LING/C SC 581:
Advanced Computational Linguistics

Lecture 27

Prof. Sandiway Fong

Announcement

- **LING696A**, a Seminar on *Syntax* + *Computation*
  - Fall Semester: Mondays 2:30PM-5PM
  - Theory: SMT (*Strong Minimalist Thesis*)
  - Computation: SMT Parser

  - *I'm hoping you'll consider signing up!*

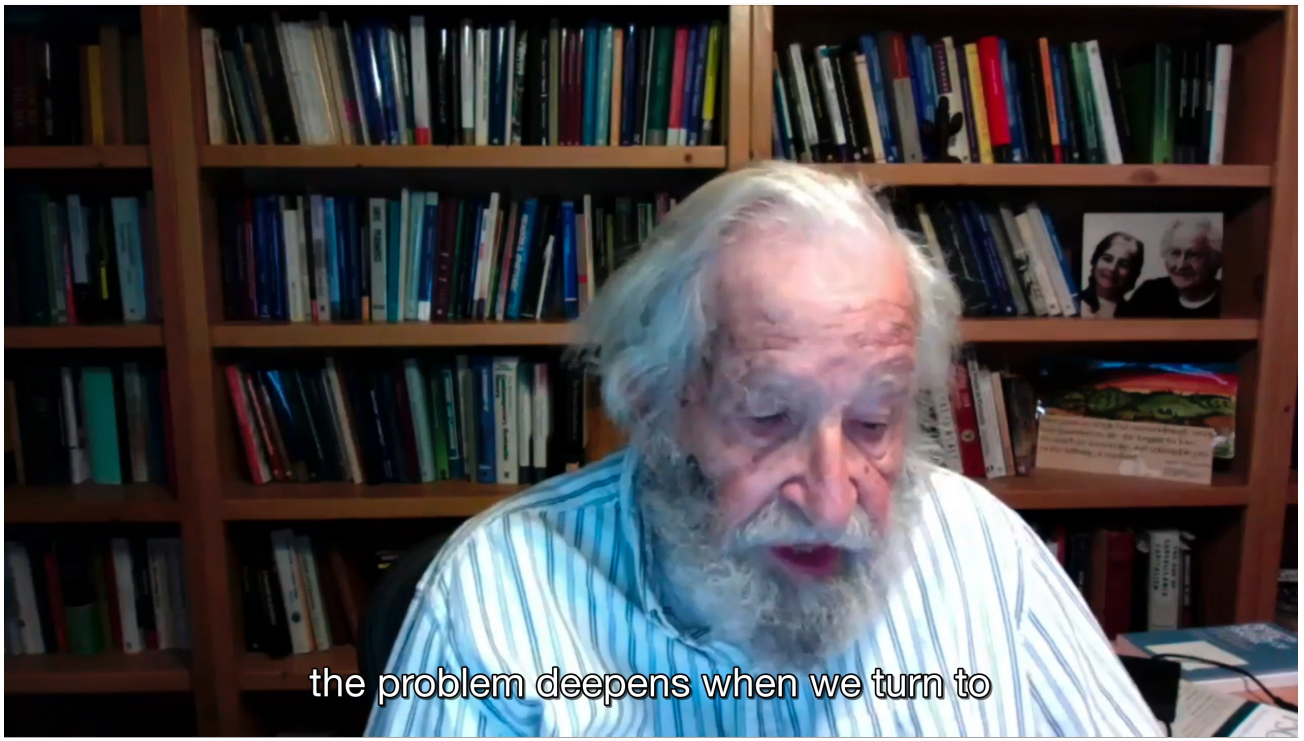
Continuing on from last time

- So far:
  - **FL**: Faculty of Language (*wetware*)
  - **UG**: Universal Grammar (*I-Language*) – a theory of FL
  - **E-Language**: language we hear and produce
  - **Darwin's Problem**: evolutionary plausibility of a sudden change (*compared to evolutionary time scale*)
  - **Plato's Problem**: explain how we know so much (given so little)
  - **POS** (*Poverty of Stimulus*): addressed by innate capacity to learn E-language

FL: Contradictory Conditions. UG: a theory of FL

Darwin's Problem

Evolution: Modern humans & Language



Recent Human Evolution

- Explosion of symbolic works in the fossil record
  - *coincides with the appearance of modern humans* (315 kya; Morocco)
  - … until the emergence of behaviorally modern *H. sapiens*: **in general, technological innovations have been sporadic and rare**. The most-striking evidence for a distinct cognitive contrast between modern humans and all their predecessors, however, comes from Europe. *H. sapiens* came late to this continent and brought a new kind of stone tool based on striking long thin "blades" from a carefully prepared long core. **In short order these Europeans, the so-called Cro-Magnons, left a dazzling variety of symbolic works of prehistoric art**. (Tattersall in *Encyclopaedia Britannica*)
- www.britannica.com/topic/Homo-sapiens/Behavioral-influences **Last Updated: Mar. 28, 2026**
  - *we can fashion tools that amplify these inherent abilities that we have to spectacular magnitudes, e.g. wrt. locomotion, computation, medicine.*

Recent Human Evolution

- (Berwick & Chomsky 2016)
  - *Vocal learning and production aspect of* [***EXT***] *is not human-specific* (*ancient*)
- (Chomsky 2021)
  - Language/thought, **I-Language**, an authentic species property (recent)
  - *Our closest relatives, otherwise intelligent apes, cannot begin to grasp the most elementary rudiments of language even with intensive training. They have about the same auditory system as humans, but acquire nothing from the sounds that lead a human infant, almost reflexively, to develop complex systems for constructing and expressing thought.*

Small Difference, Big Effect

- Basic structure of I-Language should be simple (**Merge**):
  - *the result of some […] small rewiring of the brain […] and has not changed […] since.*
- Modern human:
  - ~20K protein coding genes (*1.5% human genome*)
  - ~588 kya: Neanderthal/Modern human Y-chromosome divergence (Mendez *et al*. 2016)
  - 14,042 regions of archaic DNA (Neanderthal/Denisovans) (Weiss et al. 2021)
  - *407 […] drove differential expression between the modern and archaic alleles*

The Miracle Creed

Einstein's Miracle Creed

LLMs: *GPT-4 1,760 billion parameters (G. Holz, cited in Wikipedia)* GPT-5?

