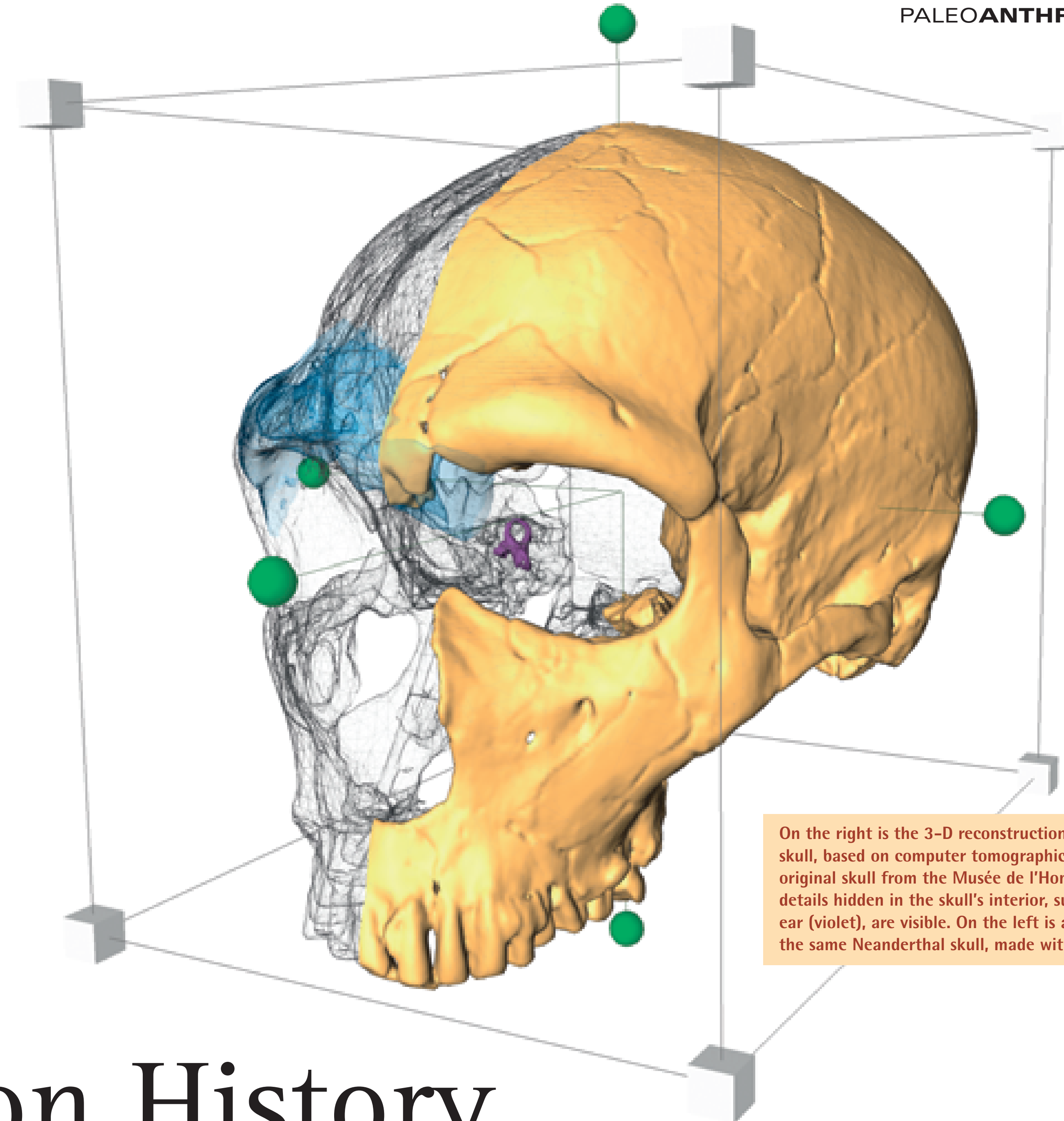


On the right is the 3-D reconstruction of a Neanderthal skull, based on computer tomographic images of the original skull from the Musée de l'Homme in Paris. Even details hidden in the skull's interior, such as the inner ear (violet), are visible. On the left is a plaster model of the same Neanderthal skull, made with a 3-D printer.

