Language emergence and neuronal replication

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A sad incident

- We could not collaborate due Michel Kerszberg's stroke
- Had to change the workplan

Main collaborators

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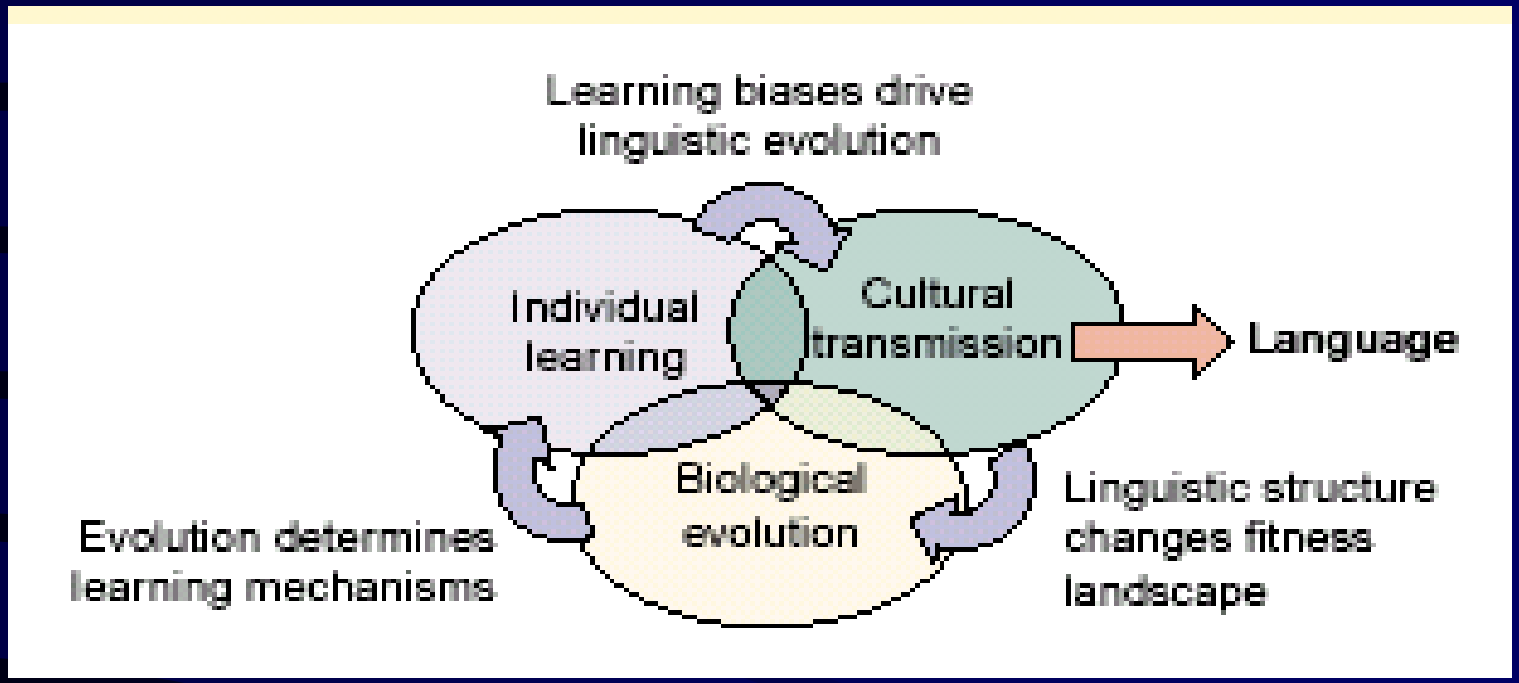
WARNING

- Very exploratory
- May not be true at all
- High risk, high gain

Design features of language

- Compositionality (meaning dependent on how parts are combined)
- Recursion (phrases within phrases)
- Symbolicism (*versus* icons and indices)
- Cultural transmission (rather than genetic)
- SYMBOLIC REFERENCE and SYNTAX

Three interwoven processes



- Note the different time-scales involved
- Cultural transmission: language transmits itself as well as other things, has its own dynamics

Origin of language in the list of major transitions

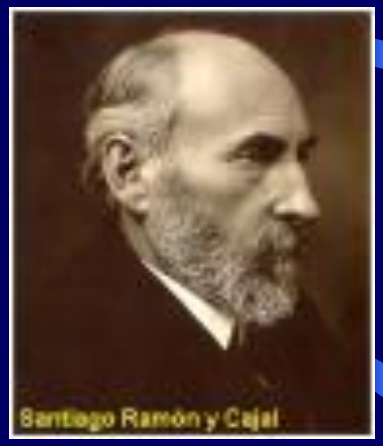
- Novel inheritance system, allows for cumulative cultural evolution
- As epigenetic inheritance systems allow cell differentiation and the division of labour, hence more complex organisms, language allows for more complex societies (Jablonka)
- Allows for culturally defined content of cooperation