APRIL 1, 1950 | 20 MIN READ

On the Generalized Theory of Gravitation

how pure a "positivist" he may fancy himself. The metaphysicist believes that the logically simple is also the real. The tamed metaphysicist believes that not all that is logically simple is embodied in experienced reality, but that the totality of all sensory experience can be "comprehended" on the basis of a conceptual system built on premises of great simplicity. The skeptic will say that this is a "miracle creed." Admittedly so, but it is a miracle creed which has been borne out to an amazing extent by the development of science.

A. Einstein in *Scientific American* Vol. 182 No. 4 (1950)

What is the Strong Minimalist Thesis (SMT)?

- a theory design guideline (Chomsky 2024)
- **SMT**: ***Language*** satisfies Einstein's *Miracle Creed*

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In 1950, Albert Einstein published an essay on general relativity in *Scientific American* magazine. Reflecting on recent discoveries, and looking back over his distinguished career, Einstein began by waxing philosophical:

> Time and again the passion for understanding has led to the illusion that man is able to comprehend the objective world rationally, by pure thought, without any empirical foundations—in short, by metaphysics. I believe that every true theorist is a kind of tamed metaphysicist. . . . The metaphysicist believes that the logically simple is also the real. The tamed metaphysicist
> ves that not all that is logically simple is embodied in ex-
> nced reality, but that the totality of all sensory experience
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> (Einstein 1950, 342)

ng his thought, Einstein offered ancient atomism as an ex-
a specific miracle creed. It was introduced, Einstein claims,

intro (McDonough 2022)

Miracle Creed: maximizing simplicity

Dialogue Concerning the Two Chief World Systems (Galileo 1632)

- "***nature*** (*which by general agreement does not act by means of many things when it can do so by means of few*)"

- *Quaderni d'anatomia IV* (Leonardo da Vinci):
  - "*Every action in* ***nature*** *takes place in the shortest way possible*."
  - quoted in *Leonardo's Optics* (Argentieri, 1956)

SMT **optimal** solution:

- *Nature adapts/optimizes what it has to work with*

Core Human Language

- *On Language*, W. von Humboldt (1836):
  - "*Language is an involuntary emanation of the mind, no work of nations, but a gift fallen to them by their inner destiny*."
  - "*Every language is produced by the original tendency or 'original talent' shared by all human beings*."
- Chomsky (1964), *Logical Basis of Linguistic Theory*, cites Humboldt extensively

What does it mean for *I-Language*?

- "The Strong Minimalist Thesis (SMT) holds that language too may satisfy the miracle creed **at its core**." (Chomsky 2024)
- At the core: **I-Language**
  - **I = internal**: the expressions computed by Merge
  - could be a **well-formed thought** but not (directly) externalizable

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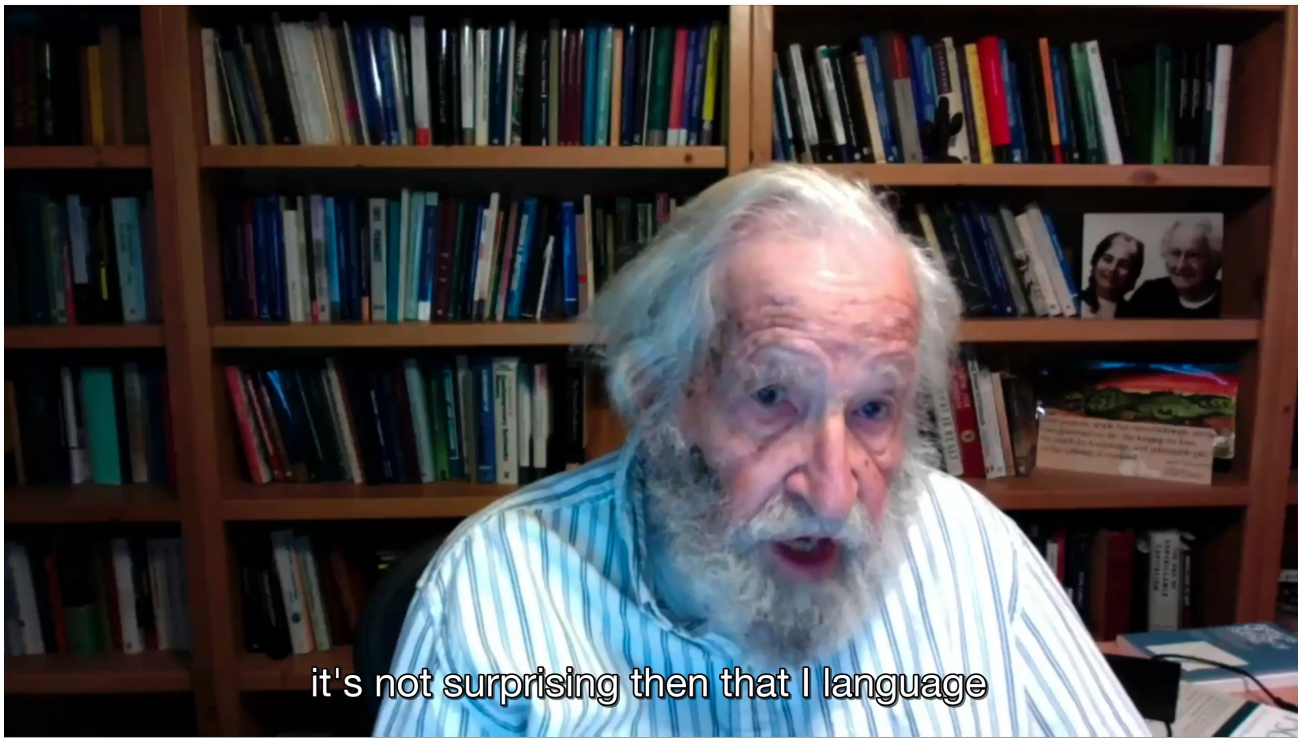
- At the core: **I-Language**
  - internal: the expressions computed by Merge
  - could be a **well-formed thought** but not (directly) externalizable
  - [illegible] orderly, see **Basic Property** (BP)
- **E-Language**:
  - Externalized I-Language (**EXT**), e.g. pronounced or signed or written
  - linear order imposed by the modality
  - word order and spellout parameterized *by particular (E-)language*

return to talk about this soon!