Boning Up on History

Anthropologists in Leipzig are working on a virtual collection of early human fossils

"This will completely transform anthropological research," declares Jean-Jacques Hublin, jumping out of the chair on which he'd just sat down. He goes over to the window and points to the courtyard below: "Do you see the container down there? We use that to transport one of the highest-resolution computer tomographs around the world to scan the unique finds we uncover on-site. The objects do not need to be taken to the scanner, the scanner comes to them."

Paleoanthropologists who wish to study the origins of mankind are dependent on bone finds. However, fossilized hominids are among the rarest finds of all. If a museum finds itself in possession of such a treasure, then it becomes a well-guarded secret. The especially important pieces, the ones that all researchers would love to have in front of them in the original, are available as a plaster cast, at best. "But castings are not really exact enough, and many bones are far too brittle to make a cast out of them anyway," says Hublin. But all these issues are about to be resolved. The French researcher's vision is to create a comprehensive virtual collection, thereby making unique early human bone finds accessible to all. This opportunity is why Hublin came to Leipzig in 2004 to join the Max Planck Institute for Evolutionary Anthropology.

"Our research field is multidisciplinary these days," explains the 54-year-old scientist. "We no longer restrict ourselves to describing the bone finds; we now use biochemical methods, sequential analyses and computer technology to try to glean more information from the bones so that we can learn something about how early humans lived, the conditions they lived in and the course of their lives in general."

It was a unique opportunity for the anthropologist, who was then teaching at the University of Bordeaux, when the Max Planck Society offered him the opportunity to establish a Department for Human Evolution at its Leipzig-based institute three years ago. Jean-Jacques Hublin has spent many years studying the world's great paleoanthropological collections and is one of the top experts on hominid fossils.

In the field of medicine, tomographic technology is used as a standard diagnostic tool. But there is nothing to stop it from being used

Photos: left - Volker Steger
right - MPI for Evolutionary Anthropology

to study fossilized bones. The way it works is the same: a rotating X-ray source screens the object layer by layer from different directions; the X-ray is weakened to different degrees depending on the density of the structures. The detectors positioned opposite the X-ray source receive this weakened signal, process it electronically and transmit it to a computer for analysis. In this way, several different projections are created of each layer, and the computer then translates them into a shaded image.

However, the resolution of medical CT machines is not particularly high. “Doctors don’t need high spatial resolution images to make a diagnosis; all they need is half a millimeter,” says Jean-Jacques Hublin. Moreover, medical devices are designed to record data quickly – patients should not be exposed to the damaging X-rays for longer than absolutely necessary. But for the study of early human bones, scientists need detailed CT images. “Nowadays, there are CT machines for the industry that can provide resolution on the micrometer scale,” explains Hublin. And the length of time the fossilized bones can stay in the tomograph is not limited either. Being thousands of years old, the remnants of ancient hominids have nothing to fear from the damaging X-rays.

Resolutions below the Micrometer Level

The institute in Leipzig has two computer tomographs: the BIR ACTIS 225/300 achieves resolutions in the range of one millimeter to five micrometers; the Skyscan 1172 can even go down to 0.8 micrometers. “There are only four CT scanners in the whole world with such high resolution for use by paleoanthropologists,” says Hublin, not without a hint of pride. “This means that we can even analyze minute structures, such as dental enamel.” These abilities enable the scientists to draw conclusions about the growth rates of hominids.

The BIR ACTIS is located in its own room on the fourth floor of the Max Planck building in Leipzig. Ten millimeters of lead line the walls from ceiling to floor to protect the surroundings from the X-rays. The whole arrangement weighs in at nine tons. In the operator’s room next door, Heiko Temming and Andreas Winzer are packing up cables and computers, preparing for the CT’s upcoming trip to Morocco. The man-

The journey begins in Leipzig: A crane heaves the container onto a waiting truck. Inside the container is the computer tomograph, which has been screwed down for the trip to Morocco, where it arrives about a week later. It is then allotted a space right next to the little archaeological museum in Rabat.