Recuerdos de mi vida (Cajal, 1917, pp. 345–350)

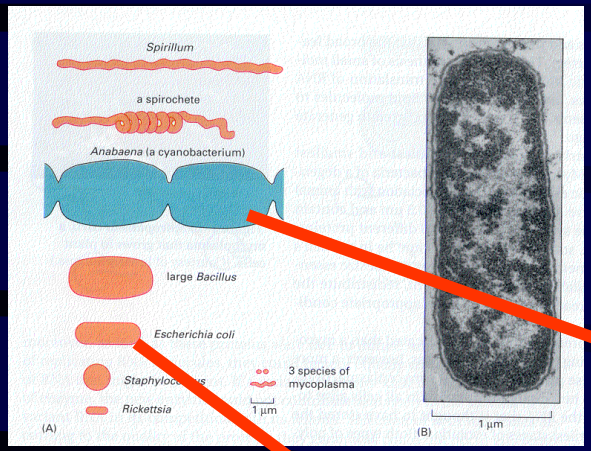
"At that time, the generally accepted idea that the differences between the brain of [non-human] mammals (cat, dog, monkey, etc.) and that of man are only quantitative, seemed to me unlikely and even a little offensive to human dignity. . .

but do not articulate language, the capability of abstraction, the ability to create concepts, and, finally, the art of inventing ingenious instruments. . .

seem to indicate (even admitting fundamental structural correspondences with the animals) the existence of original resources, of something qualitatively new which justifies the psychological nobility of *Homo sapiens*?. . . ''.

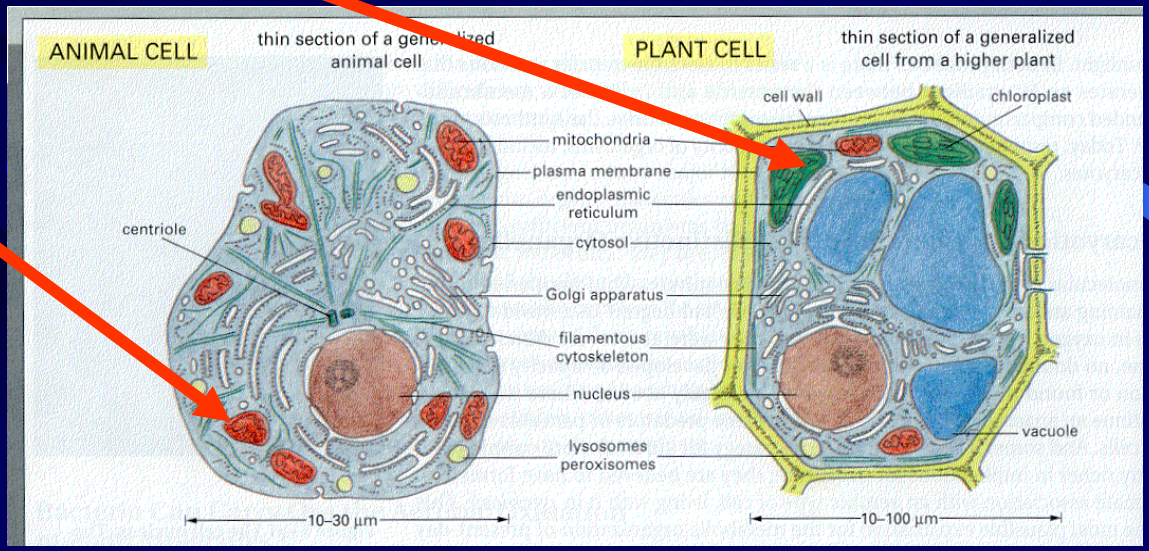


Recruitment (predaptation) is fine, except it is unlikely to give optimal solutions



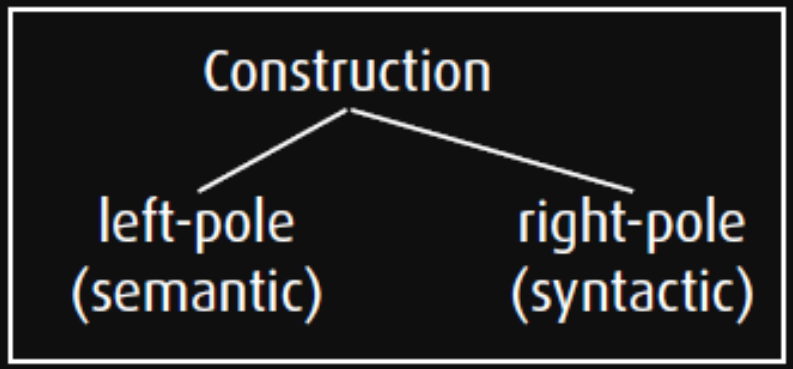
Initial engulfment of bacteria, BUT…

Hundreds of mutations must have gone to fixation!!!

