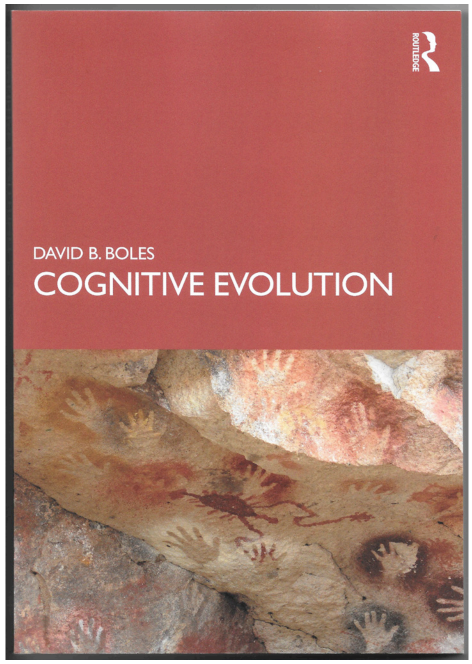
CHAPTER SUMMARIES FOR *COGNITIVE EVOLUTION*

(David B. Boles, 2019, Routledge)



SECTION I. INTRODUCTION TO EVOLUTION

Chapter 1, "Life Begins"

Chapter 1 considers both the requirements of life (e.g., a membrane to protect cell contents, and metabolism to provide energy) and the leading hypotheses for life's place of origin (e.g., Darwin's "warm little pond" and "black smokers" at the bottom of the sea). The science is most speculative in this chapter because few physical signatures of the origin of life have survived.

The earliest evidence is from a form of carbon associated with living cells, possibly dating to 4.1 billion years ago, but it is uninformative with respect to the form and function of the earliest cells. For those characteristics the oldest glimpse is afforded by stromatolites, mats of sediment formed by primitive bacteria, but these date "only" to 3.5 billion years ago.

The chapter also introduces the concepts of descent with modification and natural selection, and asks whether evolution is random. The answer is yes and no -- it is largely random in the descent with modification component but definitely nonrandom with respect to natural selection.

What does this have to do with cognitive evolution? More than you may think, because primitive transport mechanisms for exchanging chemicals across membranes were the ancestors of our sensory mechanisms.

Outline of headers and subheaders:

CHAPTER 1. LIFE BEGINS
How did life begin?
  … In a warm little pond?
  … On clay surfaces?
  … Around black smokers?
  … In space?
Membranes and metabolism
DNA world
One-celled life
The workings of evolution
  Descent with modification and natural selection
  Speciation
  Is evolution random?
Conclusion

Chapter 2, "Life Gets Complicated"

About 530 million years ago, give or take 10 million years, most of today's major groupings of multicellular life appeared in what is called the Cambrian explosion. Was it because hard body parts had recently evolved? Because of increasing oxygen levels? Or because of the availability of high-energy food on the ocean floor?

Chapter 2 considers the causes of the Cambrian explosion as well as the earlier transition from unicellular to multicellular life.

One of the animal groups originating in the explosion were the chordates. These relatively complex animals have a neural tube and a supporting rod running the length of the body, called the notochord. Early chordates had a brain with parts (forebrain, hindbrain, and probably a midbrain), and gave rise to vertebrates, including humans. The ancestral form is thought to be closely modeled by amphioxus, a living species. If so it resembled a small, translucent fish, and possessed a single eye. Thus our brain and senses had begun to evolve, important stepping stones toward cognition.

In addition, Chapter 2 considers how fossils are formed and how dates can be assigned to them. The tree of life is introduced, describing the descent of all of life's divisions from a common ancestor.