PHOTOS: ANDREAS WINZER

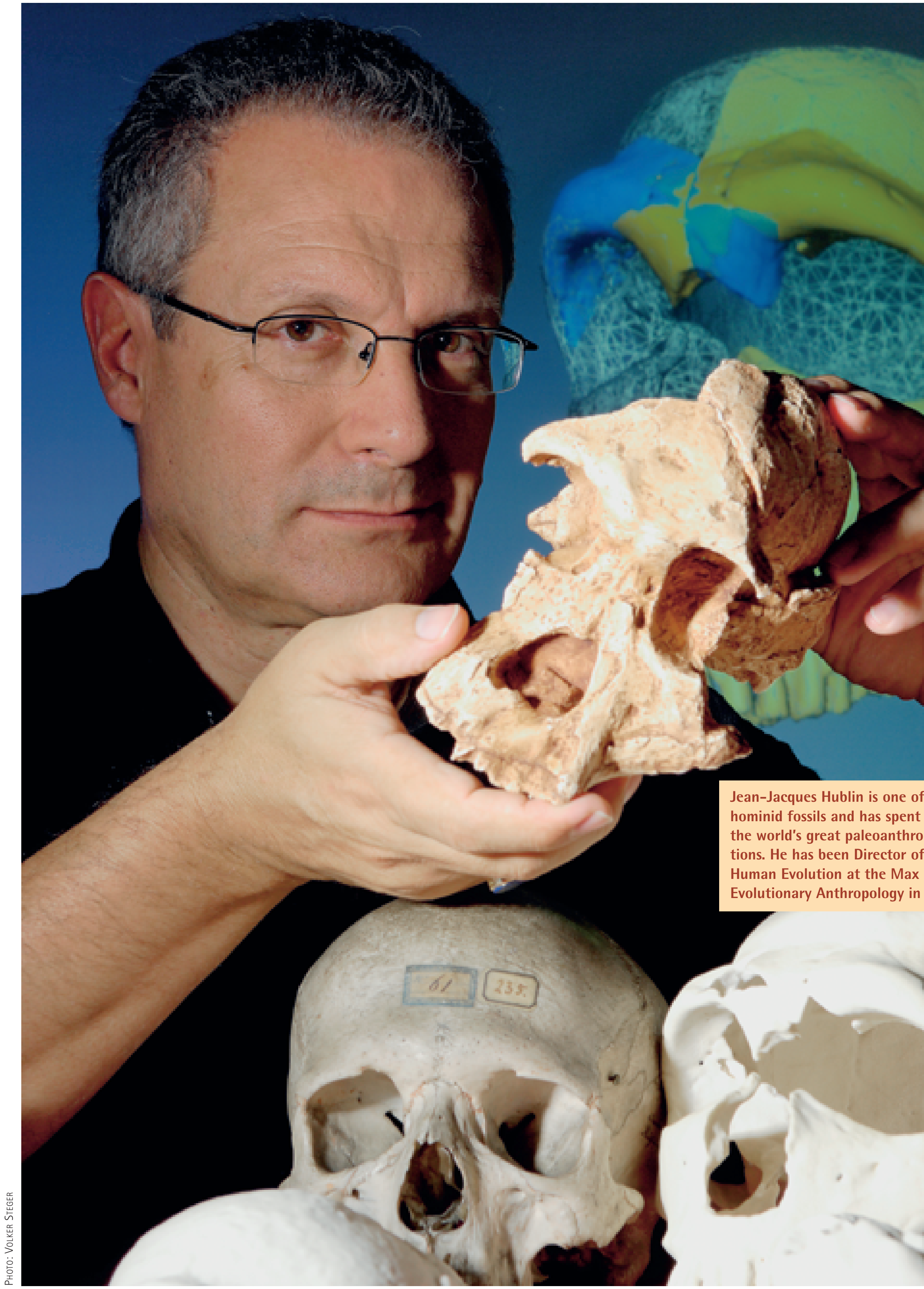


PHOTO: VOLKER STEGER

Jean-Jacques Hublin is one of the top experts on hominid fossils and has spent many years studying the world’s great paleoanthropological collections. He has been Director of the Department of Human Evolution at the Max Planck Institute for Evolutionary Anthropology in Leipzig since 2004.

Rabat is the capital of Morocco. The French made Rabat the country's administrative capital and generals' residence during the period when it was a French protectorate in the mid-20th century. The tight schedule set up for Andreas Winzer and Heiko Temming (bottom left and center) allows them only a brief excursion into the old royal city.

Photos: Andreas Winzer

sized machine is on rollers, making it relatively easy to move around. Winzer dismantles the sensitive measuring arm and stows it separately. Then the two men muster their combined strength to take the CT down to the ground floor and out into the courtyard behind the institute building, where the container stands waiting.