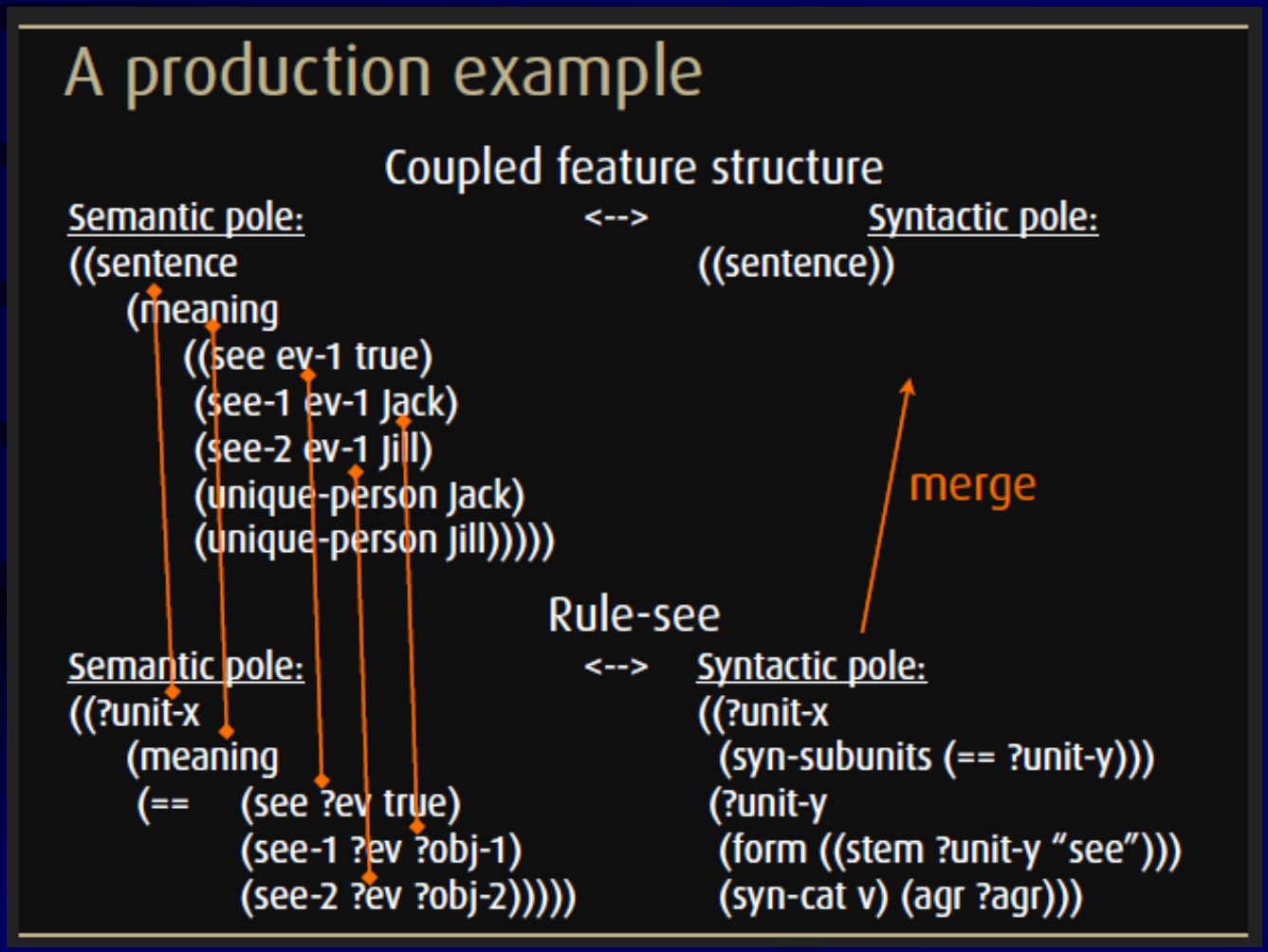


FCG: symbolic pole and semantic pole are linked

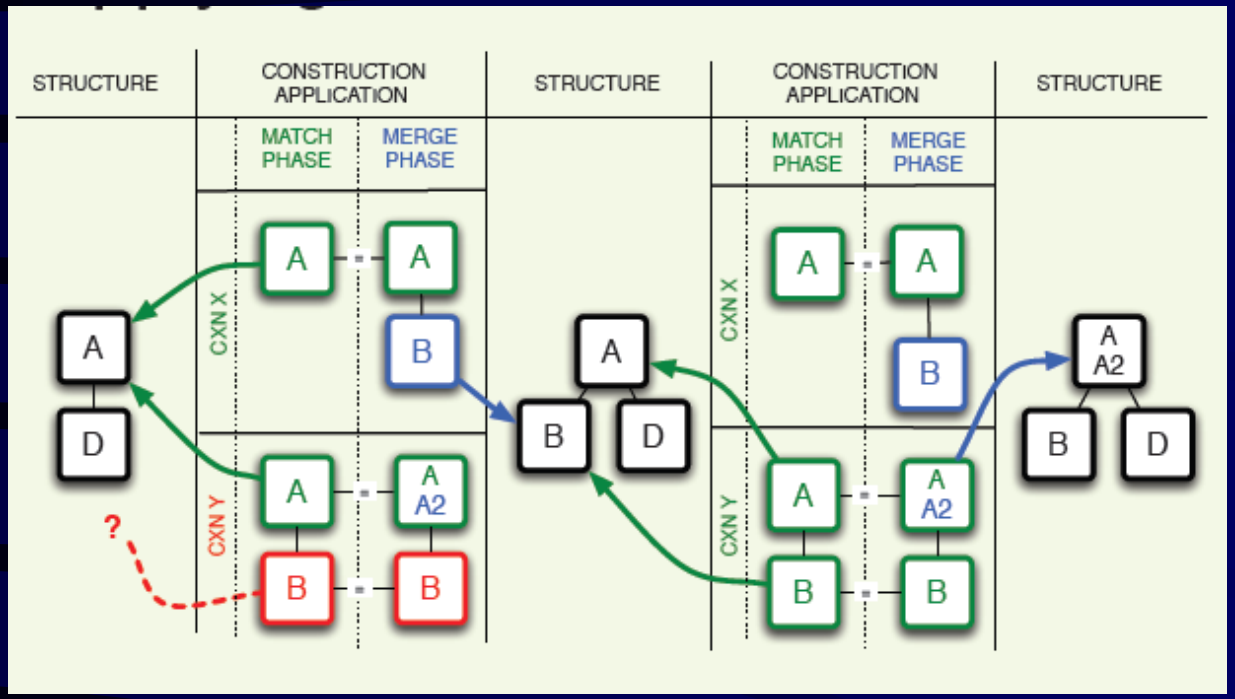
- "Colourless green ideas sleep furiously." (Noam Chomsky)
- syntactically correct, but makes no sense...
- Construction Grammar: form-meaning mappings
- **coupled** feature structures: mappings from form to meaning and vice versa



Applications are quite involved



Fluid Construction Grammar



- A key feature of grammatical constructions (cxns) is their dependence on other cxns. For example, an Adjective-Noun cxn requires an adjectival and a nominal constituent. Capturing such dependencies in a constructional dependency network (CDN) allows for much faster processing because only those cxns triggered by the network need to be considered.

•Both language parsing and production are based on a gradual buildup of a coupled feature structure