Outline of headers and subheaders:

CHAPTER 2. LIFE GETS COMPLICATED
Fossil formation

Geological clocks
Molecular clocks
- The linear molecular clock
- The nonlinear molecular clock
The tree of life
The Cambrian explosion
- Chordates
Conclusion

Chapter 3, "Vertebrates to Early Mammals"

Among the exciting developments in Chapter 3 are new hard parts, crawling the land, early fur, and asteroid-borne disaster. The hard parts were teeth and bone, emerging a little less than 500 million years ago during vertebrate evolution. They allowed effective predation while protecting the nervous system. Tying into that were the eyes, possessing for the first time a small area of detailed central vision. That would lead to cognitive advances including improved object recognition.

Crawling the land occurred by 360 million years ago, preceded by a 25-million-year transition in which lobe fins became limbs and gills gave way to lungs.

Early fur formed a "halo" around fossilized skeletons as far back as 165 million years ago. But mammalian characteristics did not evolve in one giant leap. They were acquired gradually: Warm-bloodedness by 250 million years ago; a large brain relative to body size by 195 million years ago; and in our ancestors the eutherians, a placenta by 160-170 million years ago.

Then one day, 66 million years ago, a six-mile-diameter asteroid struck the Yucatán peninsula, blasting out an enormous quantity of partially melted rock and dispersing light-blocking material into the atmosphere. A staggering 81 degree Fahrenheit drop in average global temperature followed. All large land animals became extinct. The future belonged to mammals, and to mammalian cognition.

Outline of headers and subheaders:

CHAPTER 3. VERTEBRATES TO EARLY MAMMALS
Early vertebrates
- Biomineralization
- Hox genes
- Visual system changes
- Gill arches as predecessors to jaws
Tetrapods
Amniotes
Synapsids and diapsids
- Dinosaurs
- Early Mammals
Conclusion

Chapter 4, "Later Mammals Through Primates"

Primates evolved long before the dinosaur extinction 66 million years ago, relying on their small size and body heat to hide them and keep them warm during their nocturnal activities. Early on, they evolved grasping hands and feet to help them move along fine branches, an adaptation that would prove of considerable significance in furthering human cognition.

They spread worldwide. One particularly intriguing question, covered in Chapter 4, is how they came to South and Central America. New World monkeys, as they are called, had no ancestors north or south. They simply appeared, but how? From North America? There's that ancestor problem. From Asia? Same problem, as that requires coming through North America. From Africa? That's actually the leading hypothesis.

The trip must have occurred about 45 million years ago, when the minimum distance between South America and Africa was 800 miles. Under favorable conditions a large raft of vegetation, a "floating island", could have crossed with an accidental cargo of monkeys in about 9 days. Mammals that size can survive 13 days without water, and the vegetation would have expanded the survival period.

The chapter covers all the major primate branchings down to our human ancestors. Lavishly illustrated with color photographs, it steps through the chronology with examples of both living and fossil primates, and ends with the divergence of our closest relatives from our ancestral line. Those were the ancestors of the common chimpanzees and bonobos, about 7.5 million years ago.

Outline of headers and subheaders:

Chapter 5, "Humans"

Chapter 5 is the final one in the Introduction to Evolution section. Extensively illustrated, it begins with *Sahelanthropus* ("Toumai"), an ape-like hominin from 7 million years ago. With a downward opening, oval-shaped hole in the bottom of the skull leading to the spinal column, Toumai was likely bipedal. Walking on two legs is a defining characteristic of our tribe.

Other hominin species from the Miocene epoch are covered, followed by those of the Pliocene (2.6-5.3 million years ago). "Lucy", the popular celebrity in the hominin lineup, was of the *Australopithecus afarensis* species. Members of it are believed to have left their footprints in Tanzania, graphically demonstrating advanced bipedalism. They were among the earliest stone toolmakers.

The *Homo* genus emerged about 2.4 million years ago in the early Pleistocene, as *Homo habilis*. This marked a surge in encephalization, i.e., brain size corrected for body size. Encephalization steadily increased through the middle and later Pleistocene.

Two million years ago, several hominin species coexisted on Earth. Now there is one. Our portion of the tree of life more resembles a well-pruned bush than a tree, with a single branch emerging from the top. Most likely the reason traces to competition due to similar environmental needs.

