THE FUTURE OF THE PAST

by Alison S. Brooks

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When *AnthroNotes* began publishing in 1979, what we knew about human evolution and how we studied it differed significantly from today. Field research among wild populations of great apes by Jane Goodall (chimpanzees), Dian Fossey (mountain gorillas), and Birute Galdikas (orangutans) had provided exciting new data for modeling the likely capabilities of our earliest ancestors. Ecologically focused field studies of living hunter-gatherer populations such as the Ju/'oansi in southern Africa, the Mbuti in the eastern Congo basin, the Hadza in northern Tanzania, and other groups throughout the tropical and sub-tropical world provided new ideas about how ancestral hunter-gatherers might have lived – using a mobile life style without domestic animals. Social systems were fluid. Nourishing toddlers in the absence of domestic animal milk and soft vegetable foods required mothers and infants to stay in close contact throughout the day and night. Vegetable foods were more important than meat in the diet; women brought in more calories than men did through a daily foraging round; and long-distance exchange networks alleviated the ever-present risk of starvation when local resources failed.

By 1980, teams searching for fossils in some regions could employ more precise dating techniques. Especially important were those based on an atomic "clock" in which radioactive isotopes decay at a known rate, beginning with radiocarbon in the 1950s and potassium argon in the 1960s. Deep sea and ice cores provided material and dates for understanding both climate change through time and changes in the earth's magnetic field that could be correlated to land-based sequences.

Further exploration of new regions in the rift valleys of Kenya (Lake Turkana) and Ethiopia (the Awash and Omo valleys) yielded a large number of early fossils relating to the human lineage. But the study of such fossils was largely confined to observations and direct measurements, comparing fossil specimens to one another and to skeletal remains of living apes and humans. In the dawn of the computer age, — the home computer was *Time's* 1982 "person of the year" — statistical analysis was laborious and limited.

Not only was the computer revolution in the future, but so was the genetic revolution. The 1987 publication of the "African Eve" hypothesis, arguing that all humans today are descended from a 'recent' African ancestor and not from the earlier inhabitants of Europe and Asia, strongly challenged existing ideas. Neandertals, "Peking Man," "Java Man," and others were largely (although perhaps not entirely) out of our direct ancestral line.

As in so much else of the modern world, technology revolutionized the study of human evolution. Scientists began to use new imaging techniques for studying and reconstructing fossils; new geochemical techniques for dating sites and reconstructing ancient diets and environments; and new motion sensor equipment to understand how bones and muscles are used in various activities. Today a field team looking for fossils is likely to include more geochemists and geoscientists than "physical anthropologists." Anthropology departments' laboratories now are less likely to hold skeletal remains of modern humans or caged primates and more likely to contain live mice, sheep, snakes, hyraxes and other experimental animals, along with CT scanners, treadmills, 3-D digital scanners and printers, and equipment for chemical or physical analysis.

Scanning the Past

Both fossils and artifacts are routinely "digitized" or scanned by CT (computerized tomography) or 3-D digital scanners to produce digital images that can be statistically analyzed, manipulated, and compared. These differ from digital photographs in that the images are three-dimensional and are created by complex computerized computations. A micro-CT scanner has an extremely small X-ray beam, so that each pixel has a resolution of a micron or less (one thousandth of a millimeter). After the scanner produces vertical X-ray "slices" of an object, a computer then puts the slices together to create a 3-D image that shows the internal structure of the object.

To reconstruct a fragmentary skull of the new 4.4 million-year old Ethiopian fossil hominin ancestor called "Ardi" (*Ardipithecus ramidus*), University of Tokyo anthropologist Gen Suwa used a micro-CT scanner to create digital X-ray images of 65 tiny fragments. He then spent hundreds of hours manipulating the fragments digitally to create one image of the skull. By using a 3-D printer that extrudes a plastic resin copy of each slice of the scanned object and glues the slices together, a physical model could be produced of that image. (You can sometimes see the actual slices if you look closely at the plastic.). Swiss scientist C. Zollikofer and others used this technique to reconstruct the somewhat squashed and distorted skull of "Toumai," the ca. 6-million-year-old hominin ancestor from Chad (*Sahelanthropus tugenensis*).