I-Language: Structural Dependence



Basic Property (BP) of Language

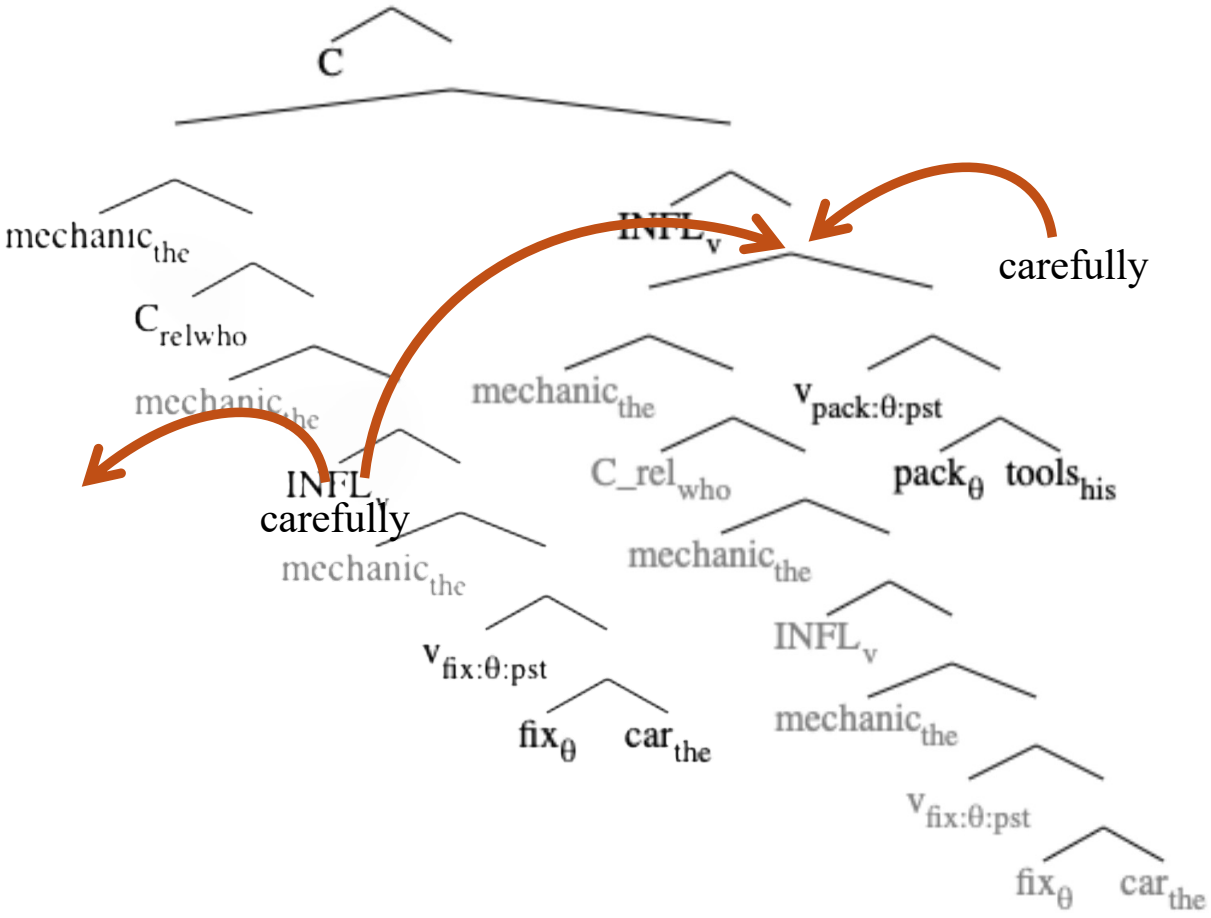
[pg.9, Chomsky GK (2021)]

- "adverb *carefully* seeks a verb [to modify], but it cannot use the simplest computation: pick the linearly closest verb."

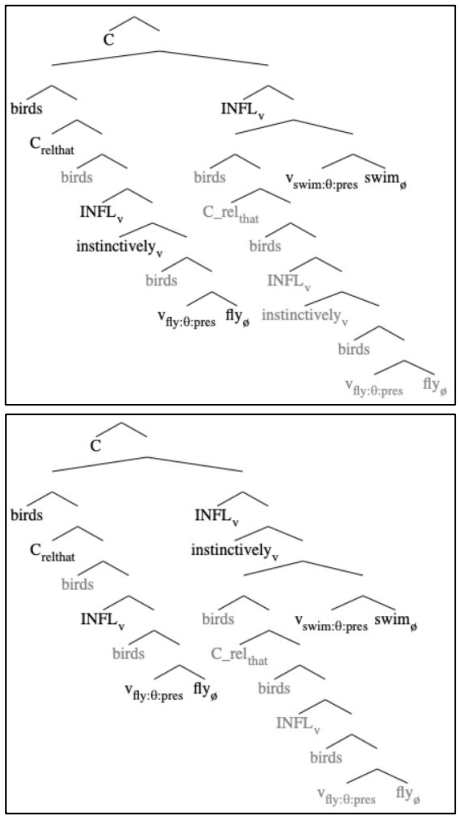
- **Construal**:
  - […] *marks linearly closest verb*
  - the mechanic who *fixed* the car *carefully* [*packed*] his tools ← [*pack*] or *fix*
  - *Carefully*, the mechanic who [*fixed*] the car *packed* his tools ← *pack*
  - the mechanic who *fixed* the car [*packed*] his tools *carefully* ← [*pack*]
  - the mechanic who *carefully* [*fixed*] the car *packed* his tools ← [*fix*]