Only one species produced an explosion of cultural innovations, drawing on a diverse toolkit of cognitive processes. That was *Homo sapiens*, or in English, "wise man".

Outline of headers and subheaders:

HUMANS
The first (Miocene) hominins
- *Ardipithecus*
- *Orrorin*
Hominins of the Pliocene
- *Anamensis*
- *Afarensis*
- *Garhi*
- *Africanus*
Hominins of the early Pleistocene
- The emergence of *Homo*
- The encephalization quotient
- *Ergaster* and *erectus*
Hominins of the middle and late Pleistocene
- *Naledi*
- *Sapiens*
- *Neanderthalensis*
- *Floresiensis*
Hominin Trends and Connections
- Size trends
- Skull trends

- Hominin phylogeny
A well-pruned bush
Conclusion

SECTION II. SENSATION AND MOVEMENT

Chapter 6, "The Mechanical and Chemical Senses"

Sensation and movement, comprising the second section of the book, provide important context for the cognitive processes bridging them. The story begins in Chapter 6 with the mechanical senses of touch, balance, and hearing. The chemical senses include smell and taste.

The earliest single-cell organisms mechanically sensed internal pressure. High pressure caused pores to open, expelling cellular contents. Later, cells evolved membrane channels that admitted or expelled particular ions. Most of today's ion transport channels appeared by 600 million years ago.

The advent of multicelled animals called for new mechanisms of mechanical sensing. Hair cells detected disturbances through the deflection of an embedded hair. Such cells were subsequently adapted for touch, hearing, and balance. Early cnidarians probably had them in the form of stinging cells, which some believe gave rise to neurons. Others, however, think that neurons evolved along with muscles, building into diffuse neural nets controlling movement.

Chemical sensing likewise originated with membrane channels. In multicellular animals, the sense of smell began with a small cluster of specialized cells connected to a nervous system, sometime during the transition from chordates to vertebrates.

It is surely significant that the senses of balance, smell, and taste all emerged 520-530 million years ago. A likely explanation is that a new type of sensory cell had evolved, a short one with a broad synaptic end that allowed immediate connections with neurons outside the central nervous system.

Outline of headers and subheaders:

CHAPTER 6. THE MECHANICAL AND CHEMICAL SENSES
Early sensing
Touch
- Mechanoreceptors
- Tactile neural pathways
Balance
Hearing
- Frequency selectivity
- Origin of the ossicles
Smell
- Olfactory genes

- The formation of olfactory pseudogenes
Taste
Common trajectories in mechanical and chemical sensing
The other mechanical and chemical senses
Conclusion

Chapter 7, "Vision"

How can evolution explain an organ as complex as the eye? Did it suddenly appear whole, and if not, what good is a half-evolved eye?

As it turns out, quite a bit. In just a few short steps, outlined in the chapter, each step improving on the last, a patch of photosensitive cells can become a complex lensed eye, complete with cornea and lens. Paired, optically reversing eyes evolved multiple times in different animal lineages, all rooted in the same Pax gene family.

In our line they likely emerged in early vertebrates, about 520 million years ago. Photopigments, the chemicals sensitive to light, appeared even earlier. To a first approximation, their combined sensitivities match the solar radiation spectrum on Earth's surface. Initially incorporated into four different cone receptors, first one and then a second were lost in early mammalian ancestors. That's because in night-dwellers, they conveyed no advantage, and incurred a metabolic disadvantage. It wasn't until 21-45 million years ago that Old World monkey and ape ancestors re-evolved a third cone type, producing so-called "three color vision".

Other themes visited include night vision's evolution and adaptations; the differing acuity of the cone and rod systems; and the visual brain.