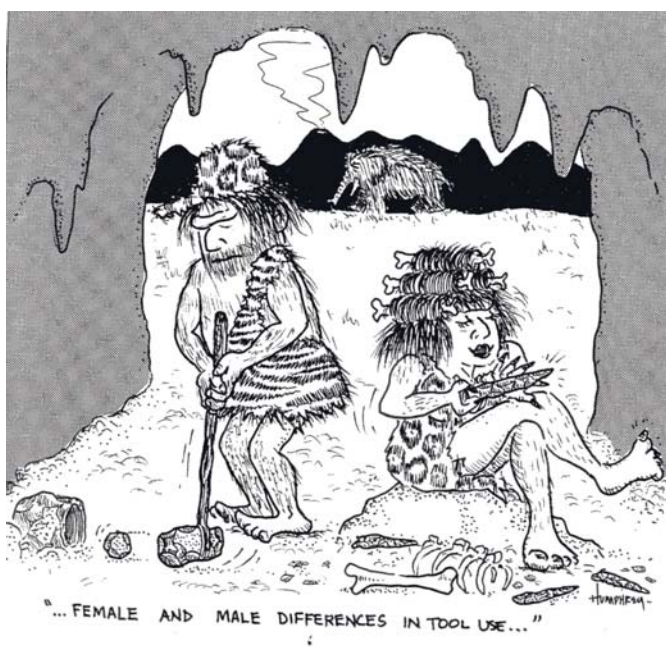
Micro-CT scans also can reveal the thickness of tooth enamel, which relates to diet; the underlying structure of the top of the dentine layer if the enamel is too worn to tell what species of hominin the tooth came from; or the orientation of the bony lines of strength or "trabecular bone" in the spongy interior of long bones. These tell us about the force exerted on the bone by the muscles and hence how the limb was used. Portable micro-CT and digital scanners have enabled researchers to digitize and CT scan fossils while they are working in the museums and labs of the host country.

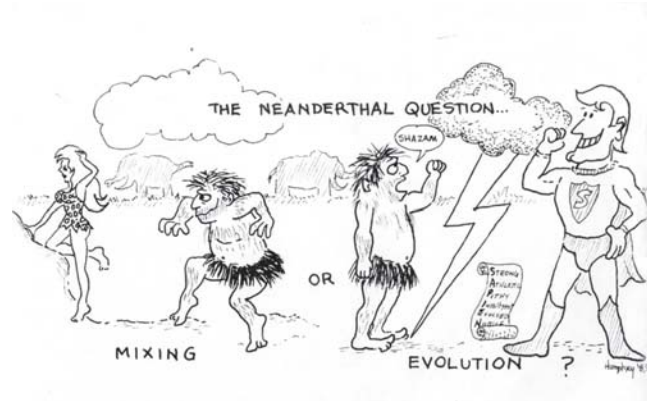
Archaeologists use 3-D digitization and statistical techniques for the geometric comparison of shapes among stone arrows, art, and spearheads. University of Toronto Ph.D. Jayne Wilkins and others used statistical scans of use wear on the edges of ca. 500,000 year-old stone points from South Africa to demonstrate that they were indeed points and not knives or scrapers, since the use-wear was equivalent on the two sides of the points.

George Washington University's Brian Richmond and Dave Braun have been experimenting with laser-scanning and composite photography to replicate and make physical copies of entire hominin footprint trails and site surfaces dating back thousands and even millions of years in Tanzania and Kenya. The photogrammetry or composite photography technique uses multiple cameras and computer techniques to stitch the images together, and then prints replicas of the footprints on a 3-D printer. The scientists and their team were able to calculate not only the size of the feet (and the attached humans) but also the probable sex (and age, for children) of the foot's owner. This information illuminated the group's social composition, which, at one point, included a group of women and children travelling with one man – a window into a prehistoric moment almost 200,000 years ago.

The Genetic Revolution

The genetic revolution brought us new data and ideas about human evolution at an ever-accelerating pace. When *AnthroNotes* began publishing, many geneticists worked on traits that were expressed in individuals, like blood groups or immune antigens. The first actual DNA sequences of





primates in the 1970s and 1980s resulted from labor-intensive methods that applied electric fields to a few DNA samples. Since about 2005, several methods and machines could analyze huge amounts of DNA simultaneously, enabling the relatively rapid sequencing of entire genomes, including our own and that of some of the great apes. Methods for extracting and studying DNA from human remains have become much improved. While applications of ancient DNA techniques to fossils have led to startling discoveries about our prehistory, the greatest need for careful analysis of DNA remains in the forensic science efforts to identify rapists and murderers, as well as the dead, including long-missing remains of fallen soldiers.

