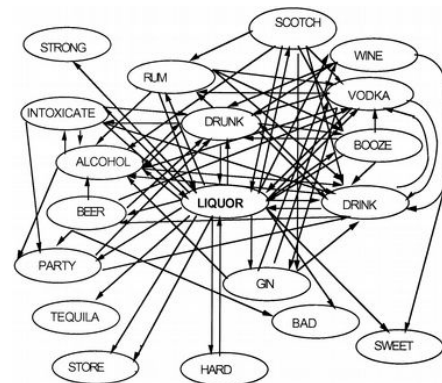
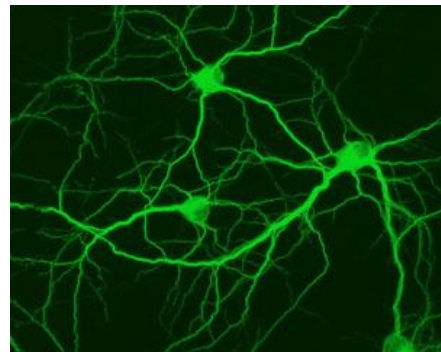
Google, semantic networks and neurons!

- Why are words with high PageRank recalled more regularly in semantic networks?
Any guesses?
- The `word' is represented by a collection of neurons.
- **Hypothesis:** The neurons which represent the word have high PageRank, and are thus more active (and therefore the concept they represent is more likely to be recalled)!



Google, semantic networks and neurons!

- **Hypothesis:** if we were to use **Katz centrality** instead of PageRank on the semantic network, it would better predict the recalled words!
- This is because Katz centrality better predicts neural activity!



Thought experiment

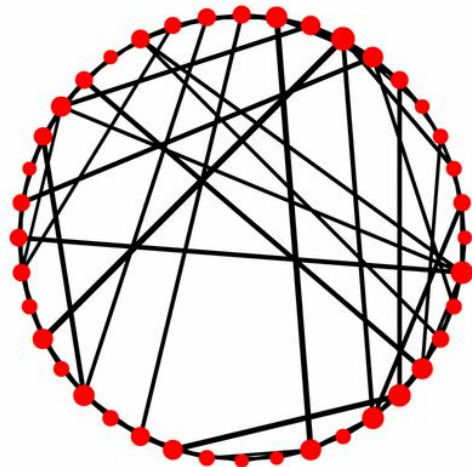
- You are allowed to remove 1 million neurons from your enemy's brain.
Your goal is to reduce brain function (consciousness?) as much as possible.
how do you decide on what neurons to remove?
- Perhaps a good tactic is to remove neurons with high Katz Centrality as these neurons may be involved in representing important concepts and actions.
- Would this tactic work in other possibly conscious networks?

Small World Networks

- The ‘**small worldness**’ of a network concerns the average path length between any two nodes in a network.
- If the typical distance (L) between two nodes is:

$$L \propto \log N$$

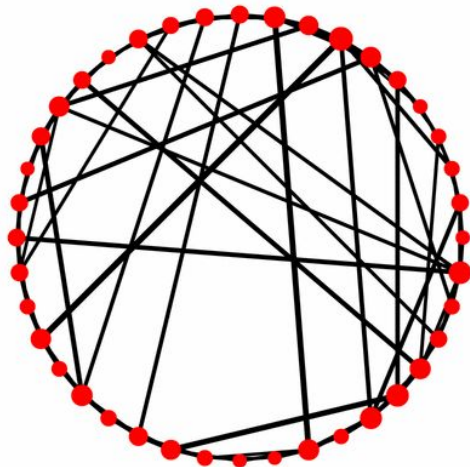
- Where N is the number of nodes in the network then we say the network is a “small world network”



Small World Networks

- This type of wiring supports efficient information exchange between nodes in the network.
- Small worldness in functional brain networks correlates with intelligence and creativity!
- Social networks satisfy this property, as do neural networks!
- **Should we see small worldness in other possibly conscious networks?**

$$L \propto \log N$$

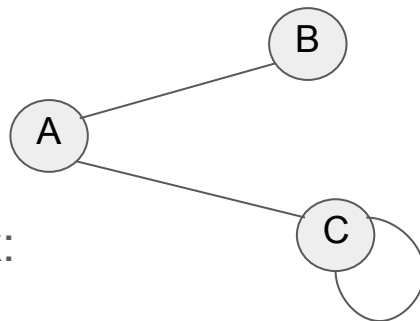


What is a network?

- A network (or graph) is a set of nodes (or vertices), $\mathbf{V}$ and a set of tuples, $\mathbf{E}$ representing edges between them. We say $\mathbf{G} = (\mathbf{V}, \mathbf{E})$.
- Example: $\mathbf{V} = \{A, B, C\}$
 $\mathbf{E} = \{(A, B), (A, C), (C, C)\}$
- We can also represent this graph as an adjacency matrix:

$\mathbf{G} =$

	A	B	C
A	0	1	1
B	1	0	0
C	1	0	1



Network theory

- Natural questions about networks arise:
 - What is the shortest path between two nodes. (Dijkstra's Algorithm)
 - **Applications:** routing packets on the internet as to reduce transmission delay, laying cables, delivering items, google maps, sat nav....
 - In walk, can we visit each node exactly once in a graph and arrive home, what is this path? (Hamiltonian paths, Travelling salesman problem)
 - **Applications:** UPS, FEDEX, Tesco delivery, optimally cutting metal with a robot arm. (In fact any NP-Complete problem!)
 - **What is the most important node in a network (centrality, will talk about this later)**
 - **What is the typical distance between two nodes? (small-world)**