Outline of headers and subheaders:

CHAPTER 7. VISION
The evolution of eyes
- The genetic basis of eyes
- Chordate and early vertebrate eyes
Color vision
- Trichromacy
Night vision
- Mechanisms for increasing light sensitivity
Acuity
- The fovea's contribution to acuity
Eye and brain
Conclusion

Chapter 8, "The Origins of Motion"

Movement, allowing passage to areas of plenty, was a major advance for single cells. Early multicellular animals, living on the sea bottom, had similar needs for motion. Fossilized trails a millimeter in width, 570 million years old, testify to creeping along mucus-lubricated paths. Flatworms adapted muscles, possibly evolved for spawning purposes, to swim using body undulations.

The story continues with tetrapods repurposing the fish tail as an anchor for muscles moving the rear legs. A step cycle evolved in which the limbs on one side moved forward, followed by the other side. Today, by inheritance, most mammals walk likewise.

Early primates, however, moved along fine branches, minimizing branch shaking by adopting a diagonal gait: Right hind - left front - left hind - right front. Today, humans crawl similarly. Like all apes, we lack the balancing tail used by smaller primates, probably because large bodies can't be shifted by tail movement.

Crossover is a notable feature of the vertebrate nervous system: One hemisphere of the brain mostly controls movement on the opposite side. Almost all the sensory systems, too, cross over. This arrangement likely traces to the image-reversing eye, resulting in the left side of space projecting to the right hemisphere, and vice versa. The other senses -- and much of the motor system -- may then have crossed over to bring inputs and outputs into register within the same hemisphere.

Outline of headers and subheaders:

Chapter 9, "Bipedalism"

For years human bipedalism seemed a puzzle because we run inefficiently compared to similarly-sized four-legged animals. However, it was eventually established that humans are considerably more efficient walkers than their ape relatives. Because our ancestors came from an ape background, they only needed to improve on ape walking to provide an evolutionary reason for bipedalism.

However, bipedalism goes way back in hominin history, probably 7 million years. This raises doubt that bipedalism was much more efficient early on. Other causes have been proposed: Among them, that food trees became more widely spaced due to climate change, magnifying any efficiency difference; that standing up exposed the body to less direct sun; and, in a view espoused in the chapter, that life in a mosaic environment of savanna, woodland, grassland, and forest, called for carrying tool materials that in places were otherwise unavailable. Judging from chimpanzee hunts, including the occasional use of crude spears, our earliest ancestors may have had similar capabilities, suggesting a hunting-carrying explanation.

Besides its obvious consequences for cognition, bipedalism resulted in anatomical changes from head to toe. The head became balanced over the trunk, the spinal column curved, the thorax became a cylinder, the pelvis lowered and broadened, the arms shortened, the fingers straightened, the legs lengthened, the feet developed arches, and the sideways angle of the big toes nearly closed. Our gait became stiffer, and more energy was returned between steps. But what would we do with our freed-up hands?

Outline of headers and subheaders:

CHAPTER 9. BIPEDALISM
The causes of bipedalism
- Efficiency
- Climate change, foraging, and thermoregulation
- Carrying
- Why aren't other apes bipedal?
Consequences of bipedalism
- The vertebral column and thorax
- The pelvis
- The arms and hands
- The legs and feet
- Conservation and change in motor patterning
Conclusion

SECTION III. PERCEPTION AND COGNITION

The first two sections of the book introduced evolution and explored its application to the inputs and outputs of the human information processing system. Section III covers the evolution of the perceptual and cognitive processes that intervene.

Chapter 10, "Praxis and handedness"

The primary motor cortex originated no later than 160 million years ago with mammals. The cerebellum also has motor function and dates to 400-500 million years ago. Other motor areas date roughly from the origin of primates 83 million years ago.

An important monkey development, extending down to apes and humans, was precise premotor cortex control over the lower limbs. Mirror neurons in its lower portion rapidly fire when action is observed and copied, playing a large role in social learning and mimicry.

