



## TOUMAI: REVERSE-ENGINEERING A HUMAN ANCESTOR

By Pam Frost Gorder

**H**E COULD BE THE EARLIEST HUMAN—  
THE MISSING LINK IN THE EVOLUTION-  
ARY CHAIN THAT CONNECTS HOMINIDS TO  
CHIMPANZEES AND OTHER GREAT APES. SEVEN

million years ago, before the Neanderthals, before *Homo erectus*, even before australopithecines like the famous Lucy ever lived, Toumai walked the earth.

Anthropologists suspected that Toumai and the rest of his species—dubbed *Sabelanthropus tchadensis*—walked upright from the moment they unearthed his skull in central Africa in 2001. But the skull had been crushed, pressed flat, and stretched out by the rock that surrounded it. To prove whether this new species was truly one of us, scientists had to do more than just reassemble it. They had to reverse-engineer the skull back into its original shape—using virtual reality.

### Picking Up the Pieces

French anthropologists led by Michel Brunet from the University of Poitiers found only one specimen of *S. tchadensis* in Chad; they named him Toumai because the word means “hope of life” in the local language. Toumai’s uniqueness made him important to anthropology as a whole, but it also made him very difficult to analyze.

Their traditional measurements of the skull fragments suggested that Toumai had both apelike and human features, but when Brunet’s team published those results in *Nature* (vol. 418, 2002, pp. 145–151), their conclusions were met with controversy. Radioactive isotope dating proved without a doubt that Toumai was 7 million years old—twice as old as Lucy. If he were a hominid, the skeptics reasoned, then humans would have to have diverged from apes much earlier in history than previously thought.

While Brunet returned to Chad to find more physical evidence to back up his claim, some of his colleagues turned to computer science to better assess Toumai’s skull. Christoph Zollikofer and Marcia Ponce de León from the

University of Zurich-Irchel in Switzerland performed a *morphometric* analysis, using computer software to reconstruct the skull and return it to its original shape (see Figure 1). They’d been performing similar analyses on Neanderthal skulls since the early 1990s.

In two companion papers published in *Nature* (vol. 434, 2005, pp. 752–755 and pp. 755–759), the teams now report that *S. tchadensis* belongs on the human family tree. The finding met less controversy this time around.

“Overall, we had very positive reactions from fellow scientists,” Zollikofer says. “We think the reconstruction and accompanying morphometric analyses convinced many of the undecided that Toumai was a bipedal hominid.”

They started by recording a high-resolution computed tomography (CT) scan of the skull fragments. CT scans are essentially X-ray images in 3D, and CT scanners are standard equipment in hospitals because they let doctors view soft tissue and bone structures inside the body. For Toumai, they used an industrial tomography machine, which is normally reserved for materials testing, because the fossil was too dense for a medical scanner.

The team used data-segmentation techniques to digitally separate remaining bits of sediment rock from the bone fragments and the fragments from each other. They then used morphometric algorithms to detect both how the fragments had been deformed and how to “undo” the deformation. The deformation was nonlinear, Zollikofer explains, so reversing it was especially difficult.

Even after they accounted for the deformation, they were left with a task akin to rebuilding a smashed car when they’d never seen that model before.

“The problem with Toumai was that nobody had ever seen a creature like this. It was beyond imagination, and also way beyond the time range of hominids known so far,” Ponce de León remembers.

Their solution was to take the reverse-engineered skull fragments and try to fit them on digital frames that represented other skull forms—specifically, chimpanzees and gorillas. In both cases, Toumai’s bones didn’t fit. They did fit in a more hominid-like arrangement, with the opening for the spinal column placed where it would need to be if the

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(a)



(b)

**Figure 1. Virtual skull reconstruction.** Anthropologists reconstructed (a) the smashed skull of an early human ancestor using computer science to create (b) a virtual image.

creature stood upright. The conclusion: although his brain couldn't have been much bigger than a chimp's, Toumai probably walked on two legs.

Frank Mendel, an anatomist at the University of Buffalo, thinks this work is very exciting. He often works with 3D reconstructions of vertebrate skulls—in particular, sabertooth tigers, of which there are many examples in the fossil record. He feels that working without a blueprint might have actually helped Zollikofer and his team make a better analysis.