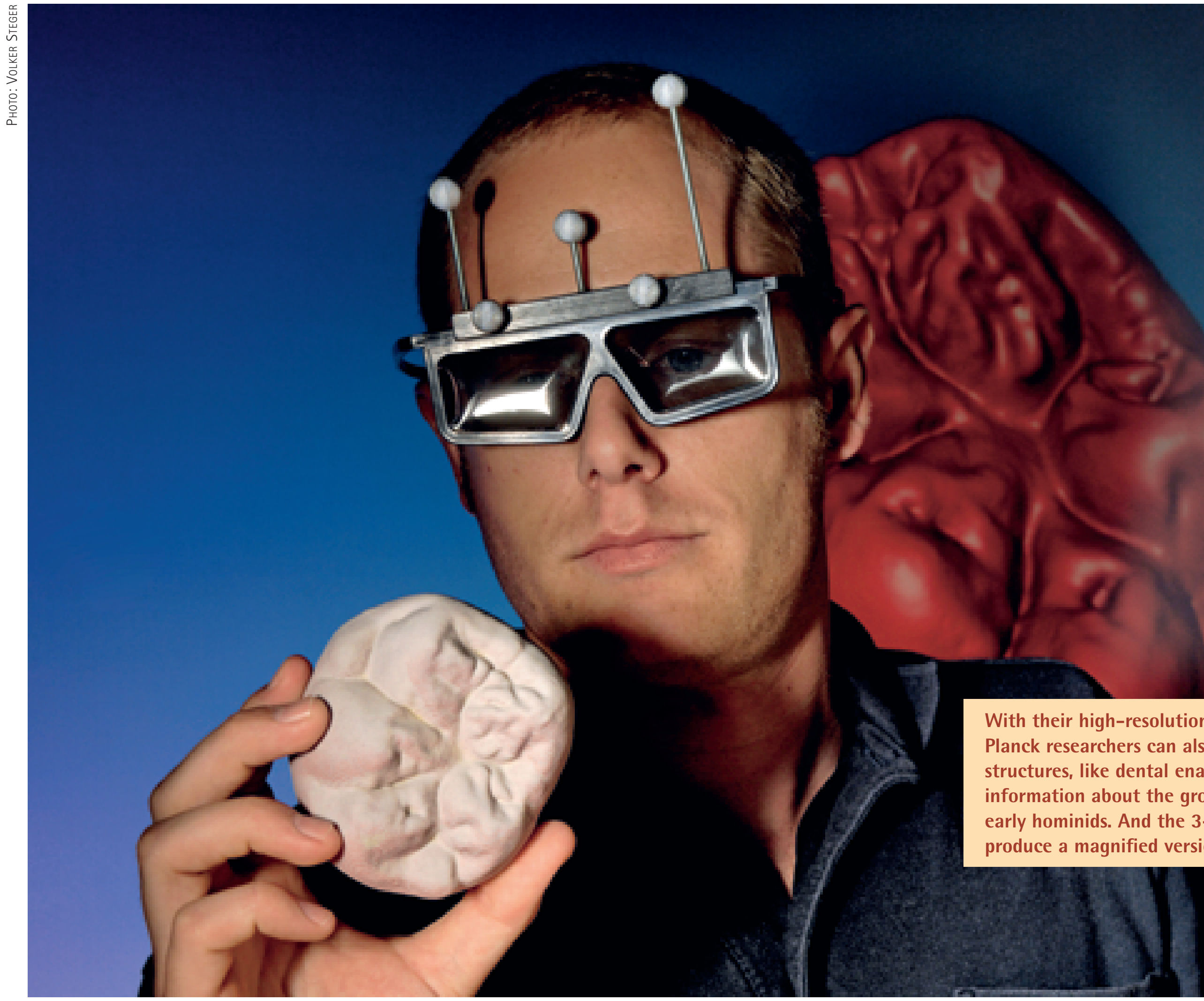
The unassuming gray steel walls conceal lead shields inside the container, into which the super-scanner fits snugly. Securely bolted down, the machine is ready to begin its journey together with its companion computer equipment, which is packed in shockproof crates. Early in the morning of October 3, 2006, a loading crane heaves the container onto the back of a truck. It then sets off on the three-day, 1,387-kilometer drive from Leipzig to Marseille in the south of France. Upon reaching the Mediterranean, the container is loaded onto a ferry, which takes a day and a half to transport the valuable cargo to Africa's northwest coast. The destination is Rabat, the capital of Morocco.

In the meantime, Heiko Temming and Andreas Winzer have also set out on the trip, but they are flying from Leipzig to Paris, then on to Casablanca. A car will pick them up at the airport and take them to Rabat. The truck with the container doesn't arrive until late in the evening. The crane is ready and waiting; offloading the cargo takes until midnight and even attracts a small audience. The container is allotted a space right next to the little archeological museum. The only thing the two technicians from Leipzig need now is a power supply for the air-conditioning system.

Rarities Stored in Cardboard Boxes

Temming and Winzer spend the next three days calibrating the highly sensitive measuring device. Only after this crucial task can the real work begin. Temming and Winzer will be scanning 30 bones: three skulls, six lower jaws and various skull fragments. Although Rabat's archeological museum looks rather unassuming from the outside, its interior houses a valuable collection of hominid bones. These bones could be the remains of the ancestors of the humans who left Africa around 50,000 years ago, constituting the European continent's founding population. This possibility is the reason these bones have piqued the interest of Hublin and his team.

Photo: Volker Steger



With their high-resolution scanner, the Max Planck researchers can also analyze smaller structures, like dental enamel. This provides information about the growth rates of the early hominids. And the 3-D printer can even produce a magnified version of the tooth.

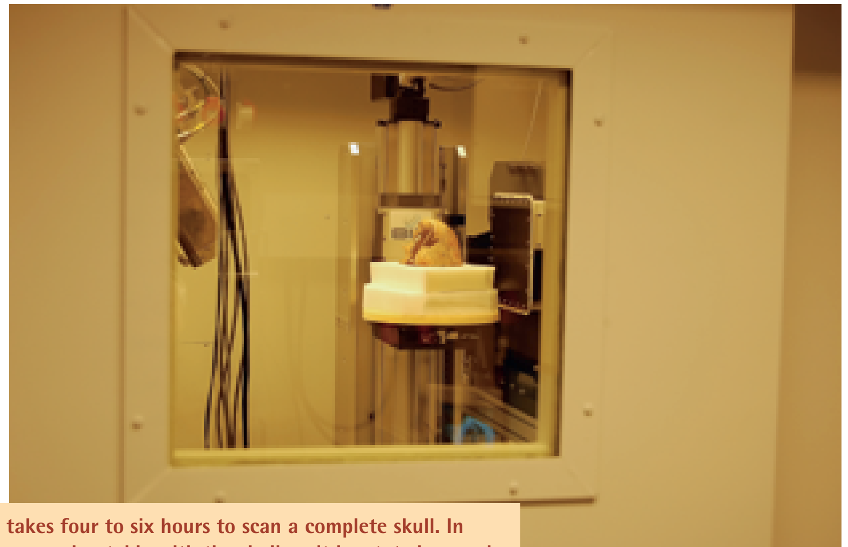
The bones, despite their rarity and importance, are stored in simple cardboard boxes. A member of the museum staff carries them out to the container. Andreas Winzer gently lifts a skull out of the box and places it on the measuring table. He carefully adjusts the scanner. Then he leaves the X-ray room and checks the settings on the computer. The Moroccan who brought him the cardboard box does not let the skull out of his sight for even a second.

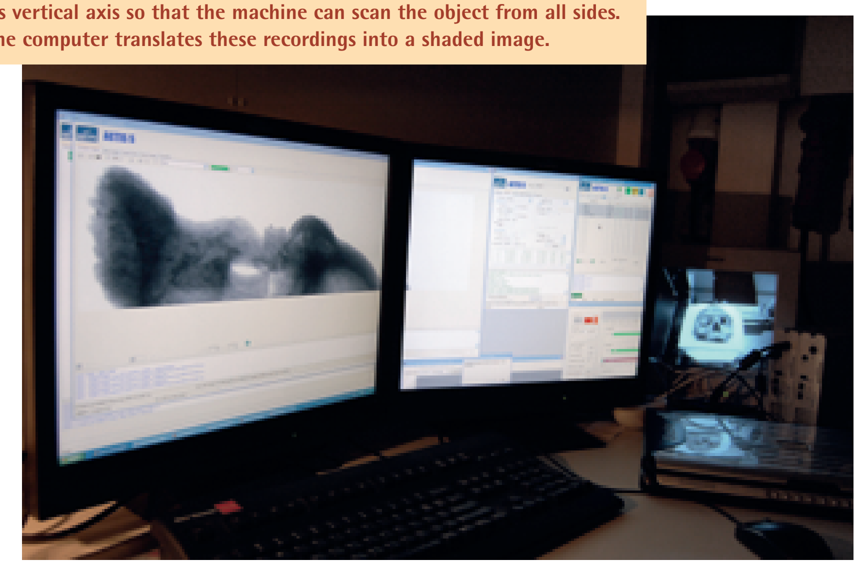
Communication is difficult, as the Moroccans speak very little English. French, the country's second official language, would be better. Unfortunately, neither Temming nor Winzer speaks more than a few words of French.

Reconstruction Exceeds the Data Memory

"The CT machine takes four to six hours to scan a complete skull," explains Heiko Temming. In the process, the measuring table with the skull on it is rotated around its vertical axis so that the machine can scan the object from all sides. Some 7,000 individual images are created per rotation, with the total number exceeding 70,000. "That's an enormous amount of data," says Temming. "The data record for a complete skull takes up about 70 to 80 gigabytes, and a high-resolution tooth scan is double that, at 150 gigabytes." Even a terabyte of memory capacity is not enough to hold such a large cache of data. To compensate, the technicians have to send their tape drive back to Leipzig to have the data transferred onto a large-capacity server.

Temming and Winzer's working days are packed – a brief excursion to the old royal city of Rabat is about all they can manage in six weeks. When their work is done, they pack everything up again, fasten it all down and send the container off on its homeward journey. It arrives in Leipzig on November 12. Heiko Temming and Andreas Winzer return by plane. ►





The CT machine takes four to six hours to scan a complete skull. In the process, the measuring table with the skull on it is rotated around its vertical axis so that the machine can scan the object from all sides. The computer translates these recordings into a shaded image.

PHOTOS: ANDREAS WINZER

Back in Leipzig, researchers have already begun reconstructing the raw data. Initially, the tomographic cross-sections don't look like much. In order to put the information they contain in an appropriate form for analysis, the massive volumes of data need to be processed with powerful graphics programs and translated into spatial images. This would take one computer six to eight weeks. To speed up the process, the scientists set 10 computers to work on the task. With such great computing power, it takes just a week to reconstruct the 70,000 images into a 3-D object that is as good as the original.

"The big advantage is that we can look into the otherwise inaccessible interior of the fossil and analyze, for example, the structures of the inner ear," says Philipp Gunz. The Austrian scientist has spent the past two years working in Jean-Jacques Hublin's department as a post-doctoral researcher, sponsored by an EU project. "Neanderthals display small but characteristic differences to the morphology of the inner ear of Homo sapiens. We only discovered this thanks to the conclusive classification of certain fragmentary fossil finds."

Moreover, human fossils can also be reconstructed on the computer. Few paleoanthropologists are lucky enough to come across an intact skeleton or a complete skull on one of their digs. They usually have to be satisfied with fragments – fragments of an ulna or radius, a lower jaw, a skullcap. Geological processes such as rock displacements, sand deposits, eluviation and weathering, and sometimes wild animals, as well, have usually ripped the bones apart and dispersed them widely throughout the area. The ability to reconstruct complete fossils is thus especially useful.

Virtual Reality – Fossils in 3-D

Putting a fossil together is tricky business. "In the past, the fragments were glued together and then taken apart again when it was thought that the positioning should be different after all," explains Philipp Gunz. "The finds suffered some fairly serious damage as a result." On the screen, however, a paleoanthropologist can rotate the virtual fragments, tip them, look at the pieces from every angle, and then fit them together in completely new ways – without damaging or destroying a single thing.

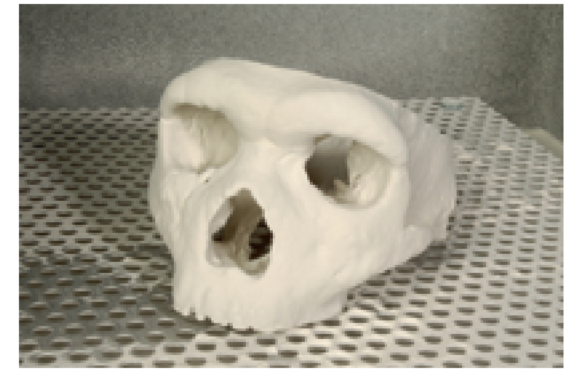
Gunz starts up the computer in the virtual reality laboratory of Hublin's department, which is the most modern lab of its kind. He clicks on a file and the skull of an early human immediately appears on the screen. Two projectors project a stereo image of the object onto a screen. It is also possible for a researcher to view the interior of the fossil he has projected. If one looks at the image through a pair of 3-D glasses, it looks as though it could actually be touched. "The first thing we need to do is correct the deformations that arose during the fossilization process," explains Gunz. To do this, hundreds of measuring points on the skull – the researchers call them landmarks – need to be determined, and their divergence from the axis of symmetry identified. Computation algorithms are used to realign these landmarks and correct the distortions.

Missing parts can be added by making mirror images of the matching parts on the opposite side. Here, too, the incalculable advantages of modern electronic image processing are brought to light. In the past, a physical mirror image had to be made after weeks of painstaking work, but now the image can be conjured up on the computer in seconds. Another way of completing an image is to copy parts from another skull and then adjust them to fit, which proves to be no problem for the computer, either. "However, the whole thing is still an extremely tricky 3-D puzzle," stresses Gunz.

For that reason, the anthropologists – despite all of these possibilities – still like to hold a real 3-D object in their hands. This gives them a better idea of the physical relationship between the structures. These kinds of physical objects communicate tactile information; they can be touched, examined and fitted together under far more realistic conditions than virtual objects on a screen. To translate the finished computer reconstruction of the virtual skull into physical reality, the scientists at the Max Planck Institute in Leipzig use a method from the field of mechanical engineering: rapid prototyping.

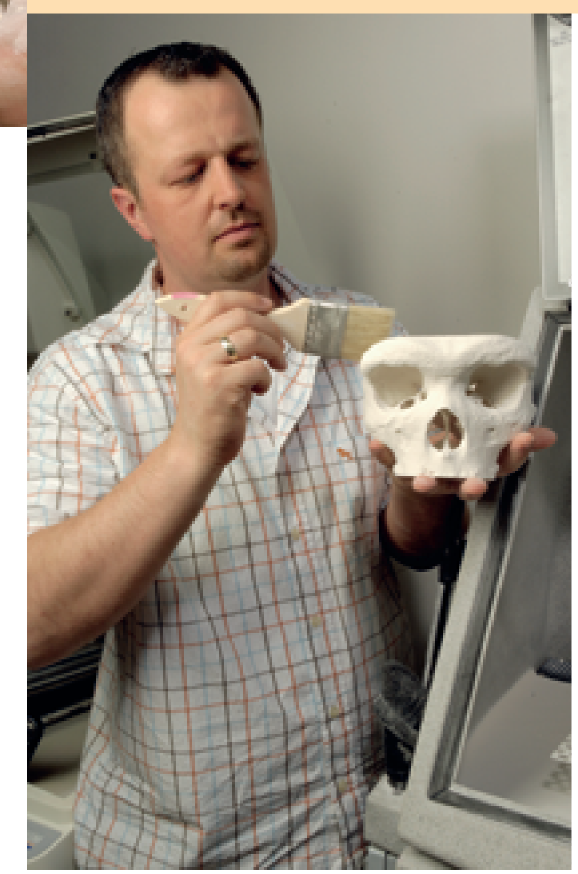
A Human Skull to Touch

The lab's 3-D printer works just like a conventional inkjet printer, but in three dimensions rather than two. The print head can move over a surface in any direction. First, it covers the surface with a thin layer of plaster powder. Then, in line with the shape of the object reconstructed on the computer, the print head applies a transparent bonding agent to the appropriate areas, which quickly causes the plaster to stick together locally. It then applies another layer of plaster powder and repeats the process. Layer by layer, a three-dimensional skull appears. Teeth are also reconstructed, many times magnified. The whole process takes just over half a second: the ZCorp Spectrum Z510 is currently the fastest 3-D printer in the world.



PHOTOS: VOLKER STEGER

A 3-D printer is used to translate the computer reconstruction into a plaster model. The printer works just like a conventional inkjet printer, but in three dimensions rather than two. At the end of the process, the skull is taken out of the plaster bed and cleaned with a brush.



Jean-Jacques Hublin estimates that his research field will be completely transformed within 15 years. By then, scientists will no longer be studying the actual bone finds, but only their virtual likenesses. The Max Planck Director's goal is to record the data, build up a virtual collection and eventually pioneer this field of analysis. Naturally, he will need the cooperation of international partners to do this, particularly museums. His two technicians, Heiko Temming and Andreas Winzer, have already been to Croatia, home of the world's largest collection of Neanderthal bones. Their next destination – naturally enough – is East Africa, the cradle of mankind.

CHRISTINA BECK