Take Home Lessons from Today 9-21-23

1. A number of myths have arisen concerning brain structure and the uniqueness of the human brain. Let's bust those.
   a. Despite a constantly used number of 100 billion neurons in a human brain, **the actual number is 86 billion neurons**. A human brain has about the same number of accessory (non-neural) glial cells to hold everything together. That is proportionately fewer glial cells than other animals.
   b. **There is no factual basis in the assertion that we only use 10% of our brains**.
   c. **When scaled against other primates, neither our total brain size or cerebral cortex is significantly larger than expected for a primate of our size (160 lbs, 5 feet 7 inches tall). Our cerebellum is slightly bigger than expected (motor function).** Note, according to this, a gorilla just has a surprisingly large body by comparison to all other primates.

2. Whales and elephants have larger brains with more neurons than humans.

3. **The basic unit of the brain is a neuron, which functions to receive signals then send signals to other neurons if appropriate input signals were received.**

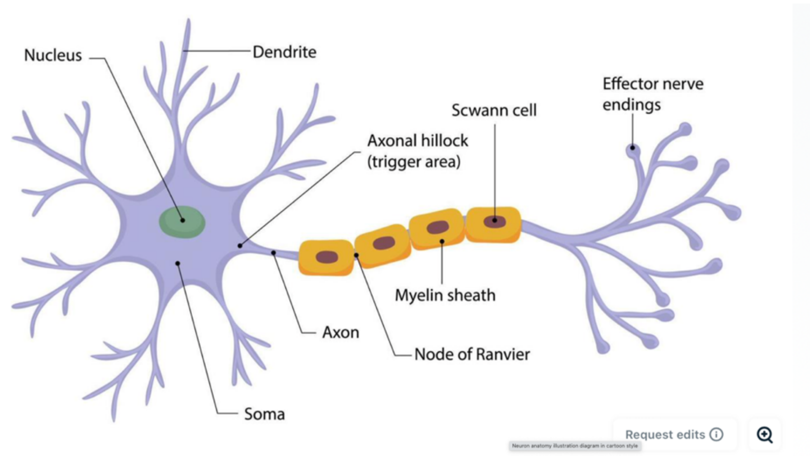
4. **Each neuron is connected to perhaps a thousand other neurons through synapses**. "Since neurons interact combinatorially through the synapses they establish with one another, and further so as they interact in networks, the increase in cognitive abilities afforded by increasing the number of neurons in the brain can be expected to increase exponentially with absolute number of neurons, **and might even be subject to a thresholding effect once critical points of information processing are reached."**

5. **The key to brain activity is the system of neuron networks that operate to provide higher-order function.** The networks are based on which neurons are connected to each other. In simulations, these types of networks behave very differently, and with much more coordinated complexity, than any individual neuron in the network.

6. **The *C. elegans* worm has 302 neurons and for 20 years we have known exactly how each neuron is connected to all of the other cells of the worm including the other neurons.** There are clearly networks that have specific function (sensory signal in, processing, signal for an appropriate action out to the muscles). *Nevertheless, we do not yet know the specifics of how this brain works to keep the worm alive.*

7. **Considering humans have 86 billion neurons, we will not know exactly how our brain works for the foreseeable future.** However, it is reassuring that we are 284 million times more complicated than a worm.

Neuron Review:



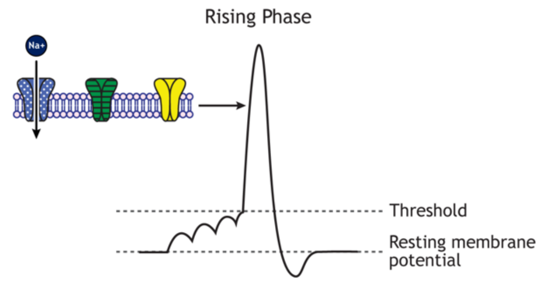


Figure 6.11. Voltage-gated sodium channels open once the cell's membrane potential reaches threshold. The rapid influx of sodium results in a large depolarization called the rising phase. The dotted, blue channels represent voltage-gated sodium channels; the striped, green channels represent voltage-gated potassium channels; the solid yellow channels represent chloride channels. 'Rising Phase' by Casey Henley is licensed under a Creative Commons Attribution Non-Commercial Share-Alike (CC-BY-NC-SA) 4.0 International License.