Population handedness, the tendency of a population to be either right- or left-handed, is a behavioral marker for aspects of cognition. Evidence suggests the existence of three handedness components. Judging from living primate species, the unskilled component, involved in reaching and pointing, became predominantly right-handed by 32 million years ago in monkeys. A slightly right-handed skilled component, used in hammering and food extraction, evolved in apes about 13 million years ago and became more right-handed in hominins. An insertion-turning component, initially slightly left-handed, became right-handed in hominins after 7.5 million years ago.

In humans, population right-handedness likely reflects the unification of movement timing and sequencing in the brain's left hemisphere. A major cognitive advance, it allowed fast, smooth control over movement, improving tool skills.

But why has left-handedness continued in 10% of the population? A good guess is that it affords an advantage in face-to-face confrontations. Interactive sports like martial arts and hockey have more left-handers than noninteractive sports like swimming and archery. Also, traditional societies with higher homicide rates have more left-handedness. These observations support an "unorthodox style" hypothesis: Right-handers are confused by left-handed defensive stances, while left-handers are familiar with much more common right-handed stances.

Outline of headers and subheaders:

CHAPTER 10. PRAXIS AND HANDEDNESS
Praxis
- Movement-related brain areas
- The evolution of movement-related brain areas
- The primate origins of handedness
- A strengthening of PRH within primates? The role of task and environment
Components of primate handedness
Components of human handedness
Genetic foundations
- Family resemblances
- Genetic models
- Individual genes
Archaeological evidence
Why handedness?

Why left-handedness?
Conclusion

Chapter 11, "Tools and Planning"

Reports of tool use by great apes are now routine, and include the use of sticks, sometimes trimmed and sharpened, for purposes as diverse as "termite fishing", probing for galagos in tree cavities, digging, pounding, defensive throwing, and depth-testing while wading. There is also evidence for tool cultures in that chimpanzee communities embody tool variations, and in some cases, diffusion between groups. Social learning also occurs, for example with capuchins acquiring nut-cracking behaviors by observing peers or older animals.

The encephalization quotient, a measure of brain size corrected for body size, is a surprisingly good initial predictor of tool use. Secondary factors include the evolution of specific brain mechanisms of praxis, and changes to the hands. However, precision grip is not exclusive to humans, even in pad-to-pad form.

The earliest hominin tools were sticks and other vegetation. Usage by nonhuman primates suggests we exploited such materials from the outset 7.5 million years ago, while the earliest known stone tools date from 3.3 million years ago. The large gap cannot be explained by the evolution of strong grip or hunting, as both predate stone tools.

Instead something cognitive must have occurred. Unsuccessful bonobo attempts to make stone tools suggest that it was our evolving ability to generate and sustain a mental model of a tool and how it is formed. Development of spatial ability and spatial memory may also have been needed.

The chapter discusses all of these issues. Tool types are covered from Lomewekian through Clovis cultures. Particularly important are hominin milestones in planning and understanding causality, supported by specific frontal and parietal brain mechanisms. Tool use in nonprimates is surveyed, as is the employment of tools and fire control in thermoregulation following our "Great Denudation".

Outline of headers and subheaders:

CHAPTER 11. TOOLS AND PLANNING
Great ape tool use
Primate tool cultures
- Defining culture
- Social learning
Brain size and tool use
The evolution of grip
- Human hand dexterity
- The earliest hominin tools
Worked stone tools

Gona and Oldowan tools
- The role of cognition
Later tools
- Acheulean tools
- Mousterian tools
- Aurignacian tools
- Gravettian and Solutrean tools
- Magdalenian tools
- Hamburgian and Ahrensburgian tools
- Clovis tools
Comparison of ape and human tool behaviors
- Increased hominin planning
Brain mechanisms of planning
- The rise of area 10
- The cognitive role of area 10
- Understanding causality
Conclusion

Chapter 12, "Spatial perception"

Judging location, depth, motion, and quantity are important spatial perception abilities. Initially, location sensing used the simple optical properties of the eye, with every point in space mapped to a specific retinal location. Beginning with early primates (83 million years ago), the superior parietal lobe of the brain began judging location relative to the body, an egocentric frame of reference. In contrast the temporal lobe judges location relative to the environment, an allocentric frame of reference that is also available to bats and rats, suggesting an origin at least 97 million years ago.