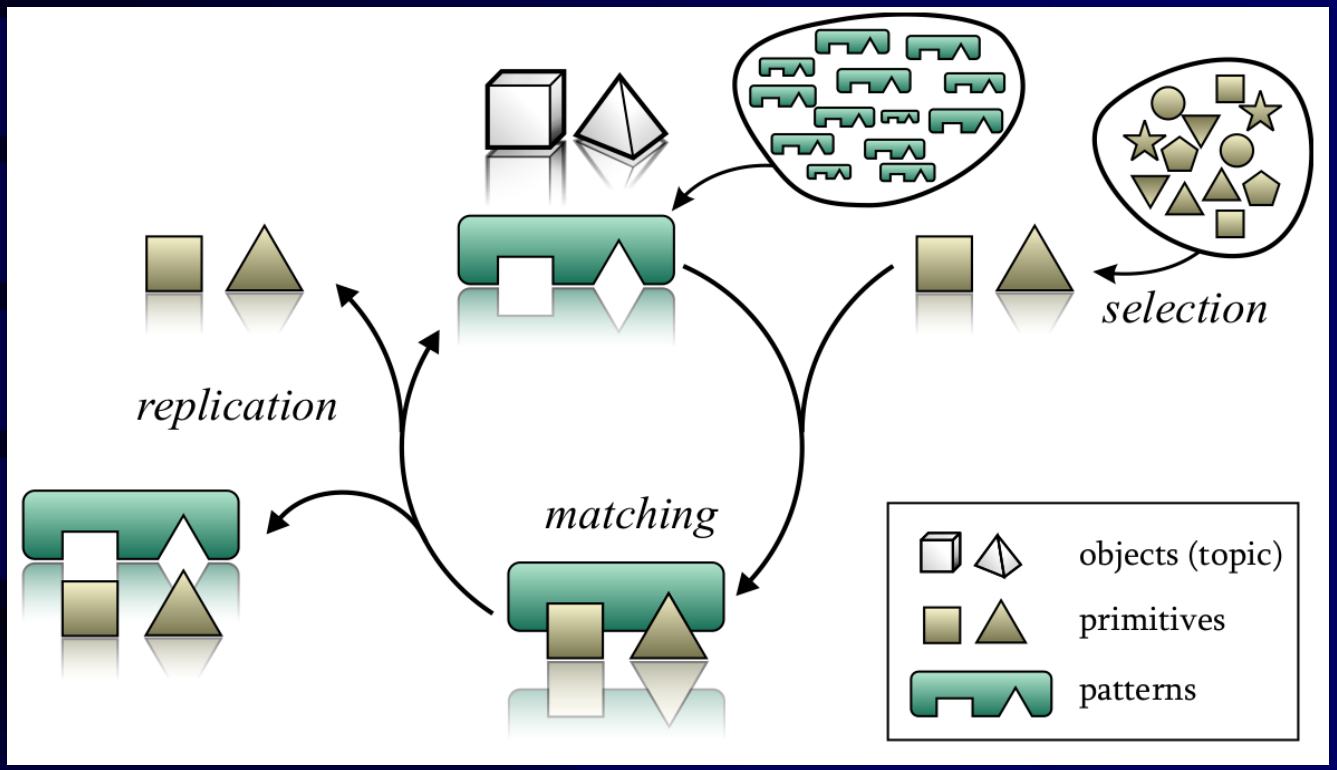
•(cfs) through the repeated application of cxns. A cxn is allowed to modify the cfs if it passes a match and a merge test.

•Given such an application sequence of cxns, we say that a cxn Y depends on a cxn X if it would not have passed the tests without the modifications due to X.

The Elba programme

- An enzyme “knows” how to convert a substrate into a product (and vice versa)
- A grammatical contruction “knows” how to transform feature structures
- Enzymes evolved by natural selection
- Constructions may evolve by “artificial selection” in the brain

Fluid Construction Grammar with replicating constructs

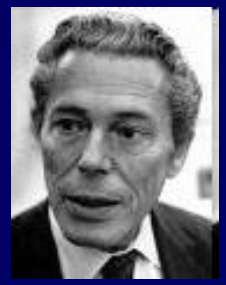


- selective amplification by linked replication
- mutation, recombination, etc.

William James, 1890

- *Every scientific conception is, in the first instance, a 'spontaneous variation' in someone's brain. For one that proves useful and applicable there are a thousand that perish through their worthlessness. Their genesis is strictly akin to that of the flashes of poetry and sallies of wit to which the instable brain-paths equally give rise. But whereas the poetry and wit (like the science of the ancients) are their own excuse for being ... the 'scientific' conceptions must prove their worth by being 'verified'. This test, however, is the cause of their preservation, not of their production...*