1. **The basic processing unit of the brain is a neuron cell.**
2. **When a neuron receives an appropriate number of signals through its dendrites, it fires an action potential down its axon and releases neurotransmitters that activate the dendrites of the neurons it is connected to and the signal moves through the brain.** When a neuron receives a signal, some sodium pores open and some sodium diffuses in. If this happens enough and from the right dendrites, it triggers a full opening of all local pores, even more sodium rushes in, eventually triggering the potassium pores to open so potassium rushes out. These actions balance the sodium and potassium "chemical springs", then the special molecular pump kicks in and restores the resting state along this part of the membrane. This whole process is called an "action potential".
3. The signal is propagated in one direction down the axon as the process in **2.** is repeated until the effector arms are reached.
4. When an action potential travels down an axon to the end of the effector arms of a neuron in the presynaptic neuron, this causes calcium channels to open and allow Ca^{2+} ions to rush in. The calcium ions trigger vesicles ("sacks") filled with neurotransmitters to release the neurotransmitters into the synaptic cleft. The neurotransmitter is received by specific receptors on the postsynaptic membrane, causing them to open sodium channels. If enough neurotransmitter is received, the action potential is transferred to the postsynaptic neuron and it fires off an action potential that proceeds down the axon and might activate other neurons that are attached by chemical synapses.
5. **A neuronal signal enters the brain, generally from the senses, is processed in the appropriate area then after it is interpreted, a signal is forwarded to different areas that generate an appropriate response or action.** The various connections between neurons facilitate appropriate responses through direct axonal connections. These connections are created during brain development in the first years of life. **Connections that are used survive, neuronal connections that are not used during development are "pruned".** Early experiences leave permanent pathways and connections in the brain.
6. **Rewarded behaviors are reinforced through release of neurotransmitters such as dopamine, serotonin and oxytocin from specific areas of the limbic system.** The neurotransmitters spread through other appropriate areas of the brain, thereby modifying how those neurons respond to inputs in their dendrites and how they fire. This is the mechanism though which behavior, mood and feelings are controlled based on experience.

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The human brain in numbers: a linearly scaled-up primate brain

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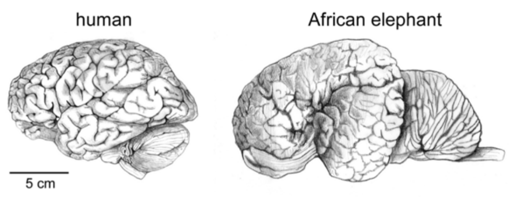

FIGURE 1 | The human brain is not the largest. Brains of a human and of an African elephant are depicted here at the same scale. Drawings by Lorena Kaz based on images freely available from the University of Wisconsin and Michigan State Comparative Mammalian Brain Collections (www.brainmuseum.org).

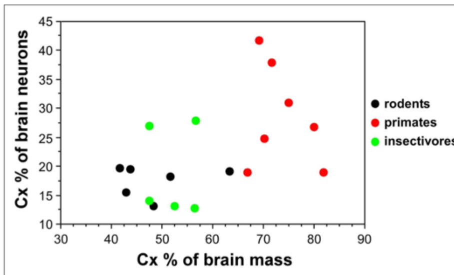

FIGURE 2 | Relative size of the cerebral cortex does not inform about the relative number of neurons in the cortex compared to the whole brain. Each point indicates, for a given species, the average relative cortical mass as a percentage of total brain mass (X-axis) and the average relative number of cortical neurons as a percentage of the total number of neurons in the brain (Y-axis). Data from Herculano-Houzel et al. (2006, 2007); Azevedo et al. (2009); and Sarko et al. (2009).