SMT Parser

- Why?
- **Answer**: on the edge between the two chunks



SMT Parser



[pgs.8,103,117 Berwick & Chomsky (2016)]

- Similarly ambiguous sentences:
  - *Birds that fly instinctively swim*
  - *The desire to fly instinctively appeals to children*
- and unambiguous counterparts:
  - *Instinctively, birds that fly swim*
  - *Instinctively, the desire to fly appeals to children*

Language and Communication

Communication and Thought

- Language organ is designed to construct thoughts efficiently
- Language is not designed for efficient communication
- If that makes expressions harder to process and even makes some thoughts impossible to express without circumlocution, too bad. Nature doesn't care. [Chomsky GK (2021), pg.11]

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Communication and Thought

- Too bad. Nature doesn't care. [Chomsky GK (2021), pg.11]
  - EXT cannot have come before Merge.
  - The modern doctrine that language may have evolved from animal communication seems quite untenable. [pg.10, Chomsky GK (2021)]
- It makes no sense to say that *some system evolved for* ***X***
  - "the spine evolved for keeping us upright," or "language evolved for communication"

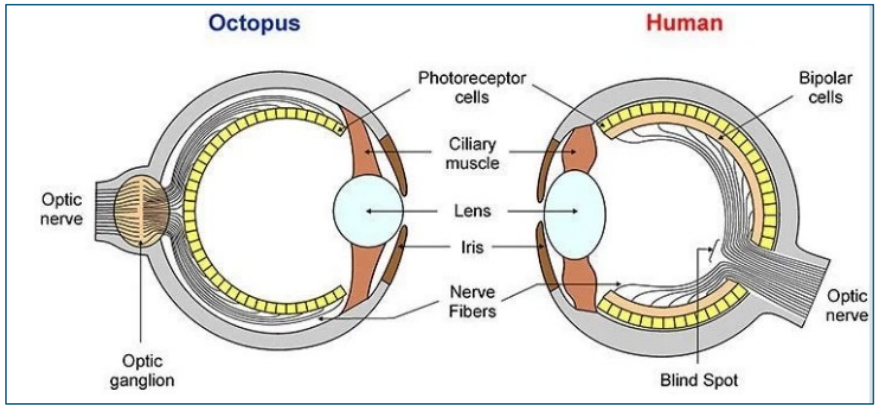
Communication and Thought

- Communicative efficiency is always sacrificed
  - The most serious cases involve deletion of copies in accord with computational efficiency, leading to some of the **hardest parsing problems**. [pg.10, fn.12, Chomsky GK (2021)]
    - *see solutions in the SMT Parser …*
  - Externalization: *John or the men *is/*are in the room*
    - *… unproblematic for expression of thought if feature valuation kept to late insertion so that only the bare copula reaches the thought level (as in some spoken dialects)*
- Note that statistical information is irrelevant to I-language as a matter of principle, though as has always been assumed in the generative enterprise (see Chomsky 1957), it can be highly relevant to processing and acquisition.

Darwin's Error

Motivation for I-Language

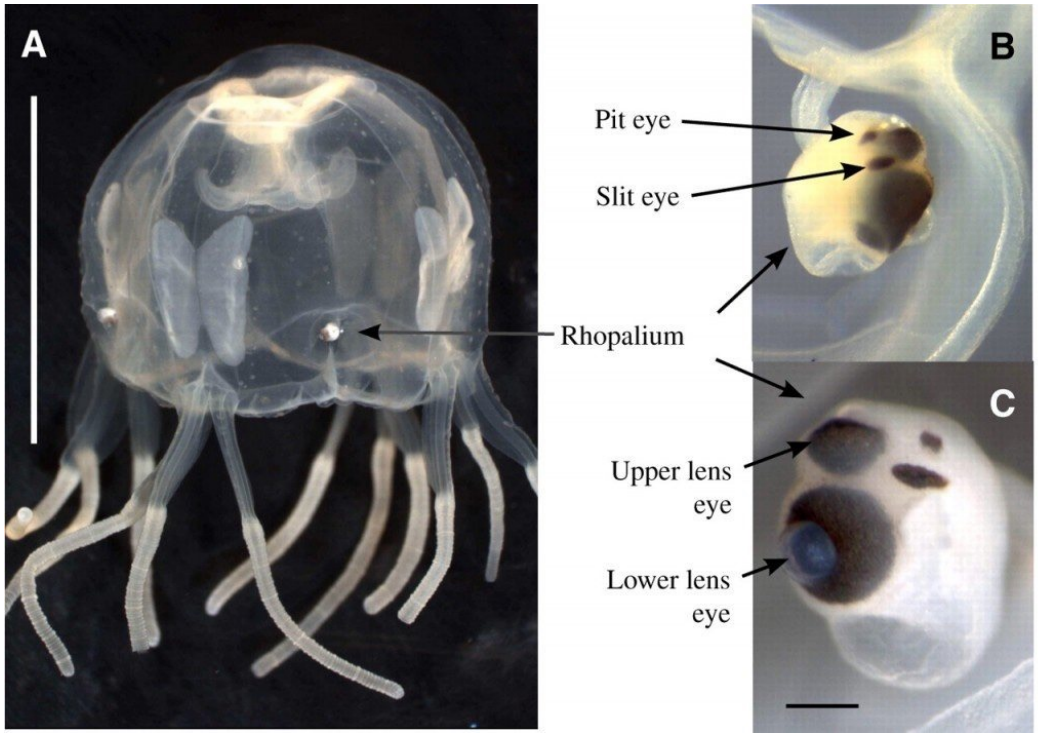
- *Nature adapts/optimizes what it has to work with …*
- Disruptive event: *new entity/functionality* (**I-Language**)
- Reconstruction: *put together a simplest system new/old* (EXT)