Monod, 1971

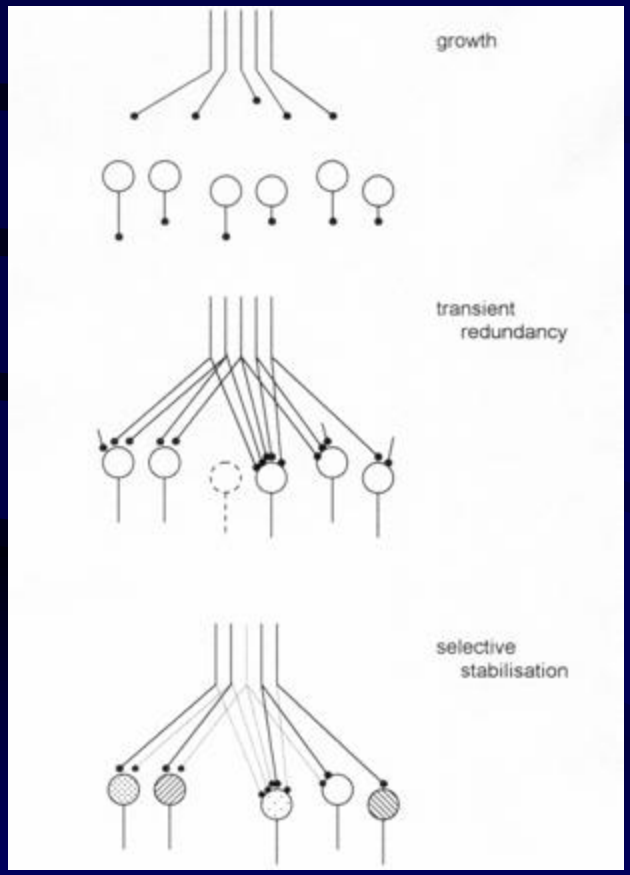


- *For a biologist it is tempting to draw a parallel between the evolution of ideas and that of the biosphere. For while the abstract kingdom stands at a yet greater distance above the biosphere than the latter does above the nonliving universe, ideas have retained some of the properties of organisms. Like them, they tend to perpetuate their structure and to breed; they too can fuse, recombine, segregate their content; indeed they too can evolve, and in this evolution selection must surely play an important role. I shall not hazard a theory of the selection of ideas. But one may at least try to define some of the principal factors involved in it. This selection must necessarily operate at two levels: that of the mind itself and that of performance.*

Changeux, 1973

- There is selection, but without the capacity for the modification of a heuristic search (permitted by the full natural selection algorithm).
- This fundamentally important limitation is admitted by the authors who write *"an organism can not learn more than is initially present in its pre-representations."*

Variation and selection in neural development (Changeux)



- There is vast overproduction of synapses
- Transient redundancy is selectively eliminated according to functional needs
- The statistics and the pruning rules for the network architecture are under genetic control

Edelman, 1987

- Edelmans theory of neuronal group selection proposes that a primary repertoire of neuronal groups within the brain compete with each other for stimulus and reward resources.
- This results in selection of a secondary repertoire of behaviourally proficient groups

There are no units of evolution here!

- We propose that the algorithms of Edelman and Changeux fundamentally consist of a population of stochastic hill-climbers.
- Each neuronal group is randomly initialized, and those groups that are closest to a good solution obtain a greater quantity of synaptic resources allowing them to ‘grow’ and/or ‘change’.
- Thus groups become strengthened but not replicated.

A crucial limitation

- Replication has the advantage of leaving the original solution intact, so that a non-functional variant does not result in loss of the original solution.
- Unless the neuronal group has the capacity to revert to its original state given a harmful variation, in which case it is effectively behaving as a 1+1 Evolutionary Strategy (Beyer 2001), there is the potential that good solutions are lost.

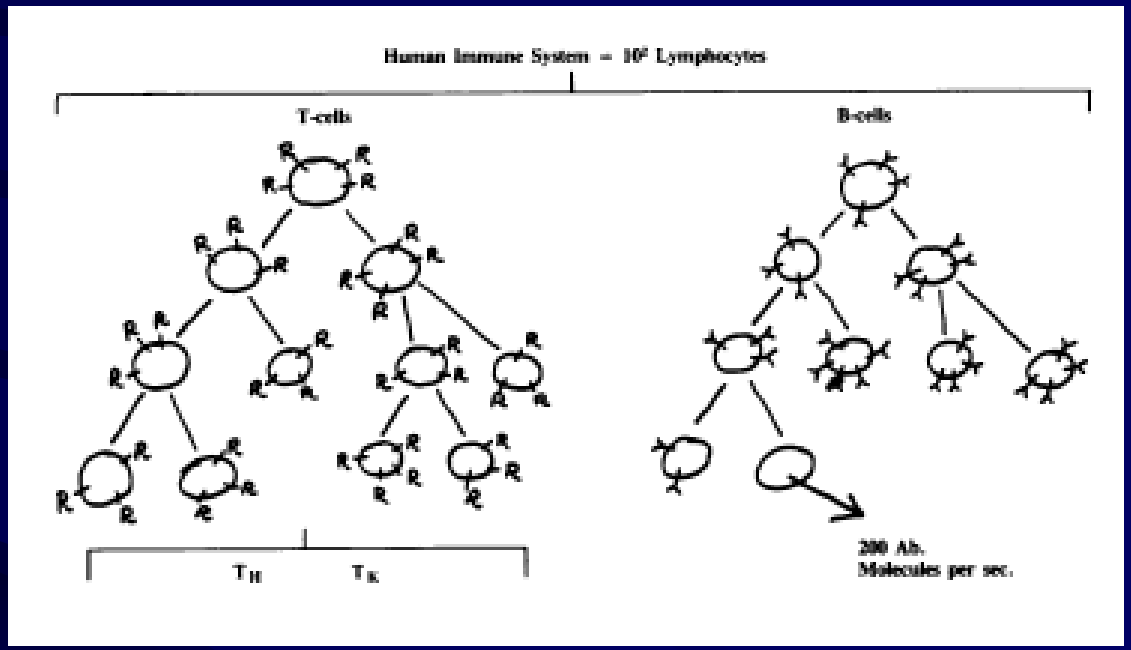
When the Darwinian dynamics reinvented itself