Depth provides many cues, with binocular disparity a particularly powerful one. Primates have always had forward-facing eyes, producing a large binocular field of view from at least 55 million years ago. It has increased in the descent to humans.

Motion detection partly depends on optic flow, in which objects rush by in the periphery while changes in central vision are slower. Area MT/V5 in the brain's temporal lobe processes it, while the parietal lobe computes heading. MT/V5 was a primate innovation, likely emerging 73-83 million years ago.

The ability to judge quantity can help determine which tree has more fruit, or which way to run when escaping groups of predators. Old World monkeys and apes, as well as humans, show evidence of "subitizing", a spatial method of fast counting small numbers of objects. It therefore appears to have originated at least 32 million years ago.

Orienting, reaching, grasping, and navigation are other important spatial abilities that in monkeys and humans involve parietal lobe mechanisms. Expansion of the lobe is visible in *Australopithecus afarensis*, and again in *Homo habilis*, suggesting a general enlargement relative to apes beginning at least 3.5 million years ago. Presumably this aided the numerous spatial processes served by our parietal lobes.

Outline of headers and subheaders:

CHAPTER 12. SPATIAL PERCEPTION
Location
- Higher brain mechanisms for recognizing location
Depth
Motion
Quantity
- Subitizing in humans
- Subitizing in other primates
Orienting
- The evolutionary background of orienting
Reaching and grasping
Navigation
- Brain mechanisms in navigation
The independence of spatial processes
Evolution of the parietal lobe
Conclusion

Chapter 13, "Pattern Recognition"

Humans depend heavily on visual pattern recognition processes laid out along ventral brain pathways. Starting in area V1 at the rear of the occipital lobe, visual information proceeds in "feed forward" fashion through a loose series of processing stages.

V1 extracts features like line slants and colors. Just forward, V2 processes an object's overall contour and separates it from the background. VP and V3 process general form. These are found in placental mammals but not marsupials, suggesting an origin about 160 million years ago. V1 is found in all mammals, originating over 170 million years ago.

V4 is sensitive to general form and color combinations; for example, an abstract red "squashed raindrop". The next area, LOC/IT, responds to 2D, 3D, and moving patterns, and originated sometime before 32 million years ago.

Particular object classes, such as faces or flowers, are processed by small patches in the fusiform gyrus bridging the occipital and temporal lobes. Similar ones are found in monkeys. Notably, orientation sensitivity is found in face patches, with upright faces providing more configural information than inverted ones. Found to varying degrees in humans, apes, monkeys, and -- counterintuitively -- sheep, it is not found in birds, and may therefore date to 95-300 million years ago.

A related human phenomenon is bias toward global processing (overall shape) and away from local processing (features). Chimpanzees show this to some degree, but not Old World monkeys. New World monkeys demonstrate the reverse, favoring local processing. Thus over the past 32 million years, there has been a striking evolutionary shift in our ancestral line.

Bigger, more interconnected brains may be better at "Seeing the forest before the trees". That may have helped us detect camouflaged prey and predators, and likely improved our global imagery of tools assembled from local parts.

Outline of headers and subheaders:

Chapter 14, "Memory"

Association is what most people mean by memory. Conditioning, involving arbitrary stimulus-response association, is found in species as diverse as snails, wasps, flatworms, birds, and mammals generally. Thus its origins extend back 520 million years. Jellyfishes may not be capable of conditioning, likely indicating its mediation by developed nervous systems.

Sensory memory is a short-lived trace of a stimulus's physical form. In vision it lasts less than half a second in daylight, and up to four seconds at nighttime. There is a peripheral component in the retina and a central component in the brain. As an aftereffect of neural stimulation, it has likely existed since the evolution of either flatworms or cnidarians 500-600 million years ago.