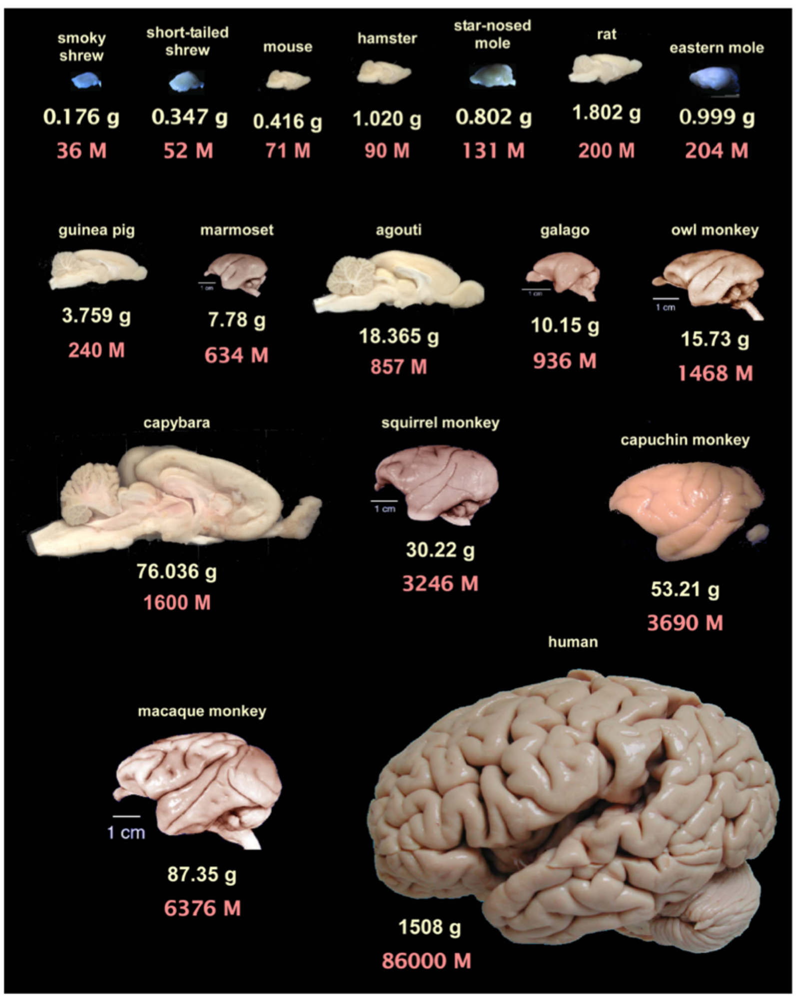

FIGURE 3 | Brain mass and total number of neurons for the mammalian species examined so far with the isotropic fractionator. Brains are arranged from left to right, top to bottom, in order of increasing number of neurons according to average species values from Herculano-Houzel et al., 2006 (rodents), Herculano-Houzel et al., 2007 (non-human primates), Sarko et al., 2009 (insectivores) and Azevedo et al., 2009 (human brain). Rodent brains face right, primate brains face left, insectivore brains can be identified in the figure by their bluish hue (due to illumination conditions). All images shown to the same scale. Primate images, except for the capuchin monkey and human brain, from the University of Wisconsin and Michigan State Comparative Mammalian Brain Collections (www.brainmuseum.org). Insectivore images kindly provided by Diana Sarko, and human brain image by Roberto Lent. Rodent images from the author. Notice that some rodent brains, such as the agouti and the capybara, contain fewer neurons than primate brains that are smaller than them.

WHALE TIMEOUT

TIME IN Back to humans

Table 2 | Expected values for a generic rodent and primate brains of 1.5 kg, and values observed for the human brain (Azevedo et al., 2009).

