

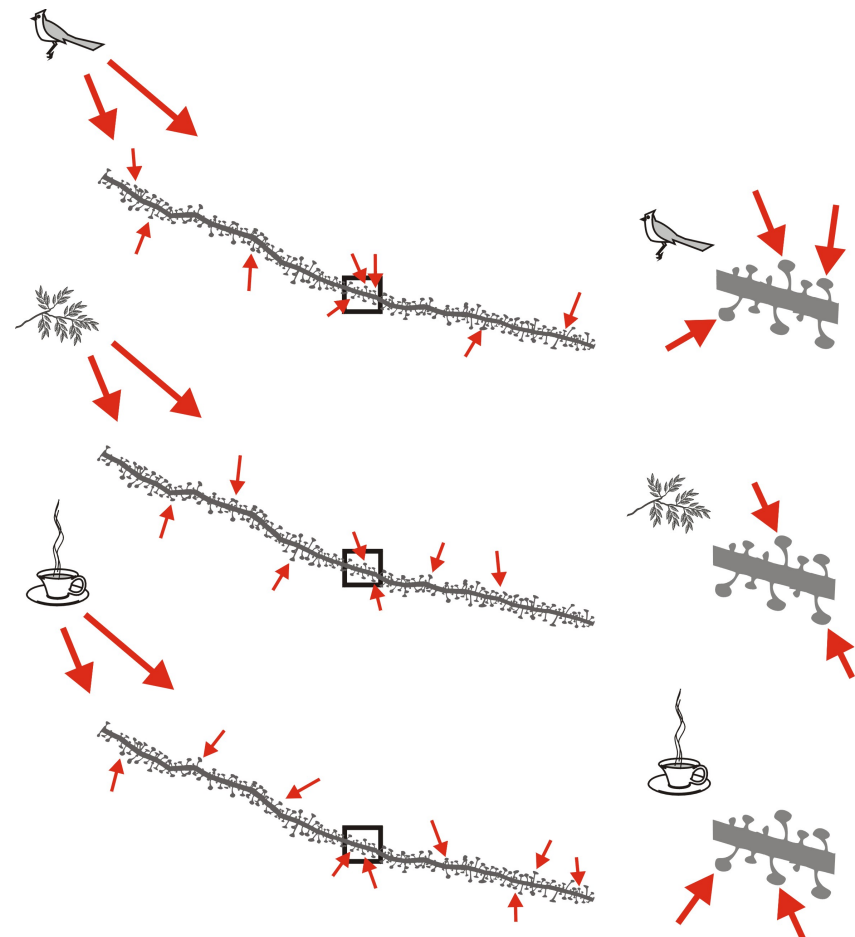
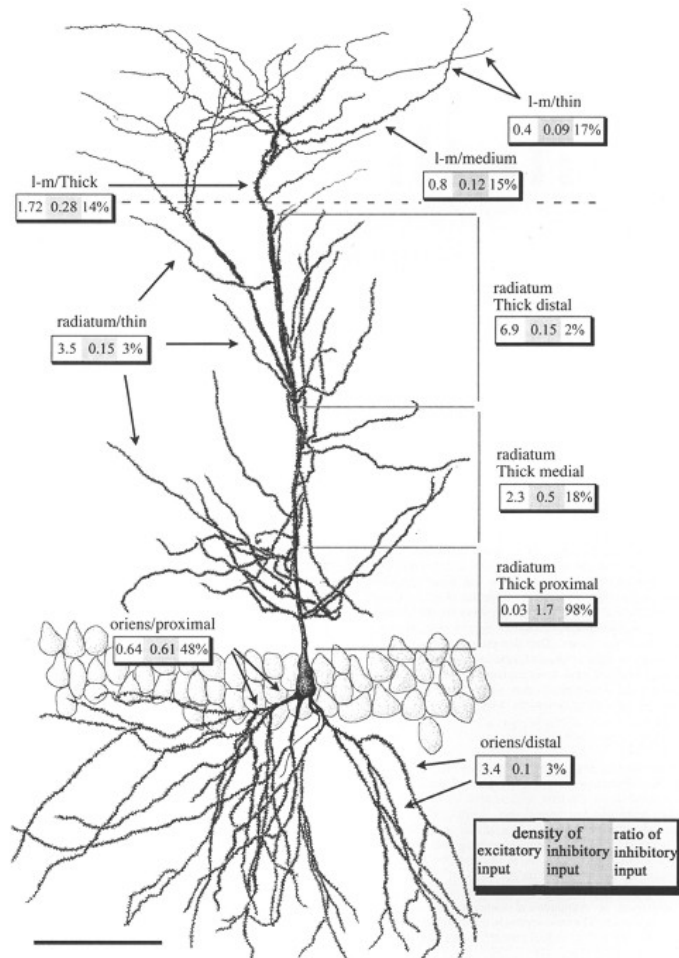
The case for quantum entanglement in the brain