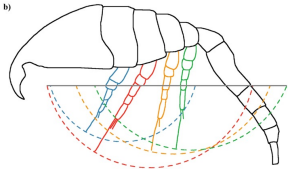
- Example of convergent evolution

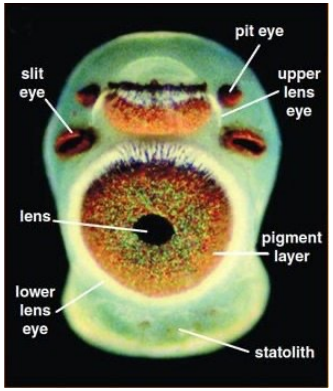
- 750-570 mya: **LCA (Last Common Ancestor)**
- 530 mya: high-res camera eyes (*re-invented many times*) (Land & Fernald 1992) (Land & Nilsson 2012)
- 500 mya: first nervous system
- 100 mya: we lost tetrachromatic vision (*cone cells*)
- 3-4 mya: first human-like brain
- 1-0.2 mya: modern brain
- octopus: "colorblind" (only 1 type of photoreceptor), but employ color (*camouflage*)

Jellyfish: eyes, but no CNS



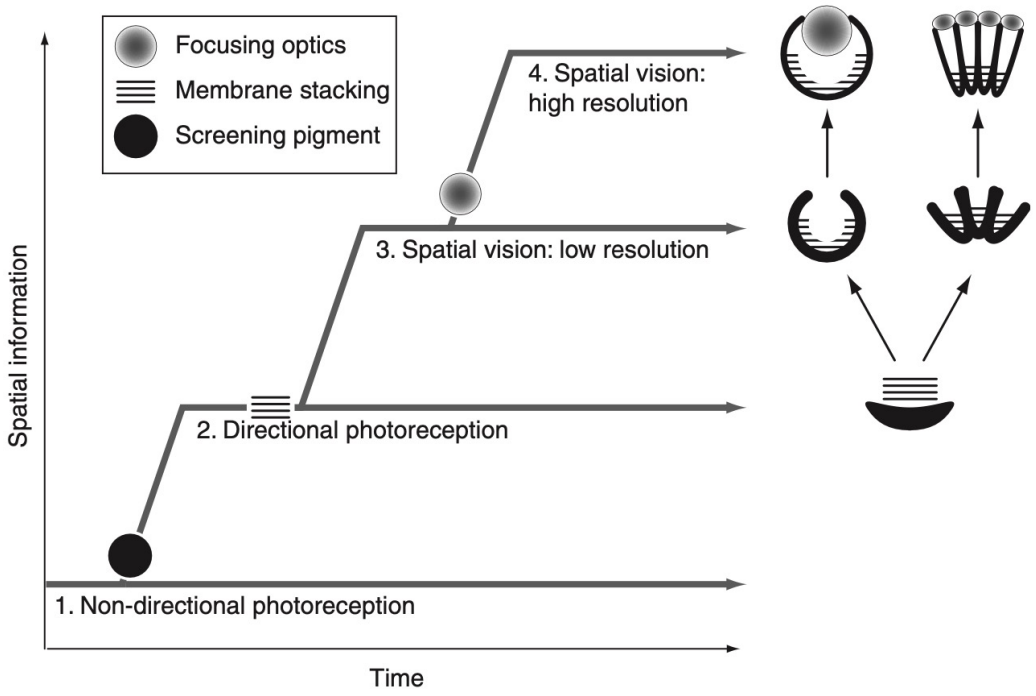
A kind of box jellyfish, *tripedalia cystophora*, hunt and eat tiny crustaceans





Innovation in Eye Design

(Land & Nilsson 2012:13–14)
To collect enough photons to the reduced angles seen by each receptor, stacking of photoreceptor membrane must evolve to allow class 3 tasks (Nilsson 2009).
Resolution (human): 1/60°



[pg.15, Land & Nilsson (2012)]