	Generic rodent brain	Generic primate brain	Human brain
Brain mass	1500 g	1500 g	1508 g
Total number of neurons in brain	12 billion	93 billion	86 billion
Total number of non-neurons in brain	46 billion	112 billion	85 billion
Mass, cerebral cortex	1154 g	1412 g	1233 g
Neurons, cerebral cortex	2 billion	25 billion	16 billion
Relative size of the cerebral cortex	77% of brain mass	94% of brain mass	82% of brain mass
Relative number of neurons in cerebral cortex	17% of brain neurons	27% of brain neurons	19% of brain neurons
Mass, cerebellum	133 g	121 g	154 g
Neurons, cerebellum	10 billion	61 billion	69 billion
Relative size of the cerebellum	9% of brain mass	8% of brain mass	10% of brain mass

Notice that although the expected mass of the cerebral cortex and cerebellum are similar for these hypothetical brains, the numbers of neurons that they contain are remarkably different. The human brain thus exhibits seven times more neurons than expected for a rodent brain of its size, but 92% of what would be expected of a hypothetical primate brain of the same size. Expected values were calculated based on the power laws relating structure size and number of neurons (irrespective of body size) that apply to average species values for rodents (Herculano-Houzel et al., 2006) and primate brains (Herculano-Houzel et al., 2007), excluding the olfactory bulb.

Since neurons interact combinatorially through the synapses they establish with one another, and further so as they interact in networks, the increase in cognitive abilities afforded by increasing the number of neurons in the brain can be expected to increase exponentially with absolute number of neurons, and might even be subject to a thresholding effect once critical points of information processing are reached. In this way, the effects of a three-fold increase in numbers of neurons may be much more remarkable when comparing already large brains, such as those of humans and gorillas, than when comparing small brains, such as those of squirrel monkeys and galagos.

SCIENTIFIC AMERICAN

100 Trillion Connections
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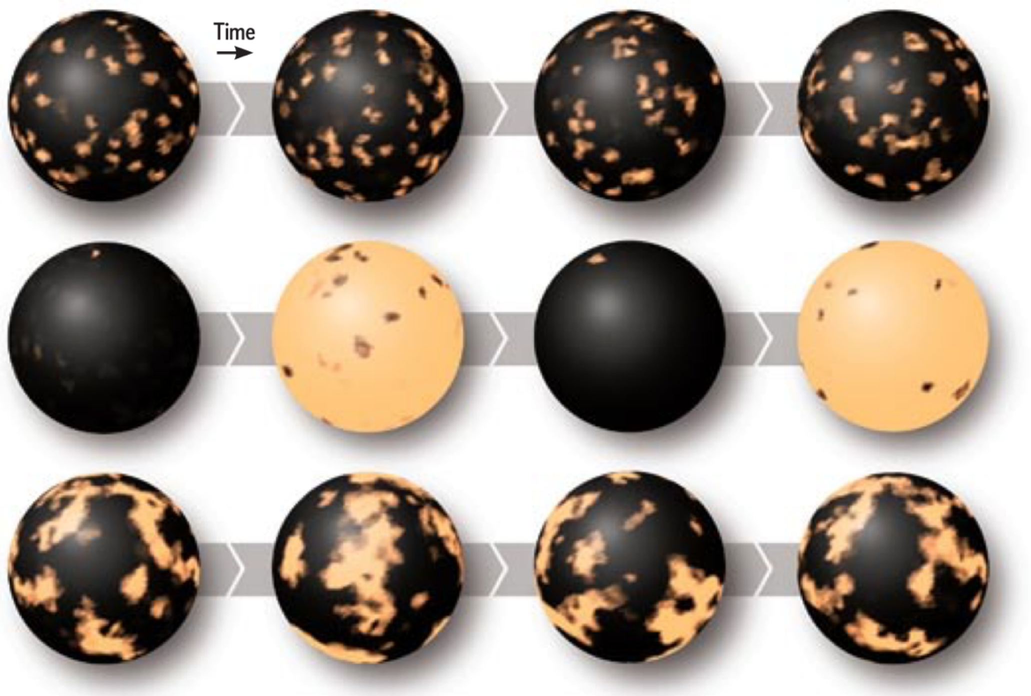
Stable URL: https://www.jstor.org/stable/10.2307/26002353