Ancient DNA and Human Evolution

DNA exists in the nuclei of cells and also in the mitochondria, small organelles in the cell that help to generate energy. Mitochondria are inherited almost entirely from the mother. DNA recovered from the dead or from fossils has largely broken down into short segments and is a mixture of human DNA, bacterial DNA, and other contaminating DNA. Bacterial sequences can be distinguished fairly easily from human ones – but contaminating sequences can prove more difficult. Unless the excavators wore gloves, fossils may contain fresh contaminants representing the DNA of the excavators, the cataloguers, the lab techs, or others. In one case, a large amount of domestic cat DNA showed up in ancient human remains from the New World, with individuals who died long before domestic cats arrived with the European colonists; the excavator turned out to have multiple cats at home.

Since informative mitochondrial DNA sequences are shorter than ones found in the nucleus, and since there are many mitochondria in each cell, the first studies of fossil DNA looked only at mitochondrial DNA. As of 1997, these studies had indicated that Neandertals and modern humans did not interbreed. Additionally, they confirmed Cann's 1987 initial argument suggesting that the genomes of modern humans were entirely derived from Africans living ca. 200ka or more years ago. The last common ancestor was termed the "African Eve" because we only had the female side of the story. With the advent of nuclear DNA sequencing, geneticists began to develop the genetics of the Y-chromosome, since it was a shorter sequence than the others and passed on only from father to son. Results of the Y-chromosome studies were similar in arguing that all modern human males descended from an African common ancestor (African 'Adam') but with a younger age for the last common ancestor.

In 2010, the draft sequence of a large part of the Neandertal nuclear genome suggested that Neandertals had, in fact, interbred with the ancestors of modern Eurasians, who are, on average, 1-4% Neandertal — but not with Africans. Furthermore, the separation of modern human and Neandertal lineages was as much as 500,000 years ago or even more. At the end of 2010 came an even more startling discovery – that an entirely new archaic species that lived at the same time as Neandertals and early modern humans had been found in western Siberia, but not "found" in the traditional sense. The entire fossil list of this species, from Denisova Cave, consisted of a molar tooth and a finger bone, — not much evidence on which to define a new species, although the tooth was different from those of Neandertals and modern humans. The DNA of these two pieces matched, but was different from the DNA of both the Neandertals and the modern humans. The degree of difference suggested that the last common ancestor lived close to 500ka, (or 400-800ka) ago.

In 2011 and 2012, other studies showed that southeast Asians and Australians have 3-5% "Denisovan" DNA, reflecting ancient admixture between the two species but also ca. 2.5% Neandertal DNA. One scenario posits that as the modern humans left Africa, they met Neandertals somewhere in the Near East and continued to Asia, where some of them — going southeast — ran into the Denisovans and interbred with them as well. Alternatively, the first SE Asians and Australians only ran into the Denisovans, and a later migration brought people who went through the Neandertal region. Denisova cave also contained evidence of Neandertals, which extended the Neandertal range about 2,500 km to the east of the previous eastern limit in Uzbekistan.

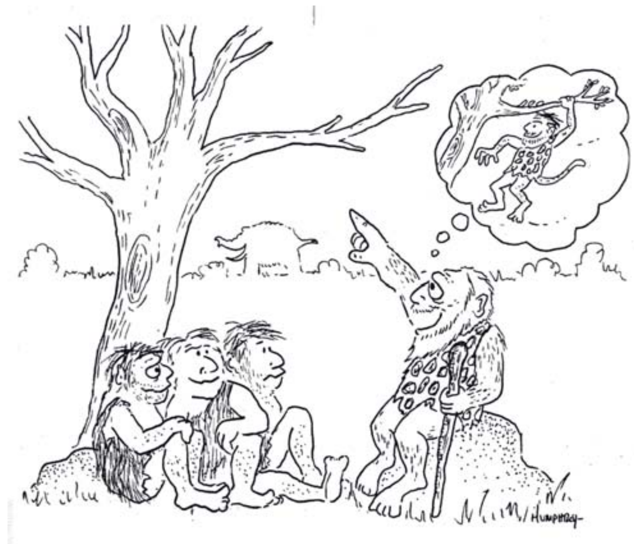
What sorts of genes did Eurasians acquire from Neandertals and Denisovans? Probably they inherited the genes for light skin, as well as for some antigens that protect against disease. Other genes will certainly be discovered as the studies proceed. In 2011, a genetic study of Africans suggested that they also carried genetic material from an admixture with an archaic species, but as yet there is little trace of the bones of the species in question, or any idea of where in Africa this species lived.