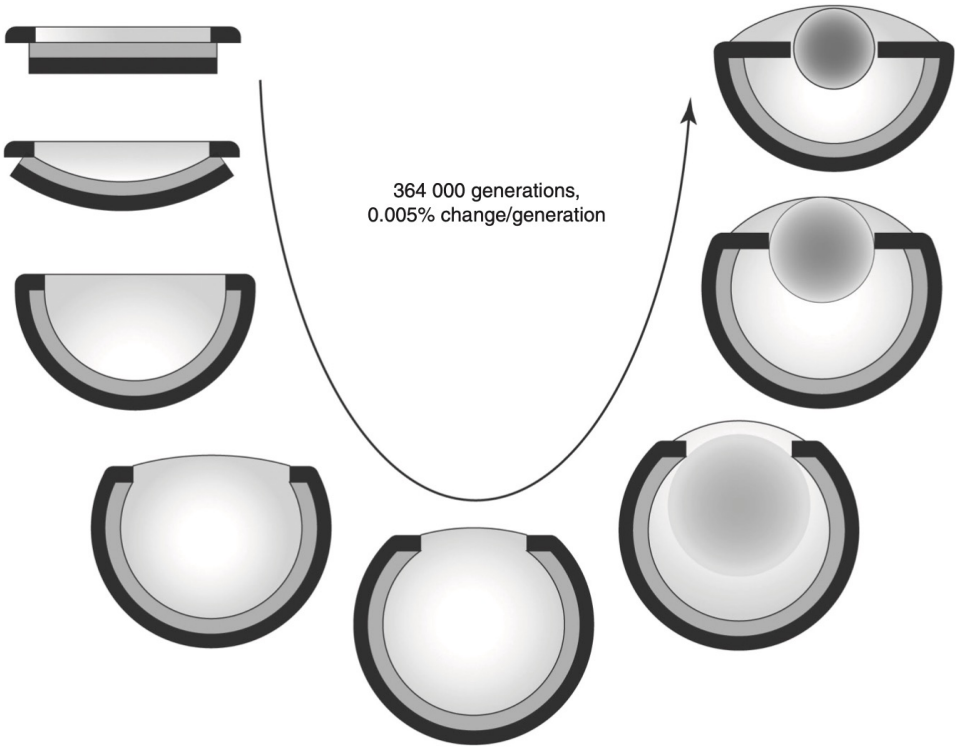
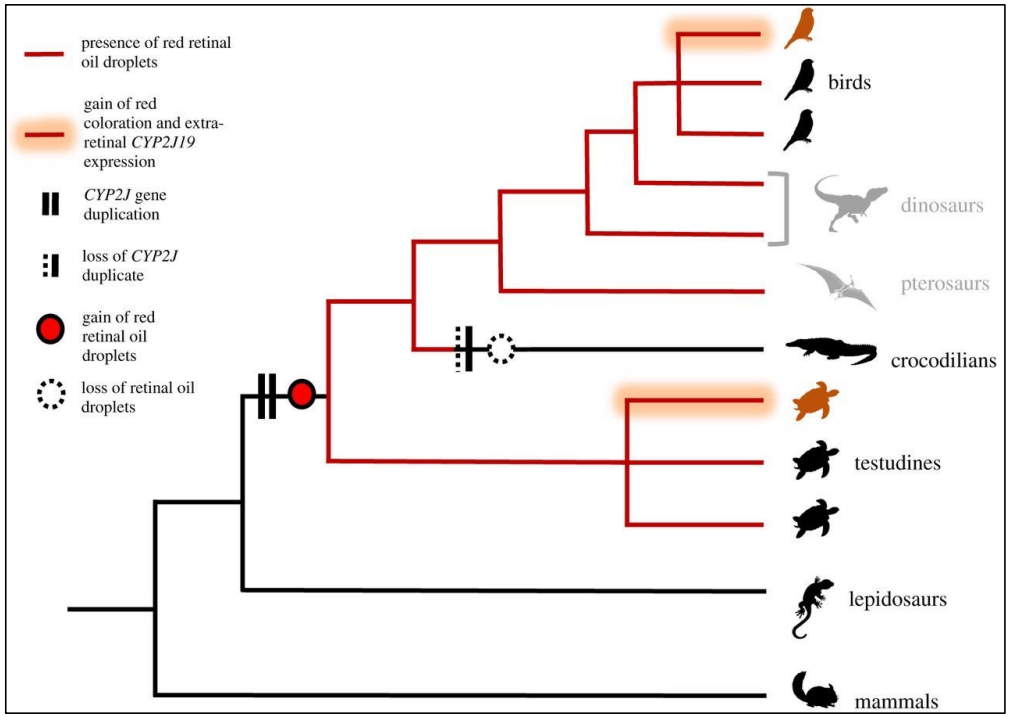


Fig. 1.6 A patch of light-sensitive epithelium can be gradually turned into a perfectly focused camera-type eye if there is a continuous selection for improved spatial resolution. A theoretical model based on conservative assumptions about selection pressure and the amount of variation in natural populations suggest that the whole sequence can be accomplished amazingly fast, in less than 400 000 generations. The number of generations between each of the consecutive

Opsin Evolution

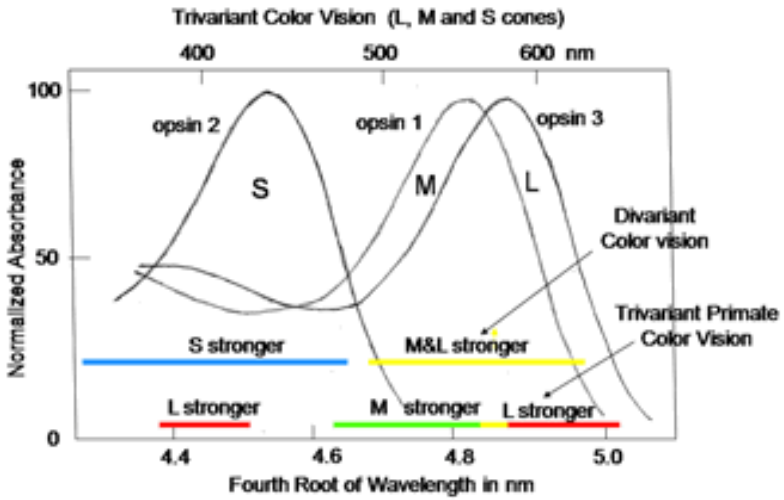
Use it or lose it? No.

- http://genomewiki.ucsc.edu/index.php/Opsin_evolution:_trichromatic_ancestral_mammal
- Despite 100 million years of playing catchup, no [Therian] mammal has ever regained the superior sharp tetrachromatic color vision enjoyed by the amniote common ancestor and contemporary turtles, birds and lizards.
- It's possible to have much better color vision than human -- and many earlier diverging vertebrate species do.