Anatomy of a Toy Brain

A brain simulation crafted by Olaf Sporns and his colleagues at Indiana University gives rise to three different patterns of connections among 1,600 virtual neurons arrayed around a sphere. The simulation—in which some neurons activate spontaneously (*yellow areas*) while the rest remain dormant—helps researchers deduce how different types of networks produce complex interactions, some of which replicate activity that occurs throughout actual brain circuits.



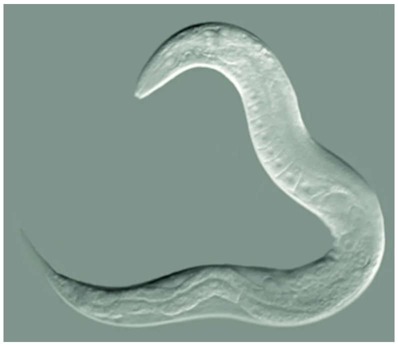
Neurons linked only to immediate neighbors show isolated random flickers of activity over time.

When every neuron links to every other, the brain develops large-scale patterns of activity in which the ensemble of cells remains almost fully activated or entirely quiescent.

A mix of short- and long-range connections produces a moderate level of hard-to-predict activity resembling that of real brains.

WORM TIMEOUT

C. elegans is a worm with 302 neurons and we know how all of them are connected.



Sydney Brenner

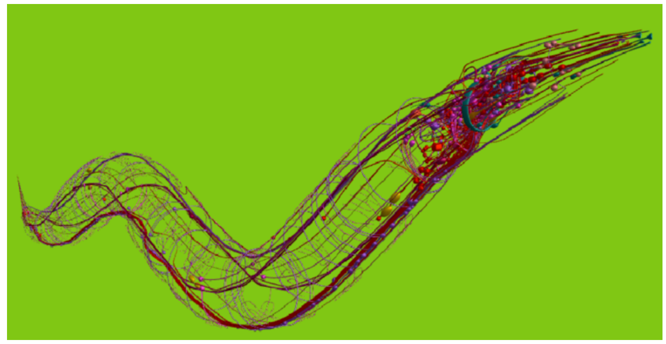
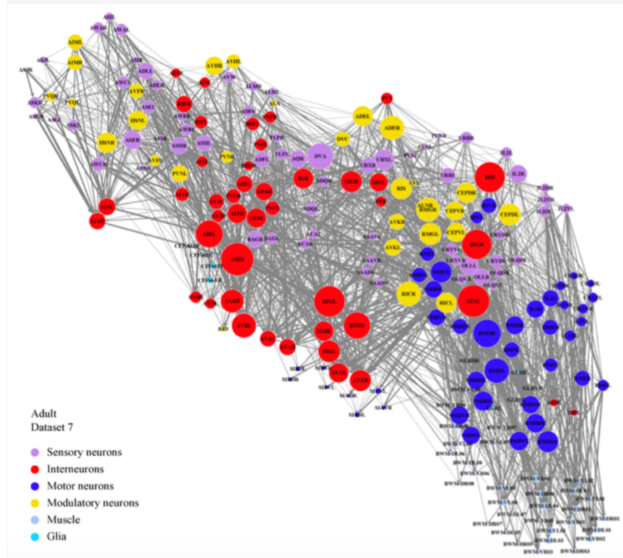


Figure A2. Closeup of an adult brain connectome (dataset 7). Each circle represents a cell. Circle colour denotes cell type. Circle size is proportional to the connection number of a cell. Each line represents a connection with at least one chemical synapse between two cells, and line width is proportional to synapse number per connection.