Short-term memory lasts about 20 seconds, or longer if refreshed through rehearsal. Its capacity depends on what is remembered: E.g., 8 colors but only 3 nonsense syllables. The concept of working memory adds an executive control component, with similar frontal lobe involvement in Old World monkeys and humans. That suggests an origin at least 32 million years ago. A short-term memory exists in birds through convergent evolution.

Of several ways to parse long-term memory, one fruitful way distinguishes between episodic and semantic memory. Episodic memory is of specific past events. Though difficult to demonstrate in animals, a lowland gorilla can remember, over several minutes, a single-trial feeding, something not attributable to mere familiarity.

Chimpanzees and rats also show evidence of episodic memory. It involves the hippocampus, a 400-million-year-old structure, although it is doubtful that the hippocampus has supported recollection over that entire span.

Semantic memory is knowledge independent of recollected events. A modality-free version engaging the lateral temporal lobe may be human-specific. Other primates rely on vision- or hearing-specific memories involving the medial temporal lobe and other local areas.

Outline of headers and subheaders:

CHAPTER 14. MEMORY
Sensory memory
- The peripheral component
- The central component
- The evolution of sensory memory
Short-term memory
- Comparative studies of short-term memory
Intermediate term memory
Long-term memory and its divisions
- Episodic memory
- Semantic memory
Conclusion

Chapter 15, "Language"

Apes trained in sign language, or using symbolic keyboards, often seem to demonstrate representational capacity, vocabulary, and elements of grammar. These are useful categories in initial considerations of language evolution.

Secondary representation is the ability to separate a primary representation (e.g., the perception of a banana) from its referent (an actual banana) for hypothetical purposes (using a banana as a symbolic telephone). Chimpanzees use secondary representations when visualizing a selected leafy twig as a stripped termite probe, or when cradling a log like a "baby". Monkeys lack this ability.

Ape language studies provide both a symbolic means of reference (signs or keyboard symbols), and instruction in comprehension. They have demonstrated acquired vocabularies of hundreds of signs or keyboard symbols. Combinations are often meaningless or repetitious, and acquisition is slow, but in many cases meaningful intent is clear. To many cognitive psychologists, these communications of meaning denote language.

To a linguist, however, language's hallmark is grammar (syntax). Here ape abilities fall short. Long combinations produce little evidence of consistent ordering. Two-sign combinations, however, do show some consistency. That suggests that natural ape gestures, often communicating an action and implying an actor, may have originated grammar.

Anatomical comparisons provide further insight. Our Broca's area was preceded by primate area F5, which is involved in sequential actions with grammar-like structure. Significantly, unlike other apes, both chimpanzee species frequently pair gestures with vocalizations, suggesting that early human language was both gestural and vocal.

Other observations indicate that language emerged from a 32-million-year background. There were then mirror cells, needed to copy gestures, and leftward asymmetry of both the temporal and inferior parietal lobes. By 17 million years ago, symbolic capacity and a simple "vocabulary" of natural communication gestures appeared. By 7.5 million years ago, gestures and vocalizations were co-produced.

Sometime after 6 million years ago, laryngeal control increased, and connections improved between Broca's area and the temporal lobe. By 2.4 million years ago well-defined gyri marked Broca's area, and inferior parietal cortex enlarged. About 1.9 million years ago the jaw began shortening, and the tongue reoriented. Crude, limited speech may have been produced and understood.

Outline of headers and subheaders:

Chapter 16, "Consciousness"

Functional approaches to consciousness emphasize what it brings to behavior. Sensory awareness is one function. Normally it results from primary cortex stimulating higher levels of cortex, with reentry back to primary cortex. When primary cortex is destroyed, however, only pathways to secondary cortex remain. Absent reentry, "blindsight" or "deaf hearing" results, in which there is no sensory awareness even though residual vision or hearing is present.