Also in 2011, a re-study of an 11,000 year-old skeleton from Nigeria, Iwo Eleru, suggested that it was not entirely a modern human but represented an archaic lineage. Thus genetics has suggested a much more complex picture than was posited earlier, with at least four and perhaps five different human species (*H. sapiens, H. neandertalensis,* 'Denisovans' in Asia, and 'hobbits' on Flores Island in Indonesia) sharing the old world between 200,000 and 50,000 years ago, and with multiple migrations out of (and into?) Africa.

Anthropologists and geneticists are also using genetics to figure out what genes contribute to the development of different body parts, capacities, and other features. Some of this is done with 'knockout' mice, in which normal mice are bred to lack the gene that is the target of interest. Such studies are combined with worldwide studies of variation in the characteristic or body part under study, and efforts to identify what is genetically unique among those who share a deficiency in the functioning of the body part or facility in question.

Capturing and Modeling Motion

When the *Lord of the Rings* film trilogy created the Gollum character using computer graphics, the developers created his movements by having a real actor model the actions by going through the same motions in a motion capture laboratory. Such a lab places markers on the moving parts of a person's anatomy, and then, using as many as 20 cameras, films the person moving in a particular way. A computer attached to the cameras integrates the sensor data, generates a moving stick figure and calculates separately the velocity and direction of each moving body part. The force exerted by or on the body part can then be calculated using the average weight of the limb in question.



Using motion capture technology, Erin Marie Williams and Brian Richmond at GWU have studied the motions and forces involved in flint knapping, or making stone tools. One surprise, but not to the knappers, was that the distinctive long human thumb did almost nothing during this activity. Dan Lieberman at Harvard studies human running, with and without shoes, and its role in the development of our odd bipedal locomotion. Dan's student, Neil Roach, now at GWU, studies throwing. His research has shown that throwing is the most unique motion made by humans, and that no other animal has the same force and accuracy. Effective human throwing depends on the body rotating toward the throwing arm side just before the throw, as well as on the step forward by the opposite leg, so that the entire side of the body propels the arm forward like a whip.

Modeling Projectile Technology

A major question in human behavioral evolution concerns the development of complex projectile weapons: stone-tipped javelins, spear throwers, and bows and arrows. Such weapons require advanced cognitive capacities for imitation and innovation, as they are composed of three or more parts (stone tip, haft, and glue/adhesive/binding material, each of which requires a complex manufacturing sequence). Many archaeologists are experimenting with calibrated crossbows that provide a standardized amount of force, a dead goat or other animal, and a machine for capturing the acceleration or force of the projectile – the latter can be as simple as a force plate, or as complex as a ballistics tester with a laser camera stopping the action at microsecond intervals. Stone points get smaller over time in Africa, and the question is: why? Were the users accomplishing the same goal with a smaller point sent with more force? Were they using poison so that they didn't have to deal a mortal blow with the first shot? Two new studies in 2012 argue that projectile technology with small projectile tips is at least 71,000 years old in Africa, and that by ca. 40,000 years ago, there is direct evidence of the use of poison on an applicator stick. And, as mentioned above, the invention of complex hafted points is as old as half a million years, and predates the first appearance of *Homo sapiens*.

Experimental Physiology and Materials Science in Archaeology

When (and why) did humans first control fire and cook their food? Was there ever a "Palaeolithic diet"? A raw foods diet? What foods are we adapted to eat? And how did we get them? For at least half a century, anthropologists have tried to derive the answers from looking at the size, shape, and enamel thickness of teeth, both human and non-human. One prevalent theory was that we had thick enamel because we ate tough objects that were hard to crack open. (A recent paper argued, however, that it was the small silica crystals in tough grasses and sedges that favored the thick enamel). Another theory was that controlled fire and cooked foods were late, since we had little evidence of it before ca. 800,000 years ago.

Medical studies have shown, however, that modern humans lose weight to the point of starvation on a purely raw foods diet, since we lost some of our primate digestive tract that would have allowed us to thrive before cooking. Diets that emphasize only animal protein and no carbohydrates also result in weight loss, as the body needs energy to digest protein foods, and if not enough energy is available, the individual will not metabolize the meat. Humans are also unique in the widespread dependence on cooked starches, (tubers, grains, nuts, etc.) and may have salivary adaptations to eating those particular foods.