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Modeling the Evolution of Biological Neural Networks Based on *Caenorhabditis elegans* Connectomes across Development

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Figure 1: Controlling the *C. elegans* neural network.

From: Network control principles predict neuron function in the *Caenorhabditis elegans* connectome

LETTER

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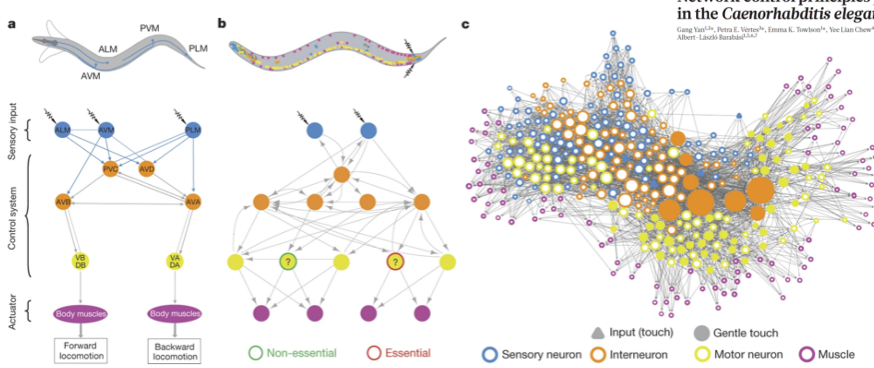
Network control principles predict neuron function in the *Caenorhabditis elegans* connectome

Gang Yan, Petra E. Vértes, Emma K. Towlson, Yee Lian Chew, Denise S. Walker, William R. Schafer & Albert-László Barabási