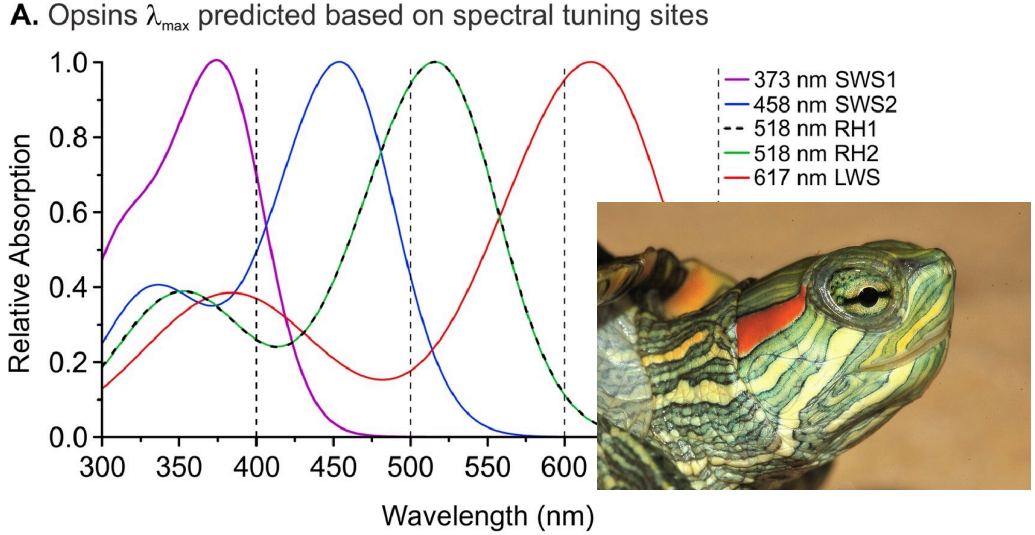


https://doi.org/10.1098/rspb.2016.1208

Trivariant Color Vision



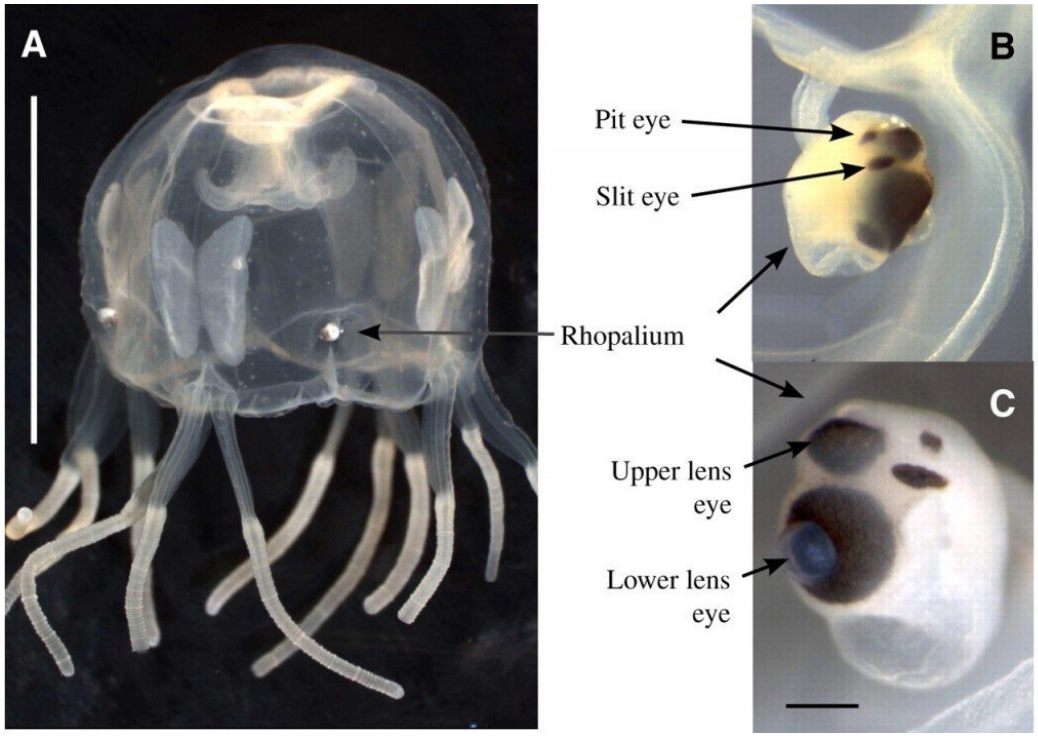
Spectral absorption curves of the five visual opsins, SWS1, SWS2, RH1, RH2, and LWS of the turtle *T. s. elegans*,



- www.webvision.pitt.edu/book/part-vii-color-vision/color-vision/

The Brain: Central Nervous System (CNS)

Jellyfish: eyes, but no (centralized) brain



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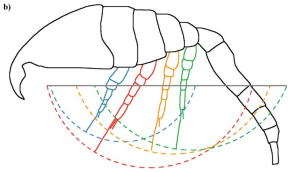
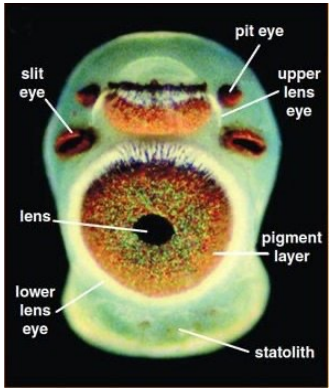
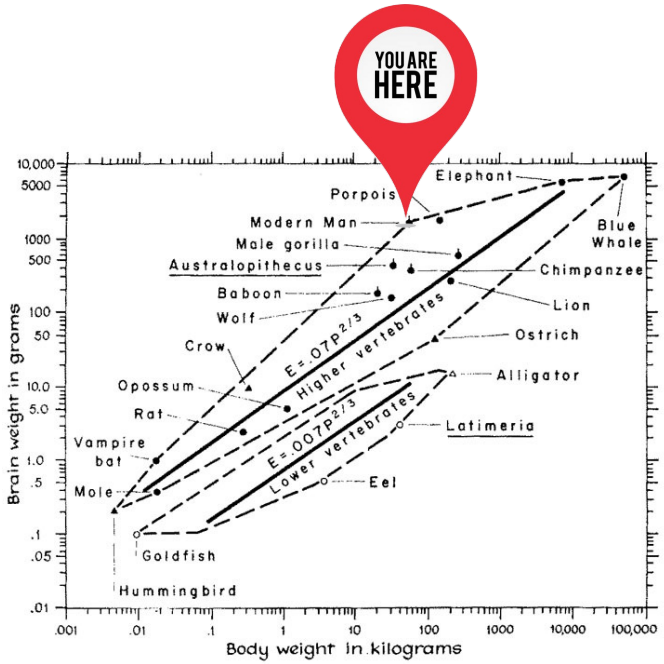