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Having to do the reconstruction without a preconceived idea of what Toumaï should look like probably made for a less biased approach, he says.

Gerhard Weber, an anthropologist at the University of Vienna, Austria, and longtime advocate of virtual anthropology (VA) techniques, says that Zollikofer, Ponce de León, and their colleagues undertook a “brave attempt to reconstruct this heavily deformed and important specimen.” His only criticism was that the brain case after the virtual reconstruction seems long in relation to its height, so he suspects that they weren’t able to “iron out” all of the deformation. For his part, Zollikofer says that he thinks Toumaï’s brain case was actually shaped that way—it’s just that nobody has seen this particular morphology before.

**Hands Off**

In the 1990s, Weber and his colleagues worked on graphics-dedicated SGI Impact workstations. Today, they typically use advanced PCs with off-the-shelf software such as Analyze and AVW from the Mayo Clinic, Amira from TGS, or Edgewarp from the University of Michigan for handling the volume and surface scans. They program some of their own algorithms in Mathematica from Wolfram Research.

Because reconstructing Toumaï presented special challenges, Zollikofer’s team used an SGI Onyx II workstation equipped with stereo screen and shutter glasses for 3D viewing. Then they used their own in-house software, called the Fossil Reconstruction and Morphometry Interactive Toolkit ([www.ifi.unizh.ch/mml/people/zolli/vr.html](http://www.ifi.unizh.ch/mml/people/zolli/vr.html)) to manipulate the skull in 3D.

As advanced graphical tools have moved from workstations to the PC, computer analysis of fossils has become more common, Weber says. The technology wasn’t always so accepted, in part because the notion of computer programmer as anthropologist clashes with the classical, romantic view of the desert-based fossil-hunter. Now, nearly every issue of the leading anthropology journals, such as the *Journal of Human Evolution* or the *American Journal of Physical Anthropology*, contains a paper that deals with virtual representations of specimens or advanced morphometric analysis.

To Weber, virtual reconstruction isn’t that different from physical reconstruction. Discussions of how a particular piece of bone should be oriented to the others, for instance, are the same in the virtual and the physical world.

There are advantages to working with “electronic fossils,” he points out. The computer allows quantitative comparisons with mathematics and statistics, which makes for more objective and reproducible studies. Instead of relying on a

few standard measurements, such as the distance between features, scientists can measure any feature at any time.

They also don't have to touch delicate specimens and risk damaging them. Anyone can construct a real-world copy of a specimen; rapid prototyping techniques developed for manufacturing make physical modeling easy and reasonably inexpensive. But in the virtual world, the bone fragments can fit together without plaster or other physical supports to lock them in place; the specimen remains infinitely adjustable.

In the past, scientists have done their best to rebuild fossils with plaster and glue, only to find later that something should have been done differently. By then, it's too late—breaking the reconstruction apart could damage it irreparably. Perhaps the biggest advantage to virtual analysis is that it gives anthropologists the chance to be wrong.

### Positive Feedback

Mendel says that Zollikofer and Ponce de León's methods will no doubt influence many in anthropology and allied

fields. VA can advance in lockstep with medical imaging and computer graphics—two lines of research that don't show signs of slowing down anytime soon.

"The most exciting thing is that virtual anthropology brings together many different perspectives, and many different people from various disciplines," Zollikofer says. "This is what we need in anthropology."

He and Ponce de León will continue to look for patterns of variability in the hominid fossil record and develop computer models of growth and development in humans and apes from an evolutionary perspective.

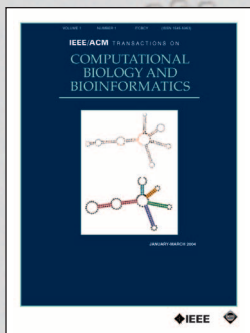
"It is not just about bones," Ponce de León says. "It is about how we can get the most out of these bones, even without touching them, and how we can implement new tools that help us answer questions in human evolution and generate even more new questions."

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