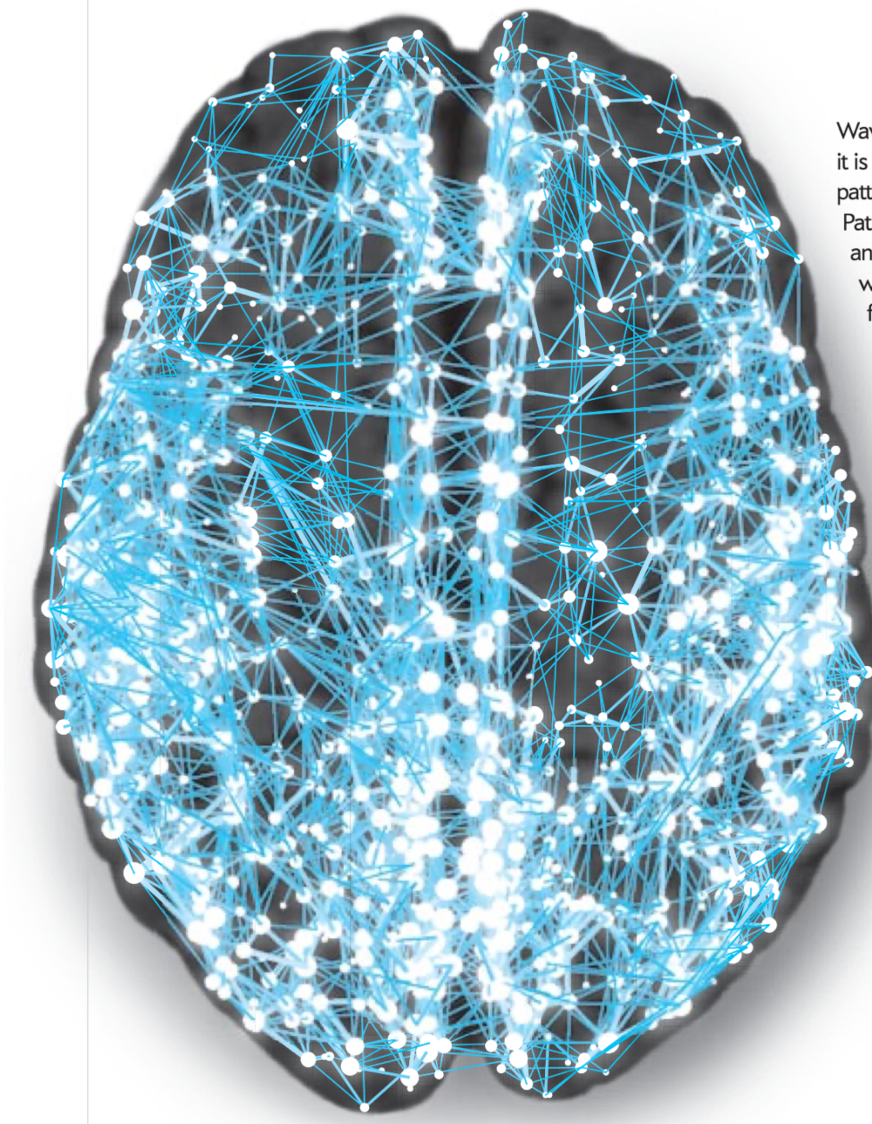


a, Schematic neural circuit for locomotor response to gentle touch in *C. elegans* (adapted after ref. 30; see Supplementary Information section IIIA). **b**, Graphical representation of the proposed control framework. According to the principles illustrated in Fig. 2a–d, if removal of a neuron disrupts controllability of the muscles, we designate it 'essential' for locomotion; if not, we call it 'non-essential'. To make this assessment, we first mapped the *C. elegans* responsive locomotor behaviours into a target network control problem, asking to what degree the sensory neurons (blue) can control the muscles (pink). This allowed us to predict the previously unknown involvement of PDB in *C. elegans* locomotion, and functional differences between individual neurons within the DD neuronal class. **c**, The *C. elegans* connectome used in our study, consisting of 279 neurons (the 282 non-pharyngeal neurons, excluding CANL/R and VC06 which do not make connections with the rest of the network) and 95 muscles. Node size is proportional to the sum of its in- and out-degrees. Filled nodes represent the neurons traditionally assigned to the circuits responsible for gentle touch response, hinting at the complexity of predicting neuronal function from the wiring diagram alone.

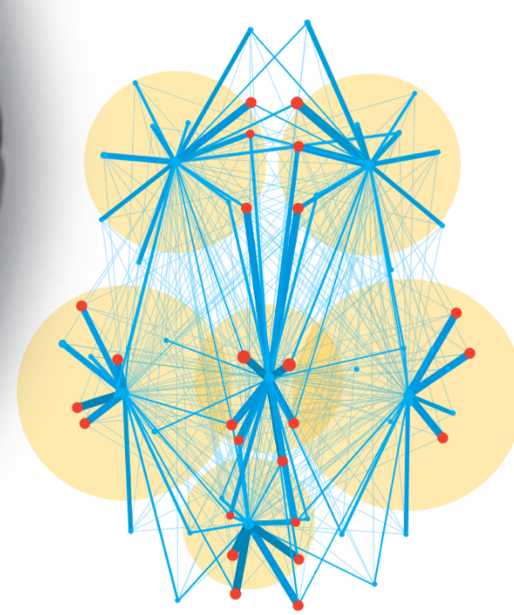
TIME IN Back to humans

Small Worlds from Large Networks

Waves of electrical activity sweep across the brain, even when it is at rest. A number of studies now try to map these neural patterns because they may play a critical role in mental life. Patric Hagmann of the University of Lausanne in Switzerland and Olaf Sporns of Indiana University have charted the brain with a technique called diffusion tensor imaging. They found that the dense network of connections (*left*) has a few well-connected hubs (*red dots*) through which many links pass (*below*). Such "small-world" networks of hubs may help our brains process information more rapidly and allow the organ to maintain its structural integrity efficiently.



Large network



Small-world network