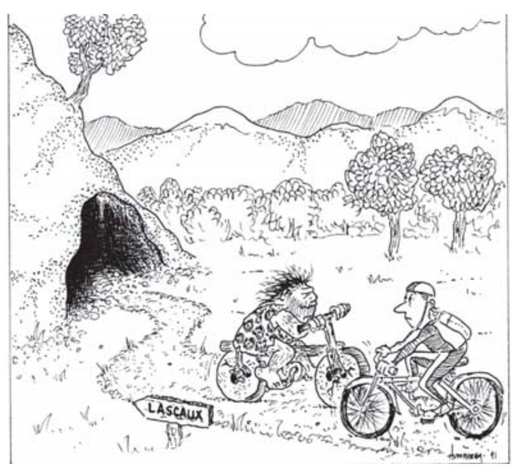
Perhaps the most unusual experiments on this topic were carried out by Richard Wrangham at Harvard and his student Rachel Carmody, who fed cooked and raw mice to snakes and measured their metabolic energy use by placing them in a chamber that measured their oxygen uptake during digestion. The cooked mice required much less energy to digest, suggesting that cooking was another way of freeing up energy to grow a bigger brain, grow taller, expand the population out of Africa, and other advances. While the evidence for early fire before 1 million years ago is very limited and inconclusive, the influence of its discovery on our anatomy and physiology was extreme.

New Dates for the Past

At least two new dating techniques have been developed in the last 10 years. One is cosmogenic nuclide dating, which depends on the decay of isotopes of aluminum and beryllium in sediments. Like many radioactive isotopes, these decay at a regular rate. Since radiation from sunlight forms the two isotopes, the sediments need to have been deeply buried since the period of interest in order to measure the decay since the time of burial. Another new technique involves using uranium-series decay methods to date the thin calcite layers that sometimes form over cave paintings. In the first publication on its use, the authors derived average dates of ca. 40,000 years ago for paintings in 11 caves in Spain, raising the possibility that Neandertals might have made them rather than modern humans.

Environments and Human Evolution

During the 6 to 7 million years for which we have evidence of our lineage's evolution, the climate was growing both cooler and more variable. The longest and most detailed records of climate change come from ice and deep-sea cores, which record fluctuations in the world's tem-



perature in multiple ways. Ice cores record changes in the concentration of heavy isotopes of oxygen, while deep-sea cores also record fluctuating populations of microscopic organisms that are temperature sensitive, as well as dust blowing off the continents during dry intervals, and leaf waxes washing off the continents in wet periods. Only a very few climate records on land, near the sites where remains of humans and their activities are found, come anywhere close to even the last 500,000 years of the deep sea record.

Climate records are built up from multiple studies of sediments, animal remains, lake cores and geochemistry – especially the stable isotopes of carbon. Light isotopes of any element in our bodies go through metabolic processes more easily while the heavy forms get left behind more often. Hence the heavy stable isotope of carbon (carbon-13) is discriminated against as plants take in carbon from the CO2 in the atmosphere and as we then eat the plant (or eat the animals that eat the plants). Plants that are heat or oxygen-stressed, however, like tropical grasses, or sea plants, do not discriminate as much, so their carbon-13 values are higher. In the tropical environments where humans evolved, the percentage of grass cover as opposed to forest or woodland can be estimated from the carbon-13 content of the carbonate nodules that form in the soil. Studies of the carbon-13 in the tooth enamel of the faunal remains will also inform about the environment of that species and its diet. Studies of the heavy oxygen isotopes in the teeth of animals can inform us about the temperature. Strontium isotopes are related to the strontium concentrations of the bedrock in the region where the animal lived when its teeth were forming. The plants take up the bedrock concentration and the animals eat the plants. So by studying several teeth in an animal's mouth, and several animals in a site, it is possible to tell how far an animal migrated during its growth period, and also if one sex moved further than the other.

Stable isotope analyses are now widespread in the study of human evolution, and expeditions often include a stable isotope geochemist who is monitoring the ancient climate. In addition, a new program starting this year will drill deep cores into lake basins that are now dry but rich in fossil and archaeological remains, like the Hadar Basin where 'Lucy' was found. These cores will provide a clearer idea of locally changing climates during human evolution. Analyses of the cores will be carried out by paleobotanists (looking for plant microfossils pollen and phytoliths), stable isotope geochemists, sedimentologists, and, where there are lake deposits, specialists in the microorganisms that live in freshwater lakes. The hope is for a better understanding of the climate in which our species evolved.

Fossils Are Still Important

New fossils and sites are still at the heart of what we do. Like the new australopithecines from Malapa in South Africa; the new jaws published this year from Kenya; the new dates for cave paintings, musical flutes, projectile points, and decorated ostrich eggshells, there are always surprises lying in the ground concerning our ancestry. But the surprises hiding in the laboratory are equally exciting and hold the promise of new questions and directions in the study of the human past.

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(Other references upon request -abrooks@gwu.edu.)

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