Are we special? Allometric scaling

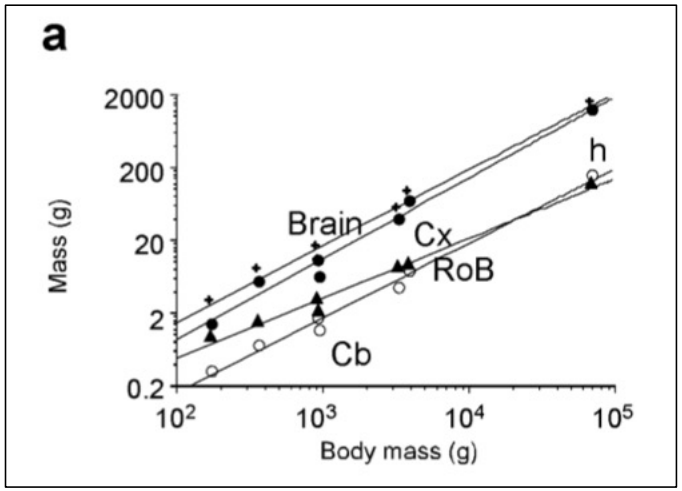
Brain: 86 billion neurons

- perinatal neuron cell death: lose 50%
- development: heavy synaptic pruning
- we lose 50K neurons every day



- Primate scaling: *uniquely human? nah*

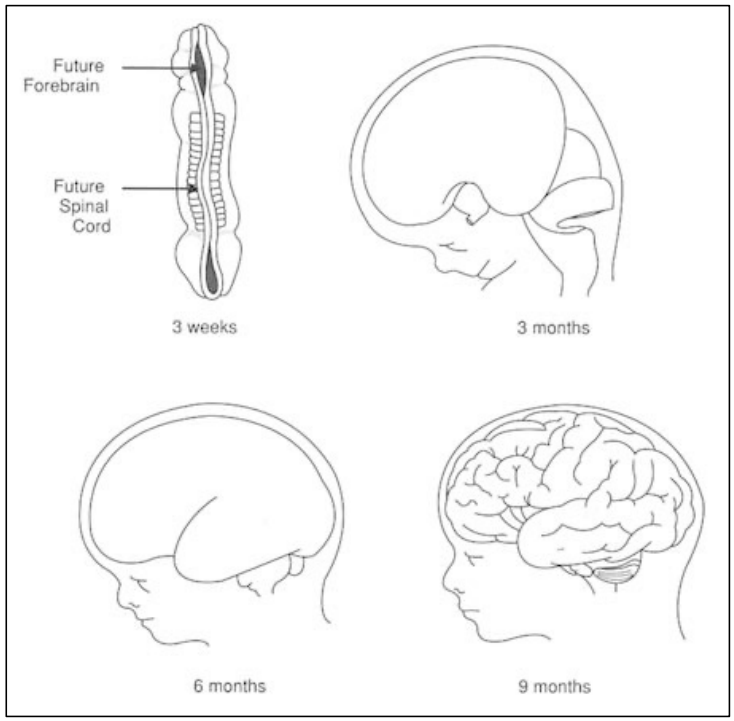
(Azevedo et al. 2009)



Human Brain Development

Ackerman (1992):
The human brain develops from the tip of a 3-millimeter-long neural tube. At three to four weeks after conception, the neural groove closes into a tube

Brodmann's areas:
Broca's area occupies some of area 44 and some of area 45, as well as a little of area 4.
Wernicke's area is located in area 22, also 39 and 40.



Vertebrates: *few new brain structures in last 300 million years*.

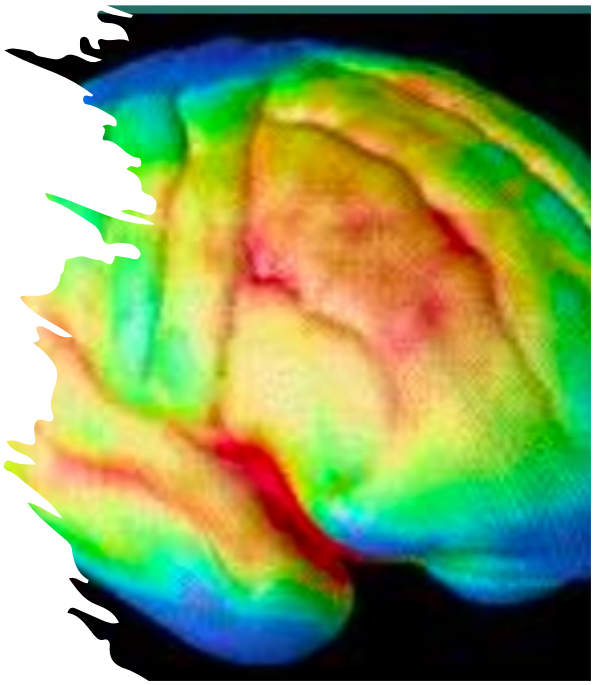
Sensing chemicals on the outer side of the cell membrane is a **fundamental feature of all cells** and sensing environmental chemicals has obvious adaptive advantages.

Olfaction is universal:
"chemicals are probably the original stimuli, since they can participate directly in biochemical reactions without needing a sensory transduction step.

Human Brain Development

Vella (2016):

- Great Adolescent Pruning: Age 5-21
  - Infant primates may have up to **twice the adult number of neurons**.
  - Circuits are sculpted from the brain by **pruning** away cells and synapses.
  - Mechanisms: Programmed cell death (apoptosis), passive loss due to lack of stimulation, learning.



Evolution is a tinkerer

Vella (2016):