Reentrant connections are a fundamental characteristic of the mammalian brain, existing in diverse species like monkeys, ferrets, and cats. Sensory awareness therefore dates back about 195 million years.

Metacognition, the awareness of one's own cognitive states and processes, is another function of consciousness. It includes "feelings of knowing" about one's level of knowledge. Old World monkeys show it, but New World monkeys yield ambiguous evidence, suggesting an origin about 45 million years ago.

Self-recognition is a third function. All great ape species can recognize themselves in mirror images. However, self-recognition is usually not immediate, and not all individuals show it. Old World and New World monkeys generally do not, although capuchins seem to know something is "different" about their image. Mirror self-recognition has been reported in scattered species, the successes usually though imperfectly accompanying encephalization.

A final function is theory of mind, the ability to impute mental states in oneself or others. Apparent successes can often be attributed to simpler mechanisms like stimulus-response association. Some observations resist such explanations, however: Among them, that chimpanzees detour to the end of a barrier to see what humans are looking at; and that they selectively retrieve food that a dominant rival can't see, in preference to what both can see. Referential pointing, helping, and deception have also been cited as demonstrating theory of mind . Again encephalization plays a role.

Outline of headers and subheaders:

CHAPTER 16. CONSCIOUSNESS
Sensory awareness
- Blindsight and deaf hearing
- The role of reentry
Attention
- Problems with attention as consciousness
Metacognition
Self-recognition
- Individual differences in self-recognition
- Self-recognizing species
- The role of encephalization
Theory of mind
- Referential pointing

- Helping and deception
Conclusion

Chapter 17, "A Summary in Nine Firsts"

Except for very early developments like neural nets and mechanoreceptors 600 million years ago, pigmented cup eyes 580 million years ago, and muscles by 540 million years ago, the events in this book can be loosely summarized under nine "firsts".

Notable achievements of the first three include a nervous system and paired eyes in the first vertebrate; limbs, an auditory system, and a hippocampus in the first tetrapod; and a large brain, mostly erect body, and loss of two cone types in the first eutherian.

The first primate had grasping hands and feet, with an opposable thumb and a diagonal gait; binocularly convergent eyes; several cortical motor areas; and an area V5 supporting movement perception.

The first ape had reduced olfactory bulbs, a re-evolved third cone type, sharp vision involving a fovea, and more differentiated parietal and temporal lobe areas. Leftward brain asymmetry began.

The first great ape was more encephalized, created simple vegetative tools, and could plan. Limited causal understanding, self-recognition, and a rudimentary gestural grammar possibly existed.

The first hominin was bipedal and could carry limited loads. A strong precision grip accompanied predominant right-handedness for some tasks. Global-over-local bias existed, as did the ability to form a basic theory of mind.

The first human had increased encephalization, created stone tools, and was substantially right-handed. New inferior parietal gyri aided planning, and Broca's cap was consistently present. Communication gestures had likely become more frequent.

Finally, the first modern human showed high encephalization and made increasingly sophisticated tools. The parietal lobe had expanded. Numerous language adaptations existed in the brain (e.g., increased larynx control, and interconnected Broca's and Wernicke's areas) and body (e.g., loss of the hyoid, and vocal cavity "verticalization"). A modality-free, general semantic memory had appeared.

Human evolution, however, has not ended. Among possible species-wide changes now occurring are weakening bones due to sedentary lifestyles; and lactase persistence, allowing adults to digest milk. Infant head circumference is under strong selection pressure, possibly increasing intelligence but also Caesarian births. As for the future, all we can be sure of is that as the environment changes, so must we.

Outline of headers and subheaders:

CHAPTER 17. A SUMMARY IN NINE FIRSTS
The first vertebrate (520 million years ago)
The first tetrapod (365 million years ago)
The first eutherian (170 million years ago)
The first primate (83 million years ago)
The first ape (32 million years ago)
The first great ape (21 million years ago)
The first hominin (7.5 million years ago)
The first human (2.4 million years ago)
The continuing story