Charles R. Legéndy

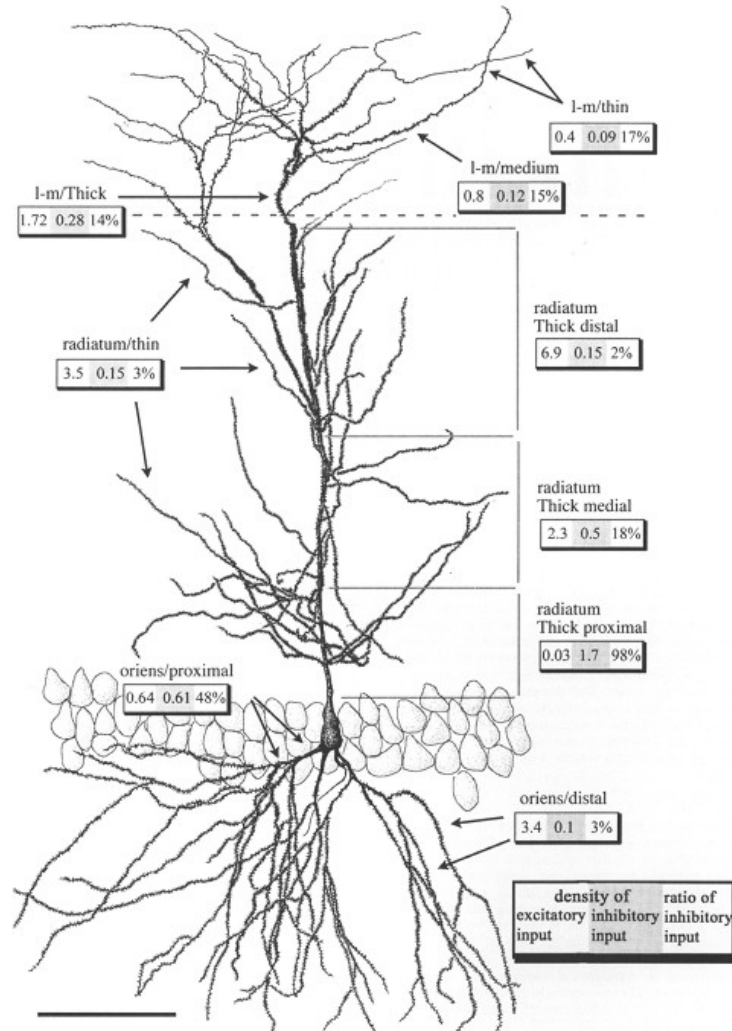
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- Introduction
- Many-neuron cooperative events
- The challenge of reviving a cell assembly after it has been overwritten by other cell assemblies
- The argument for quantum entanglement

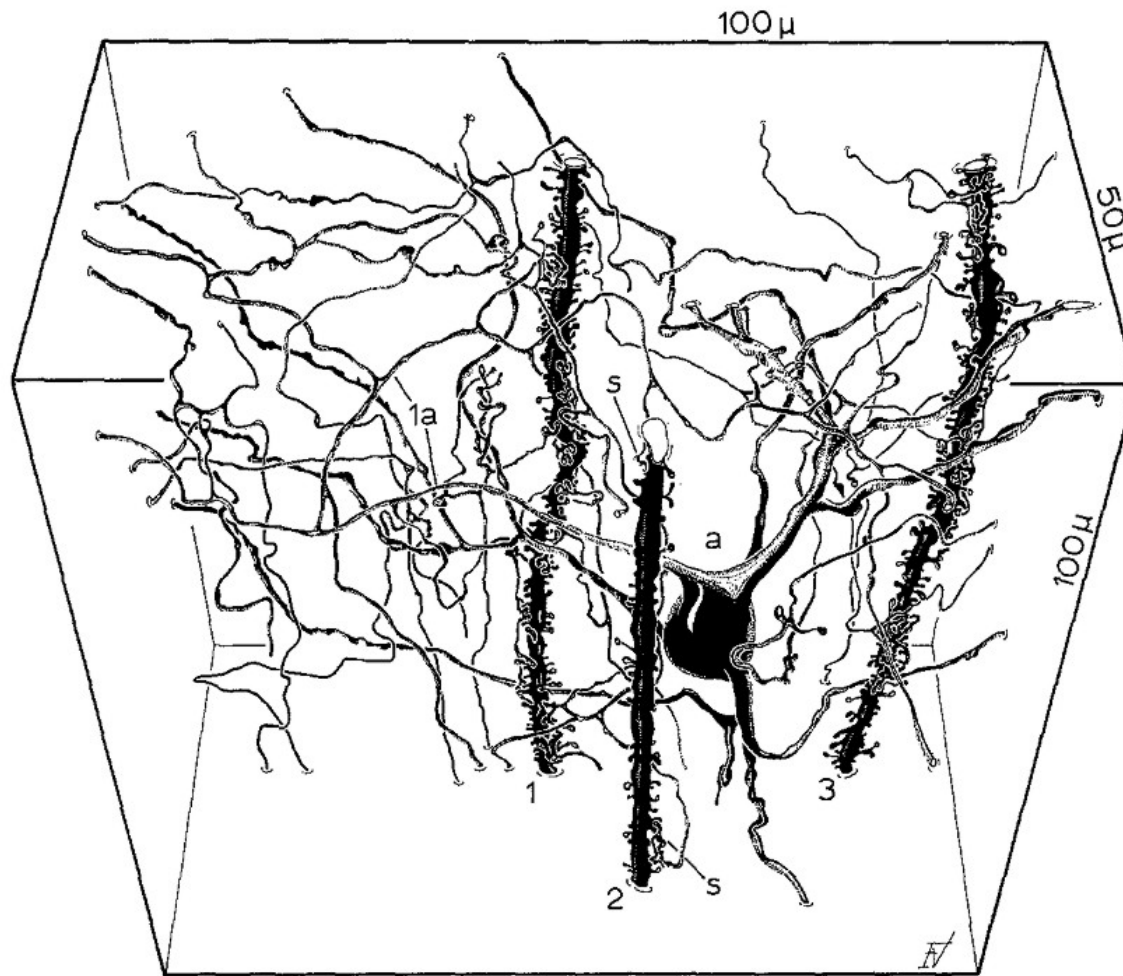
Meaningful inputs enter neurons on sets of synapses, linked by shared function – and certain contexts call for direct links to unite these synapses sets¹. Quantum entanglement is a possible candidate to provide them.



The dendritic tree from the last slide: a pyramidal cell from the hippocampus of a rat². Scale bar 100 μ m
(Megías et al, 2001)

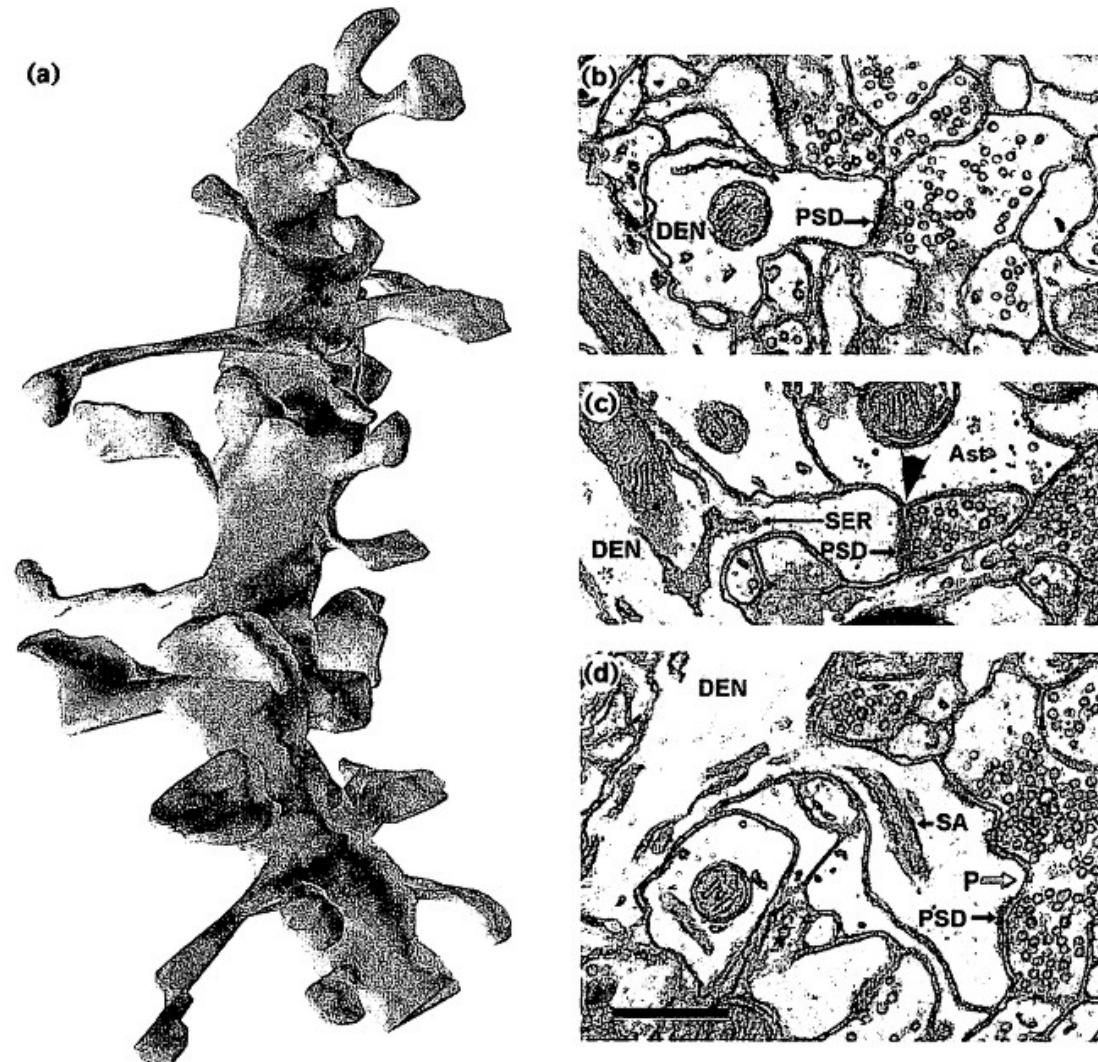


Dendrites, covered with synaptic spines, and some axons from a nearby neuron (Valverde and Ruiz-Marcos, 1969)



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The appearance of dendrites and their synaptic spines at electron microscope magnification. This is a 7 μm piece of a dendrite, with 25 synaptic spines on it (Harris, 1999)



The output of cortical neurons is a sequence of spikes
(of “firing”), usually at irregular time intervals



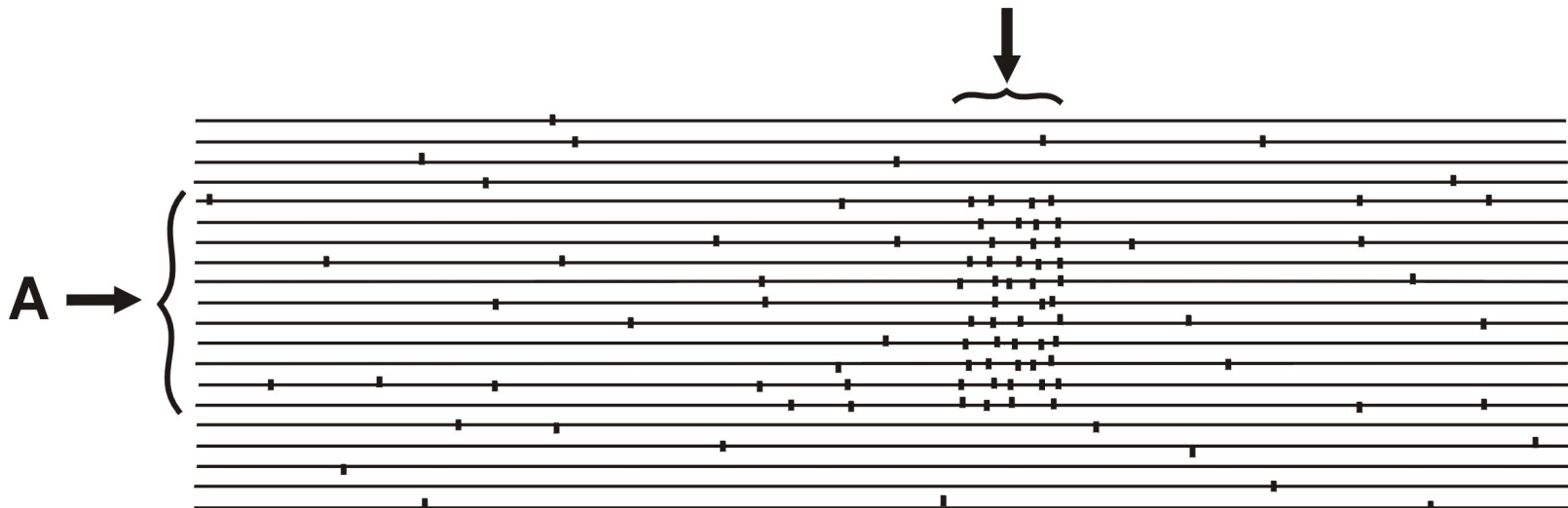
2. Many-neuron cooperative events

The cell assembly theory of the brain³

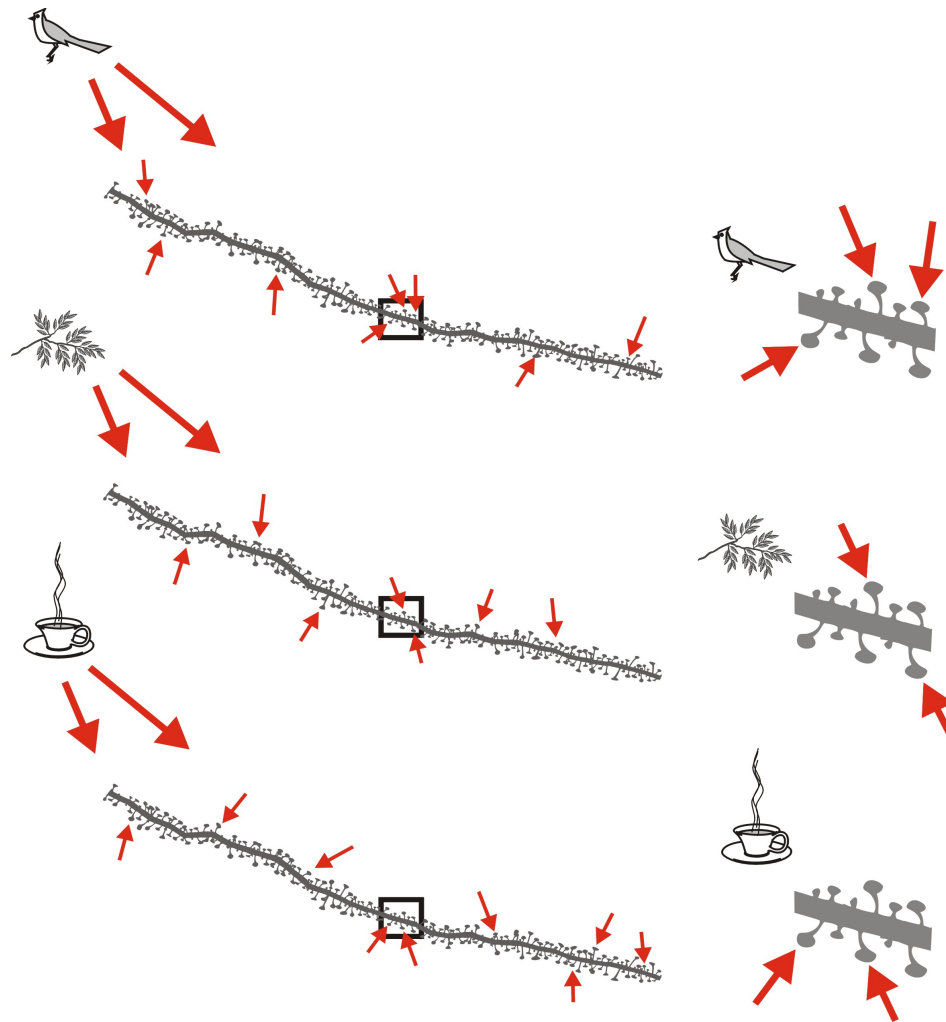
- Mental entities, as well as components of mental entities, are represented by groups of neurons (“cell assemblies”; Hebb, 1949)
- The groups are structureless; and they can overlap; existing assemblies do not constrain their membership. Once assigned, the membership remains fixed. Functional unity of the groups is provided by reinforcement of all synapses between their neurons.
- When the parameters are right, cell assemblies are capable of chain-reaction-like cascades of firing (“ignitions” – Legéndy, 1967), whereby firing spreads to all group members but not beyond, and is then silenced (by a combination of refractoriness and inhibition).
- Cell assemblies must contain enough neurons to exceed “critical size” for ignition, and to send out enough axonal branches with synapses to be “recognizable” to all neurons in their region.
- Structure is added to mental entities through linkages between different cell assemblies, resulting in reproducible timing of their ignitions, thereby conveying syntactic relations (Legéndy, 2009)

Ignitions appear to the rest of the brain as “volleys” well detectable over the usual random firing of neurons

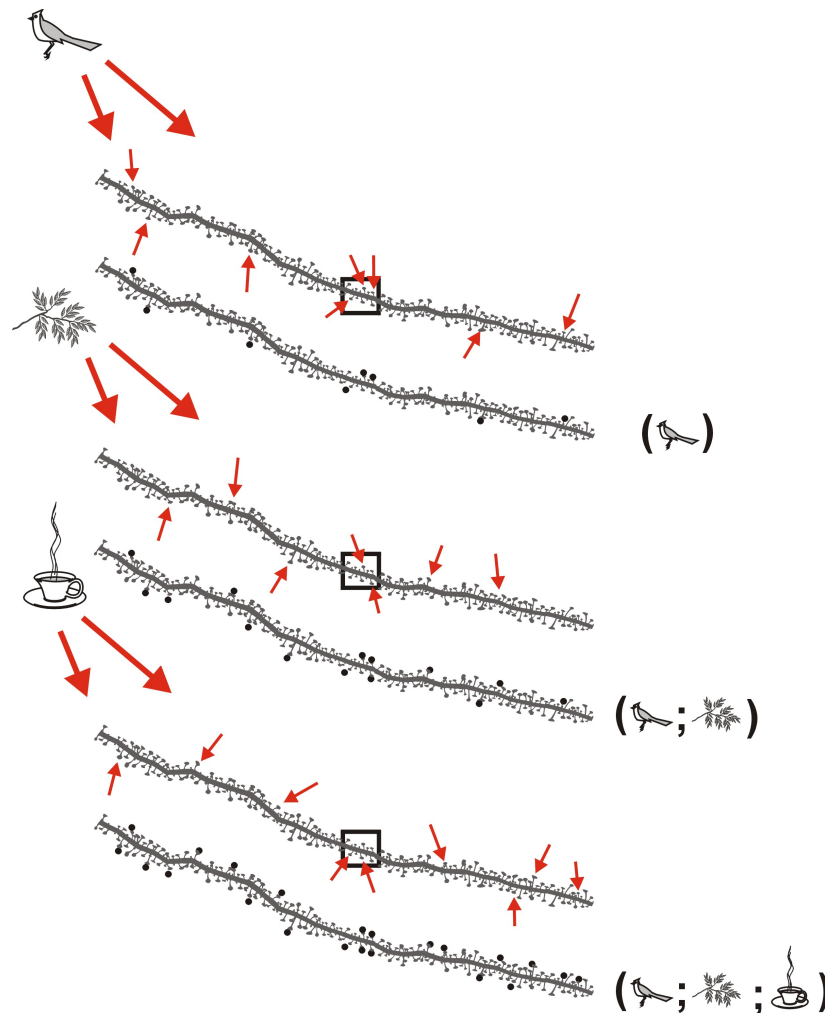
- Intense volleys like this induce long-term potentiation (LTP).
- The LTP-inducing machinery is in effect a detector of low-probability events (“surprising” events) in spike trains.
- LTP increases the synaptic weights on its synapses (A).



Multisynaptic volleys (from ignitions) have great combinatorial diversity – but the data tell us that their effect on the neurons ignores most of it – it is solely determined by the sum of synaptic weights at the inputs



“Learning” via LTP consists of increasing the synaptic weights at the synapses excited, and “normalization” by decreasing the rest of the weights, when positive (long-term depression, LTD)⁴

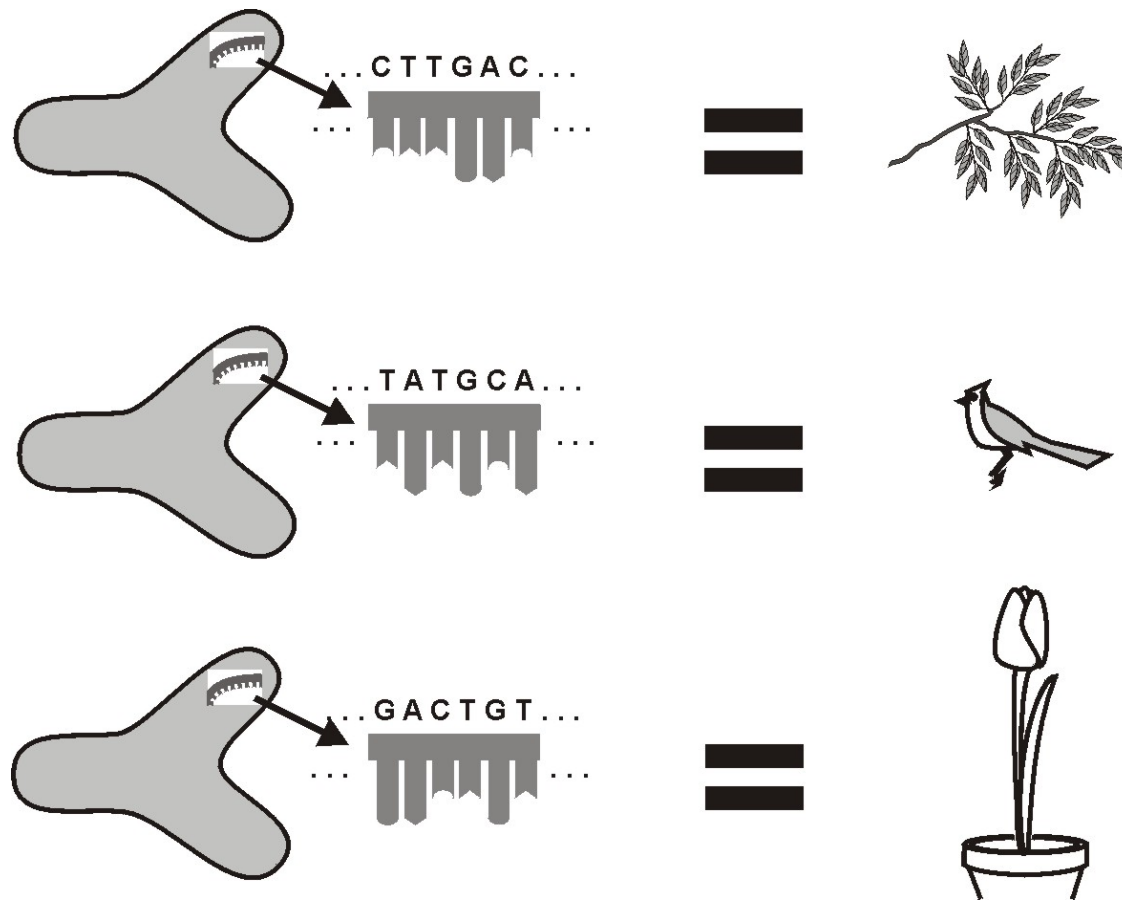


3. The challenge of reviving a cell assembly after it has been overwritten by other cell assemblies

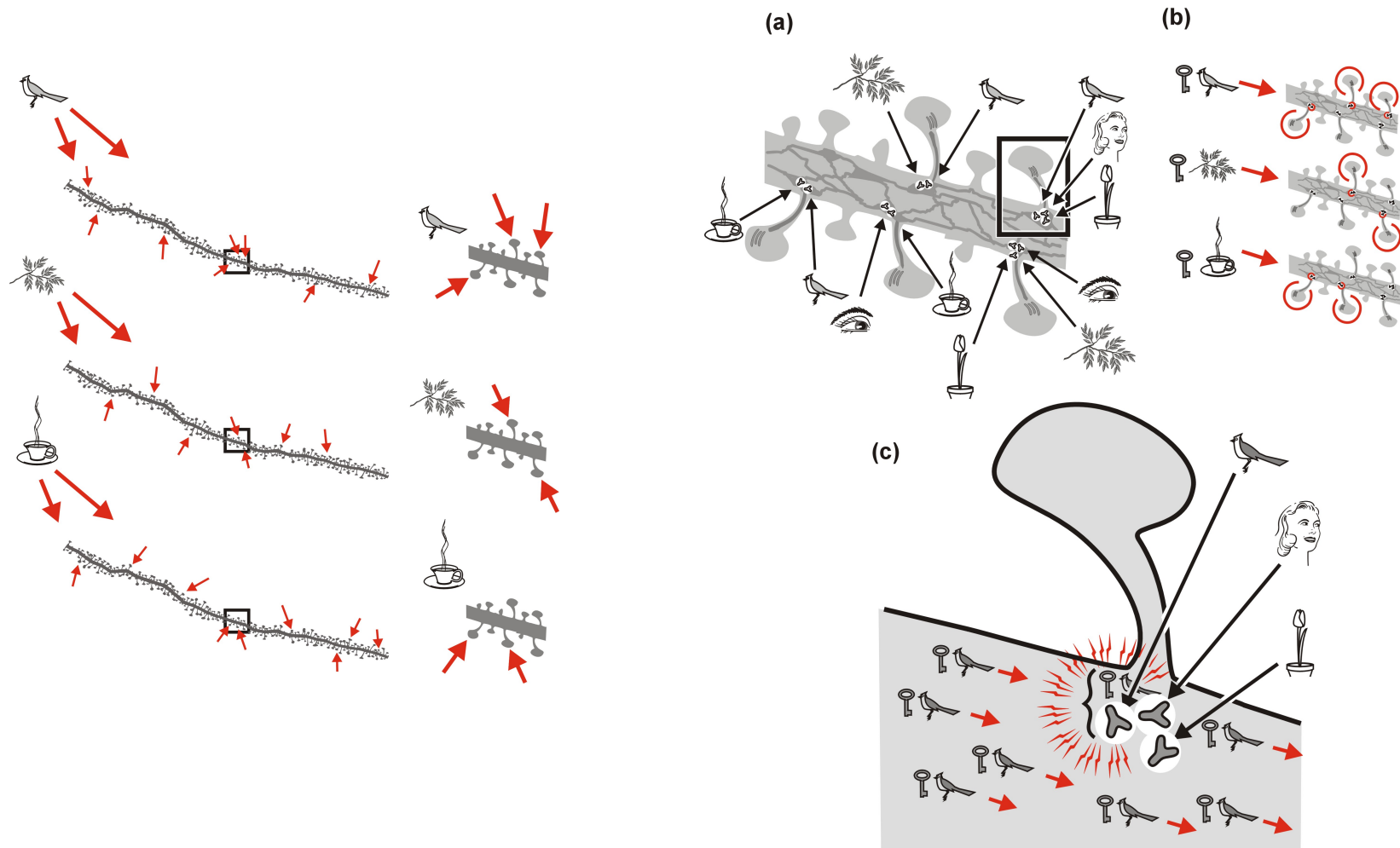
The trouble is: if learning can change nothing other than the synaptic weights, those changes will be buried after a while.⁵ Only the newest cell assemblies will be ignitable; the rest will be “lost”

- It follows that actual brains have a backup system able to revive lost cell assemblies (and the backup utilizes the full diversity of inputs!)
- Reviving a cell assembly means making its connecting synapses stronger than the rest, like when the cell assembly was newly formed.
- Reaching the right synapses (which are mixed in with other irrelevant ones), from the agent that calls for reviving the cell assembly, requires action at a distance – possibly making use of some information-rich molecular messengers.

Proposed molecules for use in targeted remote action:
Random-sequenced RNA/DNA segments, arbitrarily
assigned to mental entities, and serving as “code
words” for the entities thereafter (Legéndy, 2016)



To enable the “bird” synapses to be revived later, it is necessary to place permanent “bird markers” near them. Later, when remotely sent “bird messengers” recognize these, they can initiate synapse growth⁶



4. The argument for quantum entanglement

The disadvantage of pure molecular messaging as opposed to its combination with quantum communication

- Molecular messaging can, in principle, achieve targeted action at a distance – but the messengers needed are too large (at least 10 nm). Therefore they move too slowly. Also, they take up too much space; they'll fill up the brain.
- Alternatively, if molecular messaging is only used at the time of initial memory formation, and used for “hand-carrying” pairs of entangled fragments into their desired places, the entanglement (which is automatically a targeted affair) makes further molecular recognition unnecessary.
- Quantum communication is fast; and complexes of qubits can be super-small.
- In the desired final arrangement, a chemical “restore the assembly” process initiates a state transition at the “Alice” location (at the central decision element); and the resulting state transition at the “Bob” location (at the synapse) initiates the chemical process causing the required growth.⁷

However, in the final configuration:

- Many entangled pairs must be able to communicate simultaneously, without crosstalk
- The quantum entanglement must endure for years – it must be effectively decoherence-free

NOTES

1. There are two other such contexts I can think of, in addition to the one I chose for the purposes of this presentation (all of them having to do with long-term memory; Legédy, 2016); but I left those out to shorten the talk. I think, the one I chose (about reconstructing the lost synaptic patterns in mental images when they are being recalled; see below) was the most clear-cut of the three, and seemed best suited to make my point. In the same vein as “Alice” and “Bob” are sometimes invoked in connection with quantum communication, I sometimes use “bird,” “leaves,” “coffee,” and others, in connection with the brain (as opposed to for instance “ a_1, a_2, \dots, a_n ”).
2. The neuron shown has about 30,000 excitatory synapses (the barely visible small “hairs”). The drawing shows, for each class of dendritic segment, the number of synapses per micron (the small rectangles list the densities for excitatory and inhibitory synapses and the ratio of the two). This slide, and the next two, serve to illustrate the extraordinary number of synaptic spines on pyramidal cells and the non-trivial communication task involved in addressing a preselected set of them, to the exclusion of all the others (see later slides).
3. The conclusion reached below (that all synaptic patterns are overwritten many times over a lifetime, see next slides) does not depend on the details of the cell assembly theory; it only depends on the assumptions that mental images are represented by sets of interconnected neurons, that the sets can overlap, that they are consistent between different occurrences of the same image, and that storage involves synaptic changes of some sort, between set members.
4. Dots are placed next to the synapses modified by LTP (and kept there); showing that in successive episodes of signal interaction more and more of the synaptic weights become modified – until eventually all of them do, upward and downward, many times, and all old patterns are thoroughly overwritten.
5. The overwhelming evidence indicating that synaptic changes alone are insufficient for explaining long-term memory, or the vast capacity of human brains, is surveyed in the aforementioned paper (Legédy, 2016).
6. The small framed portion in the left-hand drawings is magnified, then magnified again (top center), to show that, as time goes by, more and more “tags” are planted inside the dendrite (some irrelevant ones are also included), each of them uniquely responsive to the messenger specific to its underlying entity. In the upper right-hand sketch the messengers of one entity (“bird”; “leaves”; “coffee”) flood the dendrite, combine with their corresponding tags (receptors) when they recognize them, and wake up the synapses near them. Because of the placement of the tags in the middle drawing, the patterns of woken-up synapses (red circles) match the red arrows in the left-hand drawings (which describe events that occurred much earlier).
7. If the last step were a measurement, as in a quantum computer paradigm, the entangled system would undergo irreversible quantum collapse. But in the system I envision the corresponding step is not strictly speaking a measurement, where the quantum system would interact with a macroscopic classical system; rather, here the entangled quantum system interacts with another quantum system (a molecule). My hope is that (maybe) in such an interaction the state of the entangled system is not ruined to the same degree, and (maybe through a multi-step process) the original situation can be reinstated well enough that the same communication can take place again, whenever needed.

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