- The case of the adaptive immune system

Niels K. Jerne

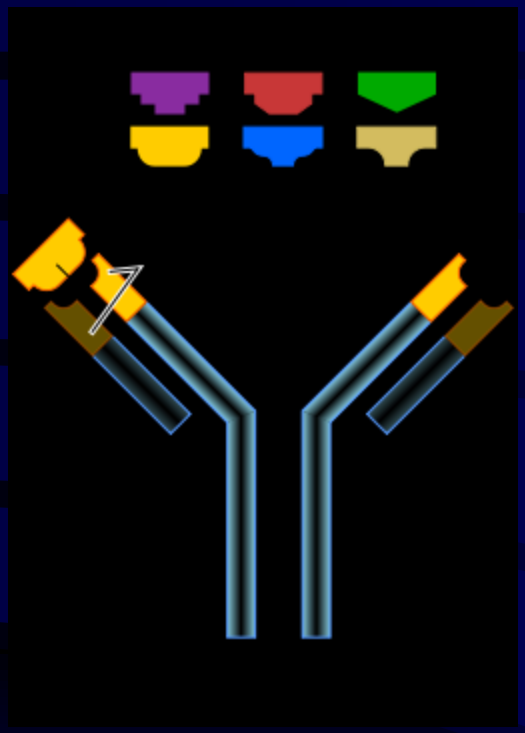
The EMBO Journal vol.4 no.4 pp.847–852, 1985

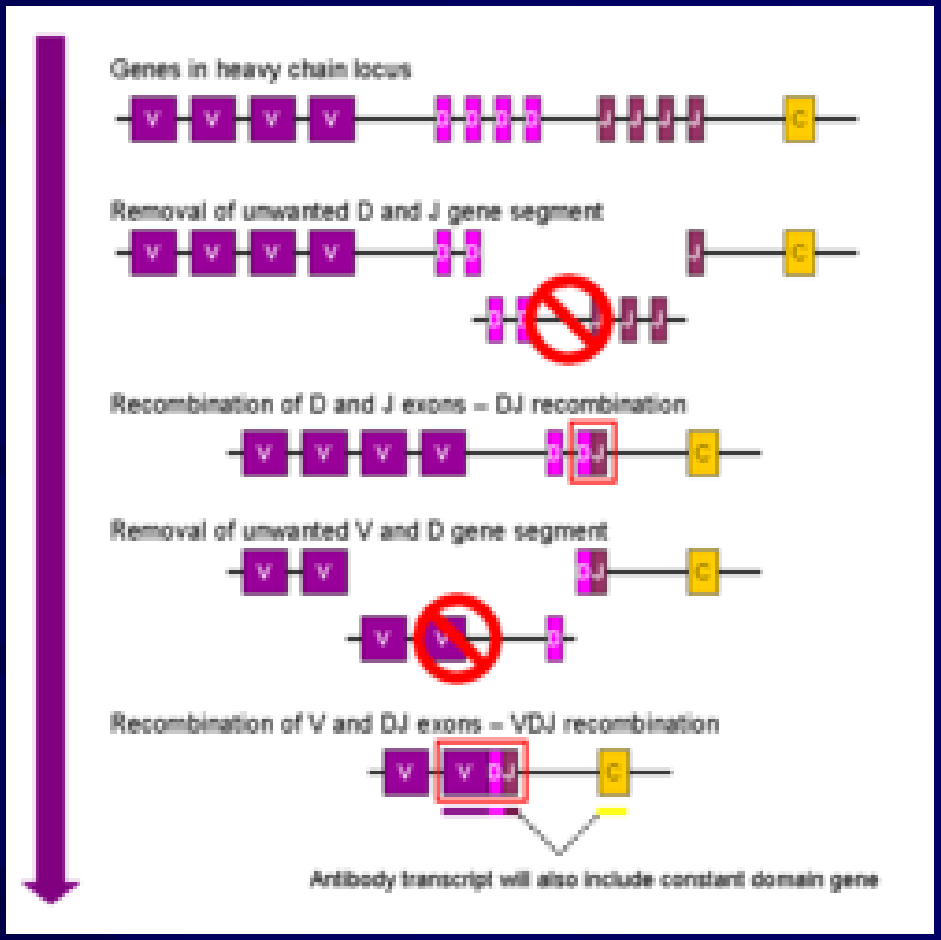
The generative grammar of the immune system



A small number of operations → huge diversity of antibodies

Antibody production





- Recombination
- Hypermutation
- Selection

Let us explore then the possibility of neuronal replication (NR)

- NOT neurons!
  - Connectivity patterns
  - Dynamical activity patterns
- Functional possibilities
- This is NOT to say that all the other mechanisms are unimportant
- NR most important in complex cognitive tasks (e.g. language and insight problems)

OPEN ACCESS Freely available online

PLoS one

Copying and Evolution of Neuronal Topology

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- *We shall hazard a theory of the selection of neuronal replicators. One may at least try to define some of the principal factors involved in it.*

With error correction and sparse activation

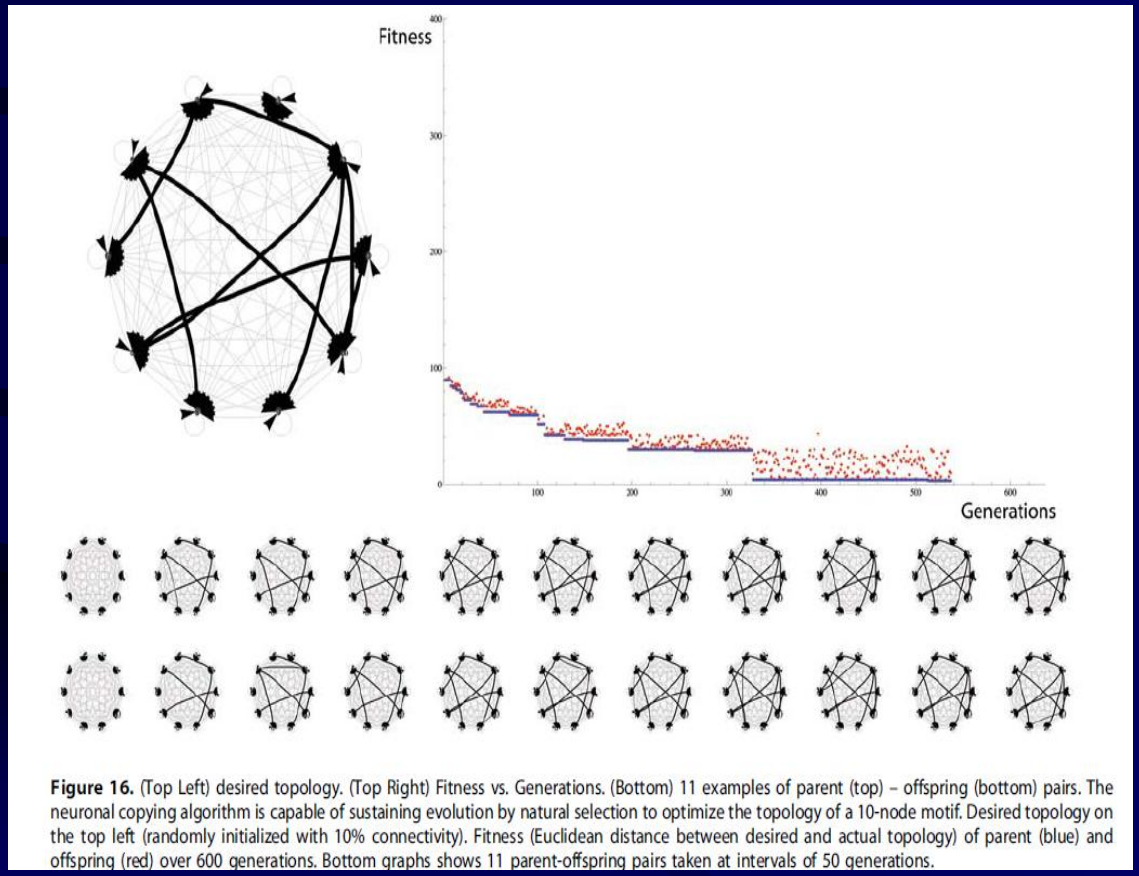

Figure 16. (Top Left) desired topology. (Top Right) Fitness vs. Generations. (Bottom) 11 examples of parent (top) – offspring (bottom) pairs. The neuronal copying algorithm is capable of sustaining evolution by natural selection to optimize the topology of a 10-node motif. Desired topology on the top left (randomly initialized with 10% connectivity). Fitness (Euclidean distance between desired and actual topology) of parent (blue) and offspring (red) over 600 generations. Bottom graphs shows 11 parent-offspring pairs taken at intervals of 50 generations.

Some essential components

- Spike-time dependent plasticity
- Gating
- Reward become propotional to fitness
- ALREADY PUBLISHED MECHANISMS in, e.g. *Neural Computation*

Some functions

- Structured search in rugged problems, e.g. insight problems, working memory
- Memory consolidation from dynamical to topological replicators
- Function passing rather than data passing
- Generation and selection of ‘actors’ in reinforcement learning
- Repair of connectivity patterns

If this is (essentially) true, then

- There must have been evolution of
  - Replication fidelity
  - Selection (reward) mechanisms
  - Corresponding niches (morphophysiological structures) in the brain